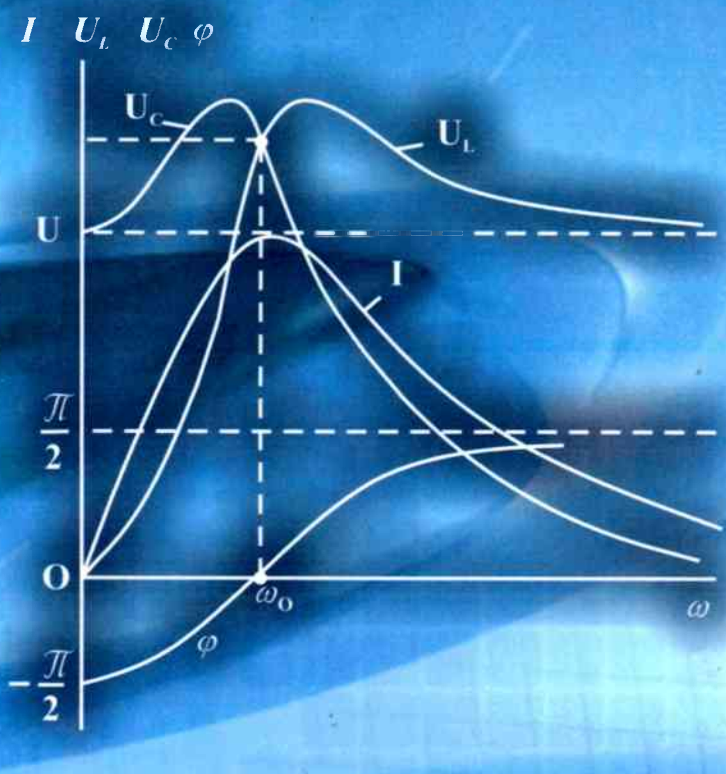
Muxtorxon Ibadullayev

NAZARIY ELEKTROTEXNIKA ASOSLARI

Masala va mashqlar to'plami



O'ZBEKISTON RESPUBLIKASI
OLIY VA O'RTA MAXSUS TA'LIM VAZIRLIGI

MUXTORXON IBADULLAYEV

NAZARIY ELEKTROTEXNIKA ASOSLARI

MASALA VA MASHQLAR TO'PLAMI

I QISM

Oliy o'quv yurtlarining 5310100-Energetika yo'nalishi talabalari uchun o'quv qo'llanma

Toshkent
«O'ZBEKISTON»
2015

UO‘K: 62130(083)
KBK 24.1
I-13

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Ibadullayev M.
I-13 Nazariy elektrotexnika asoslari / M. Ibodullayev/ Toshkent: O‘zbekiston, 2015. – 328 b.

ISBN 978-9943-28-252-0

Ushbu o‘quv qo‘llanma oliy o‘quv yurtlarining energetika, elektroenergetika, elektrotexmka, elektromexanika, elektrotexnologiya, avtomatika, radioelektronika, aloqa, telekommunikatsiya yo‘nalishlarida ta’lim olayotgan bakalavrlar uchun tavsiya etilib, shuningdek magistr, doktorant va soha mutaxassislari ham foydalanishlari mumkin.

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Abu Rayhon Beruniy nomidagi Toshkent davlat texnika universiteti uslubiy Kengashi qaroriga asosan chop etishga ruxsat etilgan. (Bayonnoma №5.13.03. 2014)

ISBN 978-9943-28-252-0

KIRISH

Mamlakatimiz sanoatining rivojlanishida elektroenergetika sohasining ahamiyati beqiyos bo‘lib, uning ilmiy-nazariy asosi bo‘lmish nazariy elektrotexnikasiz tasavvur qilib bo‘lmaydi.

Umuman olganda, elektrotexnika hamma zamonaviy elektrotexnik yo‘nalishlar (energetika, avtomatika, elektronika, radiotexnika, aloqa, telekommunikatsiya, informatika va hokazo) uchun fundamental fan tarmog‘i hisoblanadi.

Ushbu o‘quv qo‘llanma «Nazariy elektrotexnika asoslari» fani dasturi asosida tuzilgan bo‘lib, chiziqli elektr zanjir qismiga doir yechlsh uchun masala va mashqlar berilgan.

Har bir bobga oid fanning nazariy qismidan elektr zanjirni hisoblash uchun zarur bo‘lgan qonun-qoidalar, formulalar, tenglamalar, analitik, grafik, kompleks usullar, vektor ifodalari va hisoblash usullari bo‘yicha qisqacha asosiy tushunchalar o‘z ifodasini topgan.

O‘quv qo‘llanma energetika, elektroenergetika, elektrotexnika, elektromexanika, elektrotexnologiya, avtomatika, radioelektronika, aloqa, telekommunikatsiya va axborot texnologiya soha yo‘nalishlari bo‘yicha ta’lim olayotgan talabalarga mo‘ljallangan bo‘lib, undan soha mutaxassislari, bakalavr, magistr va doktorantlar ham foydalanishlari mumkin.

O‘quv qo‘llanma talabalarga amaliy mashg‘ulot darsini o‘zlashtirishda mustaqil masalalar yechlsh, hisob-grafik ishini bajarish va nazariy bilimlarini amalda sinab ko‘risblarida yordam bo‘ladi degan umiddamiz.

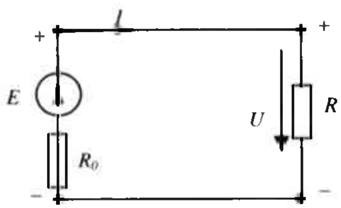
I. O‘ZGARMAS TOK ELEKTR ZANJIR

1.1. Asosiy nazariy tushunchalar

Elektrotexnika fanining rivojlanishiga buyuk fizik olimlar G. Onı, E. Lens, D. Joul, G. Kirxgof, M. Faradey, J. Maksvell va boshqalar asos solgan bo‘lib, 1827-yilda nemis olimi Om tok, kuchlanish va qarshiliklar orasidagi o‘zaro bog‘lanish qonunini yaratdi. 1842-yilda rus olimi E. Lens va ingliz olimi D.Joul elektr energiyasini issiqlik energiyasiga aylantirish qonuniga asos soldi. 1845-yilda G. Kirxgof elektr zanjirni hisoblash uchun asosiy qonun tatbiq etdi.

1. O‘zgarmas tok – vaqt bo‘yicha o‘zgarmas bo‘lib, $I = \frac{q}{t}$ (A) o‘zgarmas tok generatori, akkumulator, galvanik elementlar, foto-elementlar, termopara, pyezodatchik va hokazolar elektr yurituvchi kuch (EYK) manbai hisoblanadi.

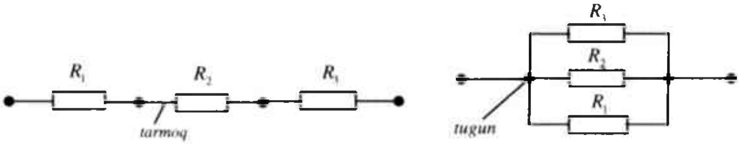
Amalda mexanik, kimyoviy, yorug‘lik va boshqa xildagi energiyani elektr energiyasiga aylantirish yo‘li bilan **elektr manbai** hosil qilinadi. Hosil qllingan elektr energiyasini iste’molchilarga uzatish liniyasi, kabel simlari va elektromagnit to‘lqin orqali yetkaziladi. Bunday bog‘lanishni elektrotexnikada **berk elektr zanjir** deyilib, quyidagi sxema ko‘rinishida ifodalash mumkin.



E – manba EYK
R – iste’molchi qarshiligi.
R_0 – manba ichki qarshiligi

Iste’molchilarda elektr energiyasi boshqa xildagi energiyaga o‘zgaradi (mexanik, issiqlik, yorug‘lik, kimyoviy va hakozolar).

Elektr zanjirlar tarmoqlangan va tarmoqlanmagan bo'lib, iste'molchilarni birlashtiruvchi simlar **tarmoq** (shoxobcha) va uchtadan ko'p shoxobchani birlashtiruvchi nuqtalar – **tugun** deb ataladi.



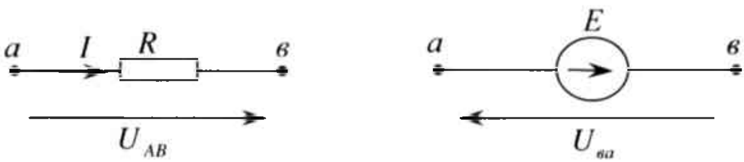
Ikki qutbli elektr zanjirda elektr energiya *aktiv* yoki aksincha, *passiv* bo'hshi mumkin.

Elektr zanjirni hisoblashdan asosiy maqsad, iste'molchilar foydalanyotgan tok, kuchlanish va sarf bo'ladigan energiya quvvatini hisoblab topishdan iborat bo'lib, Om va Kirxgof qonunidan foydalaniladi.

2. Elektr kuchianish yoki potensiallar farqi deb, elektr maydon *E* (manba) ta'sirida biror musbat *q* zaryadning *l* masofaga ko'chirilishida bajarilgan ishga aytiladi va *Volt*da o'lchanadi.

$$U_{AB} = \frac{A}{q} = \int_A^B E\,dl = \varphi_a - \varphi_в \quad (\text{V}) \qquad (1.1)$$

Masalan: *R* – qarshilikdagi kuchlamsh potensiallar ayirmasiga yoki manba kuchianishiga teng:



Bunda:

$\varphi_a - \varphi_в = U_{AB} = IR$; $\quad \varphi_b - \varphi_a = U_{ba} = E \quad U_{ba} = -U_{ab}$

3. Elektr zanjir uchun Om qonuni.

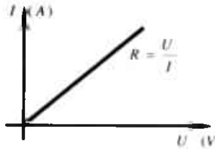
Aktiv qarshiligi bo'lgan zanjirnmg bir qismi uchun Om qonuni:

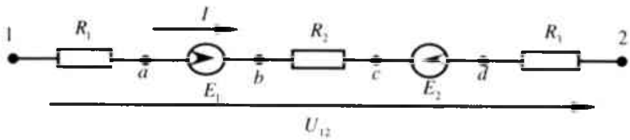
$$U_{ba} = U = RI \ (V) \qquad yoki \qquad I = \frac{U}{R} \ (A) \quad (1.2)$$

Bundan:

$$R = \frac{U}{I}(Om); \quad g = \frac{1}{R}\left(\frac{1}{Om} - Simens\right) - \text{o'tkazuvchanlik} \quad (1.3)$$

U holda qarshilik *Volt-Amper* xarakteristikasi $I = f(U)$ chiziqli o'zgaradi.





Elektr zanjirga manba ulangan holda butun zanjir uchun Om qonuni quyidagicha tenglama bilan ifodalanadi.

Potensiallar tenglamasiga asosan:

$$\varphi_d = \varphi_2 + R_3 I, \quad \varphi_C = \varphi_d + E_2, \quad \varphi_в = \varphi_C + R_2 I,$$

$$\varphi_a = \varphi_в - E_1, \quad \varphi_1 = \varphi_a + R_1 I$$

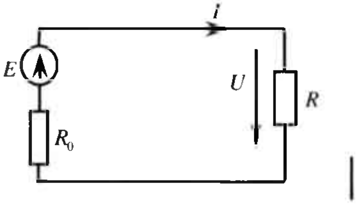
yoki $$\varphi_1 = \varphi_2 + R_3 I + E_1 + R_2 I - E_2 + R_1 I, \quad \varphi_1 - \varphi_2 = U_{12}$$

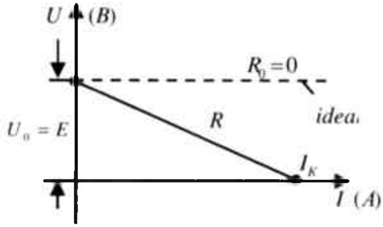
$$U_{12} = (R_1 + R_2 + R_3)I + E_1 - E_2$$

Bundan: $$I = \frac{E_1 - E_2 + U_{12}}{R_1 + R_2 + R_3} \quad (1.4)$$

4. Elektr manbai ekvivalent sxemasi.

Amalda elektr zanjir tashqi *Volt-Amper* xarakteristikasi *U(I)* quyldagicha ifodalaniladi:





Ushbu zanjirdan o'tuvchi tok: $I = \dfrac{E}{R_0 + R}$ yoki: $U = RI$

Kirxgof 2-qonuniga asosan: $R_0 I + RI = E$

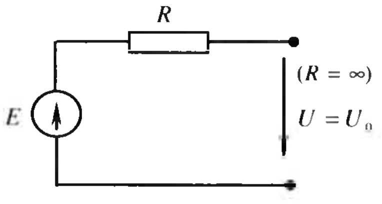
yoki: $U = E - R_0 I$ (1.5)

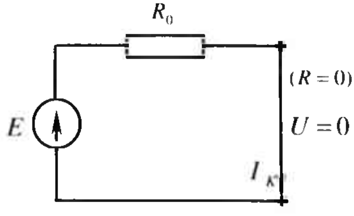
Volt-Amper xarakteristikasidan, ya'ni (15) tenglamadan: *E=const* va R_0*=const* xarakteristikasi to'g'ri chiziqli bo'lib, kuchlanish manbai tashqi xarakteristikasini *U(I)* ifodalaydi:

a) salt holatda: $R=\infty$, $I=0$ bo'lib: $U=U_0=E$ (1.6)

b) qisqa tutashtirilganda: $R=0, U=0$ bo'lib: $I=I_K=\dfrac{E}{R_0}$ (1.7)

$R_0=0$ bo'lganda esa ideal kuchlanish manbai bo'lib: *U=E=const*





Ushbu sxemani iste'molchi qarshiligiga nisbatan boshqa ko'rinishda keltirish mumkin.

Buning uchun (1.5) tenglamadan manba ichki qarshiligi R_0 ga bo'lib yuborilsa:

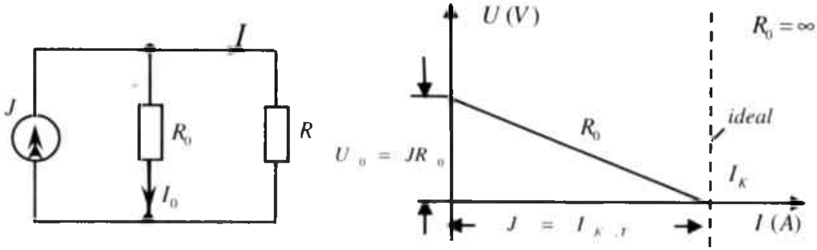
$$\frac{U}{R_0} = \frac{E}{R_0} - I \quad (1.8)$$

(1.7) tenglamaga asosan:

$$I_K = \frac{E}{R_0} = J \quad va \quad \frac{U}{R_0} = I_0 \qquad \text{yoki} \qquad I_0 = J - I \tag{1.9}$$

Bundan: $J=I_0+I$ tok manbai bo‘ladi yoki: $I = J - \frac{U}{R_0}$ (1.10)

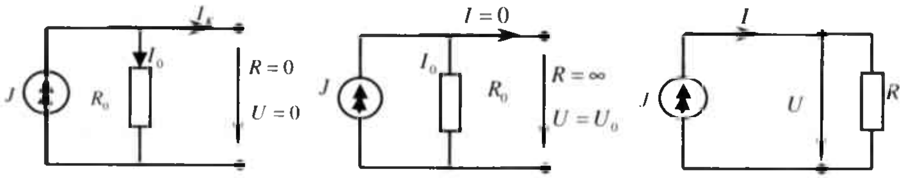
(1.10) tenglamaga asosan tok manbai (energiya) ekvivalent sxemasi va tashqi xarakteristikasi quyidagicha ifodalanadi:



Tok manbai tashqi xarakteristikasi:

a) salt holatda: $R=\infty$, $I=0$ yoki $J = I_K = \frac{U}{R_0}$; $U = U_0 = I_K R_0 = E$

b) qisqa tutashuvda: $R=0$; $U=0$ yoki $I = I_K = J = \frac{E}{R_0}$



a) Qisqa tutashuv. *b) salt holat*

Agar $R_0=\infty$, $(g_0=0)$ bo‘lsa, ideal tok manbai bo‘ladi: $J=I=const.$

Natijada elektr zanjirni hisoblashda ideal EYK manbaini ekvivalent tok manbaiga almashtirish yoki aksincha amalga oshirish mumkin bo‘ladi.

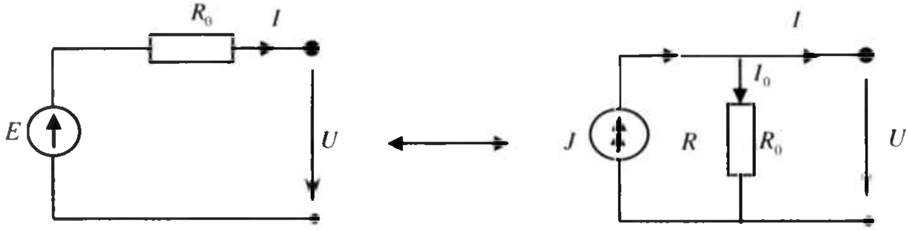
Masalan: berilgan sxemada EYK manbai $E=12$ V ichki qarshiligi $R_0=2$ Om. Tok manbainmg ekvivalent sxemasi tuzilsin:

Yechish.

Om qonuniga asosan tok manbai qiymatini aniqlaymiz:

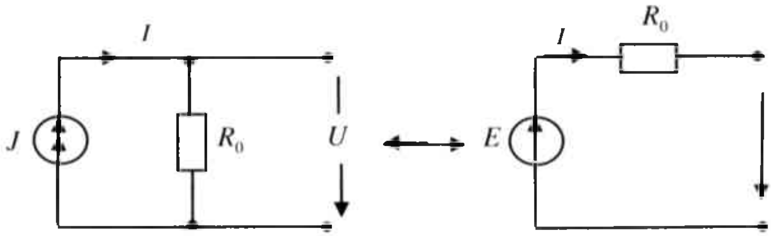
$$J = \frac{E}{R_0} = \frac{12}{2} = 6\ A$$

Ekvivalent sxemasi quyidagicha ifodalanadi:



Bunda EYK manbai E bilan tok manbai J yo‘nalishi bir xil bo‘ladi hamda ekvivalent sxemaga almashtirilganda tashqi qarshilik qiymati o‘zgarmaydi. Ammo quvvat har xil bo‘lishi mumkin.

Masalan. Elektr sxemada tok manbai $J = 10A$, ichki qarshilik $R_0 = 3\ Om$ bo‘lganda ekvivalent EYK manbai sxemasi tuzilsin.



Yechish. EYK manba kuchlanishi $E = JR_0 = 10 \cdot 3 = 30\ V$

Eslatma: Keyimchalik ekvivalent sxemaga o‘tishda manba ichki qarshiligi yoki o‘tkazuvchanligini iste’molchilar tashqi qarshiligi yoki o‘tkazuvchanligi bilan hisobga olamiz ($R_0 = 0$, $g = 0$). EYK manba bilan tok manbaini yoki aksincha almashtirilganda tashqi qarshilikga ta’siri bo‘lmaydi, lekin manbadan chiquvchi elektr quvvat turlicha bo‘lishi mumkin.

5. Elektr zanjirni hisoblashda Kirxgof qonuni.

Kirxgof qonun elektr zanjirni hisoblashda asosiy qonun bo‘lib, barcha hisoblash usullarining negizi hisoblanadi.

Kirxgof qonuniga asosan p-tarmoq q-tugundan tashkil topgan elektr zanjirni hisoblab, tarmoqdagi tok uchun $K= p -(q-1)$ tuzilgan tenglamani yechish bilan bajariladi.

Kirxgof 1-qonuni: $\sum_{k=1}^{n} I_K = 0$ – tarmoqdagi tok algebraik yig'indisi nolga teng.

Kirxgof 2-qonuni: $\sum_{k=1}^{n} E_K = \sum_{k=1}^{n} R_K I_K$ – kontur EYK algebraik yig'indisi shu konturga kiruvchi qarshilikdagi kuchianishning algebraik yig'indisiga teng.

6. Elektr zanjirda quvvat muvozanati.

Elektr zanjirda energiya muvozanatlanishi qonuniga asosan: manba elektr quvvati iste'molchilarda sarf bo'ladigan elektr quvvatga teng bo'ladi.

$$\sum_{k=1}^{n} P_{GEN} = \sum_{k=1}^{n} P_{Manb} \quad \text{yoki:} \quad \sum_{m=1}^{n} E_m I_m + \sum_{n=1}^{n} J_n U_n = \sum_{K=1}^{n} I_K^2 R_k$$

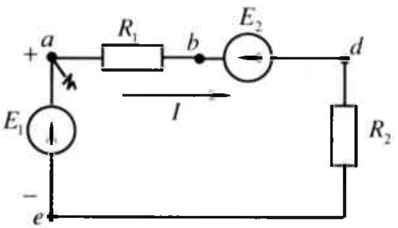
bunda: m – EYK manbalar soni n – tok manba

k – iste'molchilar soni U, I – bir xil yo'nalishdagi tok va kuchlanish.

1.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 1.1. Ketma-ket ulangan elektr zanjirda EYK $E_1=4\ V$, $E_2=2\ V$, qarshiligi $R_1=4\ Om$, $R_2=6\ Om$. Tok qiymati va potensiali aniqlanib, diagrammasi tuzilsin.

Yechish. Om qonuniga asosan tokni topamiz:



$$I = \frac{E_1 - E_2}{R_{um}} = \frac{4-2}{R_1 + R_2} = \frac{2}{10} = 0{,}2\ A$$

Bunda: $E_1 > E_2$ bo'lganligi uchun tok soat strelkasiga mos yo'nalgan bo'ladi.

Potensiallar farqini aniqlash uchun $\varphi_a = 0$ deb olamiz.

Bunda: $\varphi_b - \varphi_a = R_1 I$ yoki $\varphi_b = \varphi_a + IR_1 = 0 + 0{,}2 \cdot 4 = 0{,}8 \ (V)$

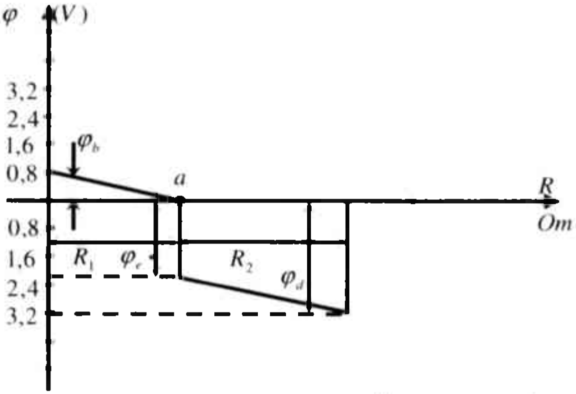
φ_d – potensiali: $\varphi_b - \varphi_d = E_1$ yoki $\varphi_d = \varphi_b - E_1 = -3{,}2 \ (V)$

φ_e – potensiali: $\varphi_e - \varphi_d = IR_2$ yoki $\varphi_e = IR_2 + \varphi_d = 0{,}2 \cdot 6 - 3{,}2 = -2 \ (V)$

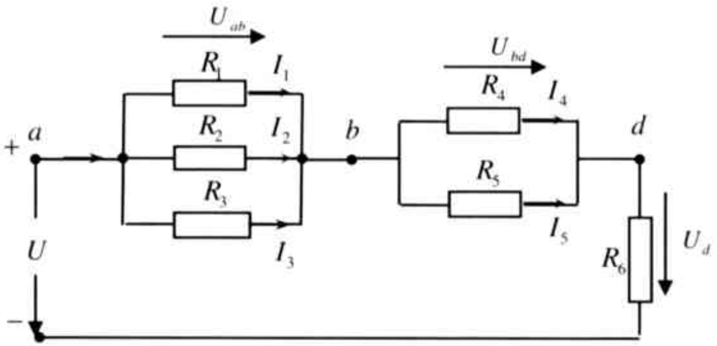
Ushbu tenglama asosida: $\varphi_a - \varphi_e = E_2$

$$\varphi_a = E_2 + \varphi_e = 2 - 2 = 0$$

Potensial diagramma chizamiz.

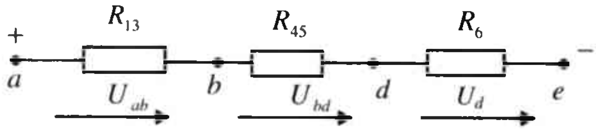


Masala 1.2. Tarmoqlangan elektr zanjir parametri $R_1 = 40\ Om$, $R_2 = 120\ Om$, $R_3 = 60\ Om$, $R_4 = 90\ Om$, $R_5 = 10\ Om$, $R_6 = 10\ Om$ bo'lib, $U = 120\ V$ o'zgarmas kuchlanishga ulangan. Ekvivalent qarshilik hamda tarmoqdagi tokni aniqlang.



Yechish.

Ekvivalent qarshilik sxemasini chizamiz:



Zanjirning ekvivalent yoki umumiy qarshiligini topamiz. Buning uchun R_{13} va R_{45} qarshilikni parallel holda qo'shamiz:

$$\frac{1}{R_{13}}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{40}+\frac{1}{120}+\frac{1}{60}=\frac{6}{120}$$

Bundan: $$R_{13}=\frac{120}{6}=20\ Om$$

$$R_{45}=\frac{R_4\cdot R_5}{R_4+R_5}=\frac{90\cdot 10}{90+10}=\frac{900}{100}=9\ \ Om$$

Umumiy ekvivalent qarshilik:

$$R=R_{13}+R_{45}+R_6=20+9+11=40\ Om$$

Umumiy tokni aniqlaymiz: $I=\frac{U}{R}=\frac{120}{40}=3\ A$

Tugun potensiali yoki kuchlanishni aniqlaymiz:

$U_{ab}=I\cdot R_{13}=3\cdot 20=60\,V \quad U_{bd}=I\cdot R_{45}=3\cdot 9=27\ V$

$U_d=I\cdot R_6=3\cdot 11=33\ V$

Endi tarmoqdagi tokini topamiz:

$$I_1=\frac{U_{ab}}{R_1}=\frac{60}{40}=1{,}5\ A$$

$$I_2=\frac{U_{ab}}{R_2}=\frac{60}{120}=0{,}5\ A$$

$$I_3=\frac{U_{ab}}{R_3}=\frac{60}{60}=1\ A$$

$$I_4=\frac{U_{bd}}{R_4}=\frac{27}{90}=0,3\ A$$

$$I_5=\frac{U_{bd}}{R_5}=\frac{27}{10}=2,7\ A$$

Masala yechimini tekshirib ko'ramiz:

$$U=U_{ab}+U_{bd}+U_d=60+27+33=120\ V$$

$$I=I_1+I_2+I_3=1,5+0,5+1=3\ A$$

Quvvat muvozanati tenglamasiga asosan:

$$P_{manb}=P_{ist}=I_1^2R_1+I_2^2R_2+I_3^2R_3+I_4^2R_4+I_5^2R_5+I_6^2R_6=$$

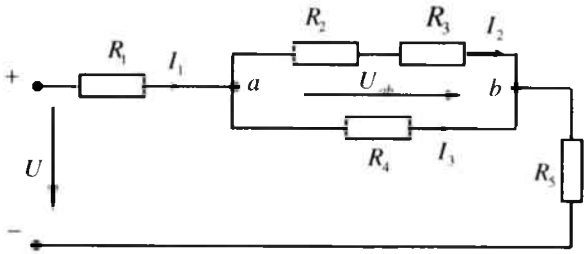
$$=(1,5)^2\cdot 40+(0,5)^2\cdot 120+(1)^2\cdot 60+(0,3)^2\cdot 90+(2,7)^2\cdot 10+(3)^2\cdot 10=351\ VT=360\ VT$$

Hisoblashdagi xatolik:

$$\gamma=\frac{P_{gen}-P_{ist}}{P_{ist}}\cdot 100\%=\frac{360-351}{351}100\%=2,7\%$$

Masala 1.3. Aralash sxemada ulangan elektr zanjir parametri: $R_1=19\ Om$, $R_2=2\ Om$, $R_3=4\ Om$, $R_4=4\ Om$, $R_5=0,6\ Om$ bo'lib, R_2 qarshilikda $P_2=32\ VT$ quvvat sarflanadi.

Zanjirning tarmoq tok manba kuchiamshi va quvvati aniqlansin.



Yechish.

R_2 qarshilikdan o'tuvchi I_2 tokni topamiz:

$$I_2=\sqrt{\frac{P_2}{R_2}}=\sqrt{\frac{32}{2}}=4\ A$$

a va *b* potensial kuchlanishni aniqlaymiz:

$$U_{ab}=I_2(R_2+R_3)=4(2+4)=24\ V$$

R_4 qarshilikdan o'tuvchi tok:

$$I_3=\frac{U_{ab}}{R_4}=\frac{24}{4}=6\ A$$

Umumiy tok: $I_1=I_2+I_3=4+6=10\ A$

Zanjirnmg umumiy qarshiligini amqlaymiz:

$$R_{um}=R_1+\frac{R_4(R_2+R_3)}{R_4+R_2+R_3}+R_5=19+\frac{4(2+4)}{4+2+4}+0{,}6=19+0{,}6+\frac{24}{10}=22\ Om$$

Manba kuchlanishi: $U=I_1R_{um}=10\cdot 22=220\ V$

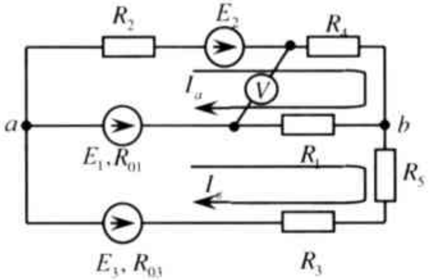
Manba quvvati: $P=U\cdot I_1=220\cdot 10=2200\ VT.$

Masala 1.4. Ikki konturli elektr zanjir manba kuchlanishi: $E_1=8\ V$, $E_2=6\ V$, $E_3=36\ V$ qarshiligi: $R_1=3\ Om$, $R_2=1\ Om$, $R_3=2\ Om$, $R_{01}=1{,}3Om$, $R_{03}=1{,}2\ Om$, $R_4=6\ Om$, $R_5=8\ Om$ konturli tok usuli va tugunlararo kuchianish usuliga asosan tarmoqdagi tok, voltmetr kuchlanishi va quvvatlar balansi aniqlansin.

Yechish.

Mustaqil konturdagi tok I_a, I_b yo'nalishini belgilaymiz.

Kirxgof 2-qonuniga asosan konturdagi tok tenglamasi quyidagicha bo'ladi:



$$\left.\begin{aligned}R_{11}\cdot I_a-R_{12}\cdot I_b=E_{11}\\-R_{11}\cdot I_a+R_{22}\cdot I_b=E_{22}\end{aligned}\right\}$$

Bu yerda: R_{11} R_{22} – konturning xususiy qarshiligi.

$$R_{11}=R_1+R_{01}+R_2+R_4$$

$$R_{22}=R_1+R_{01}+R_3+R_{03}+R_5$$

$R_{12} = R_{21}$ – konturlararo qarshilik: $R_{12} = R_{21} = R_1 + R_{01}$

E_{11} va E_{22} – mos konturga aloqador bo'lgan manbaning EYKning algebraik yig'indisi.

Bu holda, agar manba EYK yo'nalishi bilan konturdagi tok yo'naĥshi mos bo'lsa, uning isĥorasi musbat yoki aksimcha, manfiy olinadi.

Bunga asosan: $E_{11} = E_2 - E_1$ $\quad E_{22} = E_1 - E_3$

Tenglamaga aniqlangan qiymatni qo'yamiz:

$$\begin{cases}(3+1{,}3+6+2)\cdot I_a-(3+1{,}3)\cdot I_b=6-8\\ -(3+1{,}3)\cdot I_a+(3+1{,}3+1+1{,}2)\cdot I_b=8-36\end{cases}$$

yoki: $$\begin{cases}12{,}3\cdot I_a-4{,}3\cdot I_b=-2\\ -4{,}3\cdot I_a+14{,}5\cdot I_b=-28\end{cases}$$

Tenglama Kramer usulida yechiladi:

$$\Delta=\begin{vmatrix}12{,}3 & -4{,}3\\ -4{,}3 & 14{,}5\end{vmatrix}=178{,}35-18{,}49=159{,}86$$

$$\Delta_1=\begin{vmatrix}-2 & -4{,}3\\ -2{,}8 & 14{,}5\end{vmatrix}=-29-120{,}4=-149{,}4$$

$$\Delta_2=\begin{vmatrix}12{,}3 & -2\\ -4{,}3 & -28\end{vmatrix}=-344{,}4-8{,}6=-353{,}0$$

Bundan:

$$I_a=\frac{\Delta_1}{\Delta}=\frac{-149{,}4}{159{,}86}=-0{,}93\ A;\quad I_b=\frac{\Delta_2}{\Delta}=\frac{-353{,}0}{159{,}86}=-2{,}21\ A;$$

Endi tarmoqdagi tokni aniqlaymiz:

$I_1 = I_b - I_a = -\,2{,}21 - 0{,}93 = -\,1{,}28\ A;$

$I_2 = I_a = -\,0{,}93\ A$;

$I_3 = -\,I_b = 2{,}21\ A;$

I_1 va I_2 tokning minus ishorali bo'lishi, ularning zanjirdagi haqiqiy yo'nalishi, biz qabul qilganga nisbatan teskari ekanligini ifodalaydi.

Tugun potensial usuliga asosan hisoblash.

Tarmoqdagi tokni tugun potensiali orqali ifodalaymiz. Noma'lum potensialni aniqlash uchun tenglama tuzish kerak, ya'ni ixtiyoriy tugun potensiali «ma'lum» yoki «nol» ga teng deb qabul qilinadi. Berilgan sxema ikki tugundan iborat, demak φ_a tugun potensialini «nol», deb qabul qilgan holda tenglama tuzamiz.

$$g_{bb} \cdot \varphi_b = J_b$$

Bu yerda: φ_b – aniqlash kerak bo'lgan tugun potensiali.

g_{bb} – «*b*» tugunga kiruvchi tarmoqning o'tkazuvchanlik yig'indisi.

J_b – EYK ga ekvivalent bo'lgan tok manbaining algebraik yig'indisi.

Bunda, agar tok manbai yo'nalishi tugunga yo'nalgan bo'lsa, musbat va aksincha manfiy ishora bilan olinadi.

Demak:

$$g_{bb} = \frac{1}{R_2 + R_4} + \frac{1}{R_1 + R_{01}} + \frac{1}{R_3 + R_{03} + R_5}; \ (\frac{1}{Om})$$

$$J_b = \frac{E_1}{R_1 + R_{01}} + \frac{E_2}{R_2 + R_4} + \frac{E_3}{R_3 + R_{03} + R_5}; \ (A)$$

Son qiymatlari qo'yilsa:

$$\left(\frac{1}{2+6} + \frac{1}{3+1,3} + \frac{1}{1+1,2+8}\right)\varphi_b = \frac{8}{3+1,3} + \frac{6}{2+6} + \frac{36}{1+1,2+86}$$

yoki: $\varphi_b = 13,49\ (V)$

Tarmoqdagi tok:

$$I_1 = \frac{-\varphi_b + E_1}{R_1 + R_{01}} = \frac{-13,49+8}{3+1,3} = \frac{-5,49}{4,3} = -1,28A;$$

$$I_2 = \frac{-\varphi_b + E_2}{R_2 + R_4} = \frac{-13,49+6}{2+6} = \frac{-7,49}{8} = -0,936A;$$

$$I_3 = \frac{-\varphi_b + E_3}{R_3 + R_{03} + R_5} = \frac{-13,49+36}{1+1,2+8} = \frac{22,51}{10,2} = 2,206A;$$

1. Voltmetr ko‘rsatishini aniqlaymiz:

$$U_b=-I_2\ R_4 + I_1\ R_1 = -(-0{,}93)\ 6 + (-1{,}28)\ \ 3\ = 1{,}74\ V$$

2. Quvvatlar balansi tenglamasiga asosan $P_{man} = P_{ist}$ teng bo‘lib, manba quvvati:

$$P_{man} = E_1\ I_1 + E_2\ I_2 + E_3\ I_3 = 8\ (-1{,}28) +6\ (-0{,}93) + 36\ \ 2{,}21 =$$
$$= -10{,}24 - 5{,}58 + 79{,}56 = \ 63{,}74\ Vt$$

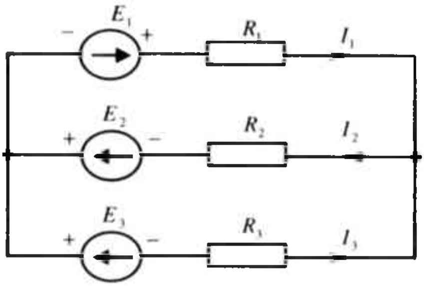
Iste’molchilarda sarf bo‘ladigan quvvat:

$$P_{ist} = I_1^2\cdot(R_1+R_{01})+I_2^2\cdot(R_2+R_4)+I_3^2(R_3+R_{03}+R_5)=1{,}28^2\cdot(3+1{,}3)+$$
$$0{,}93^2(2+6)+2{,}21^2(1+1{,}2+8)7{,}045+6{,}91+49{,}81=63{,}76\,Vt$$

Hisoblashdagi xato:

$$j\% = \frac{|P_{ist}-P_{man}|}{|P_{ist}|}\cdot 100\% = \frac{63{,}76-63{,}74}{63{,}76}\cdot 100\% = 0{,}03\%$$

Masala 1.5. Elektr zanjirning manba kuchlanishi $E_1 = 10\ V$, $E_2 = 40\ V$, $E_3 = 5\ V$, qarshiligi $R_1=35\ Om$, $R_2=5\ Om$, $R_3=10\ Om$ ga teng. Ustma-ustlik usuliga asosan tarmoqdagi tok aniqlansin.



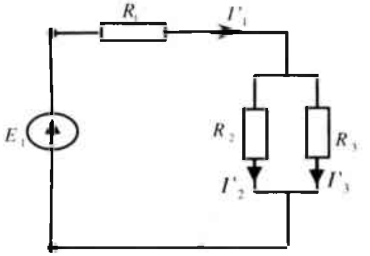
Yechish.

Ustma-ustlik usuliga asosan tarmoqdan o‘tuvchi tok har bir EYK ta’sirida tarmoqdagi tokning algebraik yig‘indisiga teng bo‘ladi:

$$I_1 = I_1' + I_1'' + I_1'''$$
$$I_2 = I_2' + I_2'' + I_2'''$$
$$I_3 = I_3' + I_3'' + I_3'''$$

Tok kuchini aniqlash uchun berilgan sxemani bitta EYK dan iborat bo‘lgan oddiy ekvivalent sxemaga ajratamiz.

a) $E_1=10$ V, $E_2=E_3=0$ bo‘lgan holat uchun tarmoqdagi tok I_1' ni aniqlaymiz:

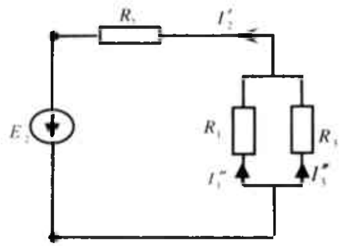


$$I_1' = \frac{E_1}{R_{ekv}} = \frac{E_1}{R_1 + \frac{R_2 \cdot R_3}{R_2 + R_3}} = \frac{10}{\frac{115}{3}} = \frac{6}{23}\ A$$

$$I_2' = I_1' \frac{R_2}{R_2 + R_3} = \frac{6}{23} \cdot \frac{10}{5+10} = \frac{4}{23}\ A$$

$$I_3' = I_1' \frac{R_3}{R_2 + R_3} = \frac{6}{23} \cdot \frac{5}{5+10} = \frac{2}{23}\ A$$

b) $E_2=40$ V, $E_1=E_3=0$ bo‘lganda I_1'' tarmoqdagi tokni topamiz:

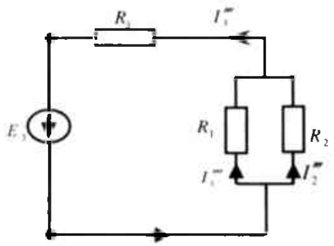


$$I_2' = \frac{E_2}{R_{ekv}} = \frac{E_2}{R_2 + \frac{R_1 \cdot R_3}{R_1 + R_3}} = \frac{40}{\frac{115}{9}} = \frac{72}{23}\ A$$

$$I_1'' = I_2'' \cdot \frac{R_3}{R_1 + R_3} = \frac{72}{23} \cdot \frac{10}{35+10} = \frac{16}{23}\ A$$

$$I_3'' = I_2'' \cdot \frac{R_1}{R_1 + R_3} = \frac{72}{23} \cdot \frac{35}{35+10} = \frac{56}{23}\ A$$

c) $E_3=5$ V, $E_1=E_2=0$ bo‘lgan I_1''' tarmoqdagi tokni aniqlaymiz:



$$I_3''' = \frac{E_3}{R_3 + \frac{R_1 \cdot R_2}{R_1 + R_2}} = \frac{5}{\frac{115}{9}} = \frac{8}{23}\ A$$

$$I_1''' = I_3''' \cdot \frac{R_2}{R_1 + R_2} = \frac{8}{23} \cdot \frac{5}{40} = \frac{1}{23}\ A$$

$$I_2''' = I_3''' \cdot \frac{R_1}{R_1 + R_2} = \frac{6}{23} - \frac{1}{23} = \frac{7}{23}\ A$$

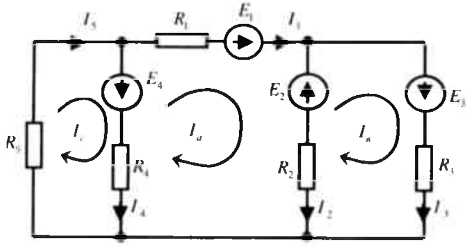
Aniqlangan tok yo‘nalishi va ishorasini hisobga olgan holda tarmoqdagi tokni topamiz:

$$I_1 = I_1' + I_1'' + I_1''' = \frac{6}{23} + \frac{16}{23} + \frac{1}{23} = 1\ A$$

$$I_2 = I_2' + I_2'' + I_2''' = \frac{4}{23} + \frac{72}{23} - \frac{7}{23} = 3\ A$$

$$I_3 = I_3' + I_3'' + I_3''' = -\frac{2}{23} + \frac{56}{23} - \frac{8}{23} = 2 \ A$$

Masala 1.6. Keltirilgan sxema parametri R_1=5 *Om*, R_2=R_3=10 *Om*, R_4=5 *Om*, R_5=3 *Om*, EYK $E_1 = 70$ *V*, $E_2 = 5$ *V*, $E_3 = 15$ *V*, $E_4 = 10$ *V*. Konturli tok usuliga asosan tarmoqdagi toki aniqlansin.



Yechish.

Berilgan elektr zanjir 3 ta konturdan tashkil topgan bo'lganligi uchun Kirxgof 2-qonuniga asosan konturdagi tok yo'nalishi bo'yicha uchta tenglama tuzamiz:

$$\left.\begin{aligned} R_{11}I_a - R_{12}I_в - R_{13}I_c &= E_a \\ -R_{21}I_a + R_{22}I_в + R_{23}I_c &= E_в \\ R_{31}I_a - R_{32}I_в - R_{33}I_c &= E_c \end{aligned}\right\} \qquad (1)$$

Kontur qarshiliklarini topamiz:

$$R_{11} = R_1 + R_2 + R_4 = 20 \ Om$$

$$R_{22} = R_2 + R_3 = 20 \ Om$$

$$R_{33} = R_4 + R_5 = 8 \ Om$$

Konturlararo qarshiliklarni topamiz:

$$R_{12} = R_{21} = R_2 = 10 \ Om; \quad R_{23} = R_{32} = 0; \quad R_{13} = R_{31} = R_4 = 5 \ Om$$

Konturga kiruvchi EYK ning qiymatini aniqlaymiz:

$$E_a = E_1 - E_4 - E_2 = 70 - 10 - 5 = 55 \ V$$

$$E_b = E_2 + E_3 = 5 + 15 = 20 \ V$$

$$E_c = E_4 = 10 \ V$$

(1) tenglamaga asosan determinant usuliga asosan tenglama tuzamiz:

$$\Delta=\begin{vmatrix}R_{11} & -R_{12} & -R_{13}\\ -R_{21} & +R_{22} & -R_{23}\\ -R_{31} & -R_{32} & +R_{33}\end{vmatrix}=\begin{vmatrix}20 & -10 & -5\\ -10 & 20 & -0\\ -5 & -10 & 8\end{vmatrix}=1900\ (Om)$$

$$\Delta_a=\begin{vmatrix}E_a & -R_{12} & -R_{13}\\ E_в & +R_{22} & -R_{23}\\ E_c & -R_{32} & +R_{33}\end{vmatrix}=\begin{vmatrix}55 & -10 & -5\\ 20 & 20 & -0\\ 10 & -0 & 8\end{vmatrix}=11400\ (V)$$

$$\Delta_в=\begin{vmatrix}R_{11} & E_a & -R_{13}\\ -R_{21} & E_в & -R_{23}\\ -R_{31} & E_c & +R_{33}\end{vmatrix}=\begin{vmatrix}20 & 55 & -5\\ -10 & 20 & -0\\ -5 & 10 & 8\end{vmatrix}=7600\ (V)$$

$$\Delta_c=\begin{vmatrix}R_{11} & -R_{12} & E_a\\ -R_{21} & +R_{22} & E_в\\ -R_{31} & -R_{32} & E_c\end{vmatrix}=\begin{vmatrix}20 & -10 & 55\\ -10 & 20 & 20\\ -5 & -0 & 10\end{vmatrix}=9500\ (V)$$

Konturdagi tokni aniqlaymiz:

$$I_a=\frac{\Delta_a}{\Delta}=\frac{11400}{1900}=6\ \ A$$

$$I_b=\frac{\Delta_b}{\Delta}=\frac{7600}{1900}=4\ \ A$$

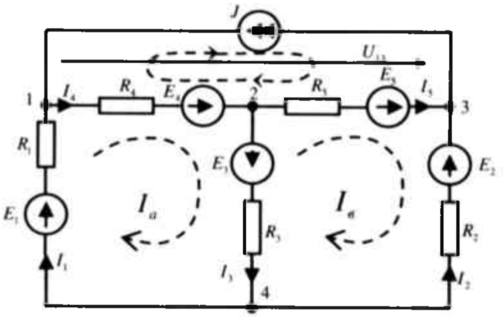
$$I_c=\frac{\Delta_c}{\Delta}=\frac{9500}{1900}=5\ \ A$$

Konturdagi tok orqali tarmoqdagi tokni aniqlaymiz:

$$I_1=I_a=6\ \ A;\ \ I_2=I_a-I_в=6-4=2\ \ A;$$

$$I_3=I_2=4\ \ A;\ \ I_4=I_a-I_c=1\ \ A;\ \ I_5=I_c=5\ \ A$$

Masala 1.7. Elektr sxema parametri: $R_1=R_3=R_5=58\ Om$, $R_2=R_4=4Om$, $E_1=10\ V$, $E_2=15\ V$, $E_3=10\ V$, $E_4=5\ V$, $E_5=20\ V$, $J=2\ A$. Tugun **potensiallar** usuliga asosan tarmoqdagi tokni aniqlab, quvvat muvozanat tenglamasi tuzilsin.



Yechish.

1)tugun potensiallar usuli murakkab elektr zanjirni hisoblashda qulay bo'lib, Kirxgof va Om qonuniga asosan tugun potensiallari nisbatan tuzilgan tenglamalarni yechish bilan tarmoqdagi tok aniqlanadi. Bunda ixtiyoriy tugun potensialini «nol» ga tenglash bilan tenglamalar somni (q – 1) kamaytirish mumkin.

Berilgan sxemada 4 ta tugun bo'lib, to'rtinchi tugunni «nol» ga tenglaymiz. ($\varphi_4=0$) va Kirxgof 1-qonuniga asosan tugunlar uchun tenglama tuzamiz:

$$\left.\begin{aligned} &1-tugun\ \ I_4+J-I_1=0\\ &2-tugun\ \ I_3+I_5-I_4=0\\ &3-tugun\ \ J-I_2-I_5=0\end{aligned}\right\} \qquad (1)$$

Om qonuniga asosan tok ifodasini tugun potensiallari ayirmasi orqali ifodalaymiz:

$$\left.\begin{aligned} &\frac{\varphi_1-\varphi_2+E_4}{R_4}-J-\frac{\varphi_4-\varphi_1+E_1}{R_1}=0\\ &\frac{\varphi_2-\varphi_3+E_5}{R_5}+\frac{\varphi_2-\varphi_4+E_3}{R_3}+\frac{\varphi_1-\varphi_2+E_4}{R_4}=0\\ &J-\frac{\varphi_4-\varphi_3+E_2}{R_2}-\frac{\varphi_2-\varphi_3+E_5}{R_5}=0\end{aligned}\right\} \qquad (2)$$

Potensial $\varphi_4=0$ ekanligini inobatga olib, tenglamani quyidagicha yozamiz:

$$
\left.\begin{aligned}
&\varphi_1\left(\frac{1}{R_1}+\frac{1}{R_4}\right)-\varphi_2\frac{1}{R_4}=E_1\frac{1}{R_1}+J-E_4\frac{1}{R_4}\\
&-\varphi_1\frac{1}{R_4}+\varphi_2\left(\frac{1}{R_4}+\frac{1}{R_3}+\frac{1}{R_5}\right)-\varphi_3\frac{1}{R_5}=E_4\frac{1}{R_5}-E_3\frac{1}{R_3}-E_5\frac{1}{R_5}\\
&-\varphi_2\frac{1}{R_5}+\varphi_3\left(\frac{1}{R_4}+\frac{1}{R_2}\right)=E_2\frac{1}{R_2}+E_5\frac{1}{R_5}-J
\end{aligned}\right\}\qquad(3)
$$

Qarshiliklar parametrini $\frac{1}{R}=g$ o‘tkazuvchanlik parametrlariga almashtirish bilan tarmoq o‘tkazuvchanligni aniqlaymiz:

$$g_1=g_3=g_5=0{,}2\ sim,\ g_2=g_4=0{,}25\ sim$$

Tugunlararo tarmoq o‘tkazuvchanligini topamiz:

$$g_{11}=g_1+g_4=0{,}45\ sim,$$
$$g_{22}=g_4+g_3+g_5=0{,}65\ sim$$
$$g_{33}=g_5+g_2=0{,}45\ sim$$

Tugunlarni bog‘lovchi tarmoqdagi o‘tkazuvchanlikni topamiz:

$$g_{12}=g_{21}=g_4=0{,}25\ sim,$$
$$g_{23}=g_{32}=g_5=0{,}2\ sim$$

(3) tenglamaning o‘ng tomoni ifodalaridan tugundagi tok qiymatini aniqlaymiz:

$$
\left.\begin{aligned}
&\text{1-tugun:}\quad I_a=E_1g_1-E_4g_4+J=2{,}75A\\
&\text{2-tugun:}\quad I_b=E_4g_4-E_3g_3-E_5g_5=-4{,}75A\\
&\text{3-tugun:}\quad I_c=E\ \ldots-E_2g_2-J=5{,}75A
\end{aligned}\right\}\qquad(4)
$$

(3) tenglamaga tarmoqdagi o‘tkazuvchanlik qiymatini qo‘yib, tugun potensiallar tenglamasini tuzamiz:

$$
\left.\begin{aligned}
&0{,}45\varphi_1-0{,}25\varphi_2=2{,}75\\
&-0{,}25\varphi_1+0{,}65\varphi_2-0{,}2\varphi_3=-4{,}75\\
&-0{,}2\varphi_2+0{,}45\varphi_3=5{,}75
\end{aligned}\right\}\qquad(5)
$$

(5) tenglamalar sistemasini yechish bilan tugun potensialli qiymatini topamiz:

$$\varphi_1=5{,}25\,V,\ \ \varphi_2=1{,}6\,V,\ \ \varphi_3=12{,}08\,V,\qquad(6)$$

Om qonuniga asosan tuzilgan (2) tenglamadan tarmoqdagi tokni topamiz:

$$I_1 = (\varphi_0 - \varphi_1 + E_1)g_1 = 0{,}95 \ A \qquad I_2 = (\varphi_0 - \varphi_3 + E_2)g_2 = 0{,}73 \ A$$
$$I_3 = (\varphi_2 - \varphi_0 + E_3)g_3 = 1{,}68 \ A \qquad I_4 = (\varphi_1 - \varphi_2 + E_4)g_4 = 2{,}96 \ A \qquad (7)$$
$$I_5 = (\varphi_2 - \varphi_3 + E_5)g_5 = 1{,}27 \ A$$

2) quvvatlar muvozanati tenglamasi quyidagicha ifodalanadi:

$$\sum EI + \sum JU = \sum I^2 R$$

Berilgan sxema uchun:

$$E_1I_1 + E_2E_2 + E_3I_3 + E_4I_4 + JU_{13} = I_1^2R_1 + I_2^2R_2 + I_3^2R_3 + I_4^2R_4 + I_5^2R_5 \qquad (8)$$

Tok manbaga J ulangan konturdagi U_{13} kuchlanishni topish uchun 1-va-3 tugun potensialiga nisbatan tenglama tuzamiz:

$$\varphi_1 - \varphi_3 = U_{13} = -E_4 - E_5 + I_4R_4 + I_5R_5 =$$
$$= -5 - 20 + 5 \cdot 1{,}27 + 4 \cdot 2{,}5 = -6{,}84 \ V$$

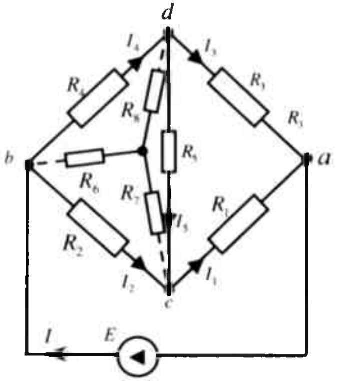
Barcha tok va kuchlanish qiymatlarini (8) tenglamaga qo‘yish bilan quvvat qiymatini aniqlaymiz:

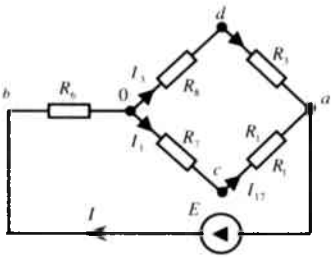
$$10 \cdot 0{,}95 + 15 \cdot 0{,}73 + 10 \cdot 1{,}68 + 5 \cdot 2{,}95 + 20 \cdot 1{,}27 + 2 \cdot (-6{,}84) =$$
$$= (0{,}95)^2 \cdot 5 + (0{,}73)^2 \cdot 4 + (1{,}68)^2 \cdot 5 + (2{,}95)^2 \cdot 4 + (1{,}27)^2 \cdot 5$$

Demak, quvvat muvozanati:

63,8 VT=63,8 VT

Masala 1.8. Ko‘prik sxemada ulangan elektr zanjir parametri: $R_1=R_3=R_5=50$ *Om*, $R_2=R_4=4$ *Om* bo‘lib, E=*30 V* o‘zgarmas manbaga ulangan. Uchburchak sxemadan ekvivalent yulduzcha sxemaga o‘tish bilan tarmoqdagi tok va sarf bo‘ladigan elektr tok quvvati aniqlansin.





Yechish.

Berilgan sxemadan b,c,d uchburchak sxema potensialini ekvivalent yulduzcha sxemaga o‘tish ifodasidan foydalanamiz:

$$R_6=\frac{R_2\cdot R_4}{R_2+R_4+R_5}=\frac{80\cdot 120}{320}=30\ Om$$

$$R_7=\frac{R_2\cdot R_5}{R_2+R_4+R_5}=\frac{120\cdot 120}{320}=45\ Om$$

$$R_8=\frac{R_4\cdot R_5}{R_2+R_4+R_5}=\frac{80\cdot 120}{320}=30\ Om$$

Tuzilgan yulduzcha sxemadan qarshilikni ketma-ket va parallel qo‘shish bilan zanjir umumiy qarshiligini aniqlaymiz:

$$R_{um}=R_6+\frac{(R_3+R_8)(R_1+R_7)}{R_3+R_8+R_1+R_7}=30+\frac{210\cdot 105}{315}=100\ Om$$

Tarmoqdagi tok: $I=\dfrac{E}{R_{um}}=\dfrac{30}{100}=0,3\ A$

Parallel tarmoqdagi tokni aniqlaymiz:

$$R_{17}=I\frac{R_8+R_3}{R_3+R_8+R_1+R_7}=\frac{210\cdot 0,3}{315}=0,2\ A$$

$$R_{38}=I\frac{R_1+R_7}{R_3+R_8+R_1+R_7}=\frac{105\cdot 0,3}{315}=0,1\ A$$

Bu yerda: $R_1=R_3$ ga teng bo‘lganligi uchun aniqlangan $I_{17}=I_1=0,2A$ va $I_{38}=I_3=0,1\ A$ ga teng.

Berilgan sxemaning qolgan tarmoqlaridan o‘tuvchi toklarni aniqlash uchun tugun potensialiga asosan tenglama tuzamiz:

$$U_{bc}=IR_6+I_1R_7=0,3\cdot 30+0,2\cdot 45=18\ V$$

$$U_{bd}=IR_6+I_3R_8=0,3\cdot 30+0,1\cdot 30=12\ V$$

$$U_{dc}=U_{bc}-U_{bd}=18-12=6\ V$$

Tarmoqdagi tok: $I_2=\dfrac{U_{bc}}{R_2}=\dfrac{18}{80}=0,225\ A$, $I_4=\dfrac{U_{bd}}{R_4}=\dfrac{12}{120}=0,1\,A$

$$I_5=\frac{U_{cd}}{R_5}=\frac{6}{120}=0,05\ A$$

Masalaning yechimini tekshirib ko‘ramiz.

Bunda: a – tarmoqdagi tok:

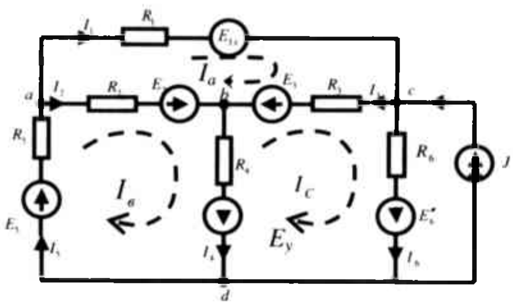
$$I = I_1 + I_3 = 0{,}2 + 0{,}1 = 0{,}3 \ A$$

b – tugundagi tok: $I = I_4 + I_2 = 0{,}1 + 0{,}225 = 0{,}3 \ A$

Zanjirda sarf bo'ladigan quvvat: $P = UI = I^2 R_{um} = 30 \cdot 0{,}3 = 9 \ VT$

Masala 1.9. Berilgan elektr tok sxemasining parametri: R_1=8 *Om*, R_2=*5 Om*, R_3=*4 Om*, R_4=*6 Om*, R_5=*6 Om*, R_6=*7 Om*, EYK lari: E_6=*30V*, E_2 = *30 V*, E_3 = *30 V*, E_4 = *40 V*, E_5 = *50 V* tok manbai J=*4A* va birinchi tarmoqdagi tok I_1=*2 A* bo'lib, konturli tok usuliga asosan tarmoqdagi tok, E_{1x} – EYK qiymati va ekvivalent generator usuliga asosan I_2 tarmoqdagi tok aniqlansin.

Yechish.

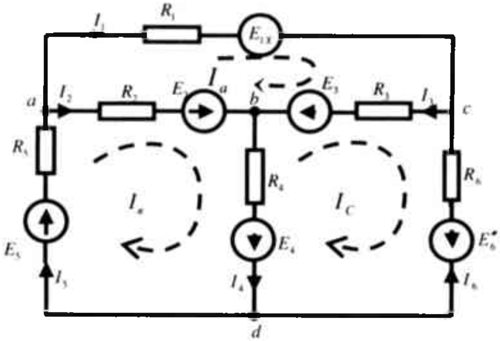


1.Tok manbaini ekvivalent kuchlanish manbai bilan almashtiramiz:

Bunda: $JR_6 = E_6'$; yoki $E_6' = 4 \cdot 7 = 28 \ V$;

Demak: $E_6'' = E_6 - E_6' = 30 - 28 = 2 \ V$;

2. Berilgan sxemani quyidagicha ekvivalent sxemaga keltiramiz.



Konturli tok usuliga asosan konturdagi tok I_a I_b I_c yo'nalishlari bo'yicha Kirxgof 2-qonuniga asosan tenglama tuzamiz:

$$\left.\begin{aligned} R_{11}I_a - R_{12}I_b - R_{13}I_c = E_a \\ -R_{21}I_a + R_{22}I_b - R_{23}I_c = E_b \\ -R_{31}I_a - R_{32}I_b - R_{33}I_c = E_c \end{aligned}\right\} \qquad (1)$$

Endi konturga kiruvchi qarshilikni aniqlaymiz:

$$R_{11} = R_1 + R_2 + R_3 = 17 \;\; Om$$

$$R_{22} = R_2 + R_4 + R_5 = 17 \;\; Om$$

$$R_{33} = R_3 + R_4 + R_6 = 17 \;\; Om$$

Konturni bog'lovchi konturlararo qarshilikni aniqlaymiz:

$$\left.\begin{aligned} R_{12} = R_{21} = R_2 = 5 \; Om \\ R_{31} = R_{13} = R_3 = 4 \; Om \\ R_{23} = R_{32} = R_4 = 6 \; Om \end{aligned}\right\}$$

Konturni tashkil etuvchi EYK ni aniqlaymiz:

$$E_a = E_{1X} + E_2 - E_3 = (E_{1X} - 17) \;\; V$$

$$E_в = E_2 + E_4 + E_5 = 140 \;\; V$$

$$E_c = E_6'' - E_4 - E_3 = -68 \;\; V$$

1– konturdagi tok: $I_a = I_1 = 2 \; A$

Aniqlangan qiymatni (1) tenglamaga qo'yamiz:

$$\left.\begin{aligned} 2 \cdot 17 - 5 \cdot I_b - 4 \cdot I_c = E_{1X} - 20 \\ -2 \cdot 5 + 17 \cdot I_b - 6 \cdot I_c = 140 \\ -2 \cdot 4 - 6I_b + 17 \cdot I_c = -68 \end{aligned}\right\} \qquad (2)$$

Ushbu tenglamadan noma'lum konturdagi tok (I_b,I_c)ni aniqlaymiz:

yoki: $$\left.\begin{aligned} 17I_b - 6I_c = 150 \\ -6I_b - 17I_c = -60 \end{aligned}\right\}$$

Bu tenglamani Kramer usuliga asosan yechamiz:

$$\Delta_a = \begin{vmatrix} 17 & -6 \\ -6 & 17 \end{vmatrix} = 289 - 36 = 253$$

$$\Delta_b = \begin{vmatrix} 150 & -6 \\ -60 & 17 \end{vmatrix} = 2550 - 360 = 2190$$

$$\Delta_c = \begin{vmatrix} 17 & 150 \\ -6 & -60 \end{vmatrix} = -1020 + 900 = -120$$

Bundan:

$$I_b = \frac{2190}{253} = 8{,}65A, \quad I_c = -\frac{120}{253} = -0{,}475$$

(2) tenglamadan E_{1x} – EYK qiymatini aniqlaymiz:

$E_{1x} = 54 - 5 \cdot 8,65 + 4 \cdot 0,475 = 12,65\ V$

Tarmoqdagi tokni aniqlaymiz:

$I_1 = 2A, \quad I_2 = I_a - I_b = 2 - 8,65 = -6,65\ A$

$I_3 = I_a - I_c = 2 + 0,475 = 2,475\ A$

$I_4 = I_b - I_c = 8,65 + 0,475 = 9,125\ A$

$I_5 = I_b = 8,65\ A$

$I_6 = -I_c = 0,475\ A$

Quvvat muvozanat tenglamasini tuzamiz:

$I_1^2R_1 + I_2^2R_2 + I_3^2R_3 + I_4^2R_4 + I_5^2R_5 + (I - I_2)R_6 =$

$E_1I_1 + E_2I_2 + E_3I_3 + E_4I_4 + E_5I_5 + E_6(I - I_6)$

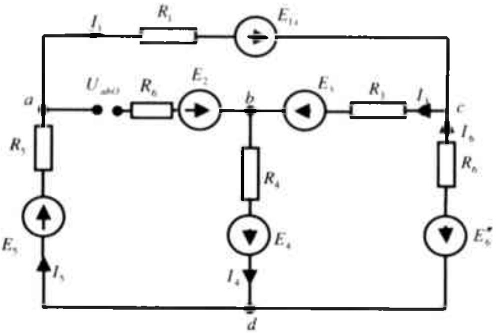
Bundan: $13335.86 \approx 13337$ *(VT)*

Hisoblashdagi xatolik *0,02%* ga teng.

3. Ekvivalent generator usuliga asosan I_2 tarmoqdagi tokni aniqlaymiz.

Bunda: $$I_2 = \frac{U_{ab0}}{R_o + R_2} \qquad (3)$$

Ekvivalent sxemasini chizamiz:



2- tarmoqda uzilish bo'lganda elektr sxema ikki tugunli potensial ayirmasi bilan ifodalanib $(\varphi_c - \varphi_d)$ tugunlararo potensiallar ayirmasi tenglamasiga asosan:

$$U_{cd} = \frac{\sum_{m=1}^{n} E_n g_n}{\sum_{m=1}^{n} g_n} = \frac{(E_5 + E_{1X})\frac{1}{R_1 + R_5} - (E_4 + E_3)\frac{1}{R_3 + R_4} - E_6'' \frac{1}{R_6}}{\frac{1}{R_1 + R_5} + \frac{1}{R_3 + R_4} + \frac{1}{R_6}} =$$

$$= \frac{\frac{62,65}{14} - \frac{70}{10} - 2\frac{1}{7}}{\frac{1}{14} + \frac{1}{10} + \frac{1}{7}} = -8,95\ V$$

Om qonuniga asosan tarmoqdagi tokni aniqlaymiz:

$$I_1 = I_5 = \frac{(E_5 + E_{1X}) - U_{cd}}{R_1 + R_5} = (62,65 + 8,95) \cdot \frac{1}{14} = 5,2A$$

$$I_3 = I_4 = \frac{(E_3 + E_4) + U_{cd}}{10} = \frac{70 - 8,95}{10} = 6,1A$$

$$I_6 = \frac{E_6'' + U_{cd}}{7} = \frac{2 - 8,95}{7} \approx -1$$

Potensial qiymatni aniqlaymiz:

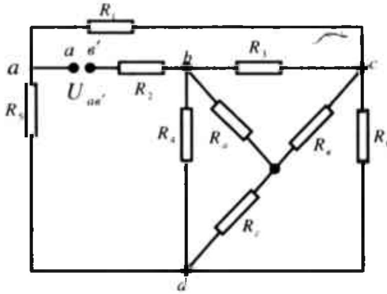
$$\varphi_a = \varphi_d + E_5 + I_5 R_5 = 0 + 50 - 5,2 \cdot 6 = 19,3\ V$$

$$\varphi_b = \varphi_d - E_4 + I_4 R_4 = 0 - 40 + 6,1 \cdot 6 = -3,37\ V$$

$$\varphi_b' = \varphi_b + E_2 = -3,37 - 50 = -53,37\ V$$

$$U_{abo} = \varphi_a - \varphi_b' = 19,3 + 53,37 = 72,67\ V$$

Endi (3) tenglamadagi R_0 – ichki ekvivalent qarshilikni aniqlaymiz. Buning uchun b, c, d potensiallarni birlashtiruvchi qarshilikni uchburchak sxemadan yulduzcha sxemaga keltirish formulasiga asosan ekvivalent sxemasini chizamiz:

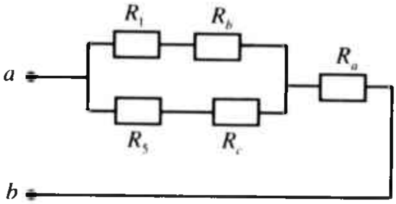


$$R_a = \frac{R_3 R_4}{R_3 + R_4 + R_6} = \frac{24}{17}(Om)$$

$$R_c = \frac{R_4 R_6}{R_3 + R_4 + R_6} = \frac{42}{17}(Om)$$

$$R_b = \frac{R_3 R_6}{R_3 + R_4 + R_6} = \frac{28}{17}(Om)$$

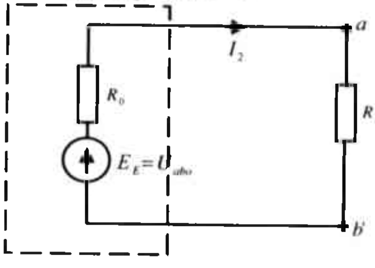
R_c qarshilikni R_5 bilan va R_1 qarshilikni R_b qarshilik bilan qo'shib ikkita parallel ulangan sxemaning umumiy qarshiligini topamiz:



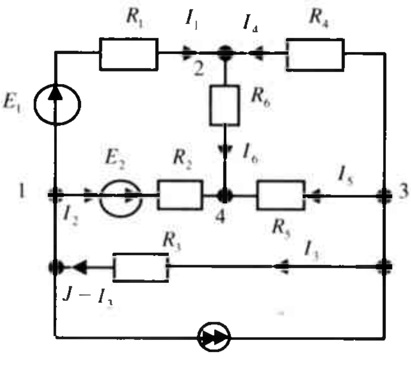
$$R_0 = R_{um} = \frac{(R_C + R_5)(R_b + R_1)}{R_C + R_5 + R_b + R_1} + R_a = 5{,}95(Om)$$

Uzilgan 2-tarmoqqa nisbatan ekvivalent sxemasini tuzamiz hamda aniqlangan qiymatni (3) tenglamaga qo'yish bilan I_2 tarmoqdagi tokni aniqlaymiz:

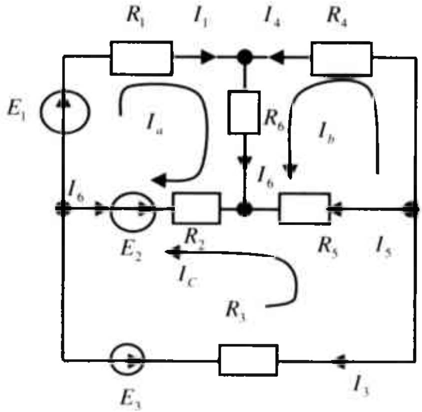
$$I_2 = \frac{U_{abo}}{R_0 + R_2} = \frac{72{,}6}{5{,}95 + 5} = 6{,}65\ (A)$$



Masala 1.10. Murakkab elektr zanjir tarmoqlaridagi qarshilik: $R_1 = R_2 = R_3 = 2\ Om$, $R_4 = R_5 = R_6 = 6\ Om$ va elektr yurituvchi kuch $E_1 = 68$, $E_2 = 12\ V$ bo'lib, tok manbai $J = 9\ A$ ga teng. Konturli tok va tugun potensiallari usullariga asosan tarmoqdagi tokni aniqlang.



a)



b)

Yechish. a) tok manbaini elektr yurituvchi kuchlar manbai bilan almashtirilgandan keyingi ekvivalent sxema uchun (b) konturli tok usuliga asosan tenglama tuzamiz: $E_3 = \mathcal{J} \cdot R_3 = 9 \cdot 2 = 18\,V$.

$$\left.\begin{aligned} I_a(R_1 + R_6 + R_2) + I_bR_6 + I_cR_2 &= E_1 - E_2 \\ I_aR_6 + I_b(R_4 + R_5 + R_6) - I_cR_5 &= 0 \\ I_aR_{2-} - I_bR_5 + I_c(R_2 + R_3 + R_5) &= E_3 - E_2 \end{aligned}\right\}$$

yoki:

$$\left.\begin{aligned} 10I_a + 6I_b + 2I_c &= -6 \\ 6I_a + 18I_b - 6I_c &= 0 \\ 2I_a - 6I_b + 10I_c &= 6 \end{aligned}\right\}$$

Tenglamalar sistemasini yechish bilan konturdagi tokni aniqlaymiz:

$I_a = I_1 = -1{,}5\,A$; $I_b = I_4 = 1a$; $I_c = I_3 = 1{,}5\,A$

Tarmoqdagi tokni aniqlaymiz:

$I_6 = I_a + I_b = -0{,}5\,A$; $I_5 = I_c - I_b = 0{,}5\,A$; $I_2 = -(I_a + I_c) = 0$

R_3 qarshilikdagi tok $\mathcal{J}\text{-}I_c = 9 - 1{,}5 = 7{,}5\,A$.

I_a va I_6 ishorasi tokning haqiqiy qiymati teskari ekanligini ifodalaydi.

b) **tugun potensial usuliga** asosan sxemadan 2-tugun potensialini $\varphi_2 = 0$ deb olamiz.

Bunda:

$$\left.\begin{aligned}
&\varphi_1(g_1+g_2+g_3)-\varphi_3 g_3-\varphi_4 g_2=-E_1g_1-E_2g_2-E_3g_3\\
&-\varphi_1 g_3+\varphi_3(g_3+g_4+g_5)-\varphi_4 g_5=E_3g_3\\
&-\varphi_1 g_2-\varphi_3 g_5+\varphi_4(g_2+g_5+g_6)=E_2R_2
\end{aligned}\right\}$$

yoki:
$$\left.\begin{aligned}
&3\varphi_1-\varphi_2-\varphi_4=-36\\
&-3\varphi_1+\varphi_3-5\varphi_4=36\\
&-3\varphi_1+5\varphi_3-\varphi_4=54
\end{aligned}\right\}$$

Tenglamani yechish bilan tugun potensiallar qiymatini topamiz: $\varphi_1=-9\ V;\ \varphi_3=6\ V;\ \varphi_4=3\ V.$

Bundan, tarmoqdagi tokni Om qonuniga asosan aniqlaymiz:

$$I_1=(\varphi_2-\varphi_1-E_1)g_1=(0+9-6)\frac{1}{2}=1{,}5\ A$$

$$I_2=(\varphi_1-\varphi_4+E_1)g_2=(-9-3+12)\frac{1}{2}=0$$

$$J\text{-}I_3=(\varphi_3-\varphi_1)g_3=(6+9)\frac{1}{2}=7{,}5\ A$$

$$I_4=(\varphi_3-\varphi_2)g_4=(6-0)\frac{1}{6}=1\ A$$

$$I_5=(\varphi_3-\varphi_4)g_5=(6-3)\frac{1}{6}=0{,}5\ A$$

$$I_6=(\varphi_4-\varphi_2)g_6=(3-0)\frac{1}{6}=0{,}5\ A.$$

Quvvat muvozanat tenglamasiga asosan:

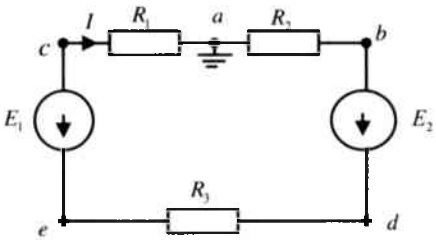
$$\sum P_{manba}=\sum P_{iste'molchi}$$

$$E_1I_1+E_2I_2+E_3I_3=I_1^2R_1+I_2^2R_2+I_3^2R_3+I_4^2\cdot R_4+I_5^2R_5+I_6^2R_6.$$

Demak: $P_{manba}=36\ VT=\ P_{iste'm}=36\ VT.$

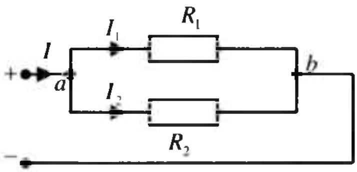
1.3. Mustaqil yechish uchun masalalar

Masala 1.1. Ketma-ket sxemada ulangan elektr zanjir parametri: $E_1=20\ V,\ E_2=12V,\ R_1=5\ Om,\ R_2=6\ Om,\ R_3=9\ Om$ ga teng. Tarmoqdagi tok va potensiallari aniqlanib, potensiallar diagrammasi tuzilsin.



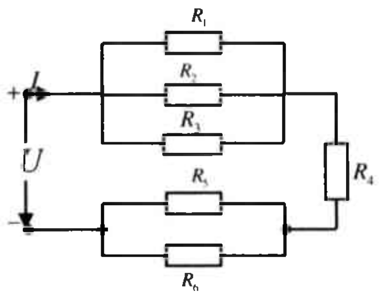
Javob: $I=0,4\ A$, $\varphi_a=0$, $\varphi_b=2,4\ V$, $\varphi_d=-14,4\ V$, $\varphi_e=-18\ V$, $\varphi_c=2\ V$

Masala 1.2. Parallel sxemada biriktirilgan elektr zanjirning *a* va *b* tugun potensiallaridagi kuchlanish $U_{ab}=60\ V$ bo'lib, kiruvchi tarmoqdagi tok $I=1,5\ A$ va qarshilik $R_2=120\ Om$ ga teng. Tarmoqdagi tok qarshiligi va ekvivalent qarshiligini aniqlang.



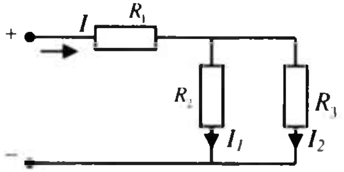
Javob: $R_1=60\ Om$, $R_{ekv}=40\ Om$, $I_1=1\ A$, $I_2=0,5\ A$,

Masala 1.3. Aralash sxemada biriktirilgan elektr zanjir $U=26\ V$ kuchlanishga ulangan bo'lib, qarshilik parametri: $R_1=8\ Om$, $R_2=14\ Om$, $R_3=4\ Om$, $R_4=5,16\ Om$, $R_5=7,5\ Om$, $R_6=5\ Om$. Zanjirning ekvivalent qarshiligi hamda tarmoqdagi tokni aniqlang.



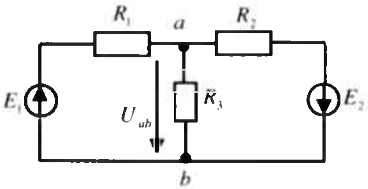
Javob: $R_{ekv}=10,4\ Om$, $I=2,5\ A$, $I_1=0,7\ A$, $I_2=0,4\ A$, $I_3=1,4\ A$, $I_5=1\ A$, $I_6=1,5A$.

Masala 1.4. Elektr zanjir $U=60\ V$ kuchlanishga ulanganda $P=300Vt$ quvvat sarflanadi. Qarshilik parametri $R_2=15\ Om$, $R_3=5\ Om$ ga teng bo'lganda, R_1 qarshilik qiymati va tarmoqdagi tokni aniqlang.



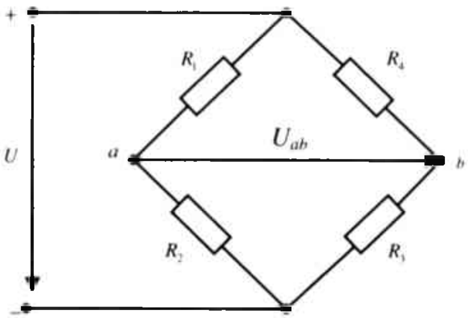
Javob: $R_1=8{,}25Om$, $I_1=3{,}75\ A$, $I_2=1{,}25\ A$, $I=5\ A$.

Masala 1.5. Keltirilgan sxemada $E_1=12V$, $E_2=24V$, $R_1=R_2=2Om$, $R_3=10\ Om$ bo'lsa, φ_a va φ_b tugunlar orasidagi kuchlanish necha voltga teng.



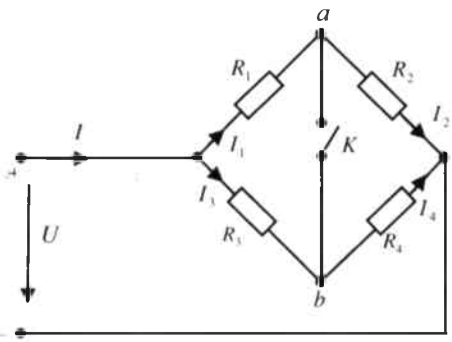
Javob: $U_{ab} = 9\ V$.

Masala 1.6. Ko'prik sxemada ulangan zanjir qarshilik parametri $R_1=10\ Om$, $R_2=20\ Om$, $R_3=40\ Om$, $R_4=30\ Om$ bo'lib, $U=210\ V$ kuchlanishga ulangan. U_{ab} – potensial kuchlanishl aniqlansin.



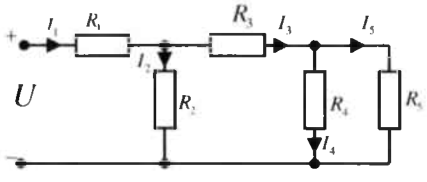
Javob: $U_{ab}=20\ V$

Masala 1.7. Qarshiliklari ko'prik sxemada ulangan zanjir parametri: $R_1=10$ *Om*, $R_2=20$ *Om*, $R_3=40$ *Om*, $R_4=30$ *Om*, kuchlanish $U=15,6$ *V*. Kalit ulangan va uzilgan hollar uchun ekvivalent qarshilik va qarshilikdan o'tuvchi tok qiymati aniqlansin.



Javob: *a)* $R_{ekv}=8$ *Om*, $I=1,95$ *A*, $I_1=I_2=0,65$ *A*, $I_3=I_4=1,3$ *A*,
b) $R_{ekv}=7,8$ *Om*, $I=2$ *A*, $I_1=0,5$ *A*, $I_2=0,8$ *A*, $I_3=1,5$ *A*, $I_4=1,2$ *A*,

Masala 1.8. Aralash sxemada ulangan elektr zanjir parametri: $R_1=50$ *Om*, $R_2=80$ *Om*, $R_3=20$ *Om*, $R_4=30$ *Om*, $R_5=60$ *Om* bo'lib, to'rtinchi tarmoqdan o'tuvchi tok $I_4=0,2$ *A* ga teng. Tarmoqdagi tok, zanjir umumiy kuchlanishi va sarf bo'ladigan elektr quvvat aniqlansin.

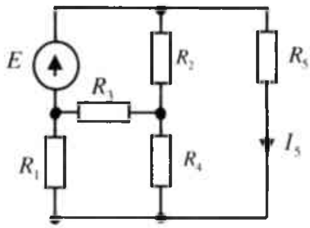


Javob: $U=34,5$ *V*, $P=15,5$ *Vt*

Masala 1.9. 1.7 masalada berilgan sxema parametri qiymati bo'yicha $U=50$ *V* kuchlanishga ulangan. I_4 tarmoqdagi tok va sarf bo'ladigan quvvat aniqlansin.

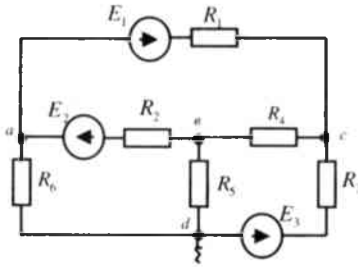
Javob: P=*32,5 Vt*, $I_4=290$ *mA*

Masala 1.10. Berilgan elektr sxemaning qarshilik parametri: $R_1=4Om$, $R_2=6\ Om$, $R_3=3\ Om$, $R_4=20\ Om$, $R_5=8{,}5\ Om$. EYK $E=24\ V$. Konturli tok va ekvivalent generator usuliga asosan beshinchl tarmoqdan o'tuvchi I_5 tok aniqlansin.



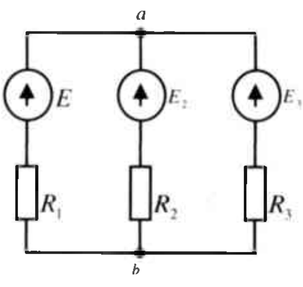
Javob: $I_5=2\ A$

Masala 1.11. Berilgan elektr zanjir qarshilik parametri: $R_1=R_3=R_6=3\ Om$, $R_2=R_4=R_5=1\ Om$, EYK $E_1=E_2=E_3=48V$. Konturli tok va tugunlararo kuchlanish usuliga asosan tarmoqdagi tok aniqlansin.



Javob: $I_4=8\ A$, $I_1=5{,}33\ A$, $I_2=8\ A$, $I_3=13{,}33\ A$, $I_5=0$, $I_6=13{,}33\ A$,

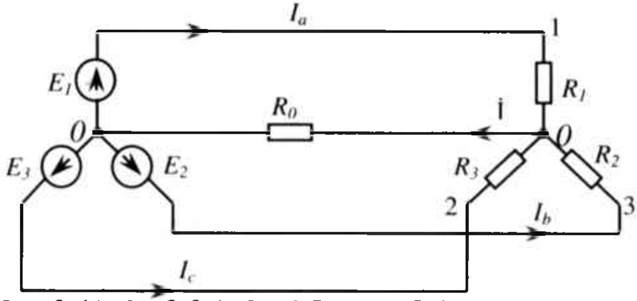
Masala 1.12. Berilgan elektr sxemanimg parametri: $E_1=40\ V$, $E_2=5V$, $E_3=30\ V$, $R_1=5\ Om$, $R_2=1\ Om$, $R_3=3\ Om$. Ikkita tugun orasida



potensiallar kuchlanishi va ustma-ustlik usuliga asosan tarmoqdagi tok aniqlansin.

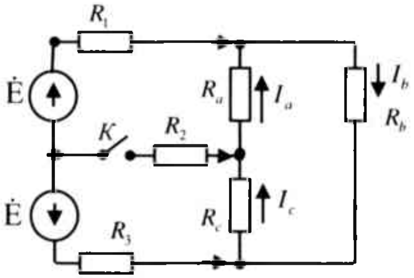
Javob: $I_1=5A$, $I_2=10\ A$, $I_3=5\ A$

Masala 1.13. Berilgan sxema parametri: $R_1=10\ Om$, $R_2=20\ Om$, $R_3=4\ Om$. EYK $E_1=20V$, $E_2=100\ V$, $E_3=80\ V$ bo‘lganda, tugunlararo kuchlanish usuliga asosan tarmoqdagi tok aniqlansin.



Javob: $I_1=-3,4A$, $I_2=2,3\ A$, $I_3=6,5\ A$, $I_4=-5,4\ A$

Masala 1.14. Berilgan elektr zanjir parametri: $R_1=R_2=R_3=10\ Om$, $R_a=25\ Om$, $R_b=50\ Om$, $R_c=50\ Om$ bo‘lib, $E_1=E_2=120\ V$ o‘zgarmas tok manbaga ulangan. Kalit (K) ulangan holat uchun tarmoqdagi tok aniqlansin.

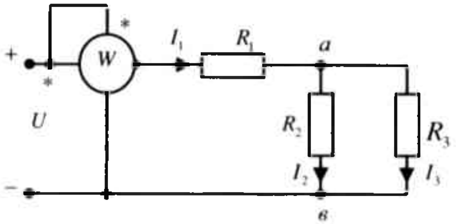


Javob: $I_a=2,4\ A$, $I_b=-2,85\ A$, $I_c=1,65\ A$

Masala 1.15. 1.13. masalada berilgan sxema sharti bo‘yicha $I_a=2A$, $I_b=-3\ A$, $I_C=2\ A$ (tok yo‘nalishi strelka ko‘rsatishiga mos) bo‘lganda E_1 va E_2 manba kuchlanishlari aniqlansin.

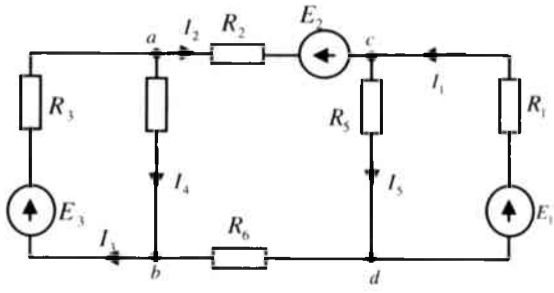
Javob: $E_1=100\ V$, $E_2=-150\ V$

Masala 1.16. Aralash sxemada ulangan elektr zanjir qarshilik parametri: $R_2=20\ Om$, $R_3=30\ Om$ bo'lib, $U=625\ V$ kuchlanishga ulangan. Vattmetr ko'rsatishi $P=32{,}25\ KVt$ bo'lgan holatda R_1 – qarshilik, tarmoqdagi tok I_2, I_3 va R_2, R_3 qarshiliklarda sarf bo'ladigan quvvat aniqlansin.



Javob: $I_2=3\ A$, $I_3=2\ A$, $R_1=113\ Om$, $P_2=180\ Vt$, $P_3=120\ Vt$

Masala 1.17. Berilgan elektr zanjirning parametri: $R_1=6\ Om$, $R_2=2Om$, $R_3=2\ Om$, $R_4=6\ Om$, $R_5=2\ Om$, $R_6=6\ Om$, EYK $E_1=80V$, $E_2=6\ V$, $E_3=120\ V$ bo'lib, birinchi tarmoq toki $I_1=8\ A$ ga teng. Om va Kirxgof qonunga asosan tarmoqdagi tok aniqlansin.



Javob: $I_2=8\ A$, $I_3=21\ A$, $I_4=13\ A$, $I_5=16\ A$

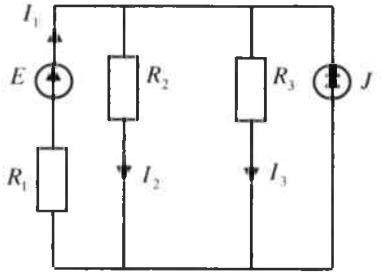
Masala 1.18. Elektr isitgich $U=220\ V$ kuchlanishga mo'ljallangan bo'lib, P=600 Vt elektr sarflaydi. Agar shu elektr isitgich $U=110\ V$ kuchlanishga ulanganda qancha quvvat sarflanadi.

Javob: P=150 Vt

Masala 1.19. Elektr tok quvvati $P=40\ Vt$ bo'lgan 10 ta lampochka har kuni 6 soat yonadi. 30 kun davomida sarf bo'ladigan elektr energiyasi aniqlanib, 1 kVt/soat energiya 135 so'm bo'lganda, bir oylik xarajat hisoblab topilsin.

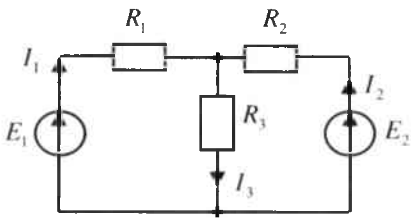
Javob: *W=72 kVt/soat,* sarf puli: *11720 so'm.*

Masala 1.20. Elektr zanjir manba qiymatlari: $E = 32\,V$, $J = 18\,A$, qarshiligi $R_1 = 1\,Om$, $R_2 = 6\,Om$, $R_3 = 2\,Om$ ga teng. Konturli tok, tugun potensiali va ustma-ustlik usullariga asosan tarmoqdagi tok aniqlansin.



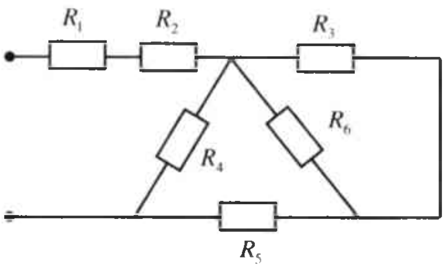
Javob: $I_1 = 2\,A$, $I_2 = 5\,A$, $I_3 = 15\,A$.

Masala 1.21. Elektr zanjir parametri: $R_1 = R_2 = R_3 = 2\,om$, EYK $E_1 = 24V$, $E_2 = 18V$ bo'lganda, Kirxgof qonuni va ustma-ustlik usullariga asosan tarmoqdagi tok hamda sarf bo'ladigan elektr quvvat qiymati topilsin:



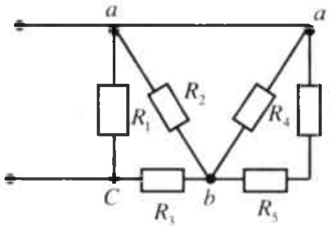
Javob: $I_1 = 5A, I_2 = 2A, I_3 = 7A$

Masala 1.22. Elektr zanjir qarshiligi $R_1 = R_2 = R_3 = R_5 = 5{,}5\,Om$, $R_4 = 12\,Om$, $R_6 = 3{,}25\,Om$ bo'lganda, umumiy qarshilik (R_{um}) aniqlansin.



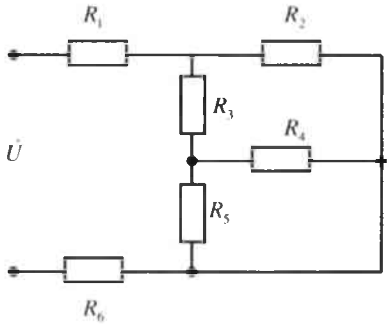
Javob: $R_{um} = 15\,Om$.

Masala 1.23. Elektr zanjir qarshiligi: $R_1 = R_4 = 60\ Om$, $R_2 = R_5 = 40\ Om$, $R_3 = 10\ Om$, $R_6 = 80\ Om$ bo‘lganda, umumiy qarshilik (R_{um}) aniqlansin.



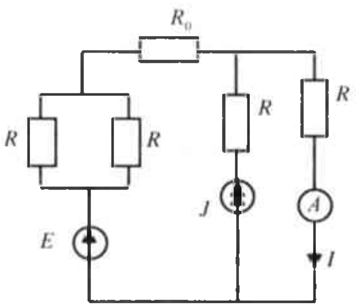
Javob: $R_{um} = 20\ Om.$

Masala 1.24. Elektr zanjir parametri $R_1 = R_6 = 4{,}5\ Om$, $R_2 = 22\ Om$, $R_3 = 7{,}6\ Om$, $R_4 = 24\ Om$, $R_5 = 36\ Om$ bo‘lib, $U = 120\ V$ kuchlanishga ulangan. Tarmoqdagi tokni aniqlang.



Javob: $I_1 = 6A$, $I_2 = I_3 = 3A$, $I_4 = 1{,}8A$, $I_5 = 1{,}2A$

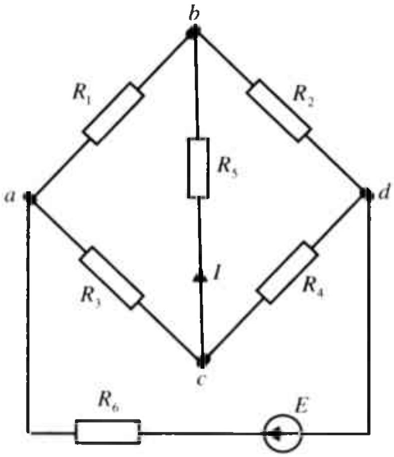
Masala 1.25. Ekvivalent generator usuliga asosan, elektr zanjir parametri $R = 1\ Om$, $R_0 = 0{,}5\ Om$, $E = 1\ V$, $J = 1\ A$ bo‘lganda ampremetr qancha tok ko‘rsatadi.



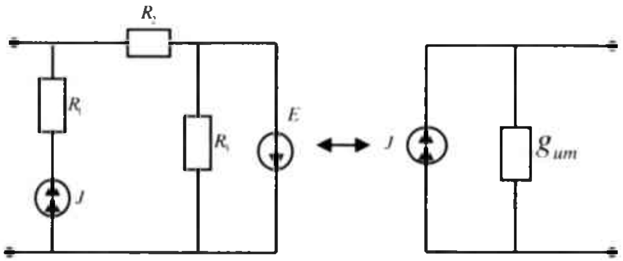
Javob: $I = 1\ A$

Masala 1.26. Ko'prik sxema parametri: R_1=120*Om*, R_2=180*Om*, R_3=120*Om*, R_4=80*Om*, R_5=80*Om*, R_6=50*Om*, EYK E=12 *V*. 5-tarmoqdagi tok I aniqlansin.

Javob: $I = -0{,}0084\ A$



Masala 1.27: a) aktiv ikki qutbli zanjir parametri: $R_1 = 8\ Om$, $R_2 = 6\ om$, $R_3 = 4\ Om$, $E = 6\ V$, $J = 2\ A$ ga teng. Ekvivalent tok manbai bo'lgan zanjirning (g_{um}) o'tkazuvchanligi va tok qiymati aniqlansin.



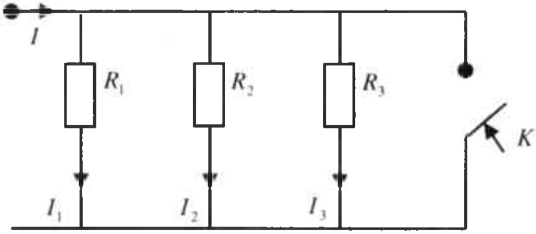
Javob: $g_{um} = \frac{1}{6}$ sim. J = 1 A.

1.4. Nazorat savollari

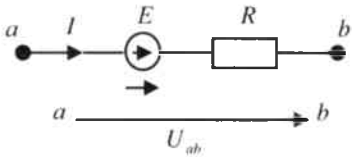
1. Elektrotexnika fani nimani o'rgatadi?
2. O'zbekiston energetikasining rivojlanish tarixidan nimalarni bilasiz?
3. Elektr zanjir qanday qismlardan iborat?
4. O'zgarmas tok manbalarini bilasizmi?
5. EYK va tok manbai nima?
6. Elektr zanjir asosiy elementlari haqida ma'lumot bering.

7. Tarmoqlangan elektr zanjirlarni chlzib, tarmoq, tugun, kontur nima ekanligini izohiab bering.
8. Elektr maydon kuchlanganligi nima?
9. Elektr sig'imni izohlab bering va o'lchov birligi nima?
10. Elektr maydonining kuch chiziqlari ekvipotensial sirtga nisbatan qanday yo'nalgan?
11. Sig'imi C=0,1 *mkF* bo'lgan havoli kondensator qoplamalari orasidagi masofa 0,5 *mm* ga teng bo'lsa, qoplamaning yuzasi (S) qancha bo'hshi kerak?
12. Kuchlanish U=1 *kV*, sig'imi C=0,1 *mkF* bo'lgan kondensatorda qancha miqdorda energiya to'planadi?
13. Kondensatorlarning ketma-ket yoki parallel sxemada ulanishidan maqsad nima?
14. Nuqtaviy zaryadlangan zarrachalarning o'zaro ta'sir kuchi qaysi qonunga asosan aniqlanadi?
15. Potensiallar farqi, kuchlanish nima va o'lchov birligi nimadan iborat?
16. Zanjirning bir qismi va butun zanjir uchun Onı qonunini yozing.
17. Elektr zanjiri uchun Kirxgof qonunini ifodalab bering.
18. Elektr tok quvvati, (aktiv quvvat) qanday ifodalanadi va nimada o'lchanadi?
19. Elektr o'lchov asboblari: ampermetr, voltmetr va vattmetr elektr sxemaga qanday ulanadi?
20. Elektr manbai tashqi xarakteristikasini chizing va izoh bering. Qisqa tutashuv va salt holat deganda nimani tushunasiz?
21. Murakkab elektr zanjirni hisoblash usullariga izoh bering.
22. Potensial diagramma nima va u qanday chiziladi?
23. Quvvat balans tenglamasini yozing.
24. Qaysi holatda ekvivalent generator usulidan foydalanish qulay hisoblanadi va qanday amalga oshiriladi?
25. Aktiv va passiv ikki qutbli zanjir nima?
26. Elektr va magnit maydon energiyasi ifodasini yozing.
27. Ikkita potensialdan iborat bo'lgan sxema uchun tugunlararo usuliga asosan tenglama tuzing.
28. Ustma-ustlik usulini izohlab bering.

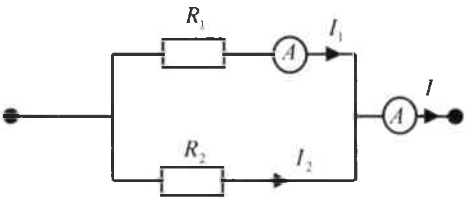
29. Yulduzchadan uchburchakga o‘tish va aksincha holat almashtirish formulasini yozing.
30. Ikki qutbli liniyadan iste’molchiga maksimal quvvat uzatish shartini tushuntiring va tenglamasini yozing.
31. Aktiv qarshilik yoki o‘tkazuvchanlik qanday ifodalanadi?
32. Manbaning ichki qarshiligi deganda nimani tushunasiz?
33. Elektr tok energiyasi bajargan ish tenglamasi qanday ifodalanadi?
34. Kuchlanishi 24 V bo‘lgan manbaga ikkita qarshilik – $R_1 = 20\ Om$; $R_2 = 28\ Om$ ketma-ket ulangan. Tok necha amperga teng?
35. Ikkita qarshiligi bo‘lgan tok zanjiri parallel ulanganda, umumiy qarshiligini ifodalang.
36. Parallel zanjirda K – kalit ulanganda tok qanday o‘zgaradi?



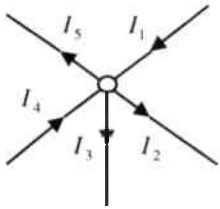
37.Ushbu sxemada tok qanday ifodalanadi?



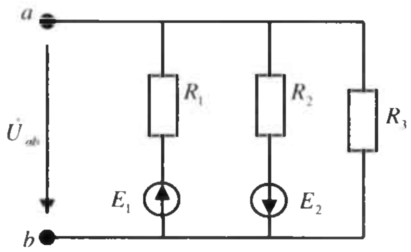
38.Parallel sxemada ulangan zanjirdagi tok $I_1 = 5\ A, I = 8\ A$ qarshiligi $R_1 = 3\ Om$ bo‘lganda, R_2 qarshilik qanchaga teng?



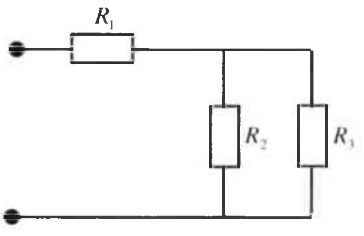
39. Tugun uchun Kirxgof 1-qonuniga asosan tenglama tuzing.



40. Parallel zanjir uchun ekvivalent kuchlanish ifodasiga asosan ekvivalent tok manbai sxemasi chizilsin .



41. Aralash sxemada ulangan zanjir qarshiligi R_1=10 *Om*, R_2=R_3=*4 Om* bo‘lib, $U = 40\,V$ kuchlanishga ulanganda qancha aktiv quvvat sarflanadi?



42.Elektr quvvati P= 600 *VT* bo‘lgan issiqlik manbai (pechka) 5 soat davomida qancha elektr energiya sarflaydi?

II. SINUSOIDAL TOK ELEKTR ZANJIR

2.1. Asosiy nazariy tushunchalar

Sinusoidal davriy o‘zgaruvchan tok, kuchlanishl va EYK oniy qiymati quyidagi funksiya ko‘rinishda ifodalanadi.

$$i = I_m \sin(\omega t + \varphi_i); \quad u = U_m \sin(\omega t + \varphi_u);$$

$$e = E_m \sin(\omega t + \varphi_u) \qquad (2.1)$$

Bunda:

i – sinusoidal o‘zgaruvchan tokning oniy qiymati

I_m – amplituda, yoki maksimal qiymat

φ_i – boshlang‘ich faza (*grad*)

ω – burchak chastota (*rad/sek*)

f – chastota (*Gs*)

T – davr (*sek*)

Sinusoidal o‘zgaruvchan toknmg effektiv yoki ta’sir etuvchi qiymati:

$$I = \sqrt{\frac{1}{T}\int_0^T i_2 dt} = \frac{I_m}{\sqrt{2}} \qquad (2.2)$$

Sinusoidal o‘zgaruvchan tokning yarim davrdagi o‘rtacha qiymati:

$$I_{ur} = \frac{2}{T}\int_0^{\frac{T}{2}} i dt = \frac{2}{\pi} I_m \qquad (2.3)$$

Sinusoidal o‘zgaruvchan tokning forma va amplituda koeffitsienti:

$$K_f = \frac{I}{i_{or}}; \quad K_a = \frac{I_m}{I}; \qquad (2.4)$$

Sinusoidal o‘zgaruvchan elektr zanjir uchun Om qonuni:

$$I = \frac{U}{z} = Uy\,(A); \qquad (2.5)$$

yoki burchak koeffitsientlari:

$$\cos\varphi = \frac{R}{z} = \frac{g}{y}; \qquad \sin\varphi = \frac{x}{y} = \frac{b}{y};$$

$$\mathrm{tg}\,\varphi = \frac{x}{R} = \frac{b}{g}; \qquad \varphi = arcctg\frac{x}{R} = \frac{b}{g}; \qquad (2.6)$$

To'la qarshilik:

$$Z = \sqrt{R^2 + x^2}\ (Om); \qquad (2.7)$$

Ketma-ket ulangan R – aktiv; L – induktiv; C – sig'im qarshiliklar bo'lganda, reaktiv qarshilik:

$$X = X_L - X_c \qquad (2.8)$$

Elektr zanjir induktiv xarakterga ega bo'lganda:

$$\omega L > \frac{1}{\omega c}; \quad \varphi > 0$$

Sig'im xarakterga ega bo'lsa: $\omega L < \frac{1}{\omega c}; \quad \varphi < 0$.

To'la o'tkazuvchanlik:

$$y = \sqrt{g^2 + b^2}\left(\frac{1}{Om} = simens\right); \qquad (2.9)$$

Ekvivalent parametr o'xshashlik tenglamasi:

$$g = \frac{R}{z^2}; \qquad b = \frac{X}{z^2}; \qquad y = \frac{1}{z}; \qquad (2.10)$$

$$R = \frac{g}{y^2}; \qquad X = \frac{b}{y^2}; \qquad z = \frac{1}{y}; \qquad (2.11)$$

Iste'molchi ketma-ket ulangan elektr zanjirlarda ekvivalent qarshilik:

$$R_e = \sum_{\kappa=1}^{n} R_n; \qquad X_e = \sum_{\kappa=1}^{n} X_n \qquad (2.12)$$

Parallel ulangan holda:

$$g_e = \sum_{\kappa=1}^{n} g_n; \qquad b_e = \sum_{\kappa=1}^{n} b_n \qquad (2.13)$$

Tok va kuchlanishning aktiv va reaktiv tashkil etuvchilari:

$$U_a = IR = U\cos\varphi; \qquad I_a = Ug = I\cos\varphi;$$

$$U_p = I_X = U \sin \varphi ; \qquad I_p = Ub = I \sin \varphi ; \qquad (2.\ 14)$$

$$U = \sqrt{Ua^2 + Up^2} ; \qquad I = \sqrt{Ia^2 + Ip^2} ;$$

1. Sinusoidal o‘zgaruvchan tokning quvvat ifodasi:

Sinusoidal o‘zgaruvchan tokning oniy qiymati $\varphi = 0$ bo‘lganda:

$$R = ui\left[\cos\varphi - \cos(2\varphi t - \varphi)\right] \qquad (2.\ 15)$$

Aktiv quvvat:

$$P = UI \cos \varphi = I^2R = U^2g = U I_a = U_a I \text{[Vt, kVt]} \qquad (2.\ 16)$$

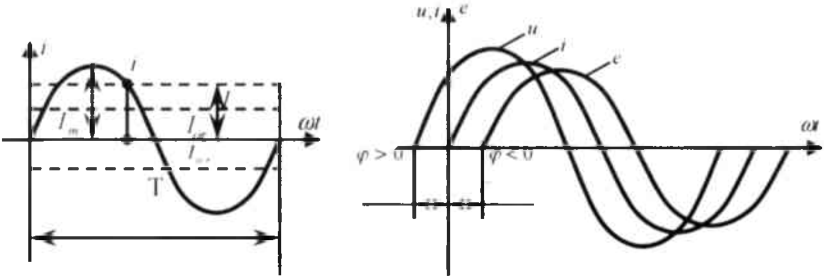
Reaktiv quvvat:

$$Q = UI \sin \varphi = I^2x = U^2b = U I_p = U_p I \quad \text{[Var, kVar]} \qquad (2.\ 17)$$

To‘la quvvat:

$$S = \sqrt{P^2 + Q^2} = UI = I^2z = U^2y \text{ [Va, kVa]} \qquad (2.\ 18)$$

2. Sinusoidal o‘zgaruvchan tok, kuchlanish va EYK grafik ifodasi:



Analitik ifodasi:

$$e = E_m \sin(\omega t + \phi_1); \; u = U_m \sin(\omega t + \varphi_u); \; i = I_m \sin(\omega t + \varphi_i) \qquad (2.\ 19)$$

Faza farqi: $$\varphi = \varphi_u - \varphi_i \qquad (2.\ 20)$$

3. Sinusoidal o‘zgaruvchan tokning vektor ifodasi yoki vektor diagrammasini tuzishda quyidagilarga e’tibor berish zarur:

a) aktiv qarshilikda tok va kuchlanish vektori ustma-ust tushadi (φ=0);

b) induktivlikda kuchlanish vektori U, tok vektori I ga nisbatan 90° farq qilib, oldinga ketadi ($\varphi>0$);

d) sig'im qarshilikda kuchlanish U, I tokka nisbatan 90° orqada qoladi ($\varphi<0$).

e) elektromagnit induksiya (o'z induksiya, o'zaro induksiya) qonuniga asosan induktivlikda, o'zgaruvchan tok hosil qiluvchi elektr yurituvchi kuch vektori E, magnit oqim vektori Ф yoki Ψ nisbatan 90° farq qilib, orqada qoladi ($\varphi_c = -90^\circ$).

f) induktivlik kuchlanish U_L vektoriga nisbatan EYK vektori E 180° farq qilib, teng va qarama-qarshi yo'nalishda ifodalanadi.

g) qarshiliklar uchburchak vektor ifodasidan R va Z hamda g va u orasidagi burchak φ ga teng.

2.2. Masalalar yechish va usluhiy ko'rsatmalar

Masala 2.1. O'zgaruvchan magnit oqimi *Ф=0,01sin314t (vb)* bo'lib, chulg'amlar soni W=50 bo'lganda g'altak aylanma harakatlanishi natijasida hosil bo'ladigan EYKni aniqlang.

Yechish.

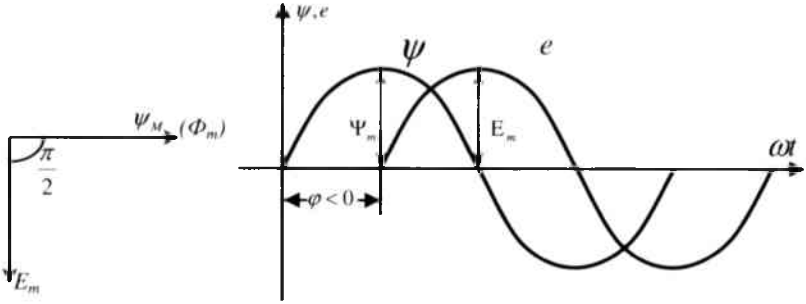
G'altakning ilashgan magnit oqimi: $\psi = w\phi = 0{,}5\sin 314t = \psi_m \sin t$

O'zinduksiya qonuniga asosan:

$$e = -\frac{d\psi}{dt} = \omega\psi_m \cos\omega t = E_m \sin(\omega t - 90^\circ) \text{ yoki: } E_m = \omega\psi_m = 157(V)$$

EYK effektiv qiymati: $E = \frac{E_m}{\sqrt{2}} = 90(V)$

Vektor ifodasi va vaqt bo'yicha o'zgaruvchan grafigini chizamiz.



Masala 2.2. O'ramlar soni W =20, yuzasi S = 100 (sm^2) bo'lgan halqa, magnit induksiyasi B=2 (vb/m) teng bo'lgan magnit maydon ichida n=6000 (ayl/min) tezlik bilan aylanganda, halqada hosil bo'ladigan magnit oqim, oniy qiymat, EYK amplitudasi, davri va chastotasi aniqlanib, vektor ifodasi va vaqtga nisbatan o'zgaruvchan diagrammasi tuzilsin.

Yechish.

Halqanimg boshlang'ich holati $\alpha = 0$, $\alpha = \omega t$ bo'lib, halqa aylanishi natijasida kesib o'tuvchi magnit oqimning oniy qiymati:

$$\Phi = BS\cos\alpha = \Phi_m \cos\omega t$$

Halqada hosil bo'ladigan ilashgan magnit oqim oniy qiymati:

$$\psi = \Phi W = W\Phi_m \cos\omega t = WBC\cos\omega t = \psi_m \cos\omega t =$$

$$= 20\cdot 2\cdot 100\cdot 10^{-4} cos 628t = 0,4\sin(628t + 90°)$$

Bunda:

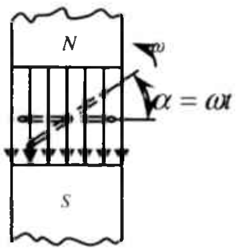
$$\omega = \frac{2\pi n}{60} = \frac{2\cdot 3,146000}{60} = 628\left(\frac{1}{sek}\right)$$ - burchak chastota

Halqada hosil bo'ladigan EYK oniy qiymati:

$$e = -\frac{d\Psi_m}{dt} = -\frac{d}{dt}(\Psi_m \cos\omega t) = \omega\Psi_m \sin\omega t =$$

$$= E_m \sin\omega t = 251,2\sin 628t$$

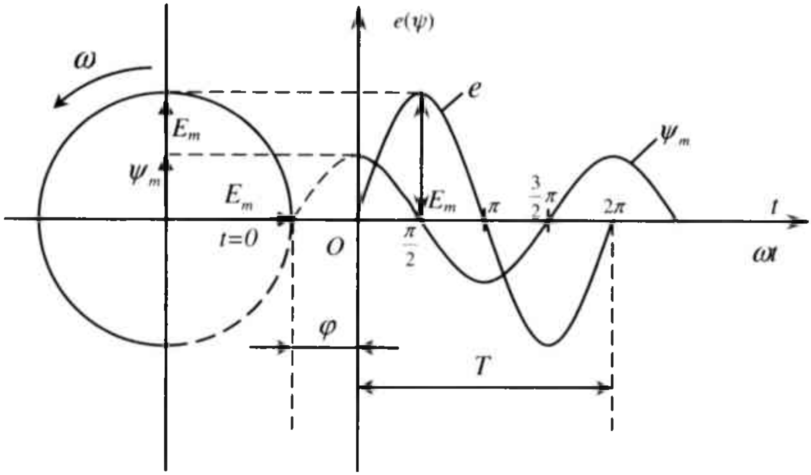
Halqa T davrda bir marotaba aylanadi: $\omega T = 2\pi$



Bundan: $T = \frac{2\pi}{\omega} = 0,01(sek)$

O'zgaruvchan tok chastotasi: $f = \frac{1}{T} = \frac{1}{0,01} = 100\,(Gs)$

Vektor ifodasi chizmada keltirilgan:



Masala 2.3. O'ramlar soni ψ bo'lgan aylanma harakatlanuvchi g'altakda induksiyalangan EYK to'g'ri burchakli impulsli formaga ega bo'lib, EYK amplitudasi: $E_m=10\ (V)$ va $f=50\ (Gs)$ ga teng. EYK E o'rtacha va effektiv qiymati, amplituda va forma koeffitsienti hamda magnit oqimi qiymatini aniqlang.

Yechish.

EYK o'rtacha qiymati: $E_{o'r}=\frac{2}{T}\int_0^{\frac{T}{2}} e dt=\frac{2}{T}E_m\frac{T}{2}=E_m=10\ (V)$

Effektiv qiymat: $E=\sqrt{\frac{1}{T}\int_0^T e^2 dt}=\sqrt{\frac{1}{T}E_m{}^2T}=E_m=10(V)$

Amplituda va forma koeffitsienti: $K_a=\frac{E_m}{E}=1, K_\Phi=\frac{E}{E_{o'r}}=1$

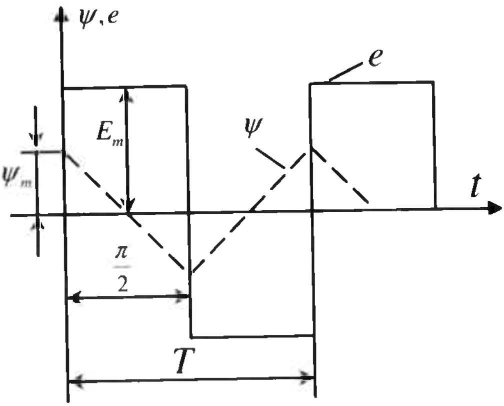
O'zinduksiya qonuniga asosan: $\psi=-\int e dt$

Keltirilgan funksiyada ψ to'g'ri burchakli uchburchak shaklida o'zgaruvchan bo'lib, T = 0,02 *sek* = 20 *m sek* teng, yoki:

$$E_{ur}=\frac{\Delta\psi}{\Delta t}$$

Bundan $\Delta\psi = E_{o'r}\Delta t$ hamda $\Delta\psi = 2\psi_m, \Delta t = \frac{T}{2}$ bo'lganligi uchun g'altakdagi magnit oqim ψ qiymati:

$$\psi_m = \frac{1}{2}\Delta\psi = \frac{1}{2}E_{cp}\frac{T}{2} = \frac{1}{2}\cdot 10\cdot\frac{0{,}02}{2} = 0{,}05\ vb = 50\ (mVb)$$



Masala 2.4. Elektr o'lchov asboblari yordamida aktiv va induktiv qarishilik bo'lgan elektr zanjirining kuchlanish va chastotasi U_R=20 V, U_L=30 V, I=5 A, f=50 gs bo'lganda, umumiy kuchlanish, parametr, quvvat va magnit maydon elektr energiyasi aniqlansin.

Yechish. (2. 14)tenglamaga asosan:

$$U = \sqrt{U^2{}_R + U^2{}_L} = \sqrt{400 + 900} = \sqrt{1300} = 36\ V$$

Umumiy qarshilik: $Z = \frac{U}{I} = \frac{36}{5} = 7{,}2\ Om$

Aktiv qarshilik: $R = \frac{U_R}{I} = \frac{20}{5{,}2} = 4\ Om\cdot$

Induktiv (reaktiv) qarshilik: $X_L = \frac{U_L}{I} = \frac{30}{5} = 6\ Om$

(2. 6) tenglamaga asosan:

$$\cos\varphi = \frac{R}{Z} = \frac{4}{7{,}2} = 0{,}55;\ \sin\varphi = \frac{X}{Z} = \frac{6}{7{,}2} = 0{,}8$$

Aktiv quvvat: P=$I^2R = UI\cos\varphi = 25\cdot 4 = 100\ Vt$

Reaktiv quvvat: $Q_L = I^2X_L = UI\sin\varphi = 25\cdot 6 = 150\ \ VAR$

To‘la quvvat: $S = UI = I^2 Z = Z\sqrt{P^2 + Q^2} = 36 \cdot 5 = 180\ VA$

Induktivlik: $L = \frac{X_L}{\omega} = \frac{6}{314} = 0{,}018 GN = 18\ MGN.$

Magnit maydon energiyasi:

$$W_M = \frac{LI^2}{2} = \frac{25 \cdot 9 \cdot 10^{-3}}{2} = 225 \cdot 10^{-3} = 0{,}225 \cdot DJ.$$

Masala 2.5. Sinusoidal o‘zgaruvchan elektr kuchlanishi *u=120sin1000t* bo‘lgan generatorga induktiv qarshilik ulangan bo‘lib, sinusoidal tok o‘tadi: $i = 8\sin(1000t - 53^\circ)$.

O‘zgaruvchan kuchlanish chastotasi ikki martaga kamayganda: induktiv g‘altakning aktiv qarshiligi, induktivligi, tok qiymati va faza burchagi aniqlansin.

Yechish.

Masalaning sharti bo‘yicha umumiy qarshilik:

$Z = \frac{U_m}{I_m} = 15(Om)$ bo‘lib, faza burchagi $\varphi = \varphi_u - \varphi_i = 53^\circ$

Qarshilik uchburchak ifodaga asosan:

$$R = Z\cos\varphi = 15\cos 53^\circ = 9\,(Om)$$

$$X = Z\sin\varphi = 15\sin 53^\circ = 12\,(Om)$$

Induktivlik: $L = \frac{x_L}{\omega} = \frac{12}{1000} = 0{,}012\,gn = 12\,(mGn)$

Kuchlanish chastotasi ikki martaga kamaytirilgan holda induktiv qarshilik ham ikki martaga kamayadi: $x_l' = 6\,Om$

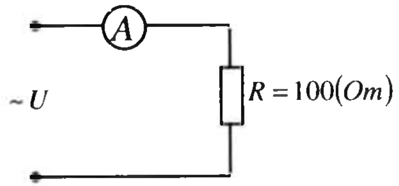
Faza farqi: $\varphi' = arctg\frac{x_L'}{R} = \frac{6}{9} = 33^\circ 40'$

To‘la qarshilik: $Z' = \frac{x_L'}{\sin\varphi'} = 10{,}8(Om)$

Tok amplitudasi: $I_m' = \frac{U_m}{z'} = \frac{120}{10{,}8} = 11{,}09(A)$

Tokning oniy qiymati: $i = 11{,}09\sin(500t - 33^\circ 40')$

Masala 2.6. O‘zgaruvchan tok kuchlanishl $U = 283\sin t$ bo‘lgan generatorga, aktiv qarshiligi *R = 10 (Om)* reostat ulangan. Reostatdan o‘tuvchi tokning effektiv oniy qiymati va o‘rtacha quvvat qiymati aniqlanib, vaqt bo‘yicha o‘zgaruvchan diagrammasi chizilsin.



Yechish.

Tokning amplituda qiymati $I_m = \frac{U_m}{R} = \frac{283}{10} = 28{,}3(A)$; effektiv qiymati: $I = \frac{I_m}{\sqrt{2}} = 20\,(A)$

Oniy qiymati: $i = I_m \sin\omega t = 28{,}3\sin 314t$

Aktiv quvvatning o‘rtacha qiymati:

$$P_{yp} = \frac{1}{T}\int_0^T Pdt = UI = I^2R = 4000\,VT = 4(kVt)$$

Quvvatning oniy qiymati:

$$P = ui = UI + UI\sin(2\omega t - 90) = [4 + 4\sin(2\omega t - 90)](kVt)$$

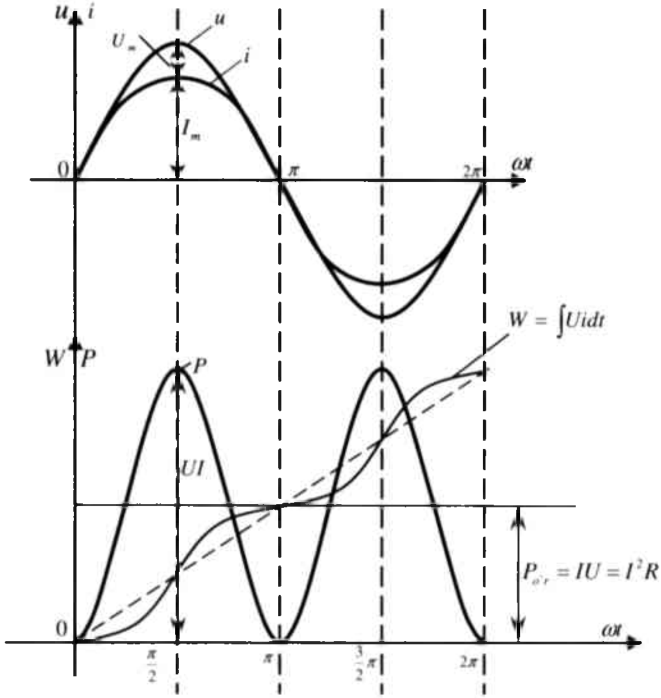
Elektr energiyasinng oniy qiymati:

$$W = \int Pdt = UIt - \frac{UI}{2\omega}\sin 2\omega t = 4000t - \frac{4000}{2\cdot 314}\sin\omega t =$$
$$= (4000 - 6{,}37\sin 2\omega t)(J)$$

Demak Djoul-Lens qonuniga asosan aktiv qarshilik (reostatda)da o‘zgaruvchan elektr tok energiyasi issiqlik energiyasi ajralib sarf bo‘ladi.

Aktiv quvvat vaqt bo‘yicha o‘zgaruvchan diagrammasi chizmada keltirilgan.

Bunda tok va kuchianish orasidagi burchak φ=0 bo‘lib, I_m va U_m vektor ifodasi ustma-ust tushadi.



Masala 2.7. Induktivligi L=0,27 (Gn), aktiv qarshiligi R=49 (Om) bo'lgan reaktiv g'altak, sinusoidal o'zgaruvchan tok chastotasi f=50(Gs), $U = 220\ V$ kuchlanishga ulangan.

Tokning effektiv qiymati I, tok va kuchlanish orasidagi burchak φ aniqlanib vektor ifodasi tuzilsin.

Yechish.

Om qonuniga asosan:

$$I = \frac{U}{z} = \frac{220}{\sqrt{R^2 + (\omega L)^2}} = \frac{220}{\sqrt{49^2 + (314 \cdot 0,27)^2}} = 2,24(A)$$

Bunda:

$\omega = 2\pi f = 314 \cdot 2 \cdot 50 = 314(rad / sek)$

Burchak fazasi: $\varphi = arctg\,\frac{x}{R} = \frac{100}{49} = 2 = 60^\circ$

yoki fazadagi farq: $\varphi = \varphi_u - \varphi_i = 0 - 60^\circ = -60^\circ$

Tokning oniy qiymati: $i = \sqrt{2}I = 3{,}16\sin(\omega t - 60^\circ)(A)$

Kuchlanish oniy qiymati: $u = 310\sin\omega t\ (V)$

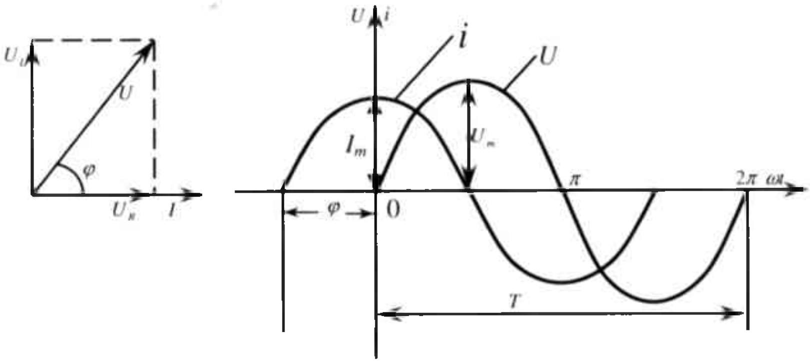
Bundan: $U_m = \sqrt{2}U = 1{,}41 \cdot 220 = 310(V)$

Masshtab tanlab, tok va kuchlanish vektor ifodasini va vaqt bo'yicha o'zgaruvchan diagrammasini tuzamiz.

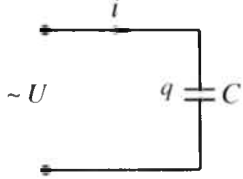
Bunda R va x_L qarshilikdagi kuchlanish:

$U_R = IR = 2{,}24 \cdot 49 = 115(V);$

$U_L = I_L X_L = 2{,}24 \cdot 100 = 224(V);$



Masala 2.8. Sig'imi $C=41{,}6(mkf)$ bo'lgan kondensator $U = 120\sin(314t + \frac{\pi}{4})$ kuchlanishga ulangan. Sig'imdagi tok i, zaryadi q, quvvat P_c va elektr maydon energiyasi W_e aniqlansin.



Yechish.

Sig'im qarshiligini aniqlaymiz: $X_c = \frac{1}{\omega c} = \frac{1}{314 \cdot 41{,}6 \cdot 10^{-6}} = 76{,}6\,Om$

Tokning amplituda qiymati: $I_m = \frac{U_m}{X_c} = 1{,}57\,(A)$

Tok va kuchlanish orasidagi faza farqi: $\varphi = \varphi_U + \varphi_i = \frac{\pi}{4} + \frac{\pi}{2} = \frac{3}{4}\pi$

Tokning oniy qiymati: $i = 1{,}57\sin(314t + \frac{3}{4}\pi)(A)$

Sig'imdagi zaryadning oniy qiymati:

$$q = CU = 41{,}6\cdot 10^{-6}\cdot 120\sin(314t + \frac{\pi}{4}) = 5\sin(314t + \frac{\pi}{4})\ (kulon)$$

Quvvatning oniy qiymati:

$$P = U_m I_m\left[\cos\varphi - \cos(2\omega t + 2\varphi_U - \varphi)\right] = -UI\cos 2\omega t$$

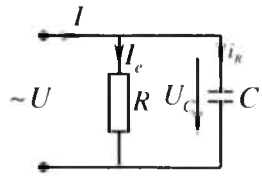
Bunda: $\varphi = -\frac{\pi}{2}$ va $\varphi_U = \frac{\pi}{4}$ bo'lganligi uchun:

$$P = \frac{120\cdot 1{,}57}{2}\cos 2\omega t = 93{,}2\cos 2\omega t(Vt)$$

Sig'imda hosil bo'ladigan elektr maydon energiyasi:

$$W_э = \frac{CU^2}{2} = \frac{1}{2}\cdot 41{,}6\cdot 10^{-6}\cdot 120^2\sin^2(314t + \frac{\pi}{4}) = 0{,}15(1 + \sin 628t)(J)$$

Masala 2.9. Parallel sxemada ulangan elektr zanjir kuchlanishl *U=150 (V), I=5(A), I_R=3(A)* va chastotasi *f=50 (Gs)* ga teng. Sig'im parametri *C*, hamda zanjirda sarf bo'ladigan to'la quvvat aniqlansin.



Yechish.

Pifagor teoremasiga asosan tok uchburchak vektor ifodasidan:

$$I_C^2 = I^2 - I_R^2 = \sqrt{25-9} = 4(A)$$

Sig'imdagi kuchlanish: $U_C = U = 150\ V$

Sig'im parametri: $C = \frac{I_C}{U_C\omega} = \frac{4}{150\cdot 314} = 85(mkF)$

Elektr zanjir to'la quvvati: $S = UI = 1505 = 750\ (VA)$

Aktiv qarshllik quvvati: $P = UI_R = 150\ 3 = 450\ (Vt)$

Sig'im qarshilik reaktiv quvvati:

$$Q_C = \sqrt{S^2 - P^2} = \sqrt{750^2 - 450^2} = 600\ (Vt)$$

Masala 2.10. O'zgaruvchan tok chastotasi f = 500 (Gs) bo'lgan elektr zanjirda induktivligi L=5(MGn), tok I = 10(A) bo'lib, P=1(KVT) quvvat sarflanadi.

Umumiy kuchlanish U va quvvat koeffitsienti cos φ aniqlansin.

Yechish.

Aktiv quvvat tenglamasidan: $P = I^2R$; $R = \frac{P}{I^2} = \frac{1000}{10} = 100(Om)$

G'altak to'la qarshiligi:

$$Z_k = \sqrt{R^2 + (\omega L)^2} = \sqrt{100^2 + (6{,}28 \cdot 500 \cdot 5 \cdot 10^{-3})^2} = 18{,}6(Om)$$

Kuchlanish: $U = IZ_k = 10\ 18{,}6 = 186\ (V)$

Quvvat koeffitsienti: $\cos\varphi = \frac{P}{S} = \frac{1000}{IU} = \frac{1000}{186 \cdot 10} = 0{,}54$

Masala 2.11. Kuchlanish $U = 283\sin 500t$ bo'lgan generatorga parametr $L = 0{,}016\ Gn$, $R = 6\ Om$ bo'lgan induktiv g'altak ulangan bo'lib, shu g'altakdan oqib o'tuvchi tokning oniy qiymati (i_l) kuchlanishi (U_a, U_p), to'la quvvat (S) aniqlanib, kuchlanish uchburchak vektor ifodasi chizilsin.

Yechish.

Induktiv qarshilik: $X_L = \omega L = 500 \cdot 0{,}016 = 8\ Om$

Fazadagi farq: $\varphi = arctg\frac{x}{R} = \frac{8}{6} = 53°$, $\varphi_i = \varphi_U - \varphi = -53°$

To'la qarshilik: $z = \sqrt{R^2 + x^2} = \sqrt{6^2 + 8^2} = 10(Om)$

Tok amplitudasi: $I_m = \frac{U_m}{z} = \frac{283}{10} = 28{,}3(A)$

Oniy qiymat: $i_m = 28{,}3\sin(500t - 53°)(A)$

Aktiv va reaktiv kuchlanish:

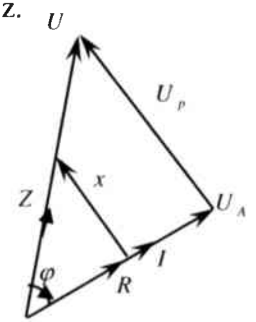
$$U_{ma} = U_m\cos\varphi = 170(V),\quad U_{mp} = U_M \sin\varphi = 226\ (V)$$

To‘la quvvat: $S = UI = \frac{U_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = 400Vt = 4(kVt)$

Aktiv quvvat: $P = S\cos\varphi = 4 \cdot 0{,}6 = 2{,}4(kVt)$

Reaktiv quvvat: $Q = S\sin\varphi = 4 \cdot 0{,}8 = 3{,}2(kVar)$

Vektor ifodasini chizamiz.

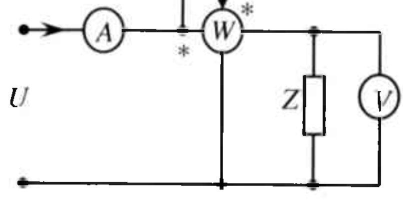


Aktiv qarshilikdagi kuchlanish vektori (U_a) tok vektori bilan ustma-ust tushadi, shu sababli $\varphi_{ua} = -53°$ ga teng.

U_P – kuchlanish esa tok vektoriga nisbatan $90°$ farq qilib $\varphi_{Up} = 37°$ ga teng.

Ya’ni: $U_a = 170\sin(500t - 53°)\,V$, $U_p = 226\sin(500t - 37°)\,V$

Masala 2.12. Berilgan elektr elektr zanjirga ulangan elektr asboblarida: ampermetr toki I=20 A, voltmetrdagi kuchlanish U=100 V va vattmetr quvvati P=1200 Vt ga teng. Elektr zanjir induktiv $(\varphi > 0)$ xarakterga ega bo‘lgan holat uchun o‘xshashlik ekvivalent sxemasi tuzilib, qarshilik parametri aniqlansin hamda uchburchak vektor ifodasi tuzilsin.



Yechish.

To'la qarshilik: $Z = \frac{U}{I} = 5(Om)$

Aktiv qarshilik: $R = \frac{P}{I^2} = \frac{1200}{20^2} = 3(Om)$

Induktiv qarshilik: $x_L = \sqrt{z^2 - R^2} = 4(Om)$

Aktiv qarshilik kuchlanishi: $U_R = U_a = IR = 60(V)$

Induktivlik reaktiv kuchlanishi: $U_L = U_P = Ix_L = 80(V)$

Aktiv o'tkazuvchanlik (2.10) ifodaga asosan:

$$g = \frac{R}{z^2} = 0{,}12\left(\frac{1}{Om}\right)$$

Induktiv o'tkazuvchanlik: $b_L = \frac{x_L}{z^2} = 0{,}16\left(\frac{1}{Om}\right)$

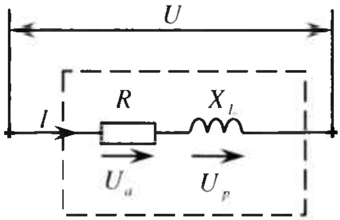
To'la o'tkazuvchanlik:

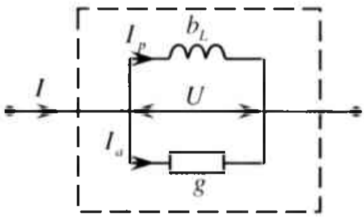
$$y = \frac{1}{z} = \sqrt{g^2 + b_L^2} = 0{,}2\left(\frac{1}{Om}\right)$$

Elektr o'lchov asboblari ko'rsatgan qiymatlari bo'yicha:

$$g = \frac{P}{U_2} = 0{,}12\left(\frac{1}{Om}\right); \qquad y = \frac{I}{U} = 0{,}2\frac{1}{(Om)}; \qquad b_L = \sqrt{y^2 - g^2} = 0{,}16\frac{1}{(Om)}$$

Aniqlangan qiymatlar asosida ekvivalent o'xshashlik sxemasini chizamiz.

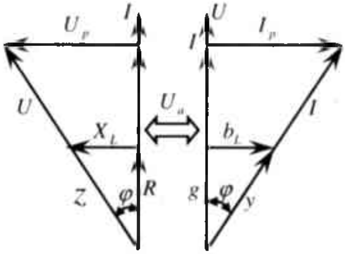




Bundan aktiv qarshilikdagi tok: $I_R = I_a = Ug = 12\ (A)$

Induktivlikdagi reaktiv tok: $I_L = I_P = Ub_L = 16\ (A)$

Qarshilik va o'tkazuvchanlik, tok va kuchlanish ekvivalent (o'xshashlik) vektor ifodasi quyidagi ko'rinishda bo'ladi.



Masala 2.13. Induktivligi $L=0,18$ (Gn), aktiv qarshlligi R=30 Om ga teng bo‘lgan induktiv g‘altak, sig‘imi $C=40$ (mkf) bo‘lgan kondensator bilan ketma-ket sxemada biriktirilib, U = 250 sin 500t (V) manba kuchianishiga ulangan. Tok (I_m), faza burchagi (φ), induktivlik va sig‘im kuchlanishi aniqlanib vektor ifodasi tuzilsin.

Yechish.

Reaktiv qarshllik ifodasiga asosan:

$$x_L = \omega L = 500\cdot 0,18 = 90(Om)$$

$$x_c = \frac{1}{\omega c} = \frac{10^6}{500\cdot 40} = 50(Om)$$

$$x = x_l - x_c = 40(Om)$$

To‘la qarshilik: $z=\sqrt{R^2+x^2}=50(Om)$

Tok amplitudasi : $I_m = \frac{U_m}{z} = \frac{250}{50} = 5(A)$

Tok va kuchlanish orasidagi faza farqi:

$$\varphi = arctg\frac{x}{R} = arctg\,1,33 = 53^\circ 8'$$

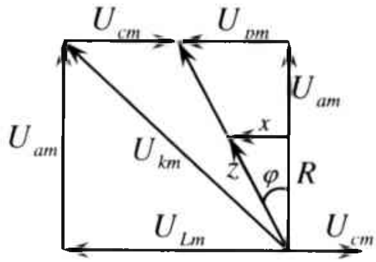
Sig‘imdagi kuchlanish: $U_{cm} = x_c I_m = 5\cdot 50 = 250\ V$

Induktivlikdagi kuchlanish: $U_{Lm} = x_L I_m = 90\cdot 5 = 450\ V\ \ V$

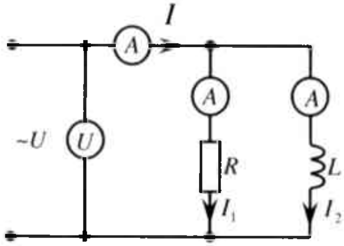
Aktiv qarshilikdagi kuchlanish: $U_{Rm} = RI_m = 30\cdot 5 = 150\ V$

G‘altakdagi umumiy kuchlanish: $U_{km} = \sqrt{U_{Rm}{}^2 + U_{Lm}{}^2} = 470\,V$

Aniqlang qiymatlar bo'yicha masshtab m_i, m_u tanlanib vektor diagrammasini tuzamiz.



Masala 2.14. Chizmada keltirilgan sxemaga ulangan elektrodinamik asboblarning ko'rsatishi: U=120 V, I=10 A, I_2=6 A bo'lib, chastotasi $f=1$ kGs bo'lganda, tok I, aktiv qarshilik R va induktivlik L aniqlansin.



Yechish.

O'zgaruvchan tok burchak chastotasi: $\omega = 2\pi f = 6280\left(\frac{1}{sek}\right)$

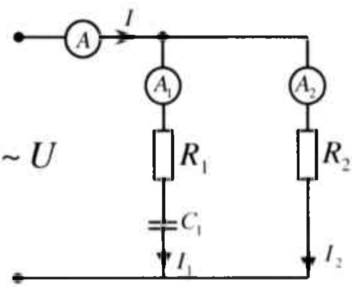
Induktiv qarshilik: $x_L = \frac{U}{I_2} = \frac{120}{6} = 20(Om)$

Induktivlik: $L = \frac{x_L}{\omega} = 3{,}18(mGn)$

Aktiv qarshilikdan o'tuvchi tok: $I_1 = \sqrt{I^2 - I_2^2} = 8(A)$

Qarshiligi: $R = \frac{U}{I_1} = 15(Om)$

Masala 2.15. Sxemaga ulangan ampermetrning ko'rsatishi: $I=25A$, $I_1=13{,}5A$, $I_2=15(A)$ va $R_2=20\,Om$, $f=50\,(Gs)$ ga teng bo'lgan holat uchun zanjir parametr va sarf bo'ladigan aktiv quvvat (P) hamda quvvat koeffitsienti $(\cos\varphi)$ hisoblab topilsin.



Yechish.

Parallel ulangan holatda umumiy kuchlanish:

$U=I_2R_2=20\cdot15=300\ (V)$

Umumiy tok: $I=\sqrt{I_a^{\,2}+I_p^{\,2}}$

Bundan: $I_a=I_2+I_1\cos\varphi_1,\quad I_p=I_1\sin\varphi$

yoki:

$$I^2=\left(I_1^{\,2}+I_1\cos\varphi_1\right)^2=I_1^{\,2}\sin^2\varphi_1=I_1^{\,2}+I_2^{\,2}+2I_1I_2\cos\psi_1$$

Birinchi tarmoq burchagi: $\cos\varphi_1=\dfrac{I^2-I_1^{\,2}-I_2^{\,2}}{2I_1I_2}=0{,}538$

To'la qarshilik: $z_1=\dfrac{U}{I_1}=\dfrac{300}{13{,}5}=22{,}2(Om)$

Aktiv qarshilik: $R_1=z_1\cos\varphi_1=11{,}9(Om)$

Sig'im qarshiligi: $x_1=\sqrt{z_1^{\,2}-R_1^{\,2}}=18{,}8(Om)$

Sig'im parametri: $C_1=\dfrac{1}{x_1\omega}=169\cdot10^{-6}\,\Phi=169(mkF)$

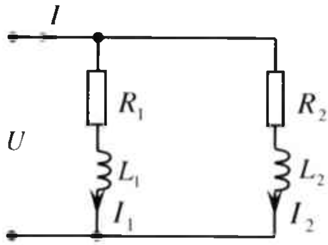
Elektr zanjirning quvvat koeffitsienti:

$$\cos\varphi=\frac{I_a}{I}=\frac{I_2+I_1\cos\varphi_1}{I}=0{,}89$$

Zanjirda sarf bo‘ladigan aktiv quvvat:

$$P = UI\cos\varphi = 300 \cdot 25 \cdot 0{,}89 = 6680VT = 6{,}68(kVt)$$

Masala 2.16. Kuchlanish U=120 V chastotasi f=50 Gs bo‘lgan elektr zanjir parametri: R_1=4Om, L_1=0,6 MGn, R_2=6 Om, L_2=25,5 MGn bo‘lgan ikkita induktiv iste’molchi parallel ulangan. Tarmoqdagi tok, zanjirning quvvat koeffitsienti va iste’molchilarda sarf bo‘ladigan aktiv quvvat aniqlansin.



Yechish.

Birinchi g‘altak induktiv qarshiligi:

$$x_{L_1} = 2\pi f L_1 = 2 \cdot 3{,}14 \cdot 50 \cdot 0{,}6 \cdot 10^{-3} = 3\,Om$$

Birinchi g‘altak to‘la qarshiligi: $Z_1 = \sqrt{R_1^2 + x_{L_1}^2} = \sqrt{4^2 + 3^1} = 5\ Om$

Birinchi tarmoqdagi tok: $I_1 = \dfrac{U}{Z} = \dfrac{120}{5} = 24\ A$

Birinchi g‘altak quvvat koeffitsienti: $\cos\varphi_1 = \dfrac{R_1}{Z} = \dfrac{4}{5} = 0{,}8$

(burchak $\varphi_1 = 36^0 50'$ bo‘lganda $\sin\varphi_1 = 0{,}6$)

Bunda birinchi tarmoqdagi tok aktiv tashkil etuvchisi:

$$I_{a_1} = I_1\cos\varphi_1 = 24 \cdot 0{,}8 = 19{,}2\ \ A$$

Reaktiv tashkil etuvchisi:

$$I_{p_1} = I_1\sin\varphi_1 = 24 \cdot 0{,}6 = 14{,}4\ \ A$$

Ikkinchi g‘altak induktiv qarshiligi:

$$x_{L_2} = 2\pi f L_2 = 6{,}28 \cdot 50 \cdot 2{,}5 \cdot 10^{-3} = 10\,Om$$

Ikkinchi tarmoqdagi tok:

$$I_2 = \frac{U_2}{Z_2} = \frac{120}{10} = 12\ A$$

Ikkinchi g'altak quvvat koeffitsienti:

$$\cos\varphi_2 = \frac{R_2}{Z_2} = \frac{6}{10} = 0{,}6$$

(burchak $\varphi_2 = 52^0 10'$ bo'lganda $\sin\varphi_2 = 0{,}8$)

Ikkinchi tarmoqdagi tok aktiv tashkil etuvchisi:

$$I_{a_2} = I_2 \cos\varphi_2 = 12 \cdot 0{,}6 = 7{,}2\ \ A$$

Reaktiv tashkil etuvchisi:

$$I_{P_2} = I_2 \sin\varphi_2 = 12 \cdot 0{,}8 = 9{,}6\ \ A$$

Umumiy tok aktiv tashkil etuvchisi qismi:

$$I_a = I_{a_1} + I_{a_2} = 19{,}2 + 7{,}2 = 26{,}4\ \ A$$

Reaktiv tashkil etuvchisi:

$$I_P = I_{P_1} + I_{P_2} = 14{,}4 + 9{,}6 = 24\ \ A$$

Umumiy tok qiymati:

$$I = \sqrt{I_a^2 + I_P^2} = 36\ A$$

Zanjirdagi quvvat koeffitsienti:

$$\cos\varphi = \frac{I_a}{I} = \frac{26{,}4}{36} = 0{,}733$$

Birinchi g'altakda sarf bo'ladigan aktiv quvvat:

$$P_1 = UI_1 \cos\varphi_1 = 120 \cdot 24 \cdot 0{,}8 = 2304\ \text{Vt}$$

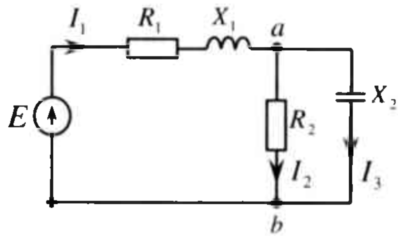
Ikkinchi g'altakda sarf bo'ladigan aktiv quvvat:

$$P_2 = UI_2 \cos\varphi_2 = 120 \cdot 12 \cdot 0{,}6 = 864\ \text{Vt}$$

Iste'molchilarda sarf bo'ladigan aktiv quvvat:

$$P = P_1 + P_2 = 2304 + 864 = 3168\ \text{Vt}$$

Masala 2.17. Chizmada keltirilgan sxemada o'zgaruvchan kuchlanish chastotasi *f=50 Gs* bo'lgan generatorning aktiv quvvati *P=31,25(kVt)*, zanjir qarshiligi $R_1=2$ *Om*, $x_1=36$ (*Om*), $R_2=75$ *Om*, $x_2=100$ (*Om*) ga teng. Elektr zanjirdagi tok va kuchlanish hisoblansin.



Yechish.

Parallel ulangan tarmoq o‘tkazuvchanligi:

$$g_{ab} = \frac{1}{R_2} = 1{,}33 \cdot 10^{-2}\left(\frac{1}{Om}\right); \quad b_{ab} = \frac{1}{x_3} = -0{,}01\left(\frac{1}{Om}\right)$$

Umumiy o‘tkazuvchanlik: $y_{ab} = \sqrt{g_{ab}^{\ 2} + b_{ab}^{\ 2}} = 1{,}67 \cdot 10^{-2}\left(\frac{1}{Om}\right)$

Ikki qutbli elektr zanjirlar ekvivalent o‘xshashlik tenglamasidan (2.11):

$$R_{ab} = \frac{g_{ab}}{y_{ab}^{\ 2}} = 48(Om); \quad x_{ab} = \frac{b_{ab}}{y_{ab}^{\ 2}} = -\frac{0{,}01}{2{,}78 \cdot 10^{-4}} = 36(Om)$$

Zanjirning umumiy aktiv va reaktiv qarshiligi:

$$R = R_1 + R_{ab} = 50\ (Om); \ x = x_1 + x_{ab} = 36\text{-}36 = 0$$

To‘la qarshilik: $Z = \sqrt{R^2 + x^2} = 50\ (Om)$

Birinchi tarmoqdagi tok: $I_1 = \sqrt{\frac{P}{R}} = \sqrt{\frac{31250}{50}} = 25(A)$

Umumiy kuchlanish $U = I_1 z = 1250\ (B)$ bo‘lib, faza burchagi $\varphi=0$

Birinchi tarmoq kuchlanishi: $U_{1a}=R_1 I_1=25 \cdot 2=50\ (V)$, $U_{1p}=x_1 I_1=25 \cdot 36=900\ (V)$

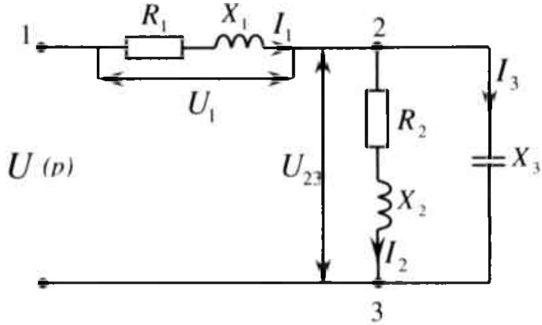
$$U_1 = \sqrt{U_{a1}^{\ 2} + U_{p1}^{\ 2}} = 900\,(V)$$

Parallel ulangan tarmoqdagi kuchlanish:

$$U_{ab} = \frac{I_{1e}}{y_{ab}} = \frac{25}{1{,}67 \cdot 10^{-2}} = 1500\ (V)$$

Tarmoqdagi tok $I_2 = \frac{U_{ab}}{R_2} = 20(A), \quad I_3 = \frac{U_{ab}}{x_3} = 15(A)$

Masala 2.18. Qarshiligi aralash sxemada ulangan elektr zanjirda sarf bo'ladigan aktiv quvvat $P=1,2$ (kVt) bo'lib, parametr qiymati: $R_1=2$ (Om), $x_1=26$ (Om), $R_2=10$ (Om), $x_2=10$, $x_3=-10$ (Om) ga teng. Zanjirdagi umumiy kuchlanish U tarmoqdagi tok I_1, I_2, I_3, reaktiv quvvati (Q) aniqlanib vektor diagrammasi tuzilsin.



Yechish.

Zanjirning aktiv va reaktiv qarshiligini, qarshilik ekvivalent parametr o'xshashlik tenglamasiga asosan (2. 10) aniqlaymiz:

$$g_2 = \frac{R_2}{R_2^2 + x_2^2} = \frac{10}{200} = 0{,}05\frac{1}{OM};$$

$$b_2 = \frac{x_2}{R_2^2 + x_2^2} = \frac{10}{200} = 0{,}05\frac{1}{OM}$$

Uchinchi tarmoq o'tkazuvchanligi: $g_3 = 0, b_3 = \frac{1}{x_3} = -0{,}1\frac{1}{Om}$

Tarmoq parallel ulangan qismi uchun: $g_{23} = g_2 + g_3 = 0{,}05\frac{1}{Om}$

Umumiy o'tkazuvchanlik: $y_{23} = \sqrt{g_{23}^2 + b_{23}^2} = \sqrt{0{,}005}\frac{1}{Om}$

O'xshashlik ekvivalent parametrlar tenglamasiga asosan (2.11) aktiv qarshilik:

$$R_{23} = \frac{g_{23}}{y_{23}^2} = \frac{0{,}05}{0{,}005} = 10\ Om$$

Reaktiv qarshilik: $x_{23} = \frac{b_{23}}{y_{23}^2} = \frac{0{,}05}{0{,}005} = -10\ Om$

To'la qarshilik: $z_{23} = \sqrt{R_{23}^2 + x_{23}^2} = 14{,}1\ Om$

Zanjirning umumiy aktiv qarshiligi: $R = R_1 + R_{23} = 12\ Om$

Umumiy reaktiv qarshiligi: $x = x_1 + x_{23} = 16\ Om$

Aktiv quvvat tenglamasiga asosan: $P = I^2 R\ (Vt)$

yoki $I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{1200}{12}} = 10A$ burchak $\sin\varphi = \dfrac{16}{20} = 0,8$

Burchak fazasi: $\varphi = arctg\dfrac{x}{R} = \dfrac{16}{12} = 1,33 = 53^{\circ}10'$

Umumiy kuchlanish: $U = \dfrac{P}{I\cos\varphi} = \dfrac{1200}{10 \cdot 0,6} = 200\ V$

To‘la quvvat: $S = UI = 200 \cdot 10 = 2000VA = 2$ KVA

To‘la qarshilik: $z = \dfrac{S}{I^2} = \dfrac{2000}{100} = 20\ Om;$

Burchak: $\sin\varphi = \dfrac{x}{z} = \dfrac{16}{20} = 0,8$

Reaktiv quvvat: $Q = S\sin\varphi = 2 \cdot 0,8 = 1600VAR = 1,6\ KVAR$

Tarmoqdagi kuchlanishlari:

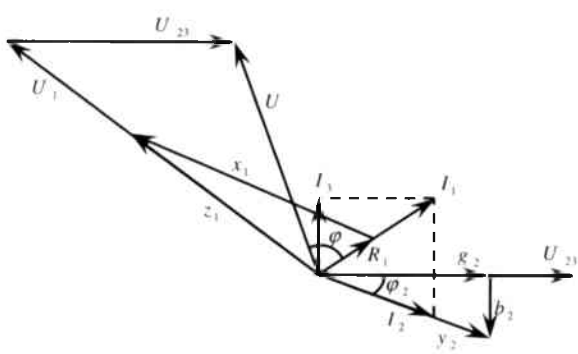
$$U_1 = z_1 I_1 = 26,2 \cdot 10 = 262V, \quad U_{23} = z_{23} I_1 = 14,1 \cdot 10 = 141V$$

Tarmoqdagi tok:

$$I_2 = \frac{U_{23}}{z_{23}} = \frac{141}{14,1} = 10A, \quad I_3 = \frac{U_{23}}{z_3} = \frac{141}{10} = 14,1A$$

Vektor diagramma chizish uchun tok va kuchlanish masshtablari tanlanadi:

$$\left(m_1 = 5a / sm, m_U = 25b / sm, m_y = 0,02\frac{1}{Om \cdot sm}, m_z = 5\frac{Om}{sm}\right)$$



Masala 2.19. Induktiv g'altak parametrlari $R = 3X_L = 4\ Om$ bo'lib, $U = 100\ V$ kuchlanishga ulangan. Aktiv, reaktiv, to'la o'tkazuvchanlik parametrlari, kuchlanish va tok qiymati aniqlanib, uchburchak vektor ifodalari chizib ko'rsatilsin.

Yechish.

To'la qarshilikni topamiz: $Z = \sqrt{R^2 + X_L^2} = \sqrt{9 + 16} = 5\ Om$

Om qonuniga asosan tokning haqiqiy qiymati: $I = \frac{U}{Z} = \frac{100}{5} = 20\ A.$

Qarshilik uchburchak vektor ifodasidan: $\cos\varphi = \frac{R}{Z} = \frac{3}{5} = 0{,}6$:

$\sin\varphi = \frac{X_L}{Z} = \frac{4}{5} = 0{,}8$

Shunga asosan: $\dot{U}_a = \dot{U}\cos\varphi = 100 \cdot 0{,}6 = 60\ V$

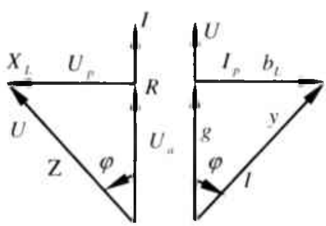
$\dot{U}_P = \dot{U}\sin\varphi = 100 \cdot 0{,}8 = 80\ V$

Tok qiymatini aniqlaymiz:

$I_a = I\cos\varphi = 20 \cdot 0{,}6 = 12\ A$; $I_P = I\sin\varphi = 20 \cdot 0{,}8 = 16\ A$

Aniqlangan tok va kuchlanish qiymatidan o'tkazuvchanlik parametri:

To'la o'tkazuvchanlik: $y = \frac{I}{U} = \frac{20}{100} = 0{,}2\ sim.$



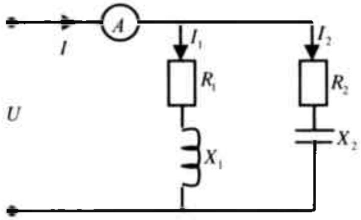
Aktiv o'tkazuvchanlik: $g = y\cos\varphi = 0{,}2 \cdot 0{,}6 = 0{,}12\frac{1}{Om}$

Reaktiv o'tkazuvchanlik: $b_L = y\sin\varphi = 0{,}2 \cdot 08 = 0{,}16\frac{1}{Om}$

Masshtab tanlash bilan vektor ifodasini tuzamiz.

Masala 2.20. Parallel sxemada ulangan zanjirga kiruvchl tok $I = 2\ A$ bo'lib, parametri $R_1 = 3\ Om,$ $X_1 = 4\ Om,$ $R_2 = 6\ Om,$ $X_2 = 8\ Om$ ga teng.

Umumiy kuchlanish U, tarmoqdagi tok I_1, I_2, aktiv, reaktiv va to'la quvvat qiymatlari aniqlanib vektor ifodasi tuzilsin:



Yechish. Birinchi tarmoq to'la qarshiligi: $Z_1 = \sqrt{R_1^2 + X_1^2} = \sqrt{3^2 + 4^2} = 5\,Om$. Ekvivalent parametr tenglamasidan (2.10) aktiv o'tkazuvchanlik: $g_1 = \frac{R_1}{Z_1^2} = \frac{3}{5^2} = 0{,}12\ {}^1\!/_{Om}$.

Reaktiv o'tkazuvchanlik: $b_1 = \frac{X_1}{Z_1^2} = \frac{4}{5_2} = 0{,}16\ {}^1\!/_{om}$.

Ikkinchi tarmoq to'la qarshilik: $Z_2 = \sqrt{2_2^2 + X_2^2} = \sqrt{6^2 + 8^2} = 10Om$.

yoki: $g_2 = \frac{R_2}{Z_2} = \frac{6}{10^2} = 0{,}06\ {}^1\!/_{Om}$; $b_c = b_2 = \frac{X_2}{Z_2} = \frac{-8}{10^2} = -0{,}08\ {}^1\!/_{Om}$

Zanjir to'la aktiv o'tkazuvchanligi:

]$g = g_1 + g_2 = 0{,}12 + 0{,}06 = 0{,}18\ {}^1\!/_{Om}$

To'la reaktiv o'tkazuvchanlik: $b = b_1 + b_2 = 0{,}16 - 0{,}08 = 0{,}08\ {}^1\!/_{Om}$

Umumiy o'tkazuvchanlik: $y = \sqrt{g^2 + b^2} = \sqrt{(0{,}18)^2 + (0{,}08)^2} = 0{,}197\ {}^1\!/_{Om}$

Om qonuniga asosan zanjirdagi kuchlanish: $U = \frac{I}{y} = \frac{2}{0{,}197} \approx 10\ V$

Tarmoqdagi tok: $I_1 = \frac{U}{Z_1} = \frac{10}{5} = 2A \quad I_2 = \frac{U}{Z_2} = \frac{10}{10} = 1A$

Faza burchagini topamiz: $\varphi = arctg\frac{b}{g} = arctg\frac{0{,}08}{0{,}18} = 24°$

$\varphi_1 = arctg\frac{X_1}{Z_1} \approx 53°$; $\varphi_2 = arctg\frac{X_2}{Z_2} = -53°$

Quvvat ifodasidan: $P = U^2 g = 100 \cdot 0{,}18 = 18Vt$

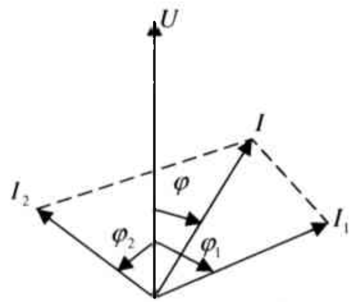
$Q = U^2 b = 100 \cdot 0{,}08 = 8var$. $S = U^2 y = 100 \cdot 0{,}197 = 19{,}7VA$

Quvvat koeffitsienti ifodasida: $\alpha = \frac{P}{S} = \frac{P}{UI} = \frac{210}{855} = 0{,}25$.

Quvvat siljish koeffitsienti ifodasidan: $P^2 + Q^2 = S^2 - T^2$

bundan:

$$T=\sqrt{S^2-\left(P^2+Q^2\right)}=\sqrt{855^2-\left(210-173{,}3^2\right)}=820VA$$



2.3. Mustaqil yechish uchun masalalar

Masala 2.1. Qutblar soni $P=3$ berk halqa magnit maydonida $n=1000$ *ayl/min* tezlik bilan aylanganda hosil bo'ladigan EYK chastotasi aniqlansin.

Javob: $f=50$ *Gs*.

Masala 2.2. O'zgaruvchan tok generatorining yakor aylanish tezligi $n=500$ *ayl/min* bo'lib, $f=50$ *Gs* chastotali EYK hosil qilganda qutblar soni nechta bo'ladi?

Javob: $P = 6$

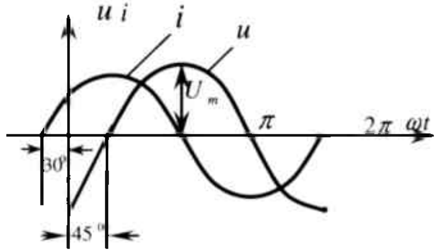
Masala 2.3. O'zgaruvchan EYK amplituda qiymati $E_m=120$ *V* chastotasi $f=100$ *Gs* bo'lganda, $t=0{,}0075$ *sek* vaqtda EYK oniy qiymati aniqlansin.

Javob: $e=120\sin 270^0$; $e=E_m=-120$ *V*

Masala 2.4. Magnit maydonida o'ramlar soni $W=40$ ga teng bo'lgan g'altak aylanganda hosil bo'ladigan magnit oqimi $\Phi=0{,}02\sin 314t$ bo'lib, g'altakda induksiyalanadigan EYK oniy qiymati aniqlansin.

Javob: $e=250\sin(314t-90^0)$

Masala 2.5. Rasmda keltirilgan sinusoidal funksiya uchun analitik ifoda yozilib, tok va kuchlanish orasidagi burchak φ aniqlansin.



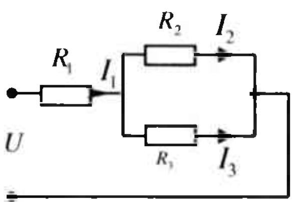
Masala 2.6. Kuchlanish va tok oniy qiymatlari $u = 170\sin(\omega t + 45°)$ $i = 10\sin(\omega t - 45°)$ bo'lganda, ular orasidagi burchak φ topilib, $t = 0$ bo'lganda oniy qiymati aniqlansin.

Javob: $U_m = 120\ V,\ I_m = 7A,\ \varphi = 90^{\circ}$

Masala 2.7. Aktiv qarshilikga ega bo'lgan sinusoidal o'zgaruvchan elektr zanjirga $U = 141\sin\omega t$ kuchlanish ulanganda, $i = 7{,}05\sin\omega t$ tok o'tadi. Elektr quvvat $P_{o'r}$ – o'rtacha qiymati va R qarshlhgi aniqlansm.

Javob: $P_{o'r} = 750VT \quad R = 70(Om)$

Masala 2.8. Sinusoidal o'zgaruvchan elektr zanjir aktiv qarshilik parametri: $R_1 = 24Om$, $R_2 = 10\ Om$, $R_3 = 15\ Om$ bo'lib, R_2 qarshilikda sarf bo'ladigan quvvat $P_2 = 58\ Vt$. Tarmoqdagi tok I_1, I_2, I_3 va umumiy kuchlanish U aniqlansm.

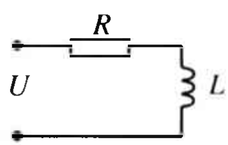


Javob: $I_1 = 4\ A$, $I_2 = 2{,}4\ A$, $I_3 = 1{,}6\ A$, $U = 120\ V$

Masala 2.9. O'zgaruvchan tok chastotasi $f = 160\ Gs$, $U = 220\ V$ kuchlanishga ulangan bo'lib g'altakdan $I = 4\ A$ tok o'tadi. G'altak induktivligi aniqlansin.

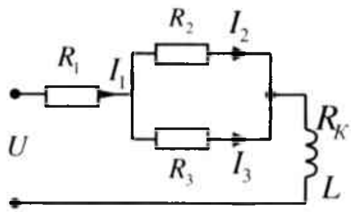
Javob: $L = 30\ MGn$

Masala 2.10. Parametri $R = 6\ Om$, $L = 25\ MGn$ bo'lgan g'altak chastotasi $f = 50\ Gs$ bo'lgan $U = 120\ V$ sinusoidal o'zgaruvchan kuchlanishga ulangan. Quvvat koeffitsienti va aktiv, reaktiv quvvat aniqlansm.



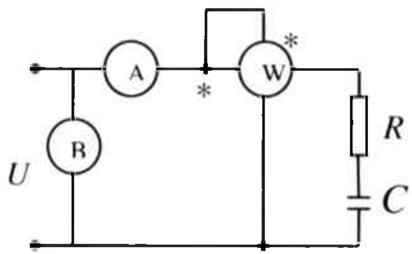
Javob: $\cos\varphi = 0{,}6$, $P = 864\ Vt$, $Q_L = 1152\ VAR$

Masala 2.11. Sinusoidal o'zgaruvchan elektr zanjir parametri: $R_1=4$ *Om*, $R_2=10$ *Om*, $R_3=15$ *Om* va induktivligi $L=95$ *MGn* bo'lib, R_2 qarshilikdan chastotasi $f=50$ *Gs* bo'lgan $I=2A$ tok o'tadi. Umumiy kuchlanish U qiymati, burchak koeffitsienti $\cos\varphi$ va aktiv quvvat P aniqlansin.



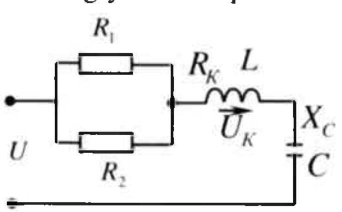
Javob: $U=100$ *V*, $\varphi=36^0 50^1$, $P=160Vt$

Masala 2.12. Elektr o'lchov asboblari ko'rsatishi: $U=200$ *B*, $I=2A$, $P=240$ *Vt* bo'lib, chastotasi $f=50$ *Gs* ga teng. Aktiv va sig'im qarshilik parametri aniqlansin.



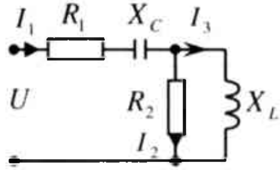
Javob: $R=60$ *Om*, $C=40$ *mkF*

Masala 2.13. Sinusoidal o'zgaruvchan elektr zanjirning qarshiligi: $R_1=R_2=100$ *Om*, $R_K=30$ *Om*, $X_C=100$ *Om*, $X_L=40$ *Om* bo'lib, g'altakdagi kuchlanish $U_K=100V$ chastotasi $f = 50$ *Gs* ga teng. Zanjirdan o'tuvchi tokning haqiqiy qiymati I, umumiy kuchlanishi U, sig'im va induktivlik parametri L, C, aktiv quvvat P hamda elektr W_E va magnit W_L maydon energiyalari aniqlansin.



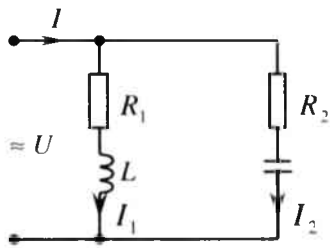
Javob: $U=200\ V$, $I=2\ A$, $L=0,127\ MGn$ $C=32\ mkF$, $P=320\ Vt$, $W_E=1,24\ Dj$, $W_L=0,5\ Dj$

Masala 2.14. Qarshilik parametri: $R_1=12Om$, $R_2=10\ Om$, $X_C=24\ Om$, $X_L=20Om$ bo'lgan elektr zanjir $f=50Gs$ bo'lgan $U=220\ V$ sinusoidal kuchlanishga ulangan. Tarmoqdagi tok I_1, I_2, I_3 haqiqiy qiymati aniqlansin.



Javob: $I_1=6\ A$, $I_2=4,4\ A$, $I_3=5,25\ A$

Masala 2.15. Parametri $R_1=160\ Om$, $L=0,04\ MGn$ bo'lgan induktiv g'altak aktiv qarshiligi $R_2=30\ Om$, sig'imi $C=50\ mkF$ bo'lib parallel sxemada ulangan. O'zgaruvchan tok kuchlanishi $U=110\ V$, chastotasi $f=314\ Gs$ bo'lganda umumiy o'tkazuvchanlik, tarmoqdagi tok va o'tkazuvchanligi aniqlansin.

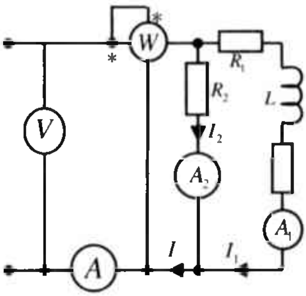


Javob: $y_1=0,036\ \frac{1}{Om}$, $y_2=0,0316\ \frac{1}{Om}$, $y=0,036\ \frac{1}{Om}$

$I_1=3,96\ A$, $I_2=1,1\ A$, $I_3=3,5\ A$

Masala 2.16. Parallel zanjir parametri: $R_1=100\ Om$, $R_2=200\ Om$, $L=0,276\ gn$, $f=100\ gs$ bo'lib, $I_1=5\ A$ ga teng. Elektr o'lchov asboblari ko'rsatish qiymati topilsin.

Javob: $U=200\ V$, $I=1,73\ A$, $P=300\ Vt$.



2.4. Nazorat savollari

1. Sinusoidal o‘zgaruvchan tok xususiyati nimadan iborat?
2. Sinusoidal o‘zgaruvchan tok qanday hosil qilinadi, manbai nima?
3. Sinusoidal o‘zgaruvchan tok bilan o‘zgarmas tokning farqi nimada?
4. Sinxron generatorning tuzilishi va ishlash prinsipini bilasizmi?
5. O‘tkazgich magnit maydonda harakatlanganda unda hosil bo‘ladigan EYK nimaga teng?
6. Elektr mashina va apparatlarida magnit o‘zak (ferromagnetik) qanday maqsad uchun xizmat qiladi?
7. Magnit doimiyligi deganda nimani tushunasiz?
8. Induktivlik nima va qanday birlikda o‘lchanadi?
9. O‘zinduksiya qonuniga asosan induktivlikda hosil bo‘lgan EYK yo‘nalishi qanday aniqlanadi va haqiqiy qiymati nimaga teng?
10. Sinusoidal o‘zgaruvchan tok qanday qiymatda ifodalanadi?
11. Sinusoidal o‘zgaruvchan tok chastotasi, davri va oniy qiymat ifodalarini yozing.
12. Sinusoidal o‘zgaruvchan tok vektor ifodasiga ta’rif bering. Elektr zanjir uchun vektor diagramma qanday tuziladi?
13. Sinusoidal o‘zgaruvchan tok va kuchlanish boshlang‘ich fazasi va faza farqi qanday aniqlanadi?
14. Aktiv induktivlik va sig‘im qarshilik parametri uchun Om qonuni ifodasini yozing.
15. Ketma-ket va parallel sxemada ulangan R, L, C zanjir uchun Om qonuni tenglamasini yozing.
16. Ikki qutbli zanjir uchun ekvivalent o‘xshashlik tenglamasini yozing.
17. Ketma-ket ulangan aktiv va induktiv qarshiligi bo‘lgan elektr zanjir uchun vektor ifodasini tuzib, to‘la qarshilik ifodasini yozing.
18. Aktiv va sig‘im qarshiligi bo‘lgan elektr zanjir uchun vektor ifoda tuzib, to‘la qarshilik tenglamasi yozilsin.
19. Ketma-ket biriktirilgan R, L, C zanjirida $X_L>X_S$, $X_L<X_C$, $X_L=X_C$ bo‘lgan holat uchun vektor ifoda tuzib, qaysi xarakterga ega ekanligini tushuntiring.
20. Aktiv, reaktiv va to‘la quvvat tenglamasini yozing.

21. Aktiv va reaktiv elementlarda elektr energiyasi qayerda va qanday sarflanadi?
22. Quvvat koeffitsienti $cos\varphi$ nima va qanday amaliy ahamiyatga ega?
23. O'zgarmas tokga nisbatan induktiv va sig'im qarshlligi nimaga teng?
24. Nima uchun sig'imdan o'zgaruvchan tok o'tadi, o'zgarmas tok esa o'tmaydi?
25. Ketma-ket sxemada ulangan R, L elektr zanjir qarshiligidagi kuchlanish: U_r =60V, U_L =80V ga teng bo'lganda umumiy (U) kuchlanish nimaga teng?
26. Parallel sxemada ulangan R, C elektr zanjirda o'tuvchi tok $I_r = 3A$, $I_c = 4A$ bo'lganda, umumiy tok (I) qanchaga teng?
27. R, L, C ketma-ket ulangan zanjirning to'la qarshiligi Z=100Om, R = 80 Om, X_C = 40 Om bo'lsa, g'altakning induktiv qarshiligi X_L necha Om ga teng?
28. Agar $C=20$ mkf bo'lgan sig'im parametri $U=220(sin314t - 60)V$ kuchlanishga ulanganda tokning oniy qiymati (i) ni aniqlang.
29. Kuchianish $U=100$ V, tok kuchi $I=5A$ va faza burchagi $\varphi= 60^0$ bo'lgan zanjirning aktiv quvvati necha $vatt$ bo'ladi?
30. Kuch qarshilik va quvvat uchburchak vektor ifodasiga asosan $Cos\varphi$, $sin\varphi$, $tg\varphi$ tenglama tuzing.
31. Qarshilik va quvvatlar uchburchak vektor ifodasidan, aktiv va reaktiv tashkil etuvchi vektor qanday ma'noni bildiradi?
32. Sinusoidal elektr zanjir kuchianishi $u = 141\sin(314 + 80^{\circ})$ va tok $i = 14{,}1\sin(314 + 20^{\circ})$ bo'lganda, aktiv quvvat necha $vatt$ ga teng. (Javob: $P = 500Vt$).
33. Sinusoidal elektr zanjirda kuchlanish
u=28,2$\sin(628 + 80^0)$ va tok $i = 2{,}82\sin(628 + 50^0)$ bo'lganda, reaktiv quvvat qancha bo'ladi? (Javob: Q=20 VAR).
34. Elektr zanjir to'la quvvati S=1000 bo'lib $\cos\varphi = 0{,}8$ bo'lganda aktiv quvvat qiyinatini toping.
35. Elektr zanjir kuchlanishi U=220 V, tok I=10 A, aktiv quvvat R=1,1 kvt ga teng bo'lganda $\cos\varphi$ nimaga teng?
36. Ketma-ket ulangan R, L, C zanjirning to'la qarshiligi Z = 100 Om, aktiv qarshiligi R=30 Om va sig'im qarshiligi $X_C = 40\ Om$ bo'lsa, induktiv qarshilik necha Om bo'ladi?

37. Ketma-ket ulangan R, L, C zanjirdagi kuchlanish U_R=30V, U_L=40V, U_C=40V bo'lganda umumiy kuchlanish (U) qancha bo'ladi?
38. Induktiv g'altakning to'la qarshiligi $Z = 10\ Om$, aktiv qarshilik qismidagi kuchlanish $U_R = 30\ V$, induktivlikda $U_L = 40\ V$ bo'lganda, umumiy kuchlanish U va tok I nimaga teng?
39. Parallel sxemada ulangan R, C zanjirdagi tok $I_R = 4A$, $I_c = 3A$ bo'lib, $U = 100\ V$ kuchlanisliga ulangan. To'la o'tkazuvchanlik (y) va to'la quvvat (S) qiymati qancha bo'ladi?
40. Tok va kuchlanish oniy qiymati: $u = 282\sin(\omega t + 60^\circ)$; $i = 141\sin(\omega t + 30^\circ)$ bo'lganda, faza burchagi φ, to'la, aktiv va reaktiv quvvat qancha bo'ladi?
41. Quvvat koeffitsienti Cos=0,85 bo'lgan elektrodvigatel $U = 120V$ kuchlanishga ulangan bo'lib, $I = 2A$ tok sarflaydi. To'la, aktiv va reaktiv quvvat qiymatini aniqlang.
42. Induktiv g'altak aktiv qarshiligi $R = 15\ Om$ bo'lib, ampermetr – 5A va voltmetr – 220 V ni ko'rsatadi. Zanjirning to'la, aktiv, reaktiv quvvati, induktiv qarshlligi, qarshiliklardagi kuchlanish va burchak $\cos\varphi$ nimaga teng?

III. SINUSOIDAL O‘ZGARUVCHAN ELEKTR ZANJIRNI KOMPLEKS (SIMVOLIK) USULDA HISOBLASH

3.1. Asosiy nazariy tushunchalar

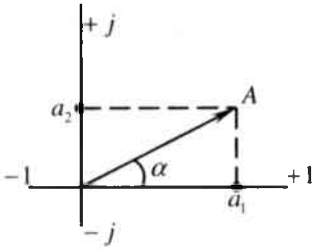
1. Kompleks son.

Kompleks son Eyler formulasiga asosan $e^{\pm j\varphi} = \cos\varphi + j\sin\varphi$ ifodalanadi, kompleks tekislikda nuqta yoki vektor ko‘rinishda tasavvur qilish mumkin bo‘lib, kompleks son uch xil ko‘rinishda ifodalanadi.

$\dot{A} = a_1 + ja_2$ – algebraik

$\dot{A} = a(\cos\alpha + j\sin\alpha)$ – trigonometrik

$\dot{A} = ae^{j\alpha}$ – ko‘rsatkichli



Bunda:

$a_1 = a\cos\alpha = \mathrm{Re}\,\dot{A}$ – haqiqiy qismi.

$a_2 = a\sin\alpha = Jm\,\dot{A}$ – mavhum qismi.

a – kompleks son moduli: $|a| = \sqrt{a_1^2 + a_2^2}$ α – kompleks son argumenti:

$\alpha = arctg\dfrac{a_2}{a_1}$ Shuningdek: $e^{\pm\pi/2} = \pm j$; $\frac{1}{j} = -j$; $j^2 = 1$;

$j^3 = j$ va $j^4 = 1$

Kompleks sonlarni qo‘shish yoki ayirish amalini bajarishda **algebraik ko‘rinishda**, ko‘paytirish va bo‘lish amalini bajarishda esa **ko‘rsatkichli** ifodasidan foydalaniladi.

Sinusoidal o‘zgaruvchan tok, kuchlanishlar va EYK funksiyasini kompleks ko‘rinishdagi ifodasi:

$$i = I_m \sin(\omega t + \varphi i) \doteqdot I_m e^{j\omega t} \cdot I_m e^{j\varphi i} = \dot{I}_m e^{j\omega t}$$

$$u = U_m \sin(\omega t + \varphi_u) \doteqdot U_m e^{j\omega t} \cdot U_m e^{j\varphi u} = \dot{U}_m e^{j\omega t}$$

$$e = E_m \sin(\omega t + \varphi e) \doteqdot E_m e^{j\omega t} \cdot E_m e^{j\varphi e} = \dot{E}_m e^{j\omega t}$$

Bunda: $\dot{I}_m, \dot{U}_m, \dot{E}_m$ – sinusoidal o'zgaruvchan tok, kuchlanish, va EYK kompleks amplitudasi.

Elektr zanjirni kompleks usulda hisoblash jarayonida faqatgina vaqt funksiyasi tarzida emas, balki uning hosilasi yoki integral tarzida ham uchrashi mumkin.

$$\frac{di}{dt} = \omega I_m \sin\left(\omega t + \psi_i + \frac{\pi}{2}\right) \doteq \omega \dot{I}_m e^{j(\omega t + \varphi i + \frac{\pi}{2})} = j\omega \dot{I}_m e^{j\varphi i} \cdot e^{j\omega t} = j\omega \dot{I}_m e^{j\omega t}$$

$$\int idt = \frac{I_m}{\omega} \sin\left(\omega t + \varphi_i - \frac{\pi}{2}\right) \doteq \frac{\dot{I}}{\omega} e^{j\left(\omega t + \varphi i - \frac{\pi}{2}\right)} = \frac{I_m}{j\omega} e^{j\varphi i} \cdot e^{j\omega t} = \frac{\dot{I}_m}{j\omega} e^{j\omega t}$$

Demak, kompleks shaklda berilgan har qanday sinusoidal funksiya tasviri $\dot{I} me^{j\omega t}$ bo'lsa, bu funksiyadan hosila olish «$j\omega$» **ko'paytirish** yoki integrallash esa «$j\omega$» ga **bo'lish** bilan barobar ekan.

2. Sinusoidal o'zgaruvchan elektr zanjirni kompleks usulda hisoblash.

Om qonunining kompleks ifodasi: $\dot{I} = \frac{\dot{U}}{\underline{Z}} = \underline{Y}\dot{U}(A)$

To'la qarshilik: $\underline{Z} = R + jx = \underline{Z}e^{j\varphi}$ (Om)

To'la o'tkazuvchanlik: $\underline{Y} = \frac{1}{\underline{Z}} = g - jb = Ye^{-j\varphi}\left(\frac{1}{Om}\right)$

To'la quvvat kompleks ifodasi:

$$\tilde{S} = \dot{U}\overset{*}{I} = \dot{U}e^{j\varphi i} \cdot \overset{*}{I} = \dot{U}Ie^{j\varphi} = \dot{U}I\cos\varphi + j\dot{U}I\sin\varphi = P + jQ \ (VA)$$

$\overset{*}{I}$ – kompleks tokning teskari ishorasi bilan olingan qiymati.

Murakkab sinusoidal o'zgaruvchan elektr zanjirni hisoblashda, *Om* va Kirxgof qonuni bilan bir qatorda Kirxgof qonunini tatbiq etish konturli tok usuli, tugun kuchlanishlar, ustma-ustlik (superpozitsiya) usuli, mutanosiblik prinsipi, ekvivalent generator usullaridan foydalaniladi.

Iste'molchilar ketma-ket ulangan oddiy elektr zanjirlarda tok umumiy bo'lib Om qonuniga asosan.

$\dot{I} = \frac{\dot{U}}{\underline{Z}}$; bunda $\underline{z} = \underline{z}_1 + \underline{z}_2 + \ldots\ldots\ldots\ldots \underline{z}_n = \sum_{b=1}^{n=v} \underline{z}_n$

Iste'molchilar parallel ulangan elektr zanjirda kuchlanish umumiy bo'lib $\dot{I} = \dot{U}\,\underline{y}$; bunda $\underline{y} = \underline{y}_1 + \underline{y}_2 + \ldots\ldots\ldots\ldots \underline{y}_n = \sum_{b=1}^{n=v} \underline{y}_n$

Aralash sxemada ulangan elektr zanjir uchun kompleks qarshiligi $\underline{Z}_{12} = \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2}$ bo'lib, tarmoqdagi tok: $\dot{I}_1 = \frac{\underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2}\dot{I}$; $\dot{I}_2 = \frac{\underline{Z}_1}{\underline{Z}_1 + \underline{Z}_2}\dot{I}$.

$\dot{I}$ – umumiy tokning kompleks qiymati. Kirxgof qonunining kompleks ifodasi. 1-qonun; $\sum_{k=1}^{n} \dot{I}_k = 0$ 2-qonun; $\sum_{k=1}^{n} \dot{E}_k = \sum_{k=1}^{n} \underline{Z}_k \dot{I}_k$

3. Murakkab sinusoidal o'zgaruvchan elektr zanjirni kompleks usulda hisoblash.

a) Kirxgof qonunini tatbiq qilish.

Murakkab elektr zanjirni Kirxgof qonuniga asosan hisoblashda berilgan zanjir uchun elektr muvozanat tenglamasi tuziladi. Tuzilgan tenglama soni tarmoqdagi tok soniga teng bo'lishi kerak. Agar zanjirning tarmoqlar soni *R*, tugunlar soni *q* ga teng bo'lsa, u holda Kirxgof 1-qonuni *(p-q+1)* tenglamasi tuziladi. Tenglamalar sistemasini yechish bilan $\dot{I}_1, \dot{I}_2, \ldots\ldots + \dot{I}_p$ tarmoqdagi tok aniqlanadi.

b) konturli tok usuli.

Konturli tok usuli Kirxgof 2-qonuniga asoslangan bo'lib, berilgan zanjirning kontur uchun tuzilgan tenglamalar sistemasini yechish bilan konturdagi tok va tarmoqdagi tok aniqlanadi.

Umumiy holda konturdagi tok tenglamalar soni *(p-q+1)* ga teng bo'ladi.

q – zanjirdagi tugunlar soni

p – tarmoqlar soni

Agar zanjir n ta kontur toklariga ega bo'lsa, uning tenglamasi quyidagicha tuziladi:

$$\left.\begin{array}{l}\dot{I}_{k1}\underline{Z}_{11}+\dot{I}_{k2}\underline{Z}_{12}+\dots\dots\dots\dots+\dot{I}_{kn}\underline{Z}_{1n}=\dot{E}_{11}\\ \dot{I}_{k1}\underline{Z}_{12}+\dot{I}_{k2}\underline{Z}_{22}+\dots\dots\dots\dots+\dot{I}_{kn}\underline{Z}_{2n}=\dot{E}_{12}\\ \dot{I}_{k1}\underline{Z}_{n1}+\dot{I}_{k2}\underline{Z}_{n2}+\dots\dots\dots\dots+\dot{I}_{k1}\underline{Z}_{nn}=\dot{E}_{nn}\end{array}\right\}$$

Bunda: $\underline{Z}_{nn}$ - n – konturnimg xususiy garshiligi $\underline{Z}_{qs}$ $-q$ *va* S – yon konturning o‘zaro qarshiligi.

Agar yondosh konturdagi tokning $\dot{I}_{kq}$ va $\dot{I}_{ks}$ yo‘nalishi mos bo‘lsa, tarmoqning qarshiligi tenglamalar sistemasiga (+) ishora, qarama-qarshi bo‘lsa, (-) ishora kiritiladi. $\dot{E}_{nn}$ - n – konturning xususiy EYK

d) tugun potensiallar usuli.

Tugunlararo kuchianishlar usulidan foydalanish asosan ko‘p elementlardan tarkib topgan tarmoqlangan murakkab elektr zanjirni hisoblashda ancha qulay bo‘lib, ixtiyoriy elektr zanjiridagi $q=(n+1)$ tugundan bittasini nisbiy kuchlanish (potensiali) nolga teng deb olinadi $(\varphi_n = 0)$. Qolgan barcha tugun potensial tenglamasi shunga nisbatan tuziladi.

$$\left.\begin{array}{l}\underline{y}_{11}\dot{U}_{10}+\underline{y}_{12}\dot{U}_{20}+\dots\dots\dots\dots+\underline{y}_{1k}\dot{U}_{ko}=\dot{I}_{11}\\ \underline{y}_{21}\dot{U}_{10}+\underline{y}_{22}\dot{U}_{20}+\dots\dots\dots\dots+\underline{y}_{2k}\dot{U}_{ko}=\dot{I}_{22}\\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\\ \underline{y}_{n1}\dot{U}_{10}+\underline{y}_{k2}\dot{U}_{20}+\dots\dots\dots\dots+\underline{y}_{nn}\dot{U}_{ko}=\dot{I}_{nn}\end{array}\right\}$$

Bunda:

$$\left.\begin{array}{l}\underline{y}_{nn}=\sum\limits_{\substack{p=1\\p\neq n}}^{n}\underline{y}_{pn}\\ \dot{I}_{nn}=\sum\limits_{\substack{p=1\\p\neq n}}^{n}\underline{y}_{pn}\dot{E}_{pn}\end{array}\right\}$$

Tenglamalar sistemasini yechish bilan tugun kompleks kuchlanishi:

$$\dot{U}_{10},\ \dot{U}_{20},\ \dot{U}_{n0} \qquad (\varphi_1-\varphi_0;\ \varphi_2-\varphi_0;\ \varphi_3-\varphi_0......)$$

va tugunlar orasidagi kompleks kuchlanishlar aniqlanadi.

$$\dot{U}_{nm}=\dot{U}_{no}-\dot{U}_{mo}$$

Tarmoqdagi tok esa butun zanjir uchun *Om* qonuniga asosan

$$\dot{I}_{nm}=\underline{Y}_{nm}\left(\dot{E}_{nm}+\dot{U}_{nm}\right)$$

Agar elektr zanjiri faqat ikkita tugundan iborat bo'lsa (q = 2) tenglama

$$\underline{Y}_{11}\cdot\dot{U}_{10}=\dot{I}_{11};\qquad \dot{U}_{10}=\frac{\dot{I}_{11}}{\underline{Y}_{11}};$$

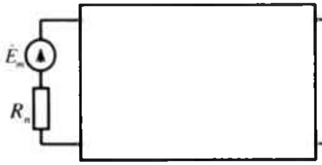
Ya'ni, tugunlararo kuchlanish tenglamasiga asosan ikkita tugun o'rtasidagi kuchlanish aniqlanib Om qonuhiga asosan tarmoqdagi tok topiladi.

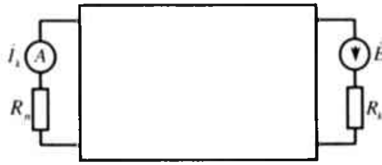
$$\dot{U}_{ab}=\frac{\underline{Y}_1\dot{E}_1+\underline{Y}_2\dot{E}_2+\underline{Y}_3\dot{E}_3+................+\underline{Y}_n\dot{E}_n}{\underline{Y}_1+\underline{Y}_2+\underline{Y}_3+........\underline{Y}_n}=\frac{\sum_{p=1}^{n}\underline{y}_n\dot{E}_n}{\sum_{p=1}^{n}\underline{y}_n}$$

e) ustma-ustlik (superpozitsiya) usuli.

Parametrlari chiziqli bo'lgan elektr zanjirning biror K tarmog'idan o'tuvchi tok shu zanjirni tashkil etuvchi EYK hosil qiladigan tokning yig'indisidan iborat bo'ladi. Shu sababli chiziqli murakkab elektr zanjirni hisoblashda, har bir EYK ta'sirida zanjir tarmoqlaridan o'tuvchi tok alohlda aniqlanadi (qolgan EYK nolga teng deb olinib, zanjirning ichki qarshlligi saqlanadi). Natijada har bir EYK ta'sirida tarmoqdan o'tuvchi tokning algebraik yig'indisi umumiy tok qiymatiga teng bo'ladi: $\dot{I}=\dot{I}'+\dot{I}''+............+\dot{I}_K''$

Ustma-ustllk usuli yordamida faqatgina zanjirdagi tok va kuchlanish aniqlanib, quvvatni hisoblashda tavsiya etilmaydi.





f) mutanosiblik prinsipi.

Bu prinsip chiziqli elektr zanjir uchun Maksvell tomonidan taklif etilgan bo'lib, har qanday murakkab elektr zanjirning (K) tartibida joylashgan $\dot{E}_k = \dot{E}$ EYK manba (boshqa manbalar bo'lmagan holda), shu zanjirnmg ixtiyoriy p tarmog'ida $\dot{I}_n = \dot{I}$ tok hosil qllgan bo'lsa, shu EYK manbamng o'zi n tarmoqqa ko'chirilgan holda $\dot{E}_k = \dot{E}$ (K) tarmoqdagi tokni hosil qiladi.

Masalan: Konturli tok usuliga asosan k tarmoq zanjirinmg q konturiga, n tarmog'i S konturiga kirgan deb faraz qilamiz. Bu holda konturda kontur toklari $\dot{I}_k = \dot{I}_q$ va $\dot{I} = \dot{I}_3$ bo'ladi va EYK qaysi tarmoqqa ulanganldan qat'i nazar, ularmng qiymati $\dot{I}_k = \dot{I}_q = \dot{E}\dfrac{\Delta qs}{\Delta}$ va $\dot{I}_n = \dot{I}_s = \dot{E}\dfrac{\Delta qs}{\Delta}$ ga teng bo'ladi.

Demak:

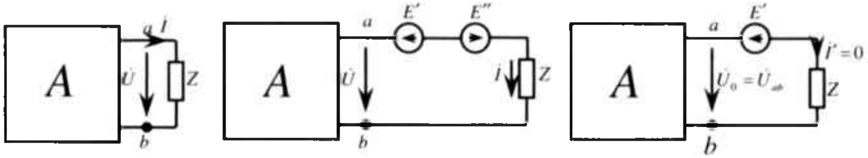
$\dot{I}_k = \dot{I}_n = \dot{I}$, chunki $\Delta_{qs} = \Delta sq$ bo'lib, $\dfrac{\dot{E}_k}{\dot{I}_n} = \dfrac{\dot{E}_n}{\dot{I}_k} = \dfrac{\dot{E}}{\dot{I}} = Z - qs$

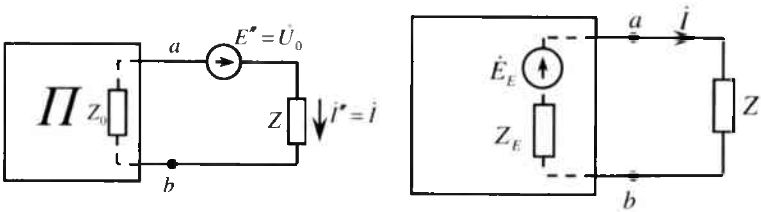
konturlararo qarshilik $Z-qs$ ga teng bo'lib, ushbu usulning mutanosibligini tasdiqlaydi.

g) ekvivalent generator usuli.

Bu usul murakkab elektr zanjirining biror qismidagi tarmoq tokini aniqlashda qulay bo'lib, amalda qisqa tutashtiruv yoki uzilish (salt holat) tajribalari o'tkaziladi. Elektr energiyasi bo'lgan ikki qutbli elektr zanjir ekvivalent manba va parametr bilan almashtiriladi. Bunda zanjir manba kuchianish salt holat kuchlanishiga teng bo'ladi. $\dot{E} = \dot{U}_0 = \dot{U}_{ab}$ ichki qarshilik esa ekvivalent qarshilikga teng (3.3) $Z_0 = Z_E$

Ikki qutbli aktiv zanjirning biror (K) tarmoqdagi R qarshllik tokni amqlash zarur bo'lsa, Om qonuniga asosan.

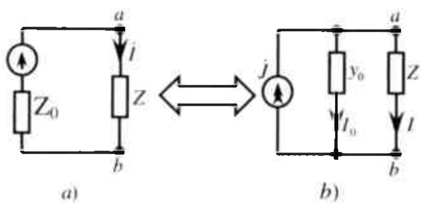




4. EYK manbaini tok manbaiga almashtirish.

Amalda EYK va tok manbaini almashtirishga imkon beruvchi, noldan farq qiladigan ichki parametrlar $R \neq 0$ *ва* $g \neq 0$ mavjud; ularni o'zaro almashtirish mumkin. (a) manba kuchlanish tenglamasi:

$$\dot{U}_{ab} = E - Z_o \dot{I}$$



Ba'zi hollarda manba kuchlanishi parallel sxema bilan almashtirilib tok manbai ko'rinishida ham ifodalanadi (b) .

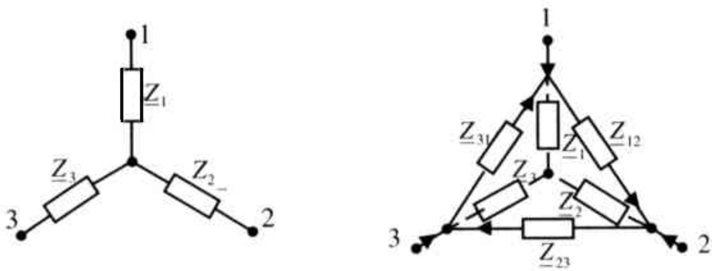
Bunda kuchlanish muvozanat tenglamasi manba qarshiligi Z_0 ga bo'linsa

$$\frac{\dot{U}_{ab}}{\underline{Z}_0} = \frac{\dot{E}}{\underline{Z}_0} - \dot{I} \text{ yoki } \dot{I}_0 = \dot{J} - \dot{I}$$

Bunda $\dot{J} = \dfrac{\dot{E}}{\underline{Z}}$ va $\underline{Y}_0 = \dfrac{1}{\underline{Z}_0}$

Yulduzcha va uchburchak tarzida ulangan tarmoqlarni o'zaro almashtirish (ekvivalent parametrlar)

a) uchburchak shaklida ulangan qarshiliklarni yulduzcha shaklida almashtirish tenglamalari:



$$\underline{Z}_1 = \frac{\underline{Z}_{31} \cdot \underline{Z}_{12}}{\underline{Z}_{12} + \underline{Z}_{31} + \underline{Z}_{23}}; \quad \underline{Z}_2 = \frac{\underline{Z}_{12} \cdot \underline{Z}_{23}}{\underline{Z}_{12} + \underline{Z}_{23} + \underline{Z}_{31}}; \quad \underline{Z}_3 = \frac{\underline{Z}_{23} \cdot \underline{Z}_{31}}{\underline{Z}_{12} + \underline{Z}_{23} + \underline{Z}_{31}};$$

b) yulduzcha shaklidan uchburchak shakliga almashtirish tenglamalari:

$$\underline{Z}_{12} = \underline{Z}_1 + \underline{Z}_2 + \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_3}; \quad \underline{Z}_{23} = \underline{Z}_2 + \underline{Z}_3 + \frac{\underline{Z}_2 \cdot \underline{Z}_3}{\underline{Z}_1}; \quad \underline{Z}_{31} = \underline{Z}_3 + \underline{Z}_1 + \frac{\underline{Z}_1 \cdot \underline{Z}_3}{\underline{Z}_2}$$

3.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 3.1. Berilgan kuchlanish va tok $u = 100\sin\left(\omega t + \frac{\pi}{6}\right)(V)$ $i = 5\sin\left(\omega t + \pi/6\right)(A)$ funksiyalarining kompleks ifodasi, kompleks to'la qarshilik $\underline{Z}$, to'la o'tkazuvchanlik $\underline{Y}$ va to'la quvvat $\tilde{S}$ aniqlansin.

Yechish.

$u = 100\sin(\omega t + 30°) \doteqdot 100e^{j30°}$ $\quad i = 5\sin(\omega t - 30°) \doteqdot 5e^{-j30°}$

Kompleks to'la qarshilik: $\underline{Z} = \frac{\dot{U}_m}{\dot{I}_m} = \frac{100e^{j30}}{5e^{-j30}} = 20e^{j60°} = 10 + j17{,}3\ (Om)$

Kompleks to'la o'tkazuvchanlik: $\underline{Y} = \frac{1}{\underline{Z}} = 0{,}1 + j0{,}06$ $\quad \left(\frac{1}{Om} = sim\right)$

Kompleks to'la quvvat:

$$\tilde{\underline{S}} = \dot{U}\overset{*}{I} = \dot{U} \cdot Ie^{j(\varphi_U - \varphi_i)} = 500e^{j60°} = 500\cos 60° + j500\sin 60° = 250 + j430(VA)$$

Bundan aktiv quvvat: *P=250 Vt;* Reaktiv quvvat: *Q=430 (VAR).*

Masala 3.2. Qarshiligi $R = 3\ Om,\ X = \pm 4\ Om$ bo'lgan elektr zanjir kuchlanishi $U = 100\ V$. Tok va to'la quvvat kompleks qiymati hisoblab topilsin.

Yechish.

To'la qarshilik kompleks ifodasi: $\underline{Z} = R \pm jx = 3 \pm j4 = 5e^{\pm j53^0}$

Tok: $\dot{I} = \dfrac{\dot{U}}{\underline{Z}} = \dfrac{100e^{j0}}{5e^{\pm j53^0}} = 20e^{\pm j53^0} = 12 \pm j16$

To'la quvvat kompleks ifodasi:

$$\tilde{S} = \dot{U}\overset{*}{I} = 100 \cdot 20e^{\pm j53^\circ} = 2000\cos 53^\circ \pm j2000\sin 53^\circ = 1200 \pm j1600(BA)$$

Masala 3.3. Kuchlanish $\dot{U} = (80 + j60)$ tok $\dot{I} = (24 - j7)$ kompleks ifodalari uchun aktiv va reaktiv qarshilik qiymati aniqlamb, tok va kuchlanish vektor ifodasi chizilsin.

Yechish.

Tok va kuchlanish ko'rsatkichli ifodasi aniqlanadi

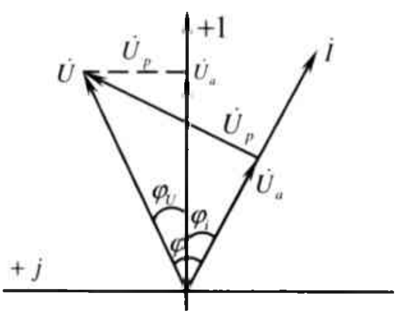
$\dot{U} = (80 + j60) = 100e^{j36^0 50}\ (V)$ $\quad \dot{I} = (24 - j7) = 25e^{-j16^0 15'}\ (A)$

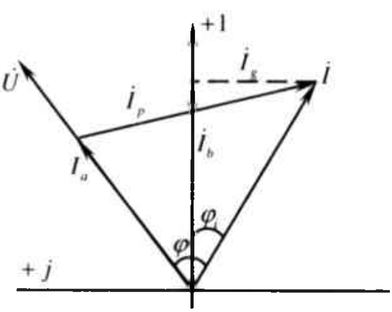
Kompleks to'la qarshilik: $\underline{Z} = \dfrac{\dot{U}}{\dot{I}} = 4e^{j53^\circ} = (2,4 + j3,2)\ (Om)$

Bundan aktiv qarshilik $R = 2,4\ Om$; reaktiv qarshilik $X = 3,2\ Om$.

Kuchlanish va tok orasidagi fazadagi farq: $\varphi = \varphi_u - \varphi_I = 53^0$

Kompleks tekislikda tok va kuchlanishlar vektor diagrammasini tuzamiz.





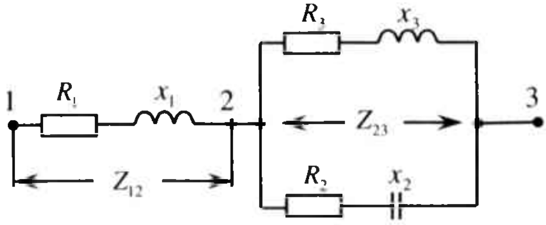
Vektor diagrammadan

$$\dot{U}_a = U\cos\varphi \qquad \dot{I}_a = I\cos\varphi$$

$$\dot{U}_p = U\sin\varphi \qquad \dot{I}_p = I\sin\varphi$$

$$U = \sqrt{U_a^2 + U_p^2} \qquad I = \sqrt{I_a^2 + I_p^2}$$

Masala 3.4. Elektr zanjir parametri: $R_1=30\ Om$, $X_1=20\ Om$, $R_2=50Om$, $X_2 = -100\ Om$, $R_3 = 100\ Om$, $X_3 = 50\ Om$ ga teng bo'lganda, ekvivalent to'la, aktiv, reaktiv qarshilik qiymati topilsin.



Yechish.

Zanjirning parallel ulanlgan qismi uchun kompleks to'la qarshilik:

$$\underline{Z}_{23} = \frac{(R_3 + jx_3)(R_2 + jx_2)}{R_3 + jx_3 + R_2 - jx_2} = \frac{112e^{j26^\circ 30} \cdot 112e^{-j63^\circ}}{150 - j50} =$$

$$= \frac{12550e^{-j37^\circ}}{150e^{-j18^\circ 26'}} = 79{,}5e^{j18^\circ 26'} = 75{,}2 - j25{,}3$$

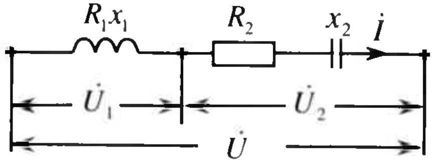
Endi umumiy kompleks ekvivalent qarshilikni topish uchun to'la kompleks qarshilikni qo'shamiz:

$$\underline{Z} = R_1 + jx_1 + \underline{Z}_{23} = 30 + j20 + 75{,}2 - j25{,}3 = 105{,}5 - j5{,}3$$

Bundan aktiv qarshilik R=105,5 Om, reaktiv qarshilik X_C=-5,3 Om ga teng bo'lib, sig'im parametriga mos keladi.

Masala 3.5. Qarshiligi $R_1 = 10\ Om$, $X_1 = 50\ Om$ bo'lgan induktiv g'altak, aktiv qarshiligi $R_2 = 10Om$ va sig'im qarshiligi $X_2 = -30\ Om$ bilan ketma-ket sxemaga biriktirilib va $U = 127\ V$ kuchlanishga ulangan. Zanjirdan o'tuvchl tok, g'altakdagi kuchlanish va sig'im kuchlanishlari aniqlansin.

Yechish. Qarshllikning kompleks ifodasini yozamiz:



$$\underline{Z}_1 = 10 + j50 = 51e^{j78°40'}$$

$$\underline{Z}_2 = 1 - j30 = 30e^{-j88}$$

Umumiy kompleks qarshilik:

$$\underline{Z} = \underline{Z}_1 + \underline{Z}_2 = 11 + j20 = 22{,}8e^{j61^0}\,Om$$

Kompleks tok: $\dot{I} = \dfrac{\dot{U}}{\underline{Z}} = \dfrac{127}{22{,}8e^{j61^0}} = 5{,}56e^{-j61^0}$

G'altakdagi kuchlanish: $\dot{U}_1 = \underline{Z}_1\dot{I} = 284e^{j17°30'}$ yoki $\varphi_1 = 17°30'$

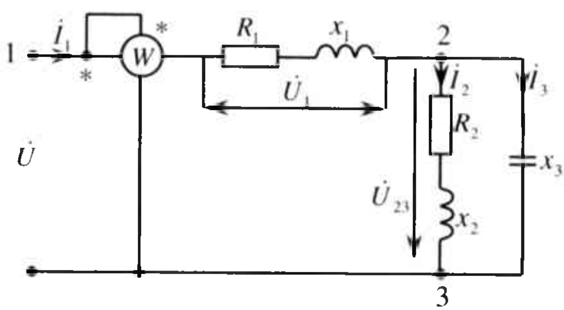
Sxemadagi kuchlanish:

$$\dot{U}_2 = \underline{Z}_2\dot{I} = 30e^{-j88^0}\cdot 5{,}56e^{-j61^0} = 167e^{-j149^0};\quad \varphi_2 = -149^0$$

Kuchlanishlar orasida fazadagi farq: $\varphi = \varphi_1 - \varphi_2 = 166^0 30^1$

Masala 3.6. 2.18-masala shartiga asosan kompleks usuldan foydalanib tarmoq toklari aniqlansin.

Yechish. Kompleks to'la qarshilik:



Bunda:

$\underline{Z}_1 = (2 + j26)\,Om$ $\underline{Z}_2 = (10 + j10)\,Om$ $\underline{Z}_3 = -j10\,Om$

Zanjirning qarshiliklari parallel ulangan qismi uchun:

$$\underline{Z}_{23} = \frac{\underline{Z}_2\underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3} = (10 - j10)\ Om$$

Zanjirning umumiy kompleks qarshiligi

$$\underline{Z} = \underline{Z}_1 + \underline{Z}_{23} = (2 + j26) + (10 - j10) = (12 + j16)\ \ Om$$

Aktiv quvvat ifodasidan $P = I_2R$, zanjiriga kiruvchi tok:

$I_1 = \sqrt{\dfrac{P}{R_1}} = \sqrt{\dfrac{1200}{12}} = 10A$, ya'ni $I_1 = 10A$ teng va haqiqiy qiymatga ega. Zanjirdagi umumiy kuchlanish:

$$\dot U = I_1\underline{Z} = (12 + j16)\cdot 10 = (120 + j160)\ V$$

Bundan: $U = \sqrt{120^2 + 160^2} = 200\ V$

Parametrlari ketma-ket ulangan qismdagi kuchlanish:

$\dot U_1 = \underline{Z}_1\dot I_1 = (2 + j26)\cdot 10 = (20 + j260)$ yoki: $U_1 = \sqrt{20^2 + 260^2} = 261\ V$

Parallel sxemada ulangan qismdagi kuchlanish:

yoki: $\dot U_{23} = \dot I_{23}(10 + j10)\cdot 10 = (100 + j100)V$

$$U_{23} = \sqrt{100^2 + 100^2} = 100\ V$$

Tarmoqdagi tok: $\dot I_2 = \dfrac{\dot U_{23}}{\underline{Z}_1} = \dfrac{100e^{-j45^0}}{10e^{j45}} = 10e^{-j90^0} = (-\ j10)\ A$

yoki: $I_2 = 10\ A.$

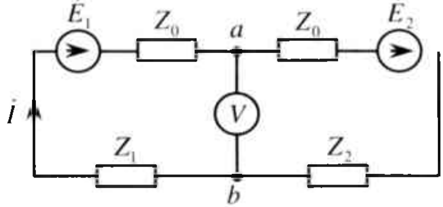
$\dot I_3 = \dfrac{\dot U_{23}}{\underline{Z}_3} = \dfrac{100e^{-j45^0}}{10e^{-j90}} = 100e^{j45^0} = (10 + j10)\ A$ yoki: $I_3 = \sqrt{10^2 + 10^2} = 14{,}1\ A.$

Masalaning yechimini tekshiramiz:

$$\dot I_1 = \dot I_2 + \dot I_3 = -j10 + 10 + j10 = 10\ A$$

Masala 3.7. Kompleks qarshiliklari:

$\underline{Z}_0 = (3 + j4)$; $\underline{Z}_1 = (44 + j74)$ $\underline{Z}_2 = -j80$ bo'lgan elektr zanjir ketma-ket sxemada ikkita generatorga ulangan bo'lib, tok qiymati va voltmetr kuchlanishi aniqlansin.



Yechish.

Zanjirdagi tok:

$$\dot{I} = \frac{\dot{E}_1 + \dot{E}_2}{2\underline{R}_0 + \underline{Z}_1 + \underline{Z}_2} = \frac{220 + j220}{(6 + j8) + (44 + j74) + (-j80)} = \frac{220e^{j45}}{50 + j2} \approx 4,4e^{j45} = (4,4 + j4,4)$$

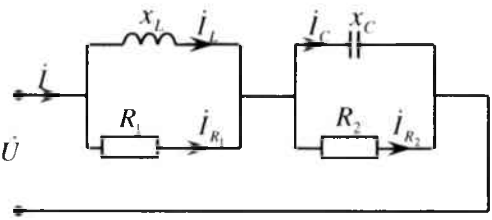
yoki: $I = \sqrt{4,4^2 + 4,4^2} \approx 6A$

Voltmetrdagi kuchlanish:

$$\dot{U}_{ab} = \frac{\dot{E}_1 + \dot{E}_2(\underline{Z}_0 + \underline{Z}_1)}{2\underline{Z}_0 + \underline{Z}_1 + \underline{Z}_2} = \frac{220 + j220\left[(3 + j4) + (4 + j74)\right]}{50 + j2} = 335 - j547$$

Bundan: $U_{ab} = \sqrt{335^2 - 547^2} = 642\ V$ V

Masala 3.8. Elektr zanjir qarshiliklari: $R_1=R_2=25Om$, $X_L=33,3Om$, $X_C=-\ 33,3Om$ bo‘lib, $U=320V$ kuchianishga ulangan. To‘la qarshilik $\underline{Z}$, burchak $cos\varphi$ va toklari amiqlansin.



Yechish. Parallel ulangan birinchi kontur to‘la qarshiligi:

$$\underline{Z}_1 = \frac{33,3e^{j90^0} \cdot 25}{25 + j33,3} = \frac{830e^{j90^0}}{41,5e^{j53^0}} = 20e^{j37^0} = 16 + j12\ Om$$

Ikkinchi kontur to‘la qarshiligi:

$$\underline{Z}_2 = \frac{33,3e^{-j90^0} \cdot 25}{25 - j33,3} = \frac{830e^{-j90^0}}{41.5e^{-j53^0}} = 20e^{-j37^0} = 16 - j12\ \ Om$$

To‘la kompleks qarshiligi: $\underline{Z} = \underline{Z}_1 + \underline{Z}_2 = 16 + j12 + 16 - j12 = 32\ Om$

Umumiy tok: $\dot{I} = \frac{\dot{U}}{\underline{Z}} = \frac{320}{32} = 10\ A$

To‘la quvvat: $\tilde{S} = \dot{U}\dot{I} = 320 \cdot 10 = 3200\ VA$

Aktiv quvvat: $P = RI^2 = 32 \cdot 10^2 = 3200\ Vt$

Zanjirning quvvat koeffitsienti: $\cos\varphi = \frac{P}{S} = 1$ bo'lib, aktiv qarshilik xarakteriga ega.

Birinchi va ikkinchi kontur kuchlanishlar:

$\dot{U}_1 = \dot{I}\underline{Z}_1 = 10 \cdot 20e^{j37^0} = 200e^{j37^0}$ (V) $\dot{U}_2 = \dot{I}\underline{Z}_2 = 10 \cdot 20e^{-j37^0} = 200e^{-j37^0}$ (V)

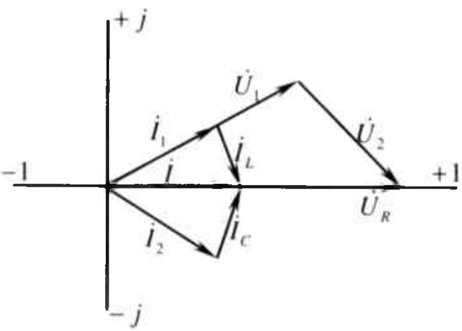
Tokni aniqlaymiz:

$\dot{I}_1 = \frac{\dot{U}_1}{R_1} = \frac{200e^{-j37^0}}{25} = 8e^{j37}A$ $\dot{I}_L = \frac{\dot{U}_L}{X_L} = \frac{200e^{j37^0}}{33{,}3e^{j90^0}} = 6e^{-j53}A$

Ikkinchi konturdagi tokni aniqlaymiz: $\dot{I}_2 = \frac{\dot{U}_2}{R_2} = \frac{200e^{-j37^0}}{25} = 8e^{-j37}A$

$\dot{I}_C = \frac{\dot{U}_C}{X_C} = \frac{200e^{-j37^0}}{33{,}3e^{-j90^0}} = 6e^{j53^0}$ A

Kompleks tekislikda tok va kuchlanish vektor ifodasi:



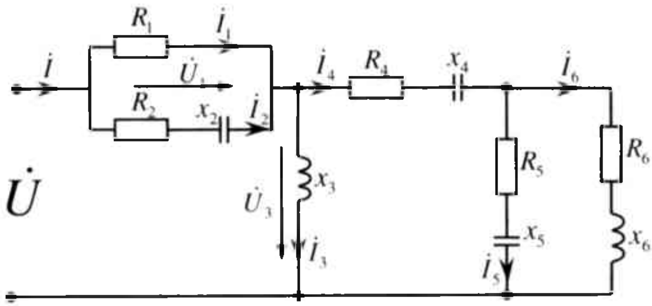
Masala 3.9. Berilgan elektr zanjir parametri: $R_1=50$ Om, $X_2=-25$ Om, $R_2=25$ Om, $X_3=10$ Om, $R_4=2{,}5$ Om, $X_4=-5Om$, $R_5=1$ Om, $X_5=-2$ Om, $R_6=1$ Om, $X_6=2$ Om bo'lib, $U=100$ V kuchlanishga ulangan.Tarmoqdan o'tuvchl $\dot{I}_1, \dot{I}_3$ va $\dot{I}_4$ kompleks tok qiymatlari aniqlansin.

Yechish.

Tarmoq kompleks qarshiligi aniqlanadi:

$\underline{Z}_6 = R_6 + jX_6 = 1 + j2 = e^{j63^0}$ $\underline{Z}_5 = R_5 - jX_5 = 1 - j2 = e^{-j63^0}$

Parallel ulangan tarmoq kompleks qarshiligi:



$$\underline{Z}_{56} = \frac{\underline{Z}_6 \cdot \underline{Z}_5}{\underline{Z}_6 + \underline{Z}_5} = 2{,}5\ Om$$

To'rtinchi tarmoq kompleks qarshiligi:

$\underline{Z}_4 = R_4 - jX_4 + \underline{Z}_{56} = 2{,}5 - j5 + 2{,}5 = 5 - j5 = 7{,}1e^{-j45^\circ}\ Om$

Uchinchi tarmoq kompleks qarshiligi:

$$\underline{Z}_3 = \frac{\underline{Z}_4 \cdot X_3}{\underline{Z}_4 + jX_3} = \frac{71e^{-j45^0} \cdot 10e^{j90^0}}{5 - j5 + j10} = 10\ Om$$

Parallel ulangan birinchi kontur kompleks qarshiligi:

$$\underline{Z}_{12} = \frac{R_1(R_2 - jX_2)}{R_1 + R_2 - jX_2} = 20{,}6 - j10{,}3 = 23e^{-j26^\circ 30'}\ Om$$

Zanjirning kompleks to'la qarshiligi:

$$\underline{Z} = \underline{Z}_{12} + \underline{Z}_3 = 20{,}6 + j10{,}3 + 10 = 30{,}6 - j10{,}3 = 32{,}4e^{-j12^\circ}\ Om$$

Zanjirdan o'tuvchi tok qiymati: $\dot I = \dfrac{\dot U}{\underline{Z}} = \dfrac{100}{32{,}4e^{-j12^0}} = 3{,}1e^{j18^0} = 3 + j\ \ A$

Tarmoqdagi kuchlanish:

$\dot U_{R1} = \dot I R_{12} = 3{,}1e^{j18^\circ} \cdot 23e^{-j26^\circ 30'} = 71{,}5e^{-j8^\circ 30'} = 70{,}5 - j10{,}5\ V$

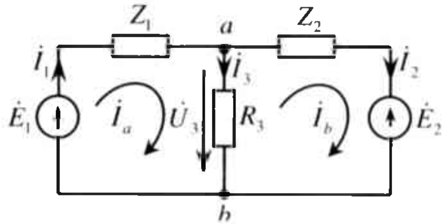
$\dot U_{X3} = \dot U - \dot U_{R1} = 100 - 70{,}5 + j10{,}5 = 29{,}5 + j10{,}5 = 31{,}5e^{j19^\circ 30'}\ V$

Tarmoqdagi tok :

$$\dot I_3 = \frac{\dot U_{X3}}{jX_3} = \frac{31{,}5e^{j19^0 30'}}{10e^{j90^0}} = 3{,}15e^{-j70^0 30'} = -j3 + 1\ \ A$$

$$\dot I_4 = \dot I_1 + \dot I_3 = 3 + j - 1 + j3 = 2 + j4\ \ \ A$$

Masala 3.10. Ikki konturli elektr zanjirga ichki qarshiliklari $Z_1=Z_2=1+j2$ *Om*; EYK E_1 = 120 *V*, E_2 = 115 *V* ga teng. Ikkita generator o'rtasidagi qarshiligi R_3=10 *Om* bo'lgan iste'molchi ulangan. Tarmoqdagi tok va kuchianishlari har xil usullar yordamida hisoblansin.



Yechish.

1. Konturli tok usuli.

Berilgan zanjir ikkita konturdan iborat bo'lib, tarmoq va konturdagi tok yo'nalishini shartli ravishda belgilab olamiz. EYK yo'nalishini hisobga olgan holda $\dot I_a, \dot I_b$ konturlar uchun ikkita tenglama tuzamiz.

$$\dot I_a(\underline{Z}_1+\underline{Z}_3)-\dot I_b\underline{Z}_3=\dot E_1 \quad \dot I_b(\underline{Z}_2+\underline{Z}_3)-\dot I_a\underline{Z}_3=\dot E_1$$

Tenglamalar sistemasini yechish bilan konturdagi tok aniqlanadi:

$$\left.\begin{aligned} &\dot I_a(11+j2)-\dot I_b 10=120 \\ &\dot I_b(11+j2)-\dot I_a 10=-115 \end{aligned}\right\} \begin{aligned} &10 \\ &(11+j2) \end{aligned}$$

$$\dot I_b(11+j2)(11+j2)-100\dot I=1200-115(11+j2)$$

Bundan: $\dot I_b=(-5{,}04-j0{,}47)\ A$

Birinchi tenglamadan: $\dot I_a=\dfrac{120+\dot I_b 10}{11+j2}=(6{,}05-j1{,}53)\ A$

Birinchi generatordagi tok konturdagi tok qiymatiga teng:

$\dot I_1=\dot I_2=(6{,}05-j1{,}53)\ A$ *yoki* $I_1=\sqrt{(6{,}05)^2+(-1{,}53)^2}=6{,}24\ A$

Ikkinchi generatordagi tok:

$\dot I_2=\dot I_b=(-5{,}04-j0{,}47)\ A$ yoki $I_2=\sqrt{(-5{,}04)^2+(-0{,}47)^2}=5{,}28A$

Iste'molchidagi tok:

$$\dot I_3=\dot I_a-\dot I_b=\dot I_1-\dot I_2=(6{,}05-j1{,}53)-(5{,}04-j0{,}47)=(11{,}09+j1{,}06)$$

yoki $\quad I_3 = \sqrt{(11,09)^2 - (1,06)^2} = 11,14\ A$

Iste'molchidagi va generatordagi kuchlanish:

$$\dot U_3 = \dot I_3 R_3 = (11,09 - j1,06)\cdot 10 = (110,9 - j10,6)\ V$$

$$U_3 = \sqrt{(110,9)^2 + (-10,6)^2} = 111,4\ V$$

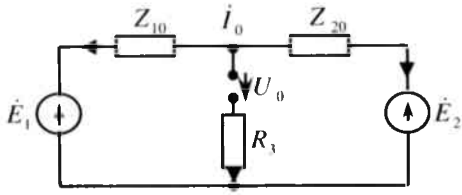
2. Ekvivalent generator usuli.

Zanjirning iste'molchi ulangan tarmog'i uzilgan bo'lsa. Bunda:

$$\dot U_0 = \dot E_1 - \dot I_0 \underline{Z}_1 = \dot E_1 - \frac{(\dot E_1 - \dot E_2)}{\underline{Z}_1 + \underline{Z}_2}\underline{Z}_1 = 120 - \frac{120-115}{2(1+j2)}(1+j2) = 117,5\ V$$

Uzilgan holatda zanjirning ichki qarshiligi $\left(\dot E_1 = 0,\ \ \dot E_2 = 0\right)$ ya'ni,

ekvivalent generator qarshiligi: $\underline{Z}_0 = \dfrac{\underline{Z}_1\underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} = (0,5 + j1)\ Om\cdot$



Iste'molchidagi tok: $\dot I_3 = \dfrac{\dot U_0}{R_3 + \underline{Z}_0} = \dfrac{117,5}{10 + (0,5 + j1)} = (11,09 - j1,06)\,A$

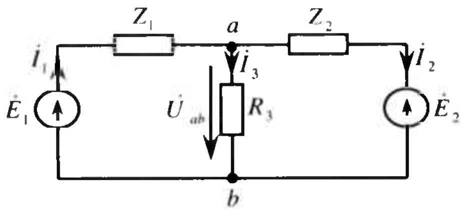
$I_3 = \sqrt{(11,09)^2 + (-1,06)^2} = 11,14\ A$

Iste'molchidagi kuchlanish: $\dot U_3 = \dot I_3 R_3 = (110,9 - j10,6)\ \ V$;

yoki: $U_3 = \sqrt{(110,9)^2 - (10,6)^2} = 111,44\ V$

3. Tugun kuchlanishlar usuli.

Zanjirning *a* va *b* tugun potensiallaridagi kuchlanish:



$$\dot{U}_{ab}=\frac{\dot{E}_1\underline{Y}_1+\dot{E}_2\underline{Y}_2}{\underline{Y}_1+\underline{Y}_2+\underline{Y}_3}=\frac{5}{2,1+j0,2}=(2,36-j0,225)$$

$$U_{ab}=\sqrt{(2,36)^2-(0,225)^2}=2,37\ V$$

Birinchi $\dot{E}_1$ generatordagi tok:

$$\dot{I}_1=\frac{\dot{E}_1-\dot{U}_{ab}}{\underline{Z}_1}=\frac{120-(2,36+j0,225)}{1+j2}=(23,6-j47)$$

yoki: $I_1=\sqrt{(23,6)^2+(-47)^2}=52,6A$

Ikkinchi E_2 generatordan o'tuvchi tok:

$\dot{I}_2=\frac{-\dot{E}_2-\dot{U}_{ab}}{\underline{Z}_2}=(23,41-j47)$ yoki $I_2=\sqrt{(23,41)^2+(-47)^2}=52,5\ A$

Iste'molchidagi tok: $\dot{I}_3=\frac{\dot{U}_{ab}}{\underline{Z}_3}=\frac{2,36-j0,225}{10}=(0,24-j0,023)\,A$

Bundan: $I_3\approx 0,24\ A$

Masala 3.11.

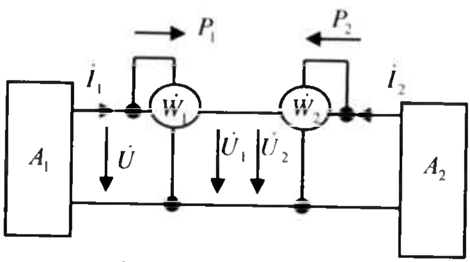
Elektr zanjir kuchlanishdagi va tok: $\dot{U}=100+j\,200\,V,$ tok $\dot{I}=8+j2,5\ A$ bo'lganda, vattmetr ko'rsatishi aniqlansin.

Yechish. Birinchi vattmetr ko'rsatishi P_1 aniqlanadi:

$\underline{U}=100+j200=223,6e^{(j63,4^\circ)}$ $\dot{I}=8+j2,5=8,4e^{j17^\circ}$

yoki $\overset{*}{I}=8,4e^{-j17^\circ}A$

$$P_1=R_e\left[\dot{U}\cdot\overset{*}{I}\right]=223,6e^{j63,4}\cdot 8,4\ e^{-j17^\circ}=R_e\left[1874e^{j46^\circ}\right]=1300\ VT$$



Ikkinchi vattmetr ko'rsatishlni P_2 aniqlanadi.

$\dot{U}=100+j200=223,6e^{j63,4^\circ}$ $\overset{*}{I}=-\left[8,4e^{j17^\circ}\right]=8,38e^{j163^\circ}A$

$$P_2=R_e\left[\dot{U}\cdot\overset{*}{I}\right]=R_e\left[223,6e^{j63,4^\circ}\cdot 8\cdot 38e^{j163^\circ}\right]=R_e\left[1873e^{j226^\circ}\right]=-1300\ VT$$

Bunda minus ishora birinchl vattmetr elektr energiyasiga nisbatan ikkinchl vattmetr energiyasiga qarama-qarshi ekanligini ifodalaydi.

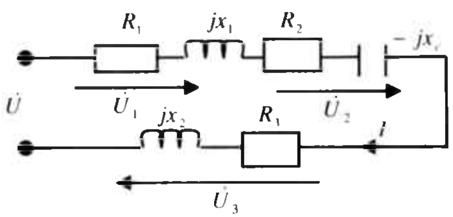
Agarda vattmetr, ampermetr va voltmetr ko'rsatish qiymati ma'lum bo'lsa, ikki qutbli passiv parametrni hisoblab topish mumkin bo'ladi.

Ya'ni: $Z=\frac{U}{I}$; $R = UI\cos\varphi$; yoki $\cos\varphi = \frac{P}{UI}$; $R = Z\cos\varphi$;

$x = \sqrt{Z^2 - R^2}$

Eslatma: Ikki qutbli zanjir parametrini aniqlashda vattmetr o'rniga fazo metrdan ham foydalanish mumkin.

Masala 3.12. Ketma-ket ulangan elektr zanjirdan $\dot{I} = 5A$ tok o'tadi. Tokga nisbatan ayrim qismlardagi kuchlanishlar: $\dot{U}_1, \dot{U}_2, \dot{U}_3$ va $\cos\varphi_1 = 0{,}707$, $\cos\varphi_2 = 0.8$, $\cos\varphi_3 = 0{,}6$ burchakka farq qilib, aktiv qarshlikdagi quvvat qiymati $P_1 = 250\,VT$, $P_2 = 200\,VT$, $P_3 = 300\,VT$ bo'lganda, zanjir parametri va kuchlanish qiymati aniqlanib, vektor ifodasi tuzilsin.



Yechish. Aktiv qarshlllk qiymatini aniqlashda quvvatlar ifodasiga asosan: $P_1 = R_1 I^2$; $P_2 = R_2 I^2$; $P_3 = R_3 I^2$

Bundan:

$$R_1 = \frac{P_1}{I^2} = \frac{250}{25} = 10\ Om;\quad R_2 = \frac{P_2}{I^2} = \frac{200}{25} = 8\ Om;\quad R_3 = \frac{P_3}{I^2} = \frac{300}{25} = 12\ Om$$

Reaktiv qarshilik qiymatini aniqlashda quyidagi ifodadan foydalanamiz: $tg\varphi_1 = \frac{x_1}{R_1}$; $tg\varphi_2 = \frac{x_2}{R_2}$; $tg\varphi_3 = \frac{x_3}{R_3}$

Bundan: $x_1 = 10\,Om$; $x_2 = 6\,Om$; $x_3 = 16\,Om$.

Kuchlanish kompleks ifodasi esa:

$\dot{U}_1 = (R_1 + jx_{L_1})\dot{I} = (10 + j10)5 = 150 + j50\ V$

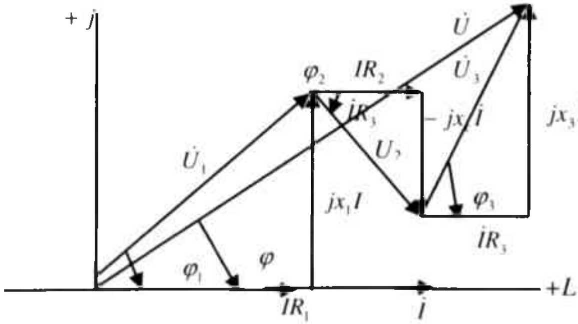
$\dot{U}_2 = (R_2 - jx_c)\dot{I} = (8 - j6)5 = 40 - j30\ V$

$\dot{U}_3 = (R_3 + jx_{L_2})\dot{I} = (12 + j16)5 = 60 + j80\ V$

Umumiy kuchlanish:

$$\dot{U} = \dot{U}_1 + \dot{U}_2 + \dot{U}_3 = 250 + j100 = 180\, e^{j33^\circ 45^1}$$

Masshtab tanlash bilan kompleks tekislikda vektor ifodasini tuzamiz.

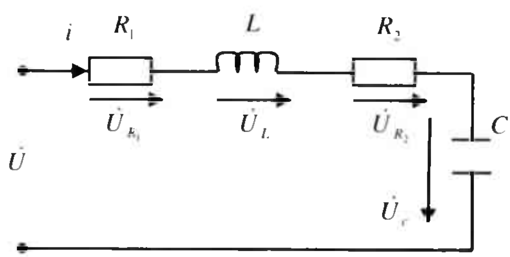


Masala 3.13. Ketma-ket ulangan zanjir parametri: $R_1 = 5\,Om$, $R_2 = 18\,Om$, $L = 50 \cdot 10^{-3} gn$, $C = 30 \cdot 10^{-4}$ bo'lib, $U = 75\sin(80t + 15^0)$ sinusoidal o'zgaruvchan kuchlanishga ulangan. To'la qarshilik, tok va kuchlanish haqiqiy qiymati va sarf bo'ladigan quvvat balans tenglamasi va vektor ifodasi tuzilsin.

Yechish. Reaktiv qarshilik qiymatini topamiz:

$$X_L = \omega L = 2\pi\, f L = 2 \cdot 3{,}14 \cdot 80 \cdot 50 \cdot 10^{-3} = 25\ Om$$

$$X_c = \frac{1}{2\pi\, fC} = \frac{1}{502 \cdot 30 \cdot 10^{-6}} = 66\ Om$$



Kompleks qarshilik:

$$Z = R_1 + jx_L + R_2 - jx_c = 5 + j25 + 18 - j66 = 23 - j41 = 47e^{-j60^\circ}$$

Tokning haqiqiy qiymat kompleks ifodasi: $\dot{I} = \frac{52,9e^{j15^\circ}}{47e^{-j60}} = 1,2e^{+j75^\circ}$

Faza farqi: $\varphi = \varphi_u - \varphi_i = 15^\circ - 75^\circ = -60^\circ$

Quvvat balans tenglamasiga asosan:

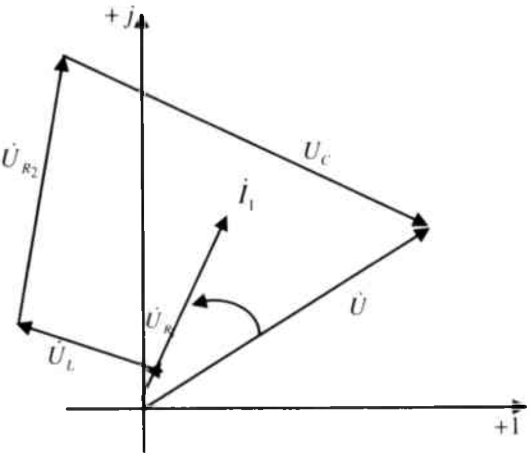
$$\tilde{S} = \dot{U}\overset{*}{I} = 52,9e^{j15} \cdot 1,2e^{-j75} = 65e^{-j60^\circ} = I^2 Z = 1,2^2 \cdot (23 - j41) =$$

$$= 32 - j57(VA) = 65e^{-j60^\circ}$$

Vektor ifodasini tuzish uchun qarshilikdagi kompleks kuchlanish qiymatini topamiz:

$$\bar{U} = \bar{U}_{R_1} + \bar{U}_{L_1} + \bar{U}_{R_2} + \bar{U}_c = \bar{I}R + \bar{I}_j X_L + \bar{I}R_2 - j\bar{I}X_c =$$
$$= 1,2 \cdot e^{j75} \cdot (5 + j2,5 + 18 - j66) =$$
$$= 6e^{j75} + 30e^{j165^\circ} + 22e^{j75} + 78e^{-j15^\circ}$$

Tok va kuchlanish masshtabini tanlash bilan kompleks tekislikda moduli va faza burchaklari bo'yicha vektorni yo'naltirgan holda chizamiz.



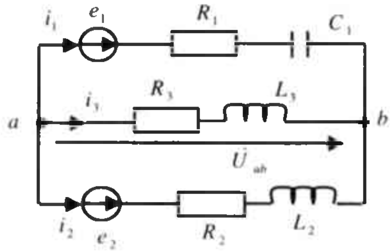
Masala 3.14. Murakkab elektr zanjir parametri:

$e_1 = 212\sin(\omega t + 30^\circ)V$, $e_2 = 212\sin\omega t(V)$, $R_1 = 8Om$, $R_2 = 10Om$, $R_3 = 7Om$, $L_2 = 32mgn$, $C_1 = 212mkf$,

chastota $f = 50gs$ bo'lganda tarmoqdagi tok aniqlansin.

Yechish. EYK kompleks ifodasini yozamiz:

$$\dot{E}_1 = \frac{212}{\sqrt{2}} e^{j30^\circ} = 150 e^{j30^\circ} = (130^\circ + j75); \; \dot{E}_2 = \frac{212}{\sqrt{2}} = 150 \; V.$$



Tarmoqdagi kompleks qarshilik:

$$Z_1 = R_1 - \frac{1}{j\omega c} = 8 - \frac{10^6}{j(314 \cdot 212)} = 8 - j15 \approx 17 e^{-j62^\circ} \; Om.$$

$$Z_2 = R_2 + j\omega L_2 = 10 + j314 \cdot 32 \cdot 10^{-3} = 10 + j10 = 10\sqrt{2} e^{j45^\circ} \; Om.$$

$$Z_3 = R_3 + j\omega L_3 = 7 + j314 \cdot 32 \cdot 10^{-3} \approx 7 + j10 = 12{,}2 e^{j55^\circ} \; Om.$$

Ikki tugun orasidagi potensiallar usuliga asosan:

$$\dot{U}_{ab} = \frac{\dot{E}_1 y_1 + \dot{E}_2 y_2}{y_1 + y_2 + y_3} = \frac{\dot{E}_1\left(\frac{1}{Z_1}\right) + \dot{E}_2\left(\frac{1}{Z_2}\right)}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}} = \frac{\frac{150 e^{j30^\circ}}{17 e^{-j62}} + \frac{150}{14{,}1 e^{j45^\circ}}}{\frac{1}{17 e^{-jj62}} + \frac{1}{14{,}1 e^{j45^\circ}} + \frac{1}{12{,}2 e^{j55}}} =$$

$$= 53{,}7 e^{j36^\circ} \approx 43{,}4 + j31{,}6 V.$$

Tarmoqdagi tok:

$$\dot{I}_1 = \frac{\dot{E}_1 - \dot{U}_{ab}}{1} = \frac{130 + j75 - 43{,}4 - j31{,}6}{17 e^{-j62^\circ}} = \frac{97 e^{j26^\circ}}{17 e^{-j62^\circ}} = 5{,}7 e^{j88^\circ}$$

$$\dot{I}_2 = \frac{\dot{E}_2 - \dot{U}_{ab}}{2} = \frac{150 - 43{,}4 - j31{,}6}{14{,}1 e^{j45^\circ}} \approx \frac{111 e^{-j16{,}5}}{14{,}1 e^{j45^\circ}} = 7{,}9 e^{j61{,}5^\circ}$$

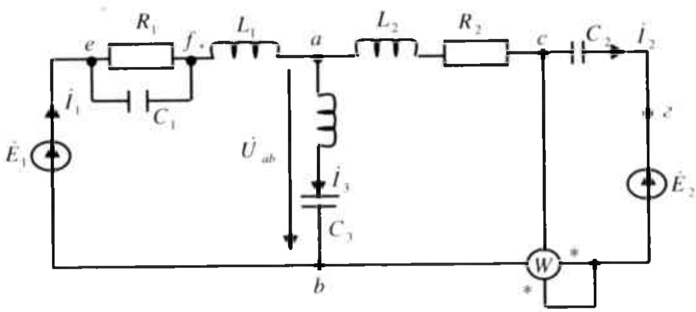
$$\dot{I}_3 = \frac{-\dot{U}_{ab}}{3} = \frac{-53{,}7 e^{j36^\circ}}{12{,}2 e^{j55^\circ}} = -4{,}4 e^{j19^\circ}$$

$$\tilde{S} = \tilde{S}_1 + \tilde{S}_2 = \dot{E}_1 \cdot \overset{*}{I}_1 + \dot{E}_2 \overset{*}{I}_2 = 150e^{j30^\circ} \cdot 5,7e^{-j88^\circ} + 150 \cdot 7,9e^{-j61,5} =$$

$$= 855e^{-j58^\circ} + 1195e^{-j61,5} = 855(\cos 58^\circ - j\sin 58^\circ) + 1195(\cos 61,5^\circ - j\sin 61,5^\circ)$$

$$= \left(427 - j\sqrt{3}\cdot 427\right) + \left(600 - j\sqrt{3}600\right) = \left(1027 - j\sqrt{3}\cdot 2\cdot 1027\right) BA$$

Masala 3.15. Murakkab elektr zanjir parametri: $\dot{E}_2 = 200^{e^{j45^\circ}}$ V; $\dot{E}_2 = 240e^{j0^\circ} V$; $R_1 = 12\, Om$; $L_1 = 2 \cdot 10^{-3}\, gn$; $C_1 = 20 \cdot 10^{-6} f$; $R_2 = 14\, Om$; $L_2 = 8 \cdot 10^{-3} gn$; $C_2 = 100 \cdot 10^{-6} f$; $R_3 = 4\, Om$; $L_3 = 5 \cdot 10^{-3} gn$; $C_3 = 50 \cdot 10^{-6} f$; $f = 500\, gs$ ga teng.



Tarmoqdagi tok, vattmetr ko'rsatish qiymati aniqlanib, quvvat muvozanat tenglamasi tuzilsin.

Yechish. Ikki tugunlararo potensiallar usuliga asosan:

$$\dot{U}_{ab} = \frac{\dot{E}_1 y_1 + \dot{E}_2 y_2}{y_1 + y_2 + y_3} \tag{1}$$

Bu yerda: $y_1 = \dfrac{1}{Z_1} = \dfrac{1}{7,67e^{j40^\circ}} = 0,13e^{-j4^\circ} = 0,13 - j0,009\ \dfrac{1}{Om}$

yoki:

$$Z_1 = Z_1^1 + j\omega L = \frac{R_1 \cdot jx_c}{R_1 + jx_c} + j\omega L = (7,67 - j5,75) + j6,28 = 7,67e^{j40} Om.$$

$$y_2 = \frac{1}{Z_2} = \frac{1}{26e^{j57^\circ 20^1}} = 0,0385e^{-j57^\circ 20^1} = 0,0208 - j0,0324\ \frac{1}{Om}$$

$$y_3 = \frac{1}{Z_3} = \frac{1}{8,63e^{j90^\circ}} = 0,107e^{-j90^\circ}\ \frac{1}{Om}$$

Aniqlangan qiymatlarni (1) tenglamaga qo'yamiz:

$$\dot U_{ab} = \frac{200e^{j45^\circ} : 0{,}13e^{-j4^\circ} - 240 \cdot 0{,}0385e^{-j57^\circ 20^1}}{(0{,}13 - j0{,}009) + (0{,}0208 - j0{,}0324) + (-j0{,}107)} =$$

$$= \frac{26e^{j41^\circ} - 9{,}25e^{-j57^\circ 20^1}}{0{,}151 - j0{,}157} = \frac{(20 + j17) - (5 - j7{,}8)}{0{,}218e^{-j45^\circ}} =$$

$$= \frac{29e^{j58^\circ 40^1}}{0{,}218e^{-j46^\circ}} = 133e^{j104^\circ 50^1} = -34 + j127{,}5\ V.$$

Om qonuniga asosan tarmoqdagi tokni aniqlaymiz:

$$\dot I_1 = (\dot E_1 - \dot U_{ab})y_1 = \left(200e^{j45^\circ} - 133e^{j104^\circ 50^1}\right)0{,}13e^{-j4^\circ} =$$

$$= (175 + j13{,}5) \cdot 0{,}13e^{-j4^\circ} = 175e^{j4^\circ 20^1} \cdot 0{,}13e^{-j4^\circ} = 22{,}7\ A.$$

$$\dot I_2 = (\dot E_1 + \dot U_{ab})y_2 = \left(240 + 133e^{j104^\circ 50^1}\right) \cdot 0{,}0385e^{-j57^\circ 20^1} =$$

$$= (206 + j127{,}5) \cdot 0{,}0385e^{-j57^\circ 20^1} = 242e^{j31^\circ 75^1} \cdot 0{,}0385e^{-j57^\circ 20^1}$$

$$= 9{,}3e^{-j25^\circ 35^1} = 8{,}35 - j4\ A.$$

$$\dot I_3 = \dot U_{ab}y_3 = 133e^{j104^\circ 50^1} \cdot 0{,}107e^{j90^\circ} = 125e^{j14^\circ 50^1} = 12{,}1 + j3{,}2\ A.$$

Masalaning yechimini tekshiramiz:

$$\dot I_1 = \dot I_2 + \dot I_3 = (-8{,}35 + j4) + (-12{,}1 - j3{,}2) = -20{,}45 + j0{,}8 \approx 21\ A.$$

Sig'imdan o'tuvchi tokni topamiz:

$$I_{c_1} = \frac{U_{cf}}{jx_{c_1}} = \frac{I_1 Z_1^1}{jx_{c_1}} = \frac{22{,}7 \cdot 9{,}6e^{-j36^\circ}50^1}{16e^{-j90^\circ}} = 13{,}6e^{j52^\circ 10^1} = 8{,}15 + j10{,}9\ A.$$

Quvvat muvozanat tenglamasiga asosan: $\tilde S_{gen} = \tilde S_{ist}$

Manbadagi to'la quvvat:

$$\tilde S_{gen} = \dot E_1 \overset{*}{I}_1 + \dot E_2 \overset{*}{I}_2 = 200e^{j45^\circ} \cdot 22{,}7 - 240 \cdot 9{,}3e^{j25^\circ 35^1} = 4550e^{j45^\circ} - 2240e^{j25^\circ 35^1} =$$

$$= (3200 + j3200) - (2002 - j965) = 5202 + j2235$$

Aktiv quvvat: $P = 5202\ VT$. Reaktiv quvvat: $Q = 2235\ VAR$.

Iste'molchilarda sarf bo'ladigan to'la quvvat:

$$\tilde S_{ist} = (I_{R1}^2)R_1 - j(I_{c1}^2)X_{c1} + j(I_1^2)X_{L_1} + j(I_3^2)(X_{L_3} - X_{c3}) + j(I_2^2)X_{L_2} +$$

$$+ I_2^2 R_2 - j(I_2^2)X_{c2} = 330 \cdot 12 - j185 \cdot 16 + j515 \cdot 6{,}28 + j156 \cdot 9{,}4 +$$

$$+ j86 \cdot 25 + 86 \cdot 14 - j86 \cdot 3{,}2 = 3960 - j2960 + j3200 +$$

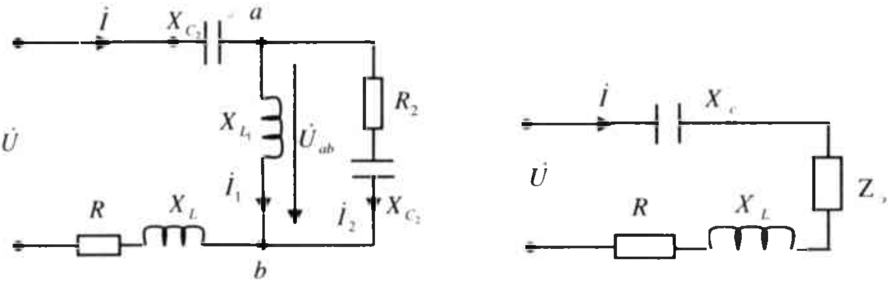
$$+ j1460 + j2150 + 1260 - j276 = 5160 + j2600.$$

Vattmetr ko'rsatish qiymatini aniqlaymiz:

$$S = \dot U_{bc} \cdot \overset{*}{I}_2 = 260e^{j174^\circ} \cdot 9{,}3e^{-j25^\circ 35^1} = 2400e^{j148^\circ 25^1} = 2040 + j1250VA.$$

Bundan: $P = 2040\,VT$,
yoki $P = U\dot{I}\cos\varphi = 260 \cdot 9{,}3\cos 148^{\circ}2 = 2040\,VT$.

Masala 3.16. Elektr zanjir qarshilik parametri:
$x_{C_1} = 10\,Om,\ \mathrm{x}_{\mathrm{L}_1} = 5\,Om,\ x_L = 4\,Om,\ R = 4\,Om,\ R_2 = 8\,Om,$
$x_{C_2} = 6\,Om$ bo‘lib, $U = 11{,}45 \cdot \sqrt{2}\sin(\omega t - 102°)V$ kuchlanishga ulangan. Tarmoqdagi tok $\dot{I}$, $\dot{I}_1$, $\dot{I}_2$ toklar kompleks qiymati va to‘la quvvat topilsin.



a) b)

Yechish. Zanjirning parallel sxemada ulangan qismini ekvivalent to‘la qarshilik bilan almashtiramiz (b)

$$Z_e = \frac{jx_{L_1}(R_2 - jx_{C_2})}{jx_{L_1} + (R_2 + jx_{C_2})} = \frac{j5(8-j6)}{j5+8-j6} = \frac{j40+30}{8-j1} = \frac{50e^{j53^C}}{8e^{-j70}} = 6{,}2e^{j6°} =$$
$3{,}08 + j5{,}4\ Om.$

Keltirilgan (b) ekvivalent sxemadan:

$$Z_{um} = -\mathrm{j}\mathrm{x}_{\mathrm{c}} + Z_{\mathrm{e}} + jx_L + R = -j10 + 3{,}08 + j5{,}4 + j4 + 4$$
$$= 7{,}08 - j0{,}6 == 7{,}1e^{-j4{,}8°}\ Om$$

Zanjirga kiruvchi tok: $\dot{I} = \frac{\dot{U}}{Z_{um}} = \frac{11{,}45e^{j102°}}{7{,}1 \cdot e^{-4{,}8°}} = 1{,}62e^{-j97{,}3°}$

Zanjirning tarmoqlangan qismlaridagi tok:

$$\dot{I}_1 = \frac{\dot{U}_{ab}}{Z_1} = \dot{I} \cdot \frac{R_2 + jx_{C_2}}{jx_{L_1} + R_2 - jx_{s_2}} = \frac{1{,}62e^{-j97°} \cdot (8 - j6)}{j5 + 8 - j6} = -1{,}2 - j1{,}6\ A$$

$$\dot{I}_2 = \frac{\dot{U}_{ab}}{Z_2} = \dot{I}\frac{jx_4}{jx_{L_1} + R_2 - jx_{C_2}} = \frac{1{,}62e^{-j97^0} \cdot 5e^{j90°}}{j5 + 8 - j6} = 1\ A$$

To‘la quvvatni topamiz: $\tilde{S} = \dot{U} \cdot \overset{*}{I} = 11{,}45e^{j102^\circ} \cdot 1{,}62e^{j97^\circ} = 18{,}4e^{j200^\circ} = 18{,}4(\cos 200^\circ + j\sin 200^\circ)\ VA$

3.3. Mustaqil yechish uchun masalalar

Masala 3.1. Tok va kuchlanishning kompleks ifodasi:

1. $\dot{U} = 100\ (V)$ $\qquad \dot{I} = (16 + j12)\ A$
2. $\dot{U} = 60 + j80\ (V)$ $\qquad \dot{I} = 20\ A$
3. $\dot{U} = 60 + j80\ (V)$ $\qquad \dot{I} = j20\ A$
4. $\dot{U} = 100e^{j\frac{\pi}{3}}\ (V)$ $\qquad \dot{I} = 20e^{j\frac{\pi}{6}}\ A$

bo‘lgan qiymatlar uchun kompleks to‘la qarshilik, aktiv va reaktiv tashkil etuvchl parametr aniqlansin.

Masala 3.2. Tok va kuchlanishning haqiqiy (effektiv) kompleks ifodasi $\dot{I} = (5 + j5)$ va $\dot{U} = (20 + j20)$ bo‘lganda, tok va kuchlanish oniy qiymat ifodasi va to‘la qarshiligi aniqlansin.

Javob: $\underline{Z} = -j4\ Om$

Masala 3.3. Tok va kuchlanish kompleks ifodasi:

1. $\dot{U} = 100e^{j\frac{\pi}{6}}\ (V)$ $\qquad \dot{I} = 10e^{j\frac{\pi}{6}}\ A$
2. $\dot{U} = 10^5 e^{-j\frac{\pi}{3}}\ (V)$ $\qquad \dot{I} = 50e^{j\frac{\pi}{6}}\ A$

bo‘lganda aktiv quvvat, to‘la qarshilik va to‘la o‘tkazuvchanlik kompleks ifodasi aniqlansin.

Javob: 1) $R = 1\ kVt$, 2) $R = 0$

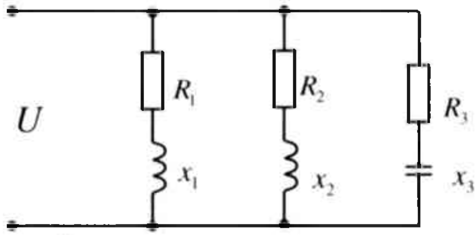
Masala 3.4. Induktiv g‘altak $\dot{U} = 100\ (V)$ kuchlanishga ulangan bo‘lib, qarshiligi *R=3 Om, X=±4 Om*. Tok va to‘la quvvat kompleks ifodasi aniqlansin.

Javob: $\tilde{S} = \dot{U}\,\overset{*}{I} = (1200 \pm j1600)\ VA$

Masala 3.5. Qarshilik parametri $R=20\ Om$, $X_L=10\ Om$. Induktiv g'altak chastotasi $f=50\ Gs$ bo'lgan $U=100\sin(\omega t+45^0)\ (V)$ kuchianish ulangan. Chastota ikki martagacha ko'paygan holat uchun kompleks to'la qarshiligi, tok va to'la quvvat aniqlansin.

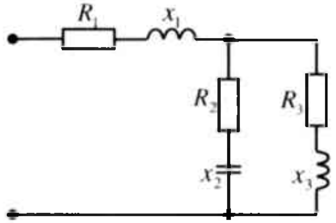
Javob: $\dot{I}=2{,}5\ A$, $\tilde{S}=177\ VA$

Masala 3.6. Parallel sxemada ulangan uchta iste'molchi parametrlari: $R_1=5\ Om$, $X_1=2\ Om$, $R_2=2{,}5\ Om$, $X_2=5\ Om$, $R_3=1{,}25Om$, $X_3=-2{,}5Om$ *ga* teng. Ekvivalent kompleks o'tkazuvchanlik parametri va umumiy zanjir uchun burchak $\cos\varphi$ aniqlansin.

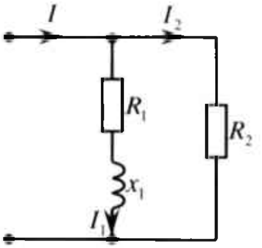


Javob: $\underline{y}=0{,}425\ (\frac{1}{Om})$; $\cos\varphi=0{,}995$

Masala 3.7. Elektr zanjir parametri: $R_1=3\ Om$, $X_1=20\ Om$, $R_2=50Om$, $X_2=-100\ Om$, $R_3=100\ Om$, $X_3=50\ Om$ zanjirning ekvivalent aktiv va reaktiv qarshilik qiymati aniqlansin.



Javob: $R=105{,}5\ (Om)$, $X=-5{,}3\ (Om)$.



Masala 3.8. Tarmoqdagi tok $I=1,6\ A$, $I_1=8,93A$, $I_2=10\ A$ va qarshilik $R_2=2\ Om$ bo'lganda R_1 aktiv quvvat, $cos\varphi$ quvvat koeffitsienti va R_1, X_1 qarshilik parametrlari aniqlansin.

Javob: $R_1=800\ Vt$, $cos\varphi=0,446$, $R_1=10\ Om$, $X_1=\pm 20\ Om$.

Masala 3.9. Elektr zanjirdagi tok $I=10\ A$ ulangan. Kuchlanish $U=130\ V$. Iste'mol qiladigan aktiv quvvati $R=500\ Vt$ bo'lib $\varphi>0$ va $\varphi<0$ bo'lgan holatlarda to'la qarshilik va o'tkazuvchanlik kompleks ifodasini yozing.

Javob: $Z=(5\pm j12)\ Om$; $Y=(2,96\pm j7,1)110^{-2}\dfrac{1}{Om}$

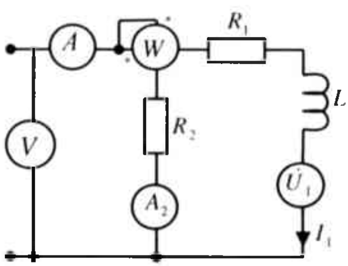
Masala 3.10. Kuchlanish va tok oniy qiymati $u = 141\sin(\omega t + 90^{\circ})$, $i = 14,1\sin(\omega t + 30^{\circ})$ bo'lganda, to'la qarshilik Z va aktiv, reaktiv va to'la quvvat qiymati topilsin.

Javob: $Z = 5 + j5\sqrt{3}\ om$, $\quad \bar{S} = 500 + j500\sqrt{3}\ VA$.

Masala 3.11. Kompleks sonlar soddalashtirilib, ko'rsatkichli va algebraik ifodalari yozilsin.

$$\frac{(4,36 - j\cdot 5,02)(-j\cdot 4,37) + 7,3e^{-j205}}{54e^{j180^{\circ}} + j0,437(j5,5)\left(e^{j90^{\circ}} + 5,07 - j2,5\right)}$$

Javob: $1,71e^{j6,8^{\circ}} = 1,7 + j0,2$.



Masala 3.12. Keltirilgan sxemada tok $I_1=1\ A$ va parametri $R_1=100\ Om$, $L=0,276\ gn$, $R_2=200\ Om$, $f=100\ gs$ bo'lganda, voltmetr, ampermetr, va vattmetr ko'rsatish qiymati aniqlansin.

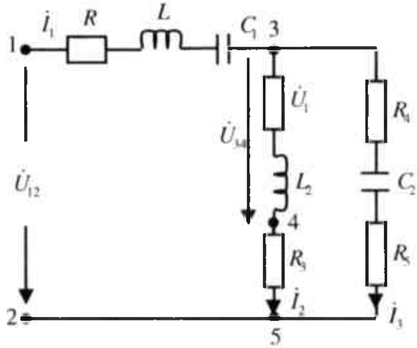
Javob:

$U = 200\ V,\ I = 1,73\ A,\ P = 300\ VT$.

Masala 3.13. Murakkab elektr zanjir parametri:

$R_1 = 10\ Om,\ X_{L_1} = 7\ Om,$
$X_{C_1} = 25\ Om,\ R_2 = 5\ Om,$
$X_{L_2} = 20\ Om,\ R_3 = 12\ Om,$
$R_4 = 15\ Om,\ R_5 = 9\ Om.$

bo‘lib, $\varphi_3 - \varphi_4$ potensial kuchlanish $\dot{U}_{34} = 60\ V$ ga teng kompleks qarshilik, kirishdagi kuchlanish U_{12}, tarmoqdagi tok va kompleks quvvat qiymat aniq-lansin.



Javob: $= 36{,}6e^{-j18^\circ}$; $\dot{I}_1 = 2{,}9e^{-j75^\circ}$; $\dot{I}_2 = 1{,}8e^{j30^\circ}$; $\dot{I}_3 = 3e^{j40^\circ}$; $\dot{U}_{12} = 109{,}8e^{j60^\circ}$; $\tilde{S} = 329e^{-j18^\circ} = 311 - j105\ VA.$

3.4. Nazorat savollari

1. Kompleks son matematik ifodasini yozing. Eyler formulasiga izoh bering.
2. Kompleks sonlar bilan qo‘shish, ayirish, ko‘paytirish va bo‘lish amallari bajarilganda qanday ko‘rinishda yoziladi?
3. Sinusoidal o‘zgaruvchan elektr zanjirni kompleks (simvolik) usulda hisoblashda qanday afzalliklar bor?
4. Nima uchun kompleks ifoda ±j yoki e $^{\pm j\varphi}$ ga burilish burchagi deyiladi?
5. Sinusoidal o‘zgaruvchan (tok, kuchlanish, EYK) funksiyalarni kompleks son ko‘rinishda ifodalanishini isbotlang.
6. Sinusoidal o‘zgaruvchan tok, kuchlanish va EYKlar kompleks ifodasini yozing.
7. Kompleks sonlarhi differensiallash va integrallash qanday bajariladi?
8. Om va Kirxgof qonuni kompleks usulda qanday ifodalanadi?
9. Aktiv, reaktiv va to‘la qarshllik kompleks ifodasini yozmg.
10. Aktiv, reaktiv va to‘la o‘tkazuvchanlik kompleks ifodasini yozing.
11. Aktiv, reaktiv va to‘la quvvat tenglamalarining kompleks ifodasini yozing.

12. $U=220\sin(\omega t \quad +45)$, $\quad i=10\sqrt{2}\sin(\omega t+90)$ tok va kuchlanish funksiyalari kompleks usulda qanday ifodalanadi?
13. Kuchlanish $\mathring{U}=100e^{j120}$ V, tok $\dot{I}=j10$ A bo'lganda, kompleks to'la qarshilik va to'la o'tkazuvchanlik qiymatini aniqlang.
14. To'la qarshilik $\underline{Z}_1=5+j11$ Om, $\underline{Z}_2 = 4-j2$ Om ga teng ketma-ket ulangan elektr zanjir sxemasini tuzing, umumiy va to'la qarshilikni aniqlang.
15. Kompleks ifodalari $\mathring{U} = 60e^{j90}$, $\dot{I} = 5e^{j30}$ bo'lganda kompleks to'la quvvat ifodasi va aktiv, reaktiv quvvat qiymati qanday aniqlanadi?
16. Parallel sxemada biriktirilgan iste'molchilar kompleks qarshiligi $\underline{Z}_1=10e^{j60}$ Om, $\underline{Z}_2= 5^{-j30}$ Om bo'lganda, kompleks ekvivalent qarshilik qanchaga teng?
17. $\mathring{U}= -220+j220$ V, $\dot{I} =15 -j5$ A kompleks ifodalarining oniy sinusoidal o'zgaruvchan qiymatini yozing.
18. $\dot{I} = -5e^{j90}$ A, $\mathring{U}=j\ 141\ e^{j90}$ V bo'lgan kompleks ifodalarning oniy qiymat tenglamasini tuzing.
19. Kompleks qarshilik $Z = 8 + j6\,Om$ bo'lganda, aktiv va reaktiv o'tkazuvchanlik qiymati nimaga teng?
20. Kompleks o'tkazuvchanlik: $y = 1{,}41 + j1{,}73\frac{1}{Om}$ bo'lganda, aktiv va reaktiv qarshilikni aniqlang.

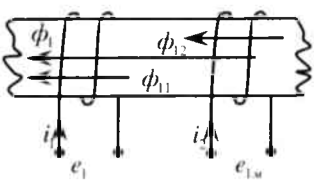
IV. O‘ZARO INDUKTIV BOG‘LANGAN O‘ZGARUVCHAN ELEKTR ZANJIRLAR

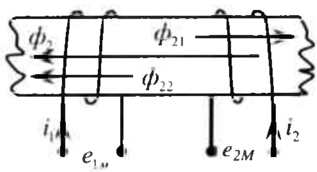
4.1. Asosiy nazariy tushunchalar

Elektromagnit induksiya qonuniga asosan induktiv g‘altakda, tok i, magnit oqimi Φ, yoki induktiv parametr L o‘zgaruvchan bo‘lsa, o‘zinduksiya EYK hosil bo‘ladi.

$$e_L = \frac{d\psi}{dt} = -W\frac{d\phi}{dt} = -L\frac{di}{dt}$$

Agarda ikkita induktiv elementlarning biridan o‘tuvchi tok ikkinchi induktivlikda EYK hosil qilsa, bunday elektr zanjir induktiv bog‘langan deyiladi (transformator).





Bunda induktivlikda hosil bo‘lgan magnit oqim:

$$\left.\begin{aligned}\Phi_1 &= \Phi_{11} + \Phi_{12}\\ \Phi_2 &= \Phi_{22} + \Phi_{21}\end{aligned}\right\} \text{ yoki } \left.\begin{aligned}\Phi_{1umumiy} &= \Phi_1 \pm \Phi_{21}\\ \Phi_{2umumiy} &= \Phi_2 \pm \Phi_{12}\end{aligned}\right\}$$

Chulg‘amga ilashgan magnit oqim:

$$\Psi_1 = W_1(\Phi_1 \pm \Phi_{21}) = \Psi_1 \pm \Psi_{21}$$

$$\Psi_2 = W_2(\Phi_2 \pm \Phi_{12}) = \Psi_2 \pm \Psi_{12}$$

Induktivlikda hosil bo‘lgan o‘zaro induksiyalanuvchi EYK:

$$e_1 = -\frac{d\Psi_1}{dt} = -\frac{d(\Psi \pm \Psi_{21})}{dt} = -\frac{d\Psi_1}{dt} \pm \frac{d\Psi_{21}}{dt} = -L_1\frac{di_1}{dt} \pm M_{21}\frac{di_2}{di} = e_{1L} + e_{1M}$$

$$e_2 = -\frac{d\Psi_2}{dt} = -\frac{d(\Psi_2 \pm \Psi_{12})}{dt} = -\frac{d\Psi_2}{dt} \pm \frac{d\Psi_{12}}{dt} = -L_2\frac{di_2}{dt} \pm M_{12}\frac{di_1}{dt} = e_{2L} + e_{2M}$$

$M_{12} = M_{21} = M$ o‘zaro induktivlik koeffitsienti deyiladi va Gn da o‘lchanadi.

M – koeffitsient induktiv g‘altakning o‘ramlar soniga, o‘zaro joylashishiga va magnit tavsifiga bog‘liq bo‘ladi.

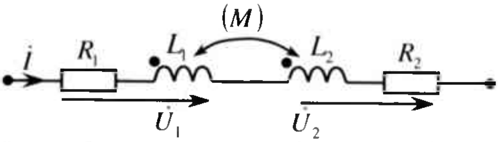
1. Ketma-ket sxemada ulangan induktiv g‘altak.

Bu holda kompleks to‘la qarshilik:

$$\underline{Z}=\underline{Z}_1+\underline{Z}_2\pm 2\underline{Z}_M=(R_1+j\omega L_1)+(R_2+j\omega L_2)\mp 2\omega M$$

yoki $\underline{Z}_M=\mp 2\omega M$ – o‘zaro induksiya kompleks qarshiligi.

Plus ishora ikkita induktivlik ketma-ket, **minus** ishora esa qarama-qarshi ulanishga mos bo‘ladi.



Ekvivalent induktivlik o‘zaro ulanish sxemasiga asosan:

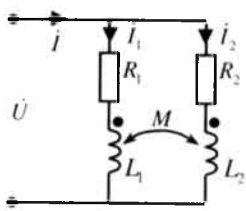
$$L_{mos}=L_1+L_2+2M \qquad L_{qarama-qarshi}=L_1+L_2-2M$$

Induktivlikdagi kuchlanish:

$$\dot{U}_1=\dot{I}_1(\underline{Z}_1\pm j\omega M) \quad \dot{U}_2=\dot{I}_2(\underline{Z}_2\pm j\omega M)$$

2. Parallel sxemada ulanish.

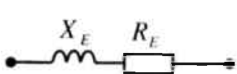
Parallel sxemada biriktirilgan induktiv bog‘langan elektr zanjirni hisoblashda Kirxgof 2-qonuniga asosan har bir tarmoq uchun tuzilgan kompleks tenglamalar sistemasini yechish bilan tarmoqdagi tok aniqlanadi.



Tarmoq ekvivalent qarshiligi:

$$\underline{Z}_{1\text{э}}=\frac{\underline{Z}_1\underline{Z}_2-\underline{Z}_M^2}{\underline{Z}_2-\underline{Z}_M} \qquad \underline{Z}_{2\text{э}}=\frac{\underline{Z}_1\underline{Z}_2-\underline{Z}_M^2}{\underline{Z}_1-\underline{Z}_M}$$

Tenglamaga asosan ekvivalent sxemasini tuzamiz.



Demak parallel sxemada ulangan induktiv g'altak elektr zanjirni ekvivalent sxema yoki qarshilik parametri orqali induktiv bog'lanmagan aktiv qarshilik R_E va X_E induktiv qarshilik ko'rinishda ifodalanishi mumkin.

$\underline{Z}_E = R_E + jx_E$ Agar ($R_1 = R_2 = 0$) bo'lsa,

$$L_{1E} = \frac{L_1 L_2 - M^2}{L_2 \mp M}, \qquad L_{2E} = \frac{L_1 L_2 - M^2}{L_1 \mp M}$$

Zanjirning umumiy qarshiligi: $\underline{Z}_E = \dfrac{\underline{Z}_1 \underline{Z}_2 - \underline{Z}_M^2}{\underline{Z}_1 + \underline{Z}_2 \mp 2\underline{Z}_M}$

3. Induktiv bog'langan zanjirni hisoblashda bog'lanish koeffitsienti K orqali ham ifodalanadi. $K = \dfrac{M}{\sqrt{L_1 L_2}} \le 1$

Induktiv bog'langan g'altak **mos** ravishda yoki **qarama-qarshl** biriktirilgan bo'lsa:

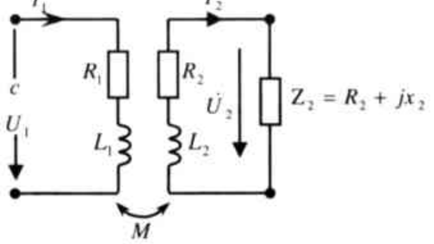
$L_{mos} = L - M > 0$; $L_{qq} = L - M < 0$ yoki $M = \dfrac{L_M - L_{qq}}{4}$

Induktivlik (L) va o'zaro induktivlik (M) muvozanat tenglamasi.

$M^2 \le L_1 L_2$ yoki $2M^2 \le L_1 + L_2$

4. O'zaksiz transformator (havo transformatori).

Sxemada berilgan o'zaksiz transformator zanjirini hisoblashda konturli tok usuli yoki ekvivalent sxemasi bilan bajariladi. Agarda transformatorning birlamchi chulg'amidagi tokni aniqlash zarur bo'lsa, murakkab induktiv bog'langan elektr zanjir ekvivalent sxemasidan foydalangan holda ikkilamchi chulg'am kompleks qarshiligi o'rniga birlamchi chulg'amga kiruvchi aktiv R_0 va reaktiv x_0 qarshiliklar bilan almashtiriladi:



$$R_0 = \frac{\underline{Z}_M^2}{R_2^2 + x_2^2} R_{22}$$

$$x_0 = \frac{\underline{Z}_M^2}{R_2^2 + x_2^2} x_{22}$$

Bunda R_{22} va x_{22} transformatorning ikkilamchi chulg'am aktiv va reaktiv qarshiligi.

Iste'molchi qarshiligi mobatga olinganda:

$R_2' = R_2 + R_H, \qquad x_2' = x_2 + x_H.$

Doimo $R' \geq 0$ bo'lib, sarf bo'ladigan quvvatni ifodalaydi.

Agar transformator ikkilamchi chulg'amiga induktiv qarshilik ulangan bo'lsa, bunda $x_{2_L} > 0, x_0 < 0$ bo'lib, transformator magnit oqimi **susayadi.**

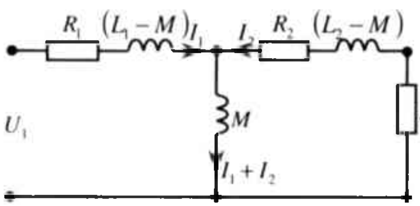
Agarda sig'im qarshiligi ulangan bo'lsa, $x_{2C} > 0$, $x_0 < 0$ bo'lib, transformatorning magnit oqimi **kuchayadi**.

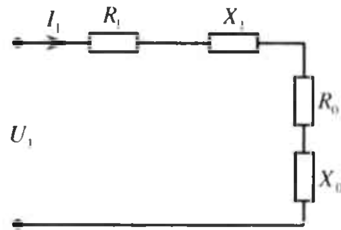
Transformator tenglamasi:

$$\begin{cases} \dot{U}_1 = R_1\dot{I}_1 + j\omega(L_1 - M)\dot{I}_1 + j\omega M(\dot{I}_1 + \dot{I}_2) \\ 0 = R_2\dot{I}_2 + j\omega(L_2 - M)\dot{I}_2 + j\omega M(\dot{I}_1 + \dot{I}_2) + Z_2\dot{I}_2 \end{cases}$$

Shunga asosan transformatorning ekvivalent sxemasini chizamiz.

5. Bir nechta induktiv bog'langan murakkab elektr zanjirni hisoblash, Kirxgof qonuni, konturli tok usuli, ustma-ustlik usuli va ekvivalent generator usulidan foydalaniladi.





O'zaro induktiv bog'langan elektr zanjirlar Kirxgof 2-qonuniga asosan tenglama tuzilganda qo'shimcha: $\dot{U}_M = \pm j\omega M_{nk} \cdot \dot{I}_k$ ifoda paydo bo'lib n g'altak $\dot{I}_k$ tok o'tganda hosil bo'ladigan kuchlanishni ifodalaydi. Bunda plus yoki minus ishora induktiv g'altakning ulanish sxemasi bilan bog'liq bo'ladi.

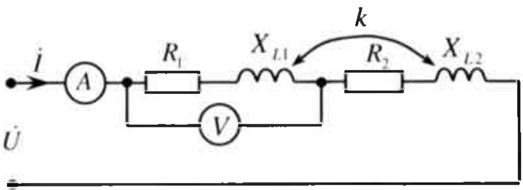
Induktiv bog'langan elektr zanjirni konturli tok usulidan foydalanib hisoblashda, n konturdagi $\pm j\omega M_{nk} \cdot \dot{I}_k$ ifoda ishorasini aniqlashda, n

va k konturlar boglovchl g'altakdagi kontur toklari $\dot{I}_n$ va $\dot{I}_k$ **hir xil** yo'nalishda bo'lsa **plus, qarama-qarshi** yo'nalishda bo'lsa **minus ishora** bilan olinadi. (Sxemada nuqta bilan belgilangan ishoralar tokning kirishiga mos keladi hamda plus ishorasi bilan hisobga olinadi.)

4.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 4.1. Ketma-ket ulangan ikkita reaktiv g'altak parametri $R_1 = 60\ Om,\ \ R_2 = 40\ Om,\ \ x_{L_2} = 8\ Om;\ x_{L_2} = 1\ Om$ bo'lib, $U = 300V$ kuchlanishga ulangan.

Bog'lanish koeffitsienti K=0,565 bo'lgan ikkita g'altakning o'zaro mos va qarama-qarshi ulangan sxemasi uchun elektr o'lchov asboblarning ko'rsatish qiymati aniqlansin.



Yechish.

a) ketma-ket (mos) ulanish.

O'zaro induktiv qarshilik:

$$x_M = \omega M = k\sqrt{\omega L_1 \cdot \omega L_2} = 0{,}565\sqrt{8\cdot 1} = 1{,}6\ Om$$

Kompleks tok: $\dot{I} = \dfrac{\dot{U}}{R + j\omega L_{mos}}$

Bunda: $L_{mos} = L_1 + L_2 + 2M$; $R = R_1 + R_2$

Kompleks kuchlanish: $\dot{U} = U = 300V$

yoki: $\dot{I} = \dfrac{\dot{U}_2}{R + j\omega L_{mos}} = \dfrac{300}{10 + j12{,}2} = 12{,}05 - j14{,}7A$

Ampermetr ko'rsatgan tokning haqiqiy qiymati:

$$I = \sqrt{12{,}05^2 + 14{,}7^2} = 19A$$

Birinchi g'altakdagi kompleks kuchianish:

$$\dot{U}_1 = \dot{I}_1(R_1 + j\omega L + j\omega M) = (12{,}05 - j14{,}7)\cdot(6 + j4 + j1{,}6) = (2133{,}3 + j27{,}5)V$$

Voltmetrdagi kuchlanish: $U_1 = \sqrt{213^2 + 27{,}5^2} = 216V$

Ikkinchi g'altakdagi kompleks kuchianish:

$$\dot{U}_2 = \dot{I}(R_2 + j\omega L_2 + j\omega M_2) = (86{,}4 - j27{,}4)(V)$$

Masalaning yechimi:

$$\dot{U} = \dot{U}_1 + \dot{U}_2 = 213{,}3 + j27{,}48 + 86{,}4 - j27{,}4 = 299{,}7 + j0{,}06 \approx 300V$$

b) qarama-qarshi ulanish.

Kompleks tok: $\dot{I} = \dfrac{\dot{U}}{R + j\omega L_{qq}}$

Bunda: $L_{qarama-qarshi} = L_1 + L_2 - 2M$

Yoki:

$$X_{L_{qq}} = \omega L_{qq} = \omega L_1 + \omega L_2 - 2\omega M = 8 + 1 - 2\cdot 1.6 = 5.8\ Om$$

Tok: $\dot{I} = \dfrac{300}{10 + j5{,}8} = (22{,}5 - j13)\ A$

Ampermetr ko'rsatgan qiymat: $I = \sqrt{(22.5)^2 + (-13)^2} = 26A$

Birinchi g'altakdagi kuchianish kompleks ifodasi

$$\dot{U}_1 = \dot{I}(R_1 + j\omega L_1 + j\omega M) = (22{,}5 - j14)\cdot(6 + j8 + j1{,}6) = (218 - j65{,}6$$

Voltmetrdagi kuchlanish:

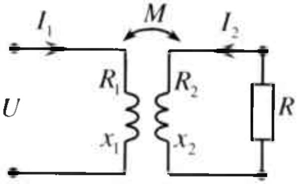
$$U_1 = \sqrt{(218)^2 + (65{,}6)^2} = 226{,}V$$

Ikkinchi voltmetrdagi kompleks kuchlanish:

$$\dot{U}_2 = \dot{I}(R_2 + j\omega L_2 - j\omega M) = (82.2 - j65.5)\ \text{v}$$

O'zaro induktiv qarshilik absolut qiymati $x_M = wM > x_{L_2} = wL_2$ bo'lib, reaktiv qarshiligi minus ishoraga teng hamda kompleks sig'im qarshiligiga mos ekanligini ifodalaydi.

Masala 4.2. O'zaksiz transformatorning (havo transformatori) ikkilamchi chulg'ami iste'molchi qarshillgi $R=10\ Om$; $x_M=18\ Om$ ulangan bo'lib, birlamchi chulg'ami $U=100\ V$ kuchlanishga ulangan.



Transformatorning salt ishlash holatida birlamchi va ikkilamchi chulg'amlaridagi tok, kuchianish va quvvat qiymatlari: $I_{10}=10A$, $P_{10}=100VT$, $U_{10}=100\ V$, $U_{20}=100\ V$, $I_{20}=2.5\ A$, $P_{20}=100\ VT$ga teng. Transformatorning birlamchi W_1 va ikkilamchi W_2 chulg'amlaridan o'tuvchi tok va foydali ish koeffitsienti aniqlansin.

Yechish.

O'zaro induktiv qarshilik: $x_M = \omega M = \dfrac{180}{10} = 18Om$

Birlamchi chulg'am aktiv qarshiligi: $R_1 = \dfrac{P_{10}}{I^2_{10}} = \dfrac{100}{10^2} = 1\ Om$

Birlamchi chulg'am to'la qarshiligi: $z_1 = \dfrac{U_{10}}{I_{10}} = 10\ Om$

Birlamchi chulg'am reaktiv qarshiligi: $x_1 = \sqrt{z_1^2 - R_1^2} = 9{,}45\ Om$

Ikkilamchi chulg'am aktiv qarshiligi: $R_2 = \dfrac{P_{20}}{I_{20}^2} = 16\ Om$

Ikkilamchi chulg'am to'la qarshiligi: $z_2 = \dfrac{U_{20}}{I_{20}} = 40\ Om$

Ikkilamchi chulg'am reaktiv qarshiligi: $z_2 = \sqrt{z_2^2 - R_2^2} = 36{,}6\ Om$

Kirxgof 2-qonuniga asosan tenglama tuzamiz:

$$\left.\begin{aligned} \dot U_1 &= \dot I_1(R_1 + jx_1) + \dot I_2 jx_M \\ \dot O &= \dot I_2(R_2 + R) + jx_2 + \dot I_1 x_M \end{aligned}\right\}$$

Ikkinchi tenglamadan:

$$\dot I_2 = -\dot I_1 \frac{jx_M}{(R_2 + R) + jx_2}$$

Tok $\dot I_2$ qiymatini birinchi tenglamaga qo'yamiz:

$$\dot U_1 = \dot I_1(R_1 + jx_1) - \dot I_1 \frac{jx_M}{(R_2 + R)} jx_M = \dot I_1\left\{\left[R_1 + \frac{x_M^2(R_2 + R)}{(R_2 + R) + x_2^2}\right] + j\left[x_1 - \frac{x_M^2 x_2}{(R_2 + R) + x_2^2}\right]\right\} =$$

$$= \dot I_1 \underline{Z}_E$$

Elektr zanjirning ekvivalent to'la qarshiligi: $\underline{z}_э = (4{,}46 + j8{,}29)\ Om$

Birlamchi chulg‘amdagi tok : $\dot{I}_1 = \frac{\dot{U}_1}{\underline{z}_3} = \frac{100}{(4{,}46 + j8{,}3)} A$

Tokming haqiqiy qiymati: $I_1 = \sqrt{(5{,}1)^2 + (2{,}5)^2} = 10{,}72A$

Ikkilamchi chulg‘amdan o‘tuvchi tokni ifodalovchi tenglama:

$$\dot{I}_2 = -\dot{I}_1 \frac{jx_M}{(R_2 + R) + jx_2} = -(5{,}1 - j9{,}5)\frac{j18}{(76 + j36{,}6)} = (-2{,}3 - j0{,}1)\ \ A$$

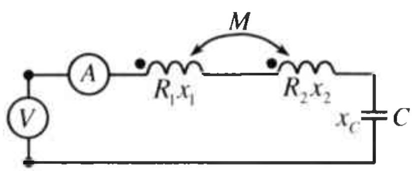
Ikkilamchi chulg‘amdan o‘tuvchi tokming haqiqiy qiymati:

$I_2 = \sqrt{(2{,}3)^2 + (0{,}1)^2} = 2{,}3A$

Foydali ish koeffitsienti:

$$\eta = \frac{P_2}{P} = \frac{I_2^2 R}{(I_1^2 R) + I_2^2 (R_2 + R)} \cdot 100\% = \frac{(2{,}3)^2 \cdot 10}{10{,}7} \cdot 100\%$$

Masala 4.3. Induktiv bog‘langan ikkita g‘altak sig‘im qarshiligi bilan ketma-ket ulangan bo‘lib, qarshiliklar: R_1=10.5 *Om*, ωL_1=14.6*Om*, R_2=10.6 *Om*, ωL_2=17 *Om*, ωM=32 *Om*, chastotasi f=*50 KGs* ga teng. Zanjirdan o'tuvchi tok I=*2,2 A*, kuchlamish U=*88mV*. Sig‘im qarshiligi va sig‘im C amiqlansin.



Yechish.

Aktiv qarshiligi: $R = R_1 + R_2 = 21{,}1\ Om$

To‘la qarshiligi: $z = \frac{U}{I} = \frac{8{,}8 \cdot 10^{-3}}{2{,}2 \cdot 10^{-3}} = 40\ Om$

Reaktiv qarshilik: $x = x_L - x_C = \pm\sqrt{z^2 - R^2} = \pm 34\ Om$

G‘altak induktiv qarshiligi $x_L = \omega L_1 + \omega L_2 + 2\omega M = 38\ Om$

Sig‘im qarshiligi $x = x_L - x_C = 38 \pm 34\ Om$

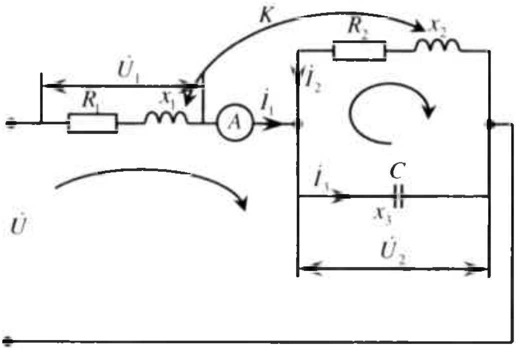
G‘altaklarning o‘zaro ulamsh sxemasiga asosan sig‘im ikki xil qarshilikga ega bo‘ladi.

$$x'_{C_{moc}} = 38 - 34 = 4Om;\quad x'_{C_{kk}} = 38 + 34 = 72Om$$

yoki:

$$C' = \frac{1}{\omega x'_C} = 0{,}8 \cdot 10^{-6}\phi = 0{,}8mkF,\quad C'' = \frac{1}{\omega x''_C} = 0{,}044 \cdot 10^{-6}\phi = 0{,}044mkF$$

Masala 4.4. Sxemada keltirilgan o'zaro induktiv bog'langan elektr zanjirning birlamchi tarmogidan o'tuvchi tok *I=10A*, bog'lanish koeffitsienti *K=0,75*. Parametr qiymati: R_1=2 *Om*, x_1=10 *Om*, R_2=1 *Om*, x_2=4 *Om*, x_3= 2 *Om*. G'altakdagi kuchlanish, umumiy kuchlanish va quvvat qiymati aniqlansin.



Yechish.

Kirxgof qonuniga asosan konturdagi tok yo'nalishi bo'yicha tenglama tuzamiz:

$$\begin{cases} \dot I_1 + \dot I_2 = \dot I_3 \\ \dot U = \dot I R_1 + \dot I_1 j\omega L_1 - \dot I_2 R_2 - \dot I_2 j\omega L_2 + \dot I_1 j\omega M - \dot I_2 j\omega M \\ O = -\dot I_2 R_2 - \dot I_2 j\omega L_2 - \dot I_3\left(-j\dfrac{1}{\omega C}\right) + \dot I_1 j\omega M \end{cases}$$

O'zaro induktiv qarshilik: $x_M = \omega M = k\sqrt{x_1 x_2} = 0{,}75\sqrt{1{,}4} = 1{,}5\ Om$

Tuzilgan tenglamalar sistemasini yechamiz. Bunda $\dot I_1 = I_1 = 10A$ bo'lib, haqiqiy son va kompleks tenglikda haqiqiy o'q bo'yicha yo'naltiriladi.

$$10 + \dot{I}_2 = \dot{I}_3 \qquad (1)$$

$$\dot{U} = 10(2 + j2,5) - \dot{I}_2(1 + j5,5) \qquad (2)$$

$$O = -\dot{I}_2(1 + j4) + j15 + \dot{I}_3 \cdot j2 \qquad (3)$$

Birinchi tenglamani $10 + \dot{I}_2 = \dot{I}_3$ (3)- tenglamaga qo'yamiz.

$$-\dot{I}_2(1 + j4) + j15 + \dot{I}_3 \cdot j2 = -\dot{I}_2(1 + j2) + j35 = 0$$

Bundan: $\dot{I}_2 = \frac{j35}{1+j2} = (14 + j7)\ A$

Tokning effektiv qiymati: $I_2 = \sqrt{14^2 + 7^2} = \sqrt{245} = 15{,}6A$

Birinchi tenglamadan:

$$\dot{I}_3 = 10 + \dot{I}_2 = 10 + 14 + j7 = (24 + j7)\ A$$

$$I_3 = \sqrt{24^2 + 7^2} = \sqrt{625} = 25\ A$$

Ikkinchi tenglamadan, zanjirdagi umumiy kuchlanish:

$$\dot{U} = 10(2 + j2.5) - (14 + j7)(1 + j5.5)\ V$$

Kuchlanish effektiv qiymati:

$$\dot{U} = \sqrt{(44.5)^2 + (59)^2} = \sqrt{5461} = 73.9\ V$$

Birinchi g'altakdagi kuchlanish:

$$\dot{U}_1 = \dot{I}_1(R_1 + j\omega L_1) - \dot{I}_2 j\omega M = (10(2 + j) - 14 + j7)\, j1.5 = (30.5 - j11)V$$

Kuchlanish effektiv qiymati:

$$\dot{U}_1 = \sqrt{(30.2)^2 + (11)^2} = \sqrt{1021.2} = 32.4\ V$$

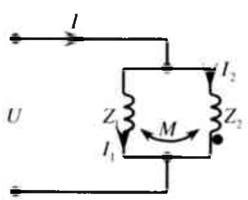
Ikkinchi g'altak yoki kondensatordagi kuchlanish:

$$\dot{U}_2 = -\dot{I}_2(R_2 + j\omega L_2) + \dot{I}_1 j\omega M = -(14 + j7)(1 + j4) + j15 = (14 - j48)V$$

Effektiv qiymat: $\dot{U}_2 = \sqrt{(14)^2 + (48)^2} = 50\ V$

Zanjir aktiv quvvati: $P = P_1 + P_2 = I_1^2 R_1 + I_2^2 R_2 = 445\ VT$

Masala 4.5. Induktiv bog'langan parallel sxemada ulangan tok zanjirining to'la qarshiligi $z_1 = (5 + j10)\ Om$, $z_2 = (100 + j20)\ Om$, $z_M = 10\ Om$ bo'lib, $\dot{U} = 120\ V$ kuchlanishga ulangan. Zanjirdan o'tuvchl tok va quvvat qiymati aniqlansin.



Yechish.

Parallel ulangan kompleks ekvivalent to'la qarshiligi

$$\underline{Z}_{1E} = \frac{\underline{Z}_1\underline{Z}_2 - \underline{Z}_M^2}{\underline{Z}_2 - \underline{Z}_M} = (6.7 + j8.9)\ om$$

$$\underline{Z}_{2E} = \frac{\underline{Z}_1\underline{Z}_2 - \underline{Z}_M^2}{\underline{Z}_1 - \underline{Z}_M} = (56.4 - j6)\ om$$

Tarmoqdagi tok:

$\dot{I}_1 = \frac{\dot{U}}{\underline{z}_1} = (6.4 - j8.6)\ I_1 = 10.8\ A$

$\dot{I}_2 = \frac{\dot{U}}{\underline{z}_2} = (2.1 - j0.27)\ \dot{I}_2 = 2.2\ A$

Umumiy tok: $\dot{I} = \dot{I}_1 + \dot{I}_2 = (8.5 - j8.38)$ yoki $I = 8,4 \cdot \sqrt{2}\ A$

Birinchi g'altakdagi real aktiv quvvat:

$P_1 = R_e(\dot{U}\dot{I}_1) = R_e[120(6.4 + j8.6)] = 768$ Vt

G'altakdagi aktiv quvvat: $P'_1 = I_1^2 R_1 = 115 \cdot 5 = 574\ VT$

Quvvatlar farqi: $\Delta P_1 = P_1 - P'_1 = 768 - 574 = 194\ VT$

Ikkinchi g'altakdagi real aktiv quvvat:

$P_2 = R_e(\dot{U}\dot{I}_2) = R_e[120(2.1 + j0.22)] = 252$ Vt

G'altakdagi aktiv quvvat: $P'_2 = I_2^2 R_2 = 4.46 \cdot 100 = 446\ VT$

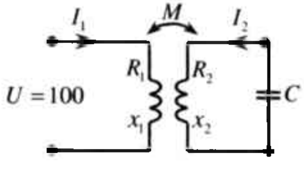
Quvvatlar farqi: $\Delta P_2 = P_2 - P'_2 = 252 - 446 = -194\ VT$

Bunda ikkinchi g'altakdagi yetishmaydigan $\Delta P_2 = -194\ VT$ aktiv quvvat o'zaro induksiya hodisasiga asosan energiya bilan ta'minlanadi:

$P_M = P_{12} = R_e[j\omega M\dot{I}_1\dot{I}_2] = R_e[j10(11.56 - j19.4)] = 194$ Vt

Masala 4.6. O'zaksiz transformatorning ikkilamchl chulg'am o'tuvchi tok $I_2 = 0{,}5A$ bo'lib, sig'im qarshiligi ulangan, g'altak parametrlari R_1=60 *Om*, ωL_1=80 *Om*, R_2=90 *Om*, ωL_2=45 *Om*, $\frac{1}{\omega C}$ =21 *Om* hamda bog'lanish koeffitsienti $k=0,5$. Birlamchi chulg'amdagi tok va kuchlanish qiymati aniqilanib, vektor ifodasi tuzilsin.

Yechish.



O‘zaro induktiv qarshilik: $x_M = \omega M = k\sqrt{\omega L_1 \cdot \omega L_2} = 30\ Om$

Kirxgof qonunlariga asosan konturdagi tok yo‘nalishl bo‘yicha tenglama tuzamiz: $\left[R_2 + j\left(\omega L_2 - \frac{1}{\omega C}\right)\right]\dot{I}_2 + j\omega M\dot{I}_1 = 0$

Bundan $\dot{I}_1 = \dot{I}_2 \frac{R_2 + j\left(\omega L_2 - \frac{1}{\omega C}\right)}{-j\omega M} = \frac{90 + j(45-21)}{-j30} \cdot 0{,}5 = 3.14e^{j28°}\ A$

Birlamchi chulg‘amdagi kuchlanish:

$\dot{U}_1 = (R_1 + j\omega L_1)\dot{I}_1 + j\omega M\dot{I}_2 = (60 + j80)14e^{j28°} + j30 \cdot 0.5 = 328e^{j82°}$

Vektor ifoda tuzish uchun kuchlanishni aniqlash kerak:

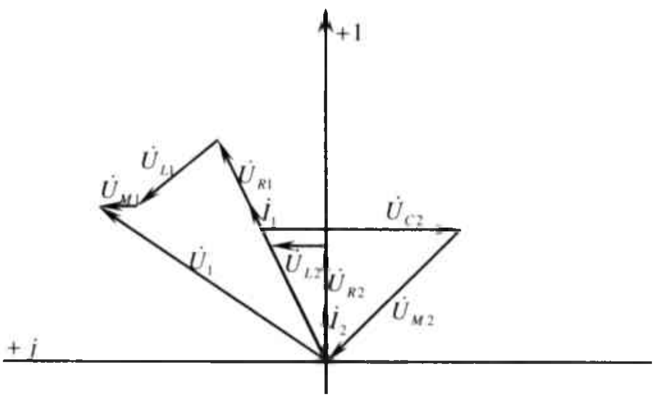
$\dot{U}_{R_1} = R_1\dot{I}_1 = (165 + j90)$ (V); $\dot{U}_{R_2} = R_2\dot{I}_2 = 45$ (V)

$\dot{U}_{L_1} = j\omega L_1\dot{I}_1 = (-120 + j220)$ (V); $\dot{U}_{L_2} = j\omega L_2\dot{I}_2 = j22.5$ (V)

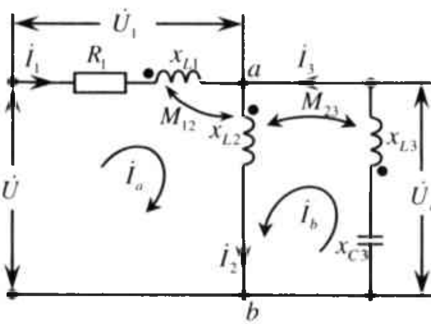
$\dot{U}_{M_1} = j\omega M_1\dot{I}_1 = (-45 + j82.5)$ (V); $\dot{U}_{M_2} = j\omega M_2\dot{I}_2 = j15$ (V)

$\dot{U}_{C_2} = \frac{1}{j\omega C} \cdot \dot{I}_2 = -j105$ (V)

Kompleks tekislikda vektor ifodasini tuzamiz.



Masala 4.7. Sxemada berilgan elektr zanjirining qarshilik parametri: R_1=2 *Om*, x_1=10 *Om*, R_2=1 *Om*, $X_{M_{23}} = 10$ *Om* bo‘lib, $\dot{U} = 150$ V kuchlanishga ulangan. Tarmoqdagi tok $\dot{U}_{ab}$ va kuchlanishni aniqlang.



1. Kirxgof qonuniga asosan yechish.

Kirxgof qonuniga asosan tenglama tuzamiz:

$$\left.\begin{aligned} &\dot I_1 - \dot I_2 + \dot I_3 = 0 \\ &\underline{z}_1 \dot I_1 + \underline{z}_{M_{12}} \dot I_2 + \underline{z}_{M_{23}} \dot I_3 + \underline{z}_2 \dot I_2 + \underline{z}_{M_{12}} \dot I_1 = \dot U \\ &\underline{z}_2 \dot I_2 + \underline{z}_3 \dot I_3 + \underline{z}_{M_{12}} \dot I_1 + \underline{z}_{M_{32}} \dot I_2 + \underline{z}_{M_{32}} \dot I_3 = O \end{aligned}\right\}$$

Bunda: $\underline{z}_1 = (50 + j20)$

$$\underline{z}_2 = j20$$

$$\underline{z}_3 = (j20 - j50) = -j30$$

$$\underline{z}_{M_{12}} = j\omega M_{12} = j10$$

$$\underline{z}_{M_{23}} = j\omega M_{32} = j10\,om$$

Tenglamaga qarshilik va kuchlanish qiymatini qo'ysak:

$$\left.\begin{aligned} &\dot I_1 - \dot I_2 + \dot I_3 = 0 \\ &(5 + j3)\dot I_1 + j3\dot I_2 + j\dot I_3 = 25 \\ &\dot I_1 + 3\dot I_2 - 2\dot I_3 = 0 \end{aligned}\right\}$$

Determinant usul bilan yechish natijasi:

$\Delta = 5(1 + j2),\ \ \Delta_1 = 25,\ \ \Delta_2 = -75,\ \ \Delta_3 = -100$

Demak: $\dot I_1 = \dfrac{\Delta_1}{\Delta} = (1 + j2)$ (MA)

$$\dot I_2 = \frac{\Delta_2}{\Delta} = -3(1 + j2) \text{ (MA)}$$

$$\dot I_3 = \frac{\Delta_3}{\Delta} = -4(1 + j2) \text{ (MA)}$$

U_{ab} potensial kuchlanish uchun tenglama tuzamiz:

$$\dot U_{ab} = j\omega M_{12}\dot I_2 + j\omega L_2 \dot I_2 + j\omega M_{23}\dot I_3 = (180 - j90)\text{ (MV)}$$

2. Konturli tok usuliga asosan yechish.

Kontur toklari yo'nalishi bo'yicha tenglama tuzamiz:

$$\left.\begin{aligned} &(\underline{z}_1 + 2\underline{z}_{M_{12}})\dot I_a + (\underline{z}_2 + \underline{z}_{M_{23}} + \underline{z}_{M_{12}})\dot I_b = \dot U \\ &(\underline{z}_2 + \underline{z}_{M12} + \underline{z}_{M_{23}})\dot I_a + (\underline{z}_{22} + 2\underline{z}_{M_{23}})\dot I_b = O \end{aligned}\right\}$$

Bunda $\underline{z}_{11} = \underline{z}_1 + \underline{z}_2 = (50 + j40)\,Om \quad \underline{z}_{22} = \underline{z}_2 + \underline{z}_3 = -j10\,Om$

Tenglamalar sistemasini yechish natijasida: $\dot{I}_a = \frac{\dot{U}(\underline{z}_{22} + 2\underline{z}_{M23})}{\Delta}$

$$\dot{I}_b = \frac{-\dot{U}(\underline{z}_2 + \underline{z}_{M12} + \underline{z}_{M23})}{\Delta}$$

Bunda: $\Delta = (\underline{z}_{11} + 2\underline{z}_{M_{12}})(\underline{z}_{22} + 2\underline{z}_{M_{23}}) - (\underline{z}_2 + \underline{z}_{M_{12}} + \underline{z}_{M_{23}})^2$

Qarshilik parametr qiymatini qo'yish bilan $\dot{I}_a$, $\dot{I}_b$ tok qiymatlari:

$\dot{I}_a = (1 + j2)$ (MA)

$\dot{I}_b = (-4 - j8)$ (MA)

Tarmoqdagi tokning kompleks ifodasi: $\dot{I}_1 = \dot{I}_a(1 + j2)$ (MA)

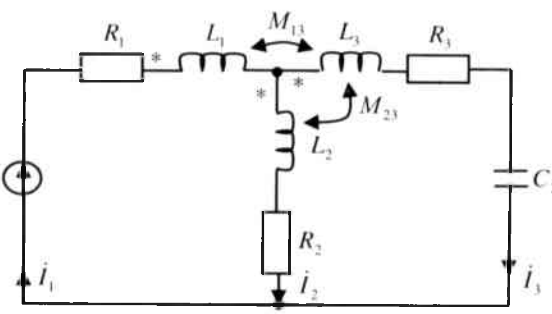
$\dot{I}_2 = \dot{I}_a + \dot{I}_b = -3(1 + j2)$ (MA)

$\dot{I}_3 = -\dot{I}_b = (4 + j8)$ (MA)

Kuchlanish:

$\dot{U}_{ab} = j\omega M_{12}\dot{I}_1 + j\omega L_2\dot{I}_2 + j\omega M_{23}\dot{I}_3 = (180 - j90)$ MV

Masala 4.8. O'zaro induktiv bog'langan zanjir parametri: $L_1 = 5\,gn$, $L_2 = 2\,gn$, $L_3 = 5\,gn$, $M_{13} = 1\,gn$, $M_{23} = 2\,gn$, $R_1 = 4\,Om$, $R_2 = 8\,Om$, $R_3 = 3\,Om$, $C = 0{,}025$ f. bo'lib, $U = 100\frac{1}{\sqrt{2}}\cos 2\omega t$ sinusoidal kuchlanishga ulangan. Kirxgof qonuniga asosan tarmoqdagi tok aniqlansin.



Yechish. Kirxgof qonuniga asosan kompleks ifodali tenglama tuzamiz:

$$-\dot{I}_1 + \dot{I}_2 + \dot{I}_3 = 0$$

$$R_1\dot{I}_1 + j\omega L_1\dot{I}_1 + j\omega M_{13}\dot{I}_3 + j\omega L_2\dot{I}_2 + j\omega M_{23}\dot{I}_2 + R_2\dot{I}_2 = \dot{E}$$

$$j\omega L_3\dot{I}_3 + j\omega M_{13}\dot{I}_1 + j\omega M_{23}\dot{I}_2 + R_3\dot{I}_3 + \frac{1}{j\omega c}I_c - R_2\dot{I}_2 - j\omega L_2 I_2$$
$$- jM_{23}\dot{I}_3 = 0$$

tenglamada tok yo'nalishiga nisbatan $M_{13} > 0$; $M_{23} < 0$, bunda $j\omega M_{23} = j2$.

Parametr qiymatlarini qo'yish bilan:

$$\begin{array}{lll} \dot{I}_1 & -\dot{I}_2 & -\dot{I}_3 = 0 \\ (4+j10)\dot{I}_1 & +(8+j4)\dot{I}_2 & -j2\dot{I}_3 = 100 \\ -j2\dot{I}_1 & -(8+j8)\dot{I}_2 & +(3-j6)\dot{I}_3 = 0 \end{array}$$

$$\Delta = \begin{vmatrix} 1 & -1 & -1 \\ (4+j10) & (8+j4) & (-j2) \\ (j2) & (-8-j8) & (3-j6) \end{vmatrix} = 76 + j82 = 111{,}8e^{j47^\circ}$$

$$\Delta_1 = \begin{vmatrix} 0 & -1 & -1 \\ 100 & (8+j4) & (-j2) \\ 0 & (-8-j8) & (3-j6) \end{vmatrix} = 1100 + j200 = 1118e^{j10^\circ 20^1}$$

Xuddi shunga o'xshash: $\Delta_2 = 300 - j400$, $\Delta_3 = 800 + j500$.

Tarmoqdagi toklarni topamiz:

$\dot{I}_1 = \frac{\Delta_1}{\Delta} = 8 - j6\,A$; $\dot{I}_2 = \frac{\Delta_2}{\Delta} = -0{,}8 - j4{,}4\,A$; $\dot{I}_3 = \frac{\Delta_3}{\Delta} = 8{,}8 - j1{,}6\,A$.

Haqiqiy qiymatlari: $I_1 = 10A$; $I_2 = 4{,}472\,A$; $I_3 = 8{,}944\,A$.

4.3. Mustaqil yechish uchun masalalar

Masala 4.1. Parallel sxemada ulangan g'altakning parametri R_1=20*Om*, R_2=20 *Om*, $x_{L_1} = 10$ *Om*, $x_{L_2} = 20$ *Om*, $x_M = 10$ *Om* ga teng. Zanjirdagi tok ekvivalent qarshiligi $\underline{Z}_0 = \underline{Z}_e$ ni aniqlang.

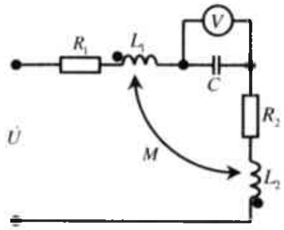
Javob: $\underline{z}_0 = \underline{z}_э = 16{,}27\ell^{j49^0 20'}$

Masala 4.2. Induktiv bog'langan g'altakning parametri $x_{L_1} = 15Om$, $x_{L_2} = 20\ Om$, $x_M = 30\ Om$ bo'lganda, bog'lanish koeffitsientini (k) aniqlang.

Javob: k=0,17

Masala 4.3. Elektromagmit zanjir parametri: C=43 *mkf*, L_1=22 *Gn*, L_2=18 *Gn*, M=6.5 *mGn*, R_1=10.5 *Om*, R_2=9,2 *Om*, U=100 *V*, f=200 *Gs* berilgan sig‘imga ulangan voltmetrning ko‘rsatish qiymatini aniqlang.

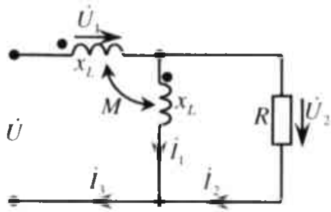
Javob: U=48 *V*



Masala 4.4. Transformatorning qarshilik parametri R_2=2,3 *Om*, $X_{L_1} = 8\,Om$, $X_{L_2} = 10\,Om$, $X_M = 8\,Om$, $\underline{Z}_H = 3{,}35 l^{-j50^\circ}$ *Om* bo‘lib birlamchi chulg‘ami $\dot U_1 = 100\,V$ kuchlanishga ulangan. Birlamchi va ikkilamchi chulg‘amdan o‘tuvchi tok kuchimi aniqlang.

Javob: $\dot I_1 = 21{,}9A; \dot I_2 = 22{,}8\ell^{j15{,}8^0}$

Masala 4.5. Sxemada keltirilgan elektr zanjirning parametri $X_L = 140\,Om$, $X_M = 60\,Om$, $R = 30$ *Om* bo‘lib, $\dot U = 200\,V$ kuchlanishga ulangan. Tarmoqdagi tok, $\dot U_1, \dot U_2$ kuchlamish va quvvat balansini aniqlang.

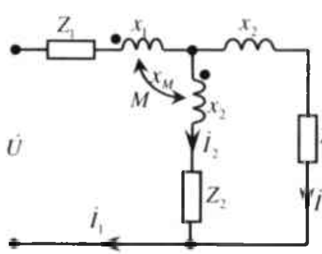


Javob: U_1=171 *V*, U_2=60 *V*, I_1=0.67 *A*, I_2=2 *A*, I_3=1.43 *A*

$\bar S = \dot U \overset{*}{I} = 120 + j260\ (VA)$

$\dot I_1 = -0{,}6 + j0{,}3A; \dot I_2 = 1{,}2 - j1{,}6A; \dot I = 0{,}6 - j1{,}3A$

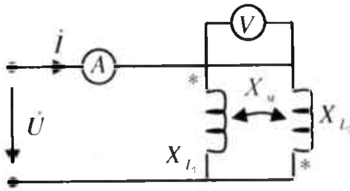
Masala 4.6. Berilgan sxemaning parametri: $\bar z_1 = (3+j)Om$, $\bar z_2 = -j10\ Om$, $\bar z_3 = (12+j5)Om$, $x_1 = 3\ Om$, $x_1 = 2\ Om$, $x_3 = 3\ Om$, $x_M = 8\ Om$ bo‘lib, uchinchi tarmoqdagi tok $I_3 = 1A$ gs ga teng.



Tarmoq toklari $\dot{I}_1, \dot{I}_2$ va $\dot{U}_1$ kuchlanish aniqlanib, topografik diagrammasini tuzing.

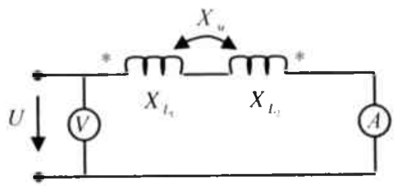
Javob: $\dot{I}_1 = j2A, \dot{I}_2 = -1 + j2A, \dot{U}_1 = j12\ V$

Masala 4.7. O'zaro induktiv bog'langan zanjir qarshiligi: $X_{L_1} = X_{L_2} = 4\ Om$, $X_m = 3\ Om$ bo'lib, ampermetr 1 A bo'lganda voltmetr necha voltni ko'rsatadi?



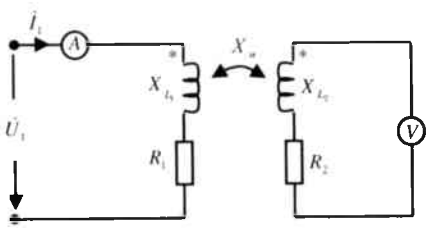
Javob: 7 V

Masala 4.8. O'zaro induktiv bog'langan zanjirga ulangan ampermetrdagi tok – 2 A, voltmetrdagi kuchlanish – 20 V ga teng. O'zaro induktiv bog'lanish qarshiligini X_m aniqlang.



Javob: $X_m = 5\ Om$

Masala 4.9. Transformator parametri $R_1 = R_2 = 1\ Om$, $X_{L_1} = 4\ Om$, $X_{L_2} = 5\ Om$, $X_m = 3\ Om$ bo'lib, ampermetrdagi tok 1 A. Voltmetr ko'rsatkichi necha voltni ko'rsatadi?



Javob: 6 V

4.4. Nazorat savollari

1. O‘zinduksiya va o‘zaro induksiya hodisalarining fizik ma’nosini tushuntirib bering.
2. Magnit induksiya, magnit oqim va induktivlik tenglamalari qanday ifodalanadi, o‘lchov birligi nima?
3. Elektromagnit induksiya qonunini ifodalovchi tenglamadagi $e = -W\frac{d\phi}{dt}$ «minus» ishorasiga izoh bering.
4. O‘zaro induktiv bog‘lanish koeffitsient ifodasini yozing.
5. O‘zaro induksiya EYK qanday ifodalanadi va yo‘nalishi qanday aniqlanadi?
6. O‘zaro induktiv bog‘langan elektr zanjirlarining ulanish sxemasini chizing.
7. O‘zaro induktiv bog‘langan ketma-ket va parallel sxemada ulangan zanjirning ekvivalent induktivlik tenglamasini tuzing.
8. O‘zaro induktiv bog‘lanish koeffitsienti M tajriba asosida qanday aniqlanadi?
9. Chiziqli havo transformatorini ta’riflab bering.
10. Transformatorning ekvivalent almashlash sxemasini chizing.
11. Transformator vazifasi, tuzilishi va ishlash prinsipini bilasizmi?
12. Transformatorning transformatsiyalash koeffitsienti nima?
13. Transformatorning ishchi holat vektor ifodasini tuzing va tushuntirib bering.
14. Induktivligi L=0,05 *Gn* va o‘zaro induktivlik koeffitsienti M=0,08 *Gn* bo‘lgan zanjirning o‘zaro induktiv bog‘lanish koeffitsientini (K) aniqlang.
15. Induktivligi L_1 = 0,1 *Gn*, L_2= 0,1 *Gn*, induktiv bog‘lanish koeffitsienti K=0,8 bo‘lgan elektr zanjiri o‘zaro induktivlik koeffitsientini (M) aniqlang.
16. Ekvivalent induktivligi $L_e = L_1 + L_2 - 2M$ tenglama bilan ifodalanuvchi o‘zaro induktiv bog‘langan elektr zanjir sxemasini chizing.
17. O‘zaro induktiv bog‘langan uchta g‘altakdan iborat ikki konturli elektr zanjiri uchun konturli elektr usuliga asosan tenglama tuzing.

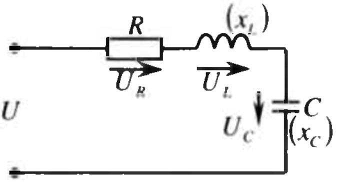
18. Mos sxemada ulangan ikkita induktiv bog'langan (g'altak) zanjir ifodalangan tenglamasini yozib, topografik vektor diagrammasini chizing.
19. Qarama-qarshi sxemada ulangan o'zaro induktiv bog'langan zanjir tenglamasini tuzib, vektor ifodasini chizig.
20. Transformatorlarning kuchlanishini kuchaytirish yoki pasaytirish nimaga bog'liq?
21. Induktiv bog'langan g'altakning o'zaro mos yoki qarama-qarshi ulanishida asosiy magnit oqim ϕ qanday o'zgaradi?
22. Transformator magnitlovchi kuchiar tenglamasini yozing va fizik ma'nosini tushuntiring.
23. Transformatorning ikkilamchi chulg'amiga induktivlik yoki sig'im qarshiligi ulanganda magnit oqim ϕ qanday o'zgaradi?

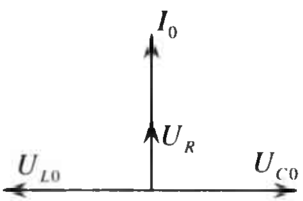
V. ELEKTR TOK ZANJIRDA REZONANS HODISALAR

5.1. Asosiy nazariy tushunchalar

Reaktiv elementlar, induktivlik va sig'im qarshiliklaridan tarkib topgan elektr zanjirda tok va kuchlanish vektorlari ustma-ust tushib, bular orasida burchak $\varphi = 0$ bo'lgan holda, **rezonans hodisasi** yuzaga keladi.

1. Ketma-ket ulangan R,L,C zanjirda kuchlanish rezonansi.





Zanjir rezonans holat vaqtida $X_L = X_C$, yoki; $\omega_0 L - \dfrac{1}{\omega_0 C} = 0$

Bundan rezonans chastota: $\omega_0 = \dfrac{1}{\sqrt{LC}}$ (rad/sek)

Rezonans hodisasiga o'zgaruvchan tok chastotasi f, induktivlik va sig'im parametrini o'zgartirish bilan erishiladi.

Rezonans holatida reaktiv element qarshiligi: $\omega_0 L = \dfrac{1}{\omega_0 C} = \rho$

yoki: $X_L = \omega_0 L = \frac{1}{\sqrt{LC}} \cdot L = \sqrt{\frac{L}{C}} = \rho$; $X_c = \frac{1}{\omega_0 C} = \frac{\sqrt{LC}}{C} = \sqrt{\frac{L}{C}} = \rho$; $\rho = \sqrt{\dfrac{L}{C}}$

to'lqin qarshilik (Om) da o'lchanadi.

Rezonans holatda tok maksimal qiymatga erishadi:

$$I_0 = \frac{U}{R} = I_{max} = \frac{U_p}{\rho}$$

Reaktiv elementlardagi kuchlanish: $U_{L0} = U_{C0} = I_0 \rho$

Agar $\rho > R$ bo'lsa, reaktiv qarshilikdagi kuchlanish manba kuchlanishidan katta bo'ladi. Necha martaga katta bo'lishi quyidagi formula bilan aniqlanadi:

$$Q = \frac{U_{L0}}{U} = \frac{U_{C0}}{U} = \frac{\omega_{OL}}{R} = \frac{\rho}{R}$$

Bunda Q – kontur **saxiyligi** yoki **aslligi**, bazan sifat koeffitsienti ham deyiladi. Odatda $Q = (200 - 300)$ oraliqda o'zgaradi.

Unga teskari bo'lgan qiymat $d = \frac{1}{Q} = \frac{R}{\rho}$ **konturning so'nishi** deyiladi.

Rezonans holatda konturning energiya tebranishiga aktiv qarshilik ta'sirini hisobga olganda, kontur xususiy tebranish chastotasi:

$$f = f_0\sqrt{1 - \frac{R^2C}{4L}}$$

Reaktiv qarshiliklardagi kuchlanish U_{Lmax} va U_{Cmax} maksimal qiymatga rezonansdan oldin yoki keyin erishadi va quyidagi ifoda bilan izohlanadi.

$$\omega_L = \frac{\omega_0}{\sqrt{\frac{2}{2-d^2}}} \quad \text{va} \quad \omega_C = \omega_0\sqrt{\frac{2-d^2}{2}}$$

Rezonans kontur chastotasi (ω), zanjir parametri, tok va kuchlanishga nisbatan bog'liqlik funksiyasiga **chastotali xarakteristika** deyiladi.

$$f_{(\omega)} = f(I_{(\omega)}, U_{(\omega)}, U_{L(\omega)}, U_{C(\omega)}, X_{L(\omega)}, X_{C(\omega)}, z_{(\omega)})$$

Bu xarakteristikani analiz qilishda tok yoki chastotani nisbiy qiymat orqali ifodalash ancha qulay bo'lib, koeffitsient $\eta = \frac{\omega}{\omega_0}$ ga teng deb olinadi.

Bunda: $\omega_o = \frac{1}{\sqrt{LC}}$ (rad/sek); $I_o = \frac{U}{R}$, $R = \rho d$, $h = \frac{\omega}{\omega_0}$, $I = \frac{U}{Z}$

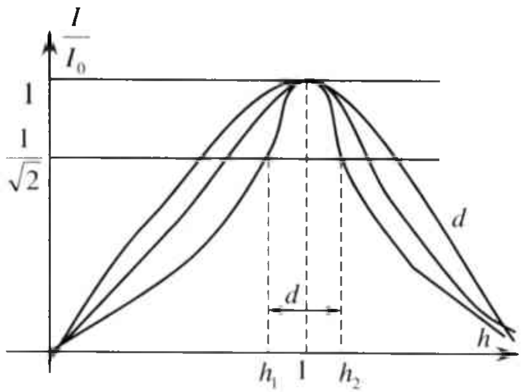
$$\frac{I}{I_0} = \frac{1}{\sqrt{1 + \left[\left(\eta - \frac{1}{\eta}\right) : d\right]^2}}$$

So'ndirish koeffitsienti: $d = \eta_1 - \eta_2$ Rezonans konturining ma'lum bir chastotani o'tkazish chegarasi:

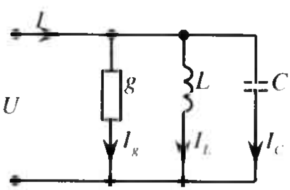
$$\omega_0(\eta_2 - \eta_1) = \omega_0 d.$$

Rezonans holatda tebranuvchan elektromagnit maydon energiyasi o‘zgarmas bo‘ladi.

$$W_0 = W_M + W_э = \frac{1}{2}LI^2 + \frac{1}{2}CU^2 = const$$



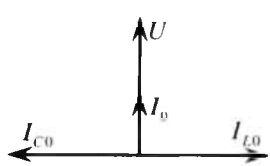
2. Parallel ulangan L, C zanjirda toklar rezonansi.



Parallel ulangan elektr zanjir rezonans holatda $в_L = в_C$ bo‘lib, rezonans chastota: $\frac{1}{\omega_0 L} - \omega_0 C = 0$

yoki: $\omega_0 = \frac{1}{\sqrt{LC}}$ (rad/sek)

Reaktiv elementlarning o‘tkazuvchanligi: $\frac{1}{\omega_0 L} = \omega_0 C = \gamma$ ga teng bo‘lib, **to‘lqin o‘tkazuvchanligi** deyiladi.



Rezonans holatda umumiy tok:

$I_0 = Ug$.

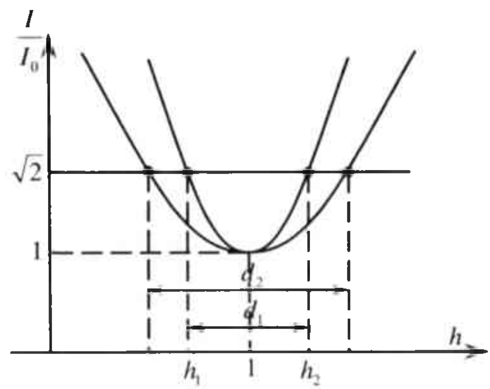
Reaktiv elementlardagi tok: $I_{L0} = I_{C0} = U\gamma$

Agarda g $< \gamma$ bo'lganda, reaktiv qarshiliklarda tok umumiy tokdan katta bo'lib: $d = \frac{I}{I_{L o}} = \frac{I}{I_{C o}} = \frac{Ug}{U\gamma} = \frac{g}{\gamma}$ **kontur so'nishi** deyiladi.

Teskari qiymat: $Q = \frac{1}{d} = \frac{\gamma}{g}$ **kontur saxiyligi** yoki **asilligi** deyiladi.

Rezonans holat uchun chastotali xarakteristikalarni tuzishda tok va chastota qiymatiga nisbatan olingan tenglamadan foydalaniladi:

$$\frac{I}{I_0} = \sqrt{1 + \left[\left(\frac{1}{h} - h\right) : d\right]^2}$$



Keltirilgan xarakteristikadan rezonans chastota so'nish chegaralari d = $h_1 - h_2$ bilan ifodalaniladi.

Tok rezonans holatda ham elektromagnit maydon energiyasinmg tebranishi kuchlanishlar rezonans holatiga o'xshash va o'zgarmas bo'ladi.

$$W = \frac{1}{2}LI^2 = \frac{1}{2}CU^2 = const$$

Radiotexnikada elektromagnit maydon energiya tarqalishi tezligi to'lqin uzunligiga nisbatan o'lchanib: $\lambda = vT$, λ – to'lqm uzunligi (m), ν – to'lqin tarqalish tezligi (m/sek), T – davr (1/sek), bunda: $\lambda = \frac{v}{f}$. f – chastota. Tebranuvchan kontur to'lqin uzunligi: $\lambda_0 = v \cdot 2\pi\sqrt{LC} =$ $= 3 \cdot 10^8 \cdot 2\pi\sqrt{LC}$ (m).

3. Tarmoqlangan elektr zanjirda rezonans.

Tarmoqlangan elektr zanjirda ham rezonans sharti $\varphi = 0$ bo'lib, tok va kuchlanish vektorlari orasidagi burchak nolga teng. x_e=0; φ_e= 0.

Bir nechta induktivlik va sig'im elementlaridan tuzilgan murakkab elektr zanjirda rezonans hodisasi ba'zi kontur va tarmoqlarda ham hosil bo'lishi mumkin.

Radiotexnika, aloqa, avtomatika va boshqa sohalarda o'zaro bog'langan tebranuvchan konturlarda hosil bo'ladigan rezonans hodisasidan keng foydalanib, bular umumiy zanjir qarshiligi yoki elektromagnit maydon energiyasi orqali bog'langan bo'lishi mumkin.

Masalan: O'zaro induktiv bog'langan (transformator, avtotrans.), zanjirsimon sxemada bog'lanish, kondensatorli bog'lanish (ichki yoki tashqi), galvanik bog'lanish yoki konturlarning induktiv va sig'im parametrlari orqali bog'langan bo'lishi mumkin.

Konturlarning o'zaro bog'lanish koeffitsienti: $K = \frac{X_m}{\sqrt{X_1 X_2}}$ (*)

bo'lib: X_m – elementlarning o'zaro bog'lanish qarshiligi.

X_1 – birinchi kontur reaktiv qarshiligi.

X_2 – ikkinchi kontur reaktiv qarshiligi.

a) o'zaro induktiv bog'langan zanjirlarda: $X_L = \omega M\ (Om)$.

Kontur reaktiv qarshiligi: $X_1 = \omega L_1, X_2 = \omega L_2 (Om)$.

Shunga asosan: $K = \frac{\omega M}{\sqrt{\omega L_1 \cdot \omega L_2}} = \frac{M}{\sqrt{L_1 L_2}}$; M – o'zaro induktiv bog'lanish koeffitsienti.

b) Konturning o'zaro sig'im yoki kondensator qarshiligi orqali bog'lanishida: $X_M = \frac{1}{\omega C_0}$; $X_1 = \frac{1}{\omega C_1}$; $X_2 = \frac{1}{\omega C_2}$ yoki: $C_1 = \frac{C_1 C_0}{C_1 + C_0}$ – birinchi kontur umumiy sig'imi.

$C_2 = \frac{C_2 C_0}{C_2 + C_0}$ – ikkinchi kontur umumiy sig'imi.

Ushbu qiymatni (*) tenglamaga qo'yish bilan: $K = \sqrt{\frac{C_1 C_2}{(C_1 + C_0)(C_2 + C_0)}}$

Kontur elektr yurituvchi kuch o'zaro induktiv bog'lanishida:

$$K = \frac{E_2}{E_{2M}} = \frac{E_2}{I_1 \omega M}.$$

Bunda I_1 – birlamchi konturdagi tok o'zaro induktiv bog'langan (transformator) zanjirda rezonans hodisasini tahlil qilishda ekvivalent keltirilgan aktiv va reaktiv qarshilik tenglamalaridan ham foydalaniladi:

$\Delta R_1 = \frac{\omega^2 M^2}{Z_2^2} R_{22}$ (aktiv qarshilik); $\Delta X_1 = -\frac{\omega^2 M^2}{Z_2^2} X_{22}$ – sig'im xarakterga ega bo'lgan reaktiv qarshillk.

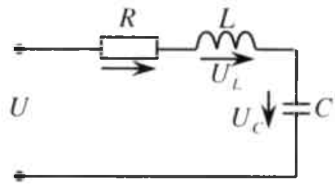
O'zaro induktiv bog'langan kontur quvvat muvozanat tenglamasi:

$$P_2 = I_1^2 \frac{\omega^2 M^2}{R_2} = \frac{E_2^2}{R_2} = I_2^2 R_2 \ (VT).$$

Foydali ish koeffitsienti: $h = \frac{P_2}{P} = \frac{P_2}{P_1 + P_2} = \frac{I_1^2 \Delta R_1}{I_1^2 R_1^2 + I_1^2 \Delta R_1} = \frac{\Delta R}{R + \Delta R_1}$.

5.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 5.1. Ketma-ket biriktirilgan elektr zanjirmng parametri $L=150 mkGn=15\cdot10^{-5} Gn$, $C=470 mkF=47\cdot10^{-7} F$, $R=5\ Om$ bo'lib, $U=10\ V$ kuchlanishga ulangan. Rezonans chastotasi f_0, reaktiv elementlardagi kuchlanish U_L, U_C, to'lqin qarshiligi ρ, kontur asilligi Q va so'nish koeffitsienti d ni aniqlang.



Yechish.

Rezonans chastota:

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{705\cdot10^{-16}}} = \frac{1}{26{,}6\cdot10^{-8}} = 376\cdot10^4 \ (rad/sek)$$

Bundan: $f_0 = \frac{\omega_0}{2\pi} = \frac{376\cdot10^4}{6{,}28} = 6\cdot10^5 \ (gs)$

Rezonans holatdagi tok: $I_0 = \frac{U}{R} = \frac{10}{5} = 2(A)$

Reaktiv qarshiligi: $x_L = \omega_0 L = 565\ Om$

$$x_C = \frac{1}{\omega_0 C} = \frac{1\cdot 10^7}{376\cdot 10^4\cdot 47} = 565\ Om$$

Reaktiv qarshiliklardagi kuchlanish:

$U_L = IX_L = 565\cdot 2 = 1130\ V$, $U_C = IX_C = -1130\ (V)$

To‘lqin qarshiligi: $\rho = \sqrt{\frac{L}{C}} = 565\ om$

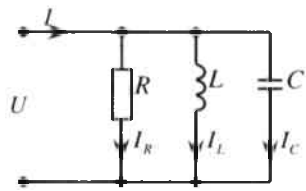
Asillik koeffitsienti: $Q = \frac{U_C}{U} = \frac{\rho}{R} = 113$

So‘nish koeffitsienti $d = \frac{1}{Q} = \frac{1}{113} = 0{,}885\cdot 10^2$

Masala 5.2.

Parallel sxemada ulangan elektr zanjir parametri

$R = 50\ Om$ $\quad (g = 0{,}02\frac{1}{Om})$, $\quad L = 16mGn = 16\cdot 10^{-3}\ Gn$, $C = 40\ mkF = 40\cdot 10^{-6}\ F$, bo‘lib, U=200 V kuchlanishga ulangan. Rezonans chastota f_0, tok I, I_L, I_C so‘nish koeffitsienti d va to‘lqin o‘tkazuvchanligi γ ni aniqlang.



Yechish.

Rezonans chastota: $\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{64\cdot 10^{-8}}} = \frac{1}{8\cdot 10^{-4}} = 1250\ \left(\frac{rad}{sek}\right)$

yoki: $f_0 = \frac{\omega_0}{2\pi} = 199\ (gs)$

Tok: $I = Ug = 200\cdot 0{,}02 = 4\ \ (A)$

Induktiv va sig‘im reaktiv o‘tkazuvchanligi:

$$b_L = \frac{1}{\omega_0 L} = \frac{1}{1250\cdot 16\cdot 10^{-6}} = 0{,}05\left(\frac{1}{Om}\right)$$

$$b_C = \omega_0 C = \frac{1}{1250\cdot 40\cdot 10^{-6}} = 0{,}05\left(\frac{1}{Om}\right)$$

Induktivlik va sig'imdan o'tuvchi tok:

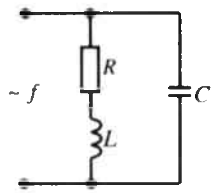
$I_L = Ub_L = 10\ (A),\quad I_C = Ub_C = 10\ (A)$

To'lqin o'tkazuvchanligi: $\gamma = \sqrt{\dfrac{C}{L}} = 0{,}05\ \left(\dfrac{1}{Om}\right)$

Kontur aslligi: $Q = \dfrac{\gamma}{g} = 2{,}5$

Kontur so'nish koeffitsienti: $d = \dfrac{1}{Q} = 0{,}4$

Masala 5.3. Sxemada keltirilgan elektr zanjir chastotasi *f=400 Gs* o'zgaruvchan tok manbaiga ulangan. Agar aktiv qarshilik *R=5 Om,* sig'im parametri *C=10,5 mkF* bo'lsa, induktivlikning qanday qiymatida rezonans holat yuzaga keladi.



Yechish.

Ushbu elektr zanjir uchun rezonans sharti, reaktiv o'tkazuvchanlikning yig'indisi nolga tengligi bo'ladi. Yani: $y = y_1 + y_2$

Bunda: $y_1 = \dfrac{1}{z_1} = j\omega c;\quad y_2 = \dfrac{1}{z_2} = \dfrac{1}{R + j\omega L} = \dfrac{R - j\omega L}{R^2 + \omega^2 L^2}$

yoki: $y = \dfrac{R}{R^2 + \omega^2 L^2} + j(\omega c - \dfrac{\omega L}{R^2 + \omega^2 L^2})$

Qavs ichidagi reaktiv o'tkazuvchanlik tenglamasini nolga tenglaymiz:

$$b = \omega c - \frac{\omega L}{R^2 + \omega^2 L^2} = 0$$

Umumiy maxrajga keltirib ω ga bo'lib yuborilsa:

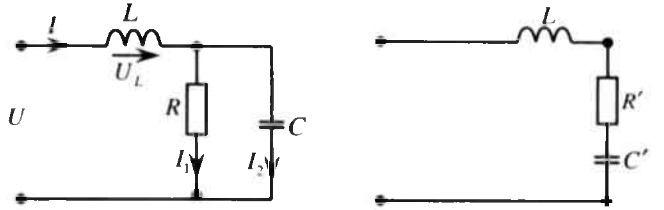
$$\omega^2 L^2 c^2 - L + cR^2 = 0$$

Induktivlikga nisbatan tenglama yechimi:

$$L_{1,2}=\frac{1\pm\sqrt{1-4\omega^2c^2R^2}}{2\omega^2c}=\frac{1\pm0{,}85}{132}$$

Demak zanjirda rezonans holat yuzaga kelishi mumkin bo'lgan induktivlik qiymati: L_1=0.014*gn*=14*mGn*; L_2=0.00114=1.14*mGn*.

Masala 5.4. Keltirilgan elektr zanjir uchun rezonans chastota (ω_0) tenglamasi va aktiv qarshilikning (Z_0) qanday qiymatida rezonans holat yuzaga kelishini aniqlang.



Yechish.

Zanjirning parallel ulangan qismini ekvivalent sxemasi bilan almashtiriladi.

$$R'=\frac{g}{y^2}=\frac{\frac{1}{R}}{\left(\frac{1}{R}\right)^2+(\omega c)^2}=\frac{R}{1+\omega^2C^2R^2}$$

$$x'=\frac{b}{y^2}=\frac{\omega C}{\left(\frac{1}{R}\right)^2+(\omega c)^2}=\frac{\omega CR^2}{1+\omega^2C^2R^2}$$

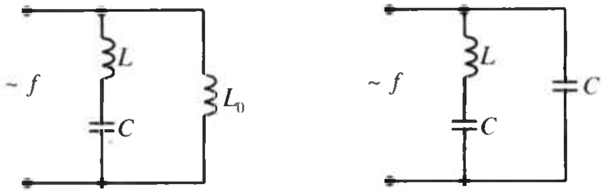
Ketma-ket ulangan ekvivalent sxema uchun rezonans sharti: $x=\omega L-\dfrac{\omega CR^2}{1+\omega^2C^2R^2}=0$

Tenglama umumiy maxraji berilib, (ω) ga bo'linsa:

$L+\omega_0^2C^2R^2L-CR^2=0$ Bundan: $\omega_0=\sqrt{\dfrac{CR^2-L}{C^2R^2L}}=\dfrac{1}{\sqrt{LC}}\sqrt{1-\dfrac{\frac{L}{C}}{R^2}}$

Elektr zanjirda $R>\sqrt{\dfrac{L}{C}}=\rho$ bo'lgandagina rezonans holat yuzaga keladi.

Masala 5.5. Berilgan elektr zanjir o'zgaruvchan tok chastotasi $f=10^{-5}$ *Gs* bo'lgan generatorga ulangan. Induktivligi $L=100$ *mkGn*, sig'imi $C=500$ *Pf*. Zanjirda kuchlanishlar rezonansini hosil qiluvchi induktivlik qiymati L_0 aniqlanib, zanjirda tok rezonansi yuzaga kelishi uchun $f=2$ *MGs* bo'lganda qanday qilib iste'molchlga ulanish mumkin?



Yechish.

Ushbu elektr zanjir uchun rezonans shartiga asosan reaktiv qarshiliklari nolga teng:

$$b=b_1+b_0=0$$

Bunda: $b_1=\frac{\omega C}{\omega^2 LC-1}$ - LC zanjir reaktiv o'tkazuvchanligi

$b_0=\frac{\omega C}{\omega L_0}$ - L_0 induktivligi reaktiv o'tkazuvchanligi

Demak: $-\frac{\omega C}{\omega^2 LC-1}+\frac{1}{\omega L_0}=0$

Bundan: $\omega^2 L_0 C+\omega^2 LC-1=0$

Tenglamani L_0 ga nisbatan yechish bilan:

$$L_0=\frac{1-\omega^2 LC}{\omega^2 LC}=\frac{1}{\omega^2 C}-L=0.0049Gn=4.9MGn$$

Zanjirda kuchlanishlar rezonansi yuzaga kelishi uchun $L_0=4,9MGn$ teng bo'lishi kerak.

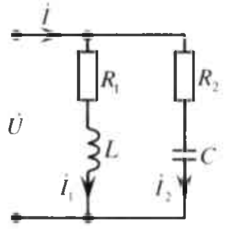
Masalaning ikkinchi sharti bo'yicha yana reaktiv o'tkazuvchanliklar tenglamasi nolga tenglanadi:

$$в=\frac{\omega C}{\omega^2 LC-1}+в_0'=0$$

$\omega=2\pi f=4\pi\cdot 10^6\ sek^{-1}$ – teng bo'lganda, bunda b'_0 – zanjir tarmog'iga ulangan reaktiv o'tkazuvchanlik: $b'_1=\frac{\omega C}{\omega^2 LC-1}=-9{,}2\cdot 10^{-4}\ \frac{1}{Om}<0$

Demak, ushbu elektr zanjirida tok rezonansi hosil bo'lishi uchun induktivlik L_0 sig'im elementi bilan almashtirilishi kerak. Sig'im parametrlari esa $C_0 = \frac{b_0'}{\omega} = \frac{9{,}2\cdot10^{-4}}{4\pi\cdot10^6} = 73{,}3\ pf$ ga teng.

Masala 5.6. Parallel ulangan elektr zanjirning parametri: R_0=100 Om, R_2=200 Om, L=0,2Gn, C=1 mkf, manba kuchlanishl $\dot{E}$=100 V. Rezonans chastota, reaktiv qarshiliklar va rezonans holatdagi tok kuchini aniqlang.



Yechish.

Umumiy ekvivalent o'tkazuvchanligi:

$$y = y_1 + y_2 = \frac{1}{R_1 + j\omega L} + \frac{1}{R_2 + \frac{1}{j\omega C}} = \frac{R_1 - j\omega L}{R_1^2 + \omega^2 L^2} + \frac{R_2 - \frac{1}{j\omega C}}{R_2^2 + \frac{1}{\omega^2 C^2}} =$$

$$= \frac{R_1}{Z_1^2} + \frac{R_2}{Z_2^2} - j\left(\frac{\omega L}{R_1^2 + \omega^2 L^2} + \frac{\frac{1}{\omega C}}{R_2^2 + \frac{1}{\omega^2 C^2}}\right) = g - jb$$

Parallel ulangan elektr zanjirida tok rezonans sharti $b_L = b_C$ bo'lib, bundan rezonans chastota tenglamasi:

$$\frac{\omega L}{R_1^2 + \omega^2 L^2} = \frac{\frac{1}{\omega C}}{R_2^2 + \frac{1}{\omega^2 C^2}} \quad \text{yoki} \quad \omega_0 = \frac{1}{\sqrt{LC}}\sqrt{\frac{\frac{L}{C} - R_1^2}{\frac{L}{C} - R_2^2}} = 2414\ \frac{1}{sek}$$

Reaktiv qarshiliklari: $x_L = \omega_0 L = 483\ (Om)$, $x_C = \frac{1}{\omega_0 C} 414\ (Om)$

Birinchi tarmoq to'la qarshiligi:

$\underline{z}_1 = R_1 + j\omega_0 L = 493 \cdot e^{j78^\circ}\ (Om)$ $\underline{z}_2 = R_2 + j\frac{1}{\omega_0 C} = 460 \cdot e^{j64^\circ}\ (Om)$

Birinchi tarmoqdagi tok: $\dot{I}_1 = \frac{\dot{U}}{\underline{z}_1} = \frac{100\, e^{j0^0}}{493\, e^{j78^0}} = (0{,}04 - j0{,}19)$ (A)

Ikkinchi tarmoqdagi tok $\dot{I}_2 = \frac{\dot{U}}{\underline{z}_2} = \frac{100 e^{j0}}{493 e^{-j64^0}} = (0{,}09 + j0{,}19)$ (A)

Umumiy tok: $\dot{I} = \dot{I}_1 + \dot{I}_2 = (0{,}04 - j0{,}19) + (0{,}09 + j0{,}19) = 0{,}13$ (A)

Rezonans holatda reaktiv qarshilik nolga teng ($x = 0$)

Masala 5.7. (5.6) masalada berilgan sxemaning qarshiligi $x_L=40\ Om$, $R_1=30\ Om$, $R_2=28\ Om$, chastotasi $f=1000\ Gs$ bo'lgan holatda zanjirda tok rezonansini yuzaga keltiruvchi sig'im qiymatini aniqlang.

Yechish.

Rezonans holatda reaktiv qarshilik nolga teng.

yani: $x_L - x_C = 0$ yoki: $x_L = x_C$

Bunda induktivlikdagi reaktiv quvvat:

$$Q_L = I_1^2 x_L = \frac{U^2}{R_1^2 + x_C^2} x_L$$

Sig'imdagi reaktiv quvvat: $Q_C = I_1^2 x_C = \frac{U^2}{R_2^2 + x_C^2} x_C$

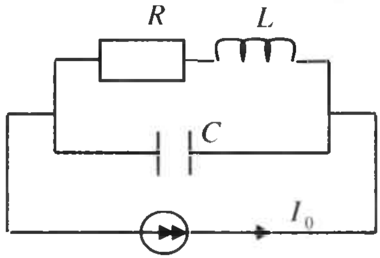
Demak: $\frac{U^2}{30^2 + 4} \cdot 40 = \frac{U^2}{28^2 + x_C^2} x_C$

Bundan sig'im qarshiligi: $x_C = 17,75\ Om$

Sig'im parametri: $C = \frac{x_C}{2\pi f} = \frac{17,75}{2 \cdot 3,14 \cdot 1000} = 2,28\ mkf$

Masala 5.8. Parallel sxemada ulangan rezonansli kontur parametri $R = 2\ Om$, $L = 0{,}4\ mg$, $C = 0{,}01\ mkf$ bo'lib, $I_0 = 10\ mA$ tok manbaiga ulangan:

Rezonans chastota ω_0, asillik koeffitsienti Q va tok chastota ± 2 % o'zgarganda rezonans kuchlanish va tok I_1, I_2 qiymatini aniqlang.



Yechish. Rezonans shartiga ko'ra: $b_1 = -b_2$ yoki: $\frac{\omega_0 L}{R+(\omega_0 L_0)^2} = \frac{1}{\omega s}$

bundan: $\omega_0 = \frac{1}{\sqrt{LC}} \sqrt{\frac{\rho^2 - R^2}{\rho^2}} \approx 5 \cdot 10^5\ {rad}/{sek}$

Kontur to'lqin qarshiligi $\rho = \sqrt{\frac{L}{C}} = \sqrt{\frac{0,4\cdot10^{-3}}{10^{-8}}} = 200\ Om.$

Kontur asilligi $Q = \frac{\rho}{R} = 100.$

Rezonans holatda $b = b_1 + b_2 = 0$, bo'lganligi uchun $R_0 = \frac{1}{g_{12}}$;

aktiv o'tkazuvchanlik: $g_{12} = g_0 = \frac{R^2}{R^2 + (\omega_0 L)^2} \approx 0,5 \cdot 10^{-4} \frac{1}{Om}.$

Demak $R_0 = \frac{1}{0,5\cdot10^{-4}} = 20 \cdot 10^{-3} Om.$

Rezonans kuchlanish: $U_p = I_0 R_0 = 10 \cdot 10^{-3} \cdot 20 \cdot 10^3 \approx= 200\ V.$

Rezonans holatda $R_1 \ll \omega_0 L$ ekanligini hisobga olinsa:

$I_1 \approx I_2 = \frac{U_p}{\rho} = \frac{200}{200} 1\ A.$

Agar tok chastotasi 2% ko'paysa reaktiv o'tkazuvchanlik qiymati:

$b_{12} = b_1 + b_2 = \frac{\omega L_1}{R_1^2 + (\omega L_1)^2} - \omega C_2 = -0,2 \cdot 10^{-3} \frac{1}{Om}.$

Bunda: $\omega^1 = (\omega_0 + 0,02\omega_0) = 5,1 \cdot 10^5\ {rad}/{sek}.$

Aktiv o'tkazuvchanlik qiymati: $g_{12} = \frac{R_{12}}{R^2 + (\omega L)^2} = 0,5 \cdot 10^{-4} \frac{1}{Om}.$

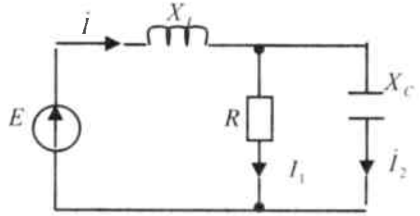
Kontur to'la o'tkazuvchanligi: $y_{12} = \sqrt{g_{12}^2 + b_{12}^2} = 2,06 \cdot 10^{-4} \frac{1}{Om}$

To'la qarshiligi: $Z_{12} = \frac{1}{y_{12}} = 4855\ Om.$

Demak rezonans kuchlanish qiymati chastota 2% o'zgarganda $\frac{R_0}{Z_{12}} = \frac{20\cdot10^3}{4855} = 4,1$ marta kamayadi. Parallel kontur asilligi ham shunga nisbatan aniqlanadi.

Masala 5.9. Keltirilgan sxemada kuchlanishlar rezonans holatida aktiv qarshilik $R = 200\ Om$, umumiy qarshilik esa $Z_{um} = 100\ Om$ bo'lib, $E = 200\ V$ kuchlanishga ulangan.

Rezonans vaqtidagi induktivlik x_L va sig'im x_C qarshiligi, tarmoqdagi tok kuchini toping.



Yechish. Umumiy kompleks qarshllik:

$$Z_{um} = jx_L + \frac{R(-jx_c)}{R - jx_c} = \frac{R(-jx_c)(R + jx_c)}{R^2 + x_c^2} + jx_L =$$

$$= \frac{Rx_c^2}{R^2 + x_c^2} + j\left(x_L - \frac{R^2 x_c}{R^2 + x_c^2}\right) = R_{um} + jx_{um}.$$

Bundan $R_{um} = 100\ Om$; $X_{um} = 0$.

Zanjir aktiv qarshiligi $R = 200\ Om$ bo'lsa, Ikkita noma'lum tenglama yozamiz:

$R_{um} = 100 = \frac{Rx_C^2}{R^2 + x_C^2}$ yoki $100 = \frac{200x_C^2}{(200)^2 + x_C^2}$.

Bundan: $x_C = 200\ Om$

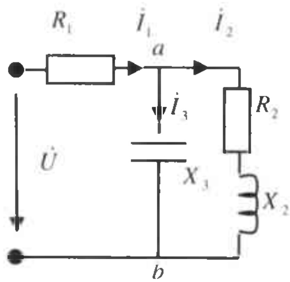
Endi umumiy reaktiv qarshilik: $X_{um} = 0 = X_L - \frac{R^2 x_C}{R}$;

$x_L = \frac{200^2 \cdot 200}{200^2 + 200^2} = 100\ Om.$

Umumiy tok: $I = \frac{E}{Rum} = \frac{200c^{j0}}{100} = 2\ A$

Tarmoqdagi tok: $\dot{I}_1 = \dot{I}\frac{-jx_C}{R - jx_C} = 1 - j1\ A$; $\dot{I}_2 = \dot{I}\frac{R}{R - jx_C} = 1 + j1\ A.$

Masala 5.10. Zanjir qarshilik parametrlari $R_1 = 6\ Om$, $R_2 = 4\ Om$, $X_2 = 4\ Om$ bo'lib, $U = 120\ V$ kuchlanishga ulangan kondensator qarshiligini X_3 aniqlab, rezonans shartiga asosan $\varphi = 0$ holat uchun tarmoqdagi tok $\dot{I}_1, \dot{I}_2, \dot{I}_3$ va vektor ifodasini tuzing.



Yechish. Rezonans shartiga asosan tok va kuchlanish vektorlari ustma-ust tushadi va bular orasidagi burchak $\varphi = 0$, shunga asosan zanjirning ekvivalent umumiy reaktiv qarshlligini nolga tenglaymiz.

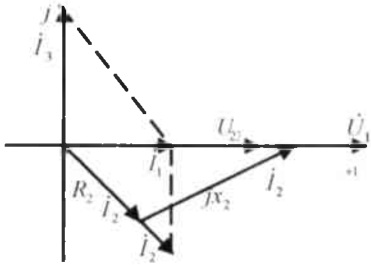
yoki: $Z_{ab} = \frac{(R_2 + jx_2)(-jx_3)}{R_2 + j(x_2 - x_3)} = \frac{R_2 x_3^2}{R_2^2 + (x_2 - x_3)^2} + j\frac{x_2 x_3^2 - x_3 x_2^2 - x_3 R_2^2}{R_2^2 + (x_2 - x_3)^2}$

Mavhum son qismini nolga tenglashtirish bilan:

$$x_2 x_3^2 - x_3 x_2^2 - x_3 R_2^2 = 0$$

Sig'im qarshiligi: $x_3 = x_2 + \frac{R_2^2}{x_2} = 4 + \frac{16}{4} = 8\ Om.$

Masalaning shartiga asosan R_1 qarshilik $\dot{I}_1$ tok bilan kuchlanish U orasidagi faza burchagiga ta'sir o'tkazmaydi. Shu sababli Om qonuniga asosan:



$$\dot{I}_1 = \frac{\dot{U}}{R_1 + \frac{R_2 X_3^2}{R_2^2 + (X_2 - X_3)^2}} = \frac{120}{6+8} = 8,57\,A$$

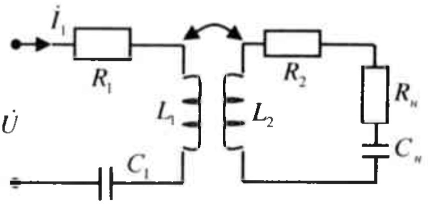
Zanjirning parallel ulangan qismi-dagi kuchlanish:

$\dot{U}_{ab} = \dot{I}_1 \frac{R_2 x_3^2}{R_2^2 + (x_2 + x_3)} = 8,57 \cdot 8 = 68,5V$ Yoki tarmoqdagi tok:

$$\dot{I}_2 = \frac{\dot{U}_{ab}}{R_2 + jx_2} = \frac{68,5}{4 + j4} = \frac{68,5}{4 \cdot \sqrt{2} e^{j45^\circ}} = 8,57 - j8,57\,A;\ \dot{I}_3 = \frac{\dot{U}_{ab}}{-jx_3} = \frac{68,5}{-j8} = j8,57\,A.$$

Tuzilgan vektor ifodadan $\dot{I}_1$ tok bilan $\dot{U}_{ab}$ va $\dot{U}$ kuchlanish vektorlari ustma-ust tushadi va R_1 qarshilik faza siljishiga ta'sir o'tkazmaydi.

Masala 5.11. O'zaro induktiv bog'langan rezonans zanjir parametri: $K = 0{,}42$, $R_1 = 5\ Om$, $R_2 = 10\ Om$, $R_H = 20\ Om$, $X_{L_1} = 30\ Om$, $X_{L_2} = 80\ Om$, $X_{C_1} = 25\ Om$, $X_{C_n} = 45\ Om$ bo'lib, $U = 60\ V$ kuchlanishga ulangan. O'zaro induktiv bog'langan reaktiv qarshilik, transformatorning «orttirma» kiritilgan aktiv ΔR va reaktiv ΔX qarshiliklari, umumiy to'la qarshilik I_1, I_2 tok qiymati hamda ekvivalent sxema parametri va rezonans holatdagi X_{C_n} – sig'im qarshilik qiymatini aniqlang.



Yechish. a) transformatorning bog'lanish koeffitsienti tenglamasiga asosan:

$$K = \frac{M}{\sqrt{L_1 \cdot L_2}} = \frac{\omega M}{\sqrt{\omega L_1 \cdot \omega L_2}}$$

Bundan: $X_M = \omega M = K\sqrt{\omega L_1 \cdot \omega L_2} = 0{,}42\sqrt{30 \cdot 80} = 20{,}6\ Om.$

Ikkilamchi kontur xususiy to'la qarshilikning kompleks ifodasi.

$$Z_{22} = X_{L_2} + R_2 + R_H - jx_c = j80 + 10 + 20 - j45^{\circ} =$$

$$= 30 + j35 = R_{22} + jx_{22} = 46e^{j49^{\circ}}\ Om$$

Yoki xususiy qarshilik: $Z_{22}^2 = \sqrt{R_{22}^2 + 35^2} = 2125\ Om.$

Shunga asosan birinchi konturga nisbatan kiritilgan qarshilik ifodasi:

$$\Delta R = \frac{x_M^2}{Z_{22}^2} R_{22} = \frac{(20{,}6)^2 \cdot 30}{2125} = 6\ Om \quad \Delta X = -\frac{X_M^2 \cdot}{Z_{22}^2} X_{22} = \frac{(20{,}6)^2 \cdot 35}{2125} = -7\ Om.$$

Zanjirning kirish qismidagi to'la qarshilik:

$$Z = R_0 + jx_1 + \Delta R_2 + j\Delta x - jx_{c_1} = 5 + j30 + 6 - j7 - j25 =$$

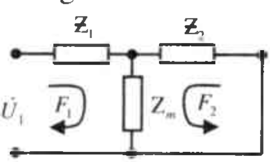
$$= 11 - j2 = 11e^{-j10^{\circ}}\ Om$$

Birlamchi konturdagi tok: $\dot{I}_1 = \frac{\dot{U}}{Z} = \frac{60}{11e^{-10}} = 5{,}5e^{10^{\circ}} = 5{,}3 + 0{,}95A$

Ikkilamchi konturdagi tok:

$$\dot{I}_2 = -\dot{I}_1 \frac{jx_M}{Z_{22}} = -5{,}5e^{j10} \frac{j20{,}6}{46e^{j49^{\circ}}} = -2{,}42e^{j51^{\circ}} = -1{,}53 - j1{,}9A.$$

Transformatorning keltirilgan ekvivalent sxemasini chizamiz:



Birinchi kontur to'la qarshiligi:

$$Z_1 = Z_{11} - Z_M = \left(R_1 + jx_{L_1} - jx_{c_1}\right) - jx_M =$$

$$= 5 + j30 - j25 - j20,6 = 5 - j15,6om$$

Ikkinchi kontur to'la qarshiligi:

$$Z_2 = Z_{22} - Z_M = \left(R_2 + R_H + jx_{L_2} - jx_H\right) - jx_M =$$

$$= (10 + 20 + j80 - j45) - j20,6 = 30 + j14,5om$$

$$\text{va } Z_M = j20,6\ Om$$

b) rezonans holatdagi sig'im qarshiligi (X_{c_H})ni topish uchun umumiy to'la qarshilik ifodasini yozamiz:

$$Z = Z_1 + \frac{Z_2 \cdot Z_M}{Z_2 + Z_M} = R_1 + j\left(X_{L_1} - X_{c_1} - X_M\right) +$$

$$+ \frac{\left[(R_2 + R_H) + j\left(X_{L_2} - jx_{c_H} - jX_M\right)\right] \bullet X_M}{\left[(R_2 + R_H) + j\left(X_{L_2} - jx_{c_H} - jx_M\right)\right] + jx_M} =$$

$$= 5 + j(30 - 25 - 20,6) + \frac{\left[(10 + 20) + j\left(80 - X_{c_H} - 20,6\right)\right] j20,6}{\left[(10 + 20) + j\left(80 - X_{c_H} - 20,6\right)\right] + j20,6} =$$

$$= 5 - j15,6 + \frac{\left[30 + j\left(60 - X_{c_H}\right)\right] j20,6}{\left[30 + j\left(60 - X_{c_H}\right)\right] + j20,6}$$

$60 - X_{C_H} = X$ deb belgilash bilan maxrajdagi mavhum sondan qutilgan holda:

$$Z = = 5 - j15,6 + \frac{12670 + j\left(20,6x^2 + 423x + 18,5\right)}{x^2 + 41x + 1,32}$$

Tenglamaning chap tomonini umumiy maxrajga keltirish bilan kompleks ifodaning haqiqiy va mavhum son ko'rinishda ifodalanadi:

$$Z = \frac{5x^2 + 205,5x + 19,3}{x^2 + 41x + 1,32} + j\frac{5x^2 - 216x - 2055}{x^2 + 41x + 1,32} = R + jx$$

Kuchlanishlar rezonans shartiga asosan $x = 0$:

$5x^2 - 216x - 2055 = 0$ yoki: $x^2 - 43,2x - 411 = 0$

Tenglamani yechish:

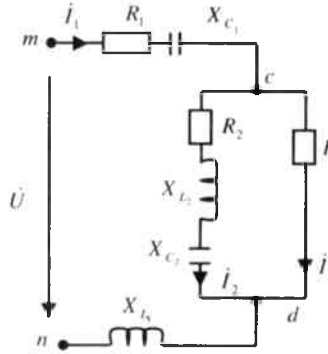
$$x = \frac{43,2}{2} \pm \sqrt{\left(\frac{43,2}{6}\right)^2 + 411} = 21,6 \pm 29,6;\ x_1 = 51,2;\ x_2 = -8$$

Bundan: $x_1 = 51.2\ Om$ qiymatni olsak, birlamchi konturda rezonans holat $x_{c1} = \frac{1}{\omega C_1} = 60 - x = 60 - 51{,}2 = 8{,}8 Om$ qarshilikka teng bo'lganda rezonans holat yuzaga keladi.

Masala 5.12. Rezonansli elektr zanjir parametri $R_1 = 5\ Om$, $X_{c1} = 7\ Om$, $X_{L1} = 10\ Om$, $R_2 = 3\ Om$, $X_{L2} = 20\ Om$, $R_3 = 12\ Om$, $I_1 = 0{,}2\ A$ bo'lganda, sig'im qarshilik qiymati X_{c2} va I_2 tarmoqdagi tok qiymatini aniqlang.

Yechish. Parallel ulangan qismdagi *cd* potensiallarga nisbatan kompleks to'la qarshilik.

$$Z_{cd} = \frac{\left[R_2 + j\left(X_{L2} - X_{c2}\right)\right] \cdot R_3}{R_2 + j\left(X_{l2} - X_{c2}\right) + R_3}$$



Surat va maxrajlarini kompleks (manfiy) qiymatga ko'paytirish bilan haqiqiy va mavhum qismlardan iborat tenglama hosil qilamiz:

$$\frac{\left[R_2R_3 + j\left(X_{L2} - X_{c2}\right) \cdot R_3\right]\left[\left(R_2 + R_3\right) - j\left(X_{L2} - X_{c3}\right)\right]}{\left(R_2 + R_3\right) + j\left(X_{L2} - X_{c2}\right) \cdot \left(R_2 + R_3\right) - j\left(X_{L2} - X_{L3}\right)} =$$

$$= \frac{R_2R_3\left(R_2 + R_3\right) + \left(X_{L2} - X_{c2}\right)^2 R_3}{\left(R_2 + R_3\right)^2 + \left(X_{L2} - X_{c2}\right)^2} + j\frac{\left(X_{L2} - X_{c3}\right) \bullet R_3\left(R_2 + R_3\right) - R_2R_3\left(X_{L2} - X_{c2}\right)}{\left(R_2 + R_3\right)^2 + \left(X_{L2} - X_{c2}\right)^2} =$$

$$= R_{cd} + jx_{cd} \quad \text{yoki} \quad Z_{cd} = R_{cd} + jx_{cd}.$$

Bundan: $X_{cd} = \frac{(X_{L2} - X_{c2})R_3^2}{(R_2 + R_3)^2 + \left(X_{L2} - X_{c2}\right)^2}$

Zanjir umumiy kompleks qarshilik ifodasini yozamiz:

$$Z = R_1 - jx_{c_1} + Z_{cd} + jx_{L_1} = R_1 - jx_{c_1} + \left(R_{cd} + jx_{cd}\right) + jx_{L_1} =$$

$$= \left(R_1 + R_{cd}\right) + j\left(X_{L_1} - X_{c_1} + X_{cd}\right) \cdot = R + jx$$

Ushbu zanjirda rezonans shartiga asosan $X = 0$ bo'lganda:

$$X_{L_1} - X_{C_1} + X_{cd} = 0$$

$$\text{yoki: } X_{L_1} - X_{C_1} \cdot \frac{(X_{L_2} - X_{C_2})R_3^2}{(R_2+R_3)^2 + (X_{L_2} - X_{L_3})} = 0$$

Bundan:

$$\left(X_{L_1} - X_{c_1}\right)\left(R_2 + R_3\right)^2 + \left(X_{L_1} - X_{c_1}\right)\left(X_{L_2} - X_{c_2}\right)^2 + \left(X_{L_2} - X_2\right)R_3^2 = 0$$

Sig'im qarshiligi (X_{C_2}) ni topish uchun:

$$\left(X_{L_2} - X_{c_2}\right)^2 + \frac{R_3^2}{X_{L_1} - X_{c_1}}\left(X_{L_2} - X_{c_2}\right) + \left(R_2 + R_3\right)^2 = 0$$

Qarshilik qiymatini qo'yish bilan:

$$\left(20 - X_{s2}\right)^2 + 48\left(20 - X_{s2}\right) + 225 = 0$$

Kvadrat tenglamani yechish bilan:

$$\left(20 - X_{s2}\right) = -\frac{48}{2} \pm \sqrt{\left(\frac{48}{2}\right)^2 - 225} = -24 \pm 18,7$$

Bundan: $\left(20 - X_{s2}\right) = -24 + 18,7 = -5,27 Om$

yoki: $X_C = 20 - 5,27 \approx 25,3 Om.$

$$\dot{I}_2 = \dot{I}_1 \frac{Z_3}{Z_2 + Z_3} = \dot{I}_1 \frac{R_3}{\left[R_2 + j\left(X_{L_2} - X_{c_3}\right)\right] + R_3} = 0,2 \cdot \frac{12}{3 + j(20 - 25,3) + 12} =$$

$$= (142,5 + j50) \cdot 10^{-3} A.$$

$\dot{I}_2$ tokning haqiqiy qiymati:

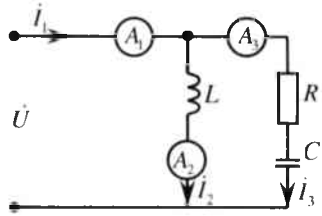
$$I_2 = \sqrt{(142,5010^3)^2 + \left(50 \cdot 10^{-3}\right)^2} = 151 \cdot 10^{-3} \approx 0,151 A.$$

5.3. Mustaqil yechish uchun masalalar

Masala 5.1. Ketma-ket ulangan elektr zanjirning parametri *R=100Om, L_1 =0,2 Gn, S = 1 mkF,* kuchlanishi *U = 100 mV* ga teng bo'lganda; rezonans chastota ω_0, tok I_0, kuchlanish U_{Cmax}, U_{Lmax}

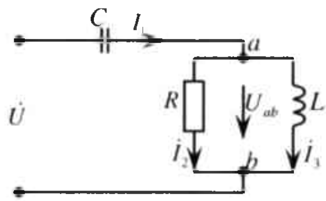
qiymatga erishgan holatdagi ω_C va ω_L chastota, U_{Cmax}, U_{Lmax} qiymatlari, kontur asilligi Q, rezonans chastota chegaralarini $d = (\omega_2 - \omega_1)$ aniqlang.

Javob: $\omega_0 = 2236 \frac{1}{sek}$, $I_0 = 1\,MA$, $\omega_L = 2264 \frac{1}{sek}$, $\omega_C = 2207 \frac{1}{sek}$, $U_{C_{max}} = 0{,}45\,V$, $U_{L_{max}} = 0{,}45\,V$, $Q = 4{,}47$, $\omega_2 - \omega_1 = 500$, $\omega_1 = 2000 \frac{1}{sek}$, $\Delta f = 79{,}6\,gs$.



Masala 5.2. Keltirilgan sxemada rezonans holatda tarmoqdagi toklar $I_1=4\ A$, $I_2=3\ A$ ga teng bo'lib, I_3 tok qiymati aniqlansin.

Javob: $I_3=5A$

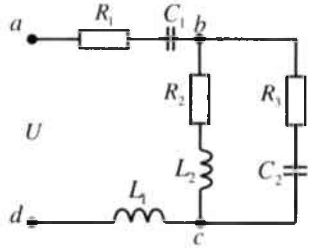


Masala 5.3. Rezonans holatdagi elektr zanjir parametri $R=20\ Om$, $X_L= 20\ Om$ va $U=300\ V$ bo'lganda, sig'im qarshiligi, umumiy ekvivalent qarshiligi va tok qiymati aniqlansin.

Javob:

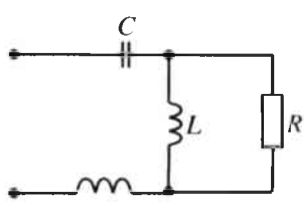
$$x_C = 10 Om,\ \underline{Z}_э = 10 Om,\ U_{ab} = 300\sqrt{2}e^{j45^\circ},$$

$$I_1 = 30e^{j0}A,\ I_2 = 15 + j15(A),\ I_3 = 15 + j15A$$



Masala 5.4. Elektr zanjir parametri $C_3=10\cdot10^{-6}\ F$, $L_2=18\cdot10^{-3}\ Gn$, $R_2=40\ Om$ $R_3=30\ Om$ bo'lganda, tok rezonansini yuzaga keltiruvchi rezonans chastotasini (ω_0) aniqlang.

Javob: $\omega_0=1560\ rad/sek$



Masala 5.5. Induktiv galtakga, aktiv qarshilik R parallel va sig'im qarshiligiga $X_C=20\ Om$ ketma-ket ulangan.

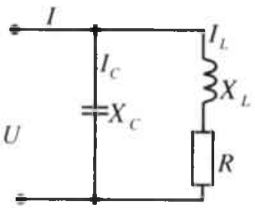
Chastota $f=50\ Gs$ qarshiliklari esa $R=40\ Om$ va $X_L=80\ Om$ bo'lganda rezonans hosil qiluvchi induktivlik L qiymatini aniqlang va qanday hollarda umumiy qarshilik z_{min} minimal bo'ladi.

Javob: 1) $R=40$ Om bo'lganda, rezonans induktivlik $L=0,0128Gn$, umumiy qarshiligi $Z=Zmin$, $L=0,052$ Gn.

2) $R=80$ Om bo'lganda rezonans induktivlik

$L=0,069Gn$ *va* $L=0,95$ Gn, $Z=Zmin$; $L=0,061$ Gn.

Masala 5.6. Elektr tok zanjir rezonans holatda bo'lib, umumiy tok $I=10$ A, qarshilik $R=6$ Om, $x_L=8$ Om. Sig'imdan o'tuvchi tok I_C, reaktiv qarshilik va kuchlanishni aniqlang.

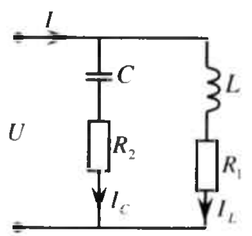


Javob: $I_C=13,3$ A, $x_C=12,5$ Om, $U=166,7$ V.

Masala 5.7. 5.6 masalada berilgan sxemaning induktiv qarshiligi $X_L=R$ va tok $I=10$ A. Rezonans holatdagi I_C, I_L, X_C, U tok qiymatini aniqlang.

Javob: $I_C=10$ A, $I_L=10\sqrt{2}A$, $X_C=2X_L$, $U=20$ V

Masala 5.8. Parametri $L=6,4$ Gn, $R=1Om$ bo'lgan parallel zanjir chastotasi $f=50$ Gs, $U=100$ V, $I=75$ A tokka ulangan. Rezonans holatdagi R_2,C tok qiymatni aniqlang.

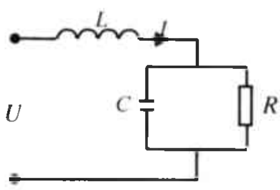


Javob: $R_2=1,16$ Om, $C=3540$ mkF

Masala 5.9. Ketma-ket ulangan elektr zanjirnmg parametri $R=40$ Om, $L=0,2$ Gn, $C=10$ mkF ga teng bo'lgan holat uchun rezonans, chastota f_0 induktivlikdagi $U_{L\ max}$ kuchlanishi va manba kuchlanishiga nisbatan necha marta katta bo'lishini aniqlang.

Javob: $f_0=112$ Gs, $X_L=140$ Om $U_{L\ max}=3,5$ V

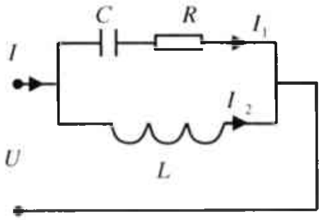
Masala 5.10. Elektr zanjir rezonans holatda bo'lib chastotasi $\omega_0=0$ bo'lganda $Z_{um(0)}=50$ Om va rezonans chastota $\omega=\omega_0$ da $Z_{um(0)}=2.5$ Om.



Qarshilik parametri: R_l, X_L va X_C aniqlang hamda vektor ifodasini tuzing.

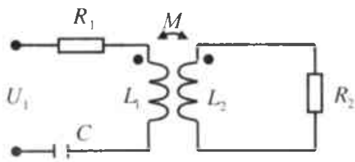
Javob: R_l=5 *Om*, X_L=2,5 *Om*, X_C=5 *Om*

Masala 5.11. Elektr zanjirda rezonans holatdagi tok $I_l = 7A$, $I=3,6\ A$ ga teng. Induktivlikdagi I_2 tokni aniqlab, vektor ifodasini tuzing.



Javob: $I_2 = 6$ A

Masala 5.12. Induktiv bog'langan elektr zanjiri parametri: $R_1 = 2\ Om$, $X_{L_1} = 10\ Om$, $X_C = 8\ Om$, $X_{L_2} = 9\ Om$, $X_M = 6\ Om$ bo'lib, $U=100\ V$ kuchlanish ulangan. R_2 ning qaysi qiymatida zanjirda rezonans holat yuzaga keladi.

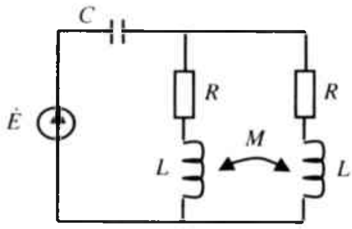


Javob: R_2=*9 Om*.

Masala 5.14. Ikkita o'zaro induktiv bog'langan zanjir parametri: $L_1 = 100mkgn$, $L_2 = 250mkgn$, $R_2 = 80\ Om$, $M = 50mkgn$, $f = 800kgs$ va $C_2 = 1000pf$. Birlamchi kontur sig'im C_1 qiymati aniqlansin.

Javob: $C_1 = 440 \cdot 10^{-12} f = 440pf$.

Masala 5.15. Parametrlari R,L,C bo'lgan o'zaro induktiv bog'langan zanjir chastotasi f bo'lgan sinusoidal kuchlanishga ulangan. *M* koeffitsient qanday qiymatida rezonans holat yuzaga keladi?



Javob: $M = L - \frac{2}{\omega^2 c}$

5.4. Nazorat savollari

1. Elektr zanjirda rezonans holat qanday yuzaga keladi?
2. Rezonans hosil qilish uchun elektr zanjir qaysi elementlardan tuzilgan bo'lishi zarur va sharti nimada?
3. Rezonans hodisasidan amalda qaysi sohalarda foydalaniladi?
4. Rezonans chastota tenglamasini yozib, rezonans holatga qanday erishilishini tushuntiring.
5. Tebranuvchan kontur induktivligi L=25 MGn, sig'imi C=4 mkF bo'lganda, rezonans chastota f_0 qancha bo'ladi?
6. Kuchlanishiar rezonansi qanday hosil bo'ladi? Vektor ifodasini chizing. Tok va quvvat tenglamalarini yozing.
7. Tok rezonansi qanday hosil bo'ladi? Tok va quvvat tenglamalarini yozing.
8. Nima sababdan kuchlanishiar rezonans paytida sig'im va induktivlikdagi kuchlanishlar umumiy kuchlanishga nisbatan katta bo'ladi?
9. Chastotaga nisbatan reaktiv qarshilik yoki o'tkazuvchanlik qanday o'zgaradi? Chastota xarakteristikasini chizing.
10. Rezonans holatda quvvat koeffitsienti nimaga teng?
11. Kontur saxiyligi yoki kontur so'nishi nima va qanday ifodalanadi?
12. To'lqin qarshiligi yoki o'tkazuvchanligi nima, qanday ifodalanadi?.
13. Rezonans holatda elektr zanjirning tarmoqlanmagan qismidagi tok qanday qiymatga erishadi?

14. Rezonans kontur reaktiv qarshiliklari $X_L > X_C$, $X_L = X_C$ $X_L < X_C$ holatlar uchun vektor ifodasini tuzing va qanday xarakterga ega ekanligini tushuntiring.
15. Rezonans holatda elektromagnit maydon energiyasi tebranishi fizik ma'nosini tushuntiring.
16. Tok rezonans hodisasi bilan kuchlanish rezonansida qanday o'xshashliklar bor?
17. Rezonans holatda aktiv, reaktiv va to'la quvvatlar qanday bog'langan?
18. Qanday konturda va qaysi shartlar bajarilganda rezonans hodisasi yuzaga keladi?
19. Kuchlanishlar rezonansi vaqtida nima uchun tok maksimal qiymatga erishadi?
20. Tok rezonansi holatida nima uchun kuchlanish maksimal qiymatga erishadi?
21. Rezonans holatida sarf bo'lgan elektr energiyasi nimaning hisobiga to'ldiriladi?
22. Murakkab elektr zanjirida rezonans hosil bo'lish shartini tushintiring.
23. Rezonans holatda to'la qarshilik yoki o'tkazuvchanlik nimaga teng?
24. Rezonansli kontur parametri $R = 10\,Om,\ \ L = 400\,mkgn$ va $C = 400\,pf$ bo'lsa, to'lqin uzunligi λ va Q nimaga teng? (Javob: λ=750m, $Q = 100$)
25. Parallel sxemada ulangan zanjir rezonans holatda umumiy tarmoqdagi tok $I = 1{,}1A$, sig'imdagi tok $I_C = 6A$ ga teng. Agar kontur aktiv qarshiligi $R = 1\,Om$ bo'lsa, aktiv quvvat qancha bo'ladi? (Javob: P=37, 21 VT).

VI. UCH FAZALI SINUSOIDAL O'ZGARUVCHAN ELEKTR ZANJIR

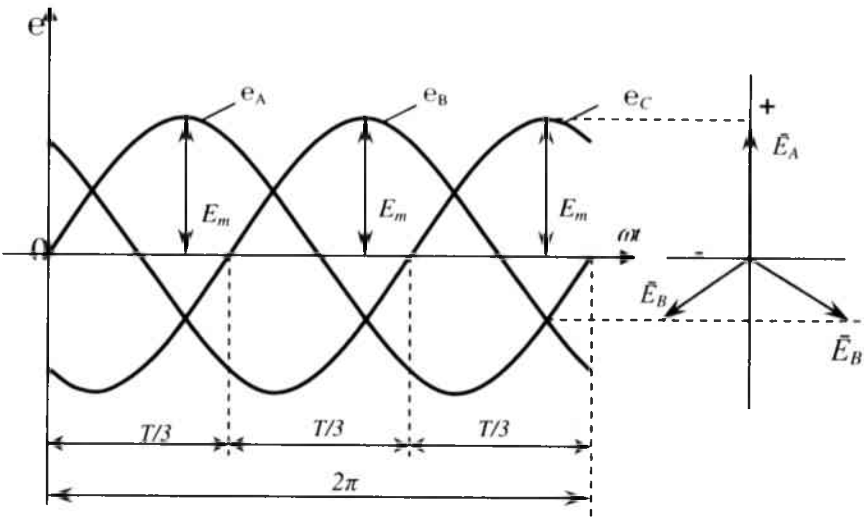
6.1. Asosiy nazariy tushunchalar

Fazalari bilan 120° farq qiluvchi, chastota va amplitudalari bir xil bo'lgan uchta bir fazali sinusoidal o'zgaruvchan elektr zanjirga **uch fazali tok sistemalari** yoki **zanjirlari** deyiladi.

Uch fazali tok manbai uch fazali **sinxron generatori** bo'lib, rotor aylanma harakatlanish natijasida stator qismida 120° farqi bilan joylashtirilgan chulg'amlarda induksiyalanadigan EYK analitik ifodasi quyidagicha ifodalanadi.

$$e_A = E_m \sin\omega t$$
$$e_B = E_m \sin(\omega t - 120^0) \qquad (6.1)$$
$$e_C = E_m \sin(\omega t + 120^0)$$

Uch fazali sinusoidal o'zgaruvchan tok vaqt bo'yicha o'zgaruvchan grafigi va vektor ifodasi quyidagicha ifodalanadi:



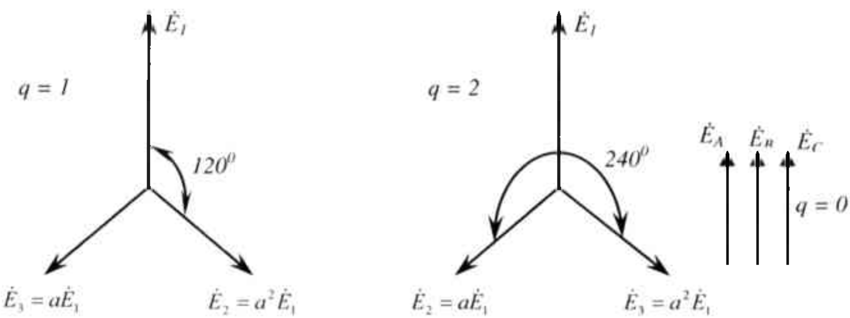
EYK (kuchlanish, tok) kompleks shakldagi ifodasi.

$$\dot{E}_A = E, \qquad \dot{E}_B = Ee^{-j\frac{2\pi}{3}} \qquad \dot{E}_C = Ee^{+j\frac{2\pi}{3}} \qquad (6.2)$$

Vektorlarni kompleks shaklda qisqa yozish uchun fazoviy ko'paytiruvchi (buruvchi) belgilash kiritiladi yoki

$\alpha = \ell^{j\frac{2\pi}{3}} = (\cos 120° + j\sin 120°) = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$ faza burchagi 120° ga teng.

U holda q=1, $\dot{E}_1 = E$; $\dot{E}_2 = \alpha^2 E$; $\dot{E}_3 = \alpha E$ to'g'ri ketma-ketlik. q=2, $\dot{E}_1 = E$; $\dot{E}_2 = \alpha E$; $\dot{E}_3 = \alpha^2 E$ teskari ketma-ketlik bo'ladi. q=0, $\dot{E}_1 = \dot{E}_2 = \dot{E}_3$ – nol ketma-ketlik bo'ladi



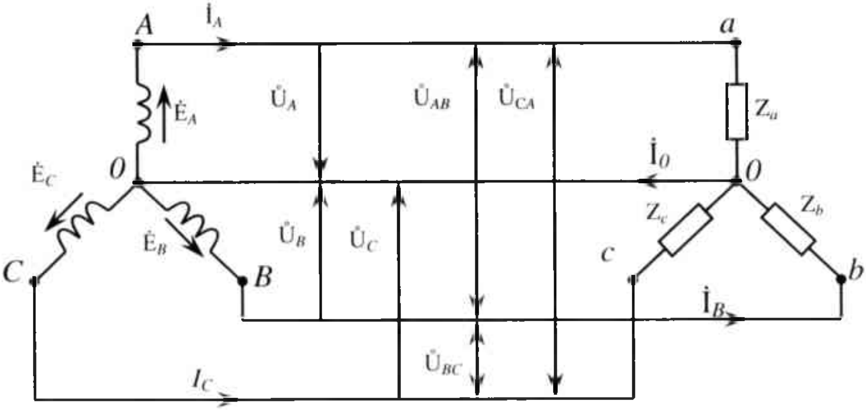
yoki $\alpha^2 = e^{-j\frac{2\pi}{3}}$; $\qquad \alpha^3 = e^{j2\pi} = 1$; $\qquad \alpha^4 = \alpha = e^{j\frac{2\pi}{3}}$

Shu ma'noda $\alpha+\alpha^2+\alpha^3=0$ yoki $1+\alpha+\alpha^2=0$.

Demak, vektorni «α»ga ko'paytirish, $\varphi = \frac{2\pi}{3}$ burchakga burish bilan barobar.

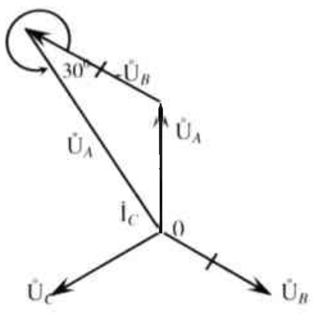
Uch fazali elektr zanjirda generator (manba) bilan iste'molchilar o'zaro yulduzcha, uchburchak shaklida ulanishi mumkin.

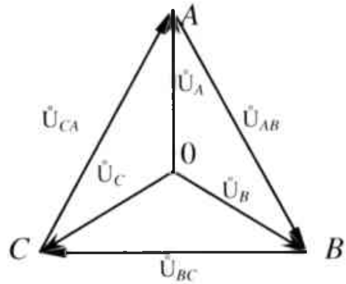
1. Uch fazali elektr zanjirning yulduzcha shaklida ulanishi.



Simmetrik yulduzcha shaklida ulangan elektr zanjirdagi $\bar{U}_{Л}$ liniyadagi kuchlanishi fazadagi kuchlanishga nisbatan: $\bar{U}_{Л}=\bar{U}_{AB}=\bar{U}_{A}-\bar{U}_{B}$.

yoki: $$U_{Л} = \sqrt{3}\cdot\dot{U}_{\varphi} \qquad \dot{I}_{A} = I_{\varphi} \qquad (6,3)$$



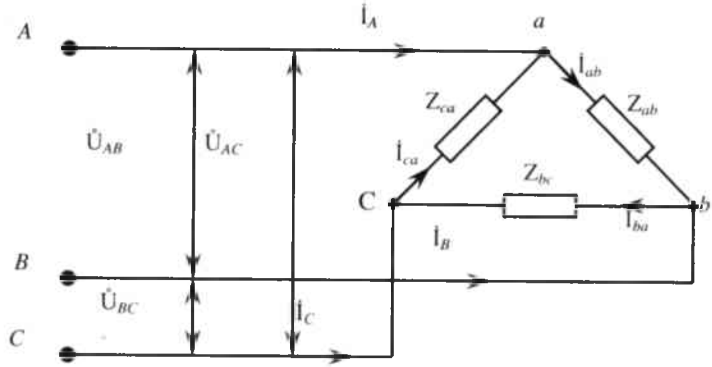


2. Uchburchak shaklda ulanish.

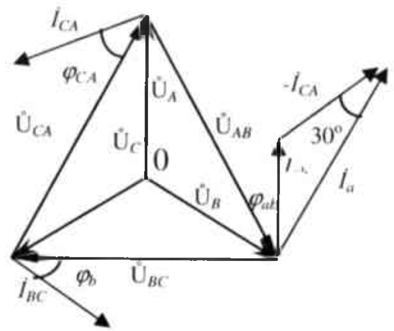
Liniyadagi tok fazadagi tok orqali ifodalanganda.

$$\dot{I}_{A}=\dot{I}_{ab}-\dot{I}_{ca}\ ,\ \dot{I}_{b}=\dot{I}_{bc}-\dot{I}_{ab}\ ,\ \dot{I}_{c}=\dot{I}_{ca}-\dot{I}_{bc} \qquad (6.4)$$

Bunda: $\dot{I}_{A}=\sqrt{3}\cdot\dot{I}_{F}$; $\dot{U}_{L}=\dot{U}_{AB}=\dot{U}_{F}$



a)



b)

Agar neytral simli uch fazali elektr zanjirning faza kuchlanish va iste'molchi qarshiliklari berilgan bo'lsa:

$$\dot{U}_a = \dot{U}_A - \dot{U}_O; \quad \dot{U}_в = \dot{U}_B - \dot{U}_O; \quad \dot{U}_c = \dot{U}_C - \dot{U}_O.$$

Tugun potensiallar usuliga asosan manba bilan iste'molchi orasidagi 00^1 nuqtalar potensiali:

$$\varphi_0 - \varphi_{0'} = \dot{U}_{00'} = \frac{\dot{U}_A \underline{y}_a + \dot{U}_B \underline{y}_в + \dot{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_в + \underline{y}_c + \underline{y}_0} \tag{6.5}$$

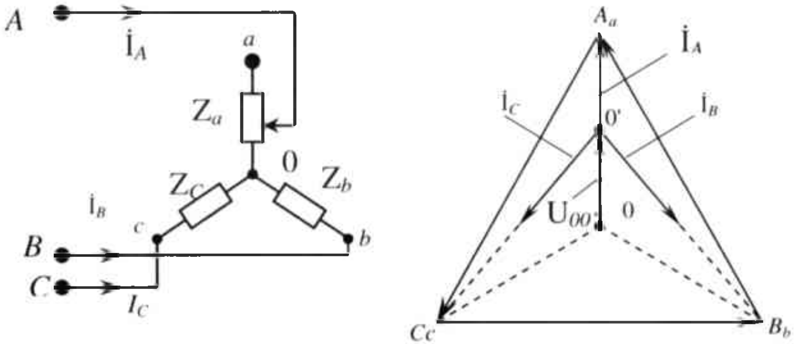
Neytral simsiz uch fazali elektr zanjirning liniya kuchlanishi ma'lum bo'lsa, faza kuchlanishi uchun tenglama:

$$\dot{U}_A = \frac{\dot{U}_{AB} \underline{y}_в - \dot{U}_{BC} \underline{y}_c}{\underline{y}_a + \underline{y}_в + \underline{y}_c} \qquad \dot{U}_B = \frac{\dot{U}_{BC} \underline{y}_c - \dot{U}_{AB} \underline{y}_a}{\underline{y}_a + \underline{y}_в + \underline{y}_c}$$

$$\dot{U}_C = \frac{\dot{U}_{CA}\underline{y}_a - \dot{U}_{BC}\underline{y}_в}{\underline{y}_a + \underline{y}_в + \underline{y}_c} \quad (6.6)$$

1. Simmetrik yulduzcha yoki uchburchak shaklda ulangan uch fazali elektr zanjirlarni hisoblashda bir fazali elektr zanjirlar qoida va usullaridan foydalaniladi.

2. Nosimmetrik uch fazali elektr zanjir.



a) iste'molchi qarshiliklari nosimmetrik: $\underline{Z}_a = var$, $\underline{Z}_b = \underline{Z}_c = const.$

Bunday holatda I_A tok generator bilan iste'molchi potensiallari orasida

$U_{00'}$ kuchlanish (0) nuqta bo'yicha siljiydi, hamda:

$$\Sigma I = I_a + I_b + I_c = 0 \qquad \underline{Z}_a > R$$

b) $\mathring{U}_A$ – fazada qisqa tutashuv:

$(\underline{Z}_a = 0,\ \underline{Y}_a = \infty,\ \underline{Z}_b = \underline{Z}_c = R = const,\ \underline{y}_b = \underline{y}_c = \frac{1}{R} = y = const)$

Qisqa tutashuv holatda $\mathring{U}_{00'}$ – kuchlanish:

$$\dot{U}_{00'} = \frac{\dot{U}_A\underline{y}_a + \dot{U}_B\underline{y}_b + \dot{U}_C\underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{\dot{U}_A}{2}$$

$\mathring{U}'_A$ – faza kuchlanishi: $\mathring{U}'_A = \mathring{U}_A - \mathring{U}_0 = \mathring{U}_A - \mathring{U}_A = 0$

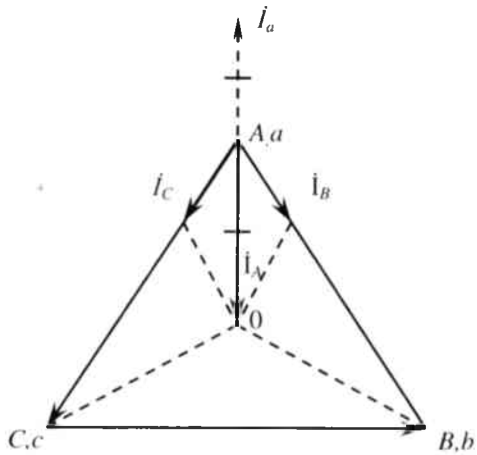
$\mathring{U}'_B$ va $\mathring{U}'_C$ – fazadagi kuchlanish tenglamasi:

$$\mathring{U}'_B = \mathring{U}_B - \mathring{U}_0 = \mathring{U}_B - \mathring{U}_A = \mathring{U}_{BA} = -\mathring{U}_{AB} = -\mathring{U}_{ab}$$
$$\mathring{U}'_C = \mathring{U}_C - \mathring{U}_0 = \mathring{U}_C - \mathring{U}_A = \mathring{U}_{CA} = \mathring{U}_{CA} = \mathring{U}_{ca}$$

Fazadagi tok: $I_b = I_C = \frac{U_Л}{\underline{Z}_\phi} = \sqrt{3}I_\phi$

A – fazadagi tok: $\dot{I}_a = -(\dot{I}_b + \dot{I}_c) = \sqrt{3}\dot{I}_b = 3I_\phi$

Demak, A faza qisqa tutashtirilganda fazadagi tok 3 martaga ortadi va fazadagi kuchlanish $\mathring{U}_A = 0$ bo'lib, bu fazaga ulangan lampochka o'chadi.



d) $\mathring{U}_A$ – faza simining uzilishi:

$\underline{Z}_a = \infty$; $\underline{Z}_b = \underline{Z}_c = R = const$; $\underline{y}_a = 0$; $\underline{y}_a = \underline{y}_c = \dfrac{1}{R}$

Tugunlar orasidagi kuchlanish:

$$\dot{U}_{00'} = \frac{\dot{U}_A \underline{y}_a + \dot{U}_B \underline{y}_b + \dot{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{(\dot{U}_B + \dot{U}_C)\underline{y}_b}{2\underline{y}_b} = -\frac{\dot{U}_A}{2} = -\frac{U_\Phi}{2}$$

Demak, iste'molchi kuchlamishi 00' nuqta bo'ylab pastga yo'naladi va $\overline{cb}$ vektor o'rtasini kesadi. Bunda $\dot{U}_A = 0$; $\dot{I}_A = 0$ bo'lib:

$$\dot{U}_{aA} = \dot{U}_{A0'} = \dot{U}_A - \dot{U}_0 = \dot{U}_A - \left(-\frac{\dot{U}_A}{2}\right) = \frac{2}{3}\dot{U}_A$$

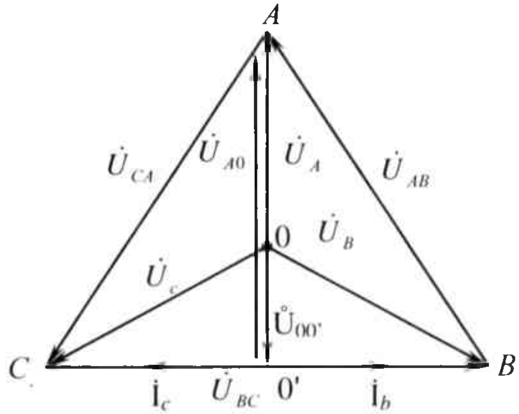
A va B fazadagi kuchlanish: $\dot{U}_B = \dot{U}_C = \dfrac{\dot{U}_Л}{2}$

yoki $\dot{U}_\phi = \dfrac{\dot{U}_Л}{\sqrt{3}}$; $\dfrac{\dot{U}_Л}{\dot{U}_B} = \dfrac{\dot{U}_A}{\sqrt{3}} \div \dfrac{\dot{U}_Л}{2} = \dfrac{2}{\sqrt{3}} \cdot \dot{U}_\phi$;

B va C fazadan o'tuvchi tokga teng bo'lib:

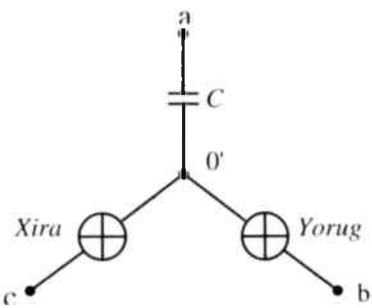
$$\dot{I}_B = \dot{I}_C - \frac{\frac{\dot{U}_L}{2}}{\underline{Z}_b} = \frac{\sqrt{3}\dot{U}_\phi}{2\underline{Z}_\phi} = \frac{\sqrt{3}}{2}\dot{I}_\phi$$

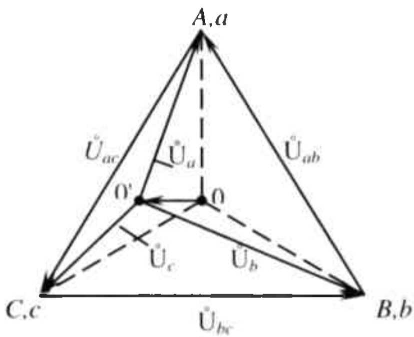
Demak, fazaga ulangan iste'molchi (lampa) A fazada o'chadi, B va C fazada xira yonadi.



e) uch fazali elektr fazalar ketma-ketligini aniqlash.

Bunda uch fazali elektr zanjirning A fazasiga sig'im C yoki induktivlik L ulanib, qolgan ikkita fazasiga bir xil qarshilikdagi lampochkalar ulanadi.





1) sxemada A fazaga sig'im qarshilik ulangan: $\underline{Z}_a = -\underline{jx}_c$;

$\underline{Z}_b = \underline{Z}_c = R$

yoki $\underline{y}_a = \frac{1}{-j\underline{X}} = b$; $\quad \underline{y}_b = \underline{y}_c = \frac{1}{R} = g$

Demak:

$$\dot{U}_{00} = \frac{\dot{U}_A\underline{y}_a + \dot{U}_B\underline{y}_b + \dot{U}_C\underline{y}_c}{\underline{y}_a + \underline{y}_a + \underline{y}_a} = \frac{U_A jb + \left(-0{,}5 - \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A g + \left(-0{,}5 + \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A g}{jb + g + g} =$$

$$= 0{,}63\dot{U}_A e^{j105°26'} = (-0{,}2 + j0{,}6)\dot{U}_A$$

Iste'molchilardagi faza kuchlanishi:

$$\dot{U}_a = \dot{U}_A - \dot{U}_0 = \dot{U}_A - (-0{,}2 + \underline{j}0{,}6)\dot{U}_A = 1{,}34\dot{U}_A \underline{e}^{-j26°34'}$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_0 = \left(-0{,}5 - \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A - (-0{,}2 + \underline{j}0{,}6)\dot{U}_A = 1{,}5\dot{U}_A \underline{e}^{-j101°33'}$$

$$\dot{U}_C = \dot{U}_C - \dot{U}_0 = \left(-0{,}5 - \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A - (-0{,}2 + \underline{j}0{,}6)\dot{U}_A = 0{,}4\dot{U}_A \underline{e}^{-j138°20'}$$

2) A fazaga induktiv qarshilik ulaymiz:

$\underline{z}_a = \underline{jx_L} = \underline{jR}$; $\quad \underline{z}_b = \underline{z}_c = R$

yoki $\underline{y}_a = \frac{1}{\underline{j}R} = -\underline{jg}$; $\quad \underline{y}_b = \underline{y}_c = \frac{1}{R} = g$

Tugun kuchlanishlar tenglamasiga asosan:

$$\dot{U}_{00} = \frac{\dot{U}_A\underline{y}_a + \dot{U}_B\underline{y}_b + \dot{U}_C\underline{y}_c}{\underline{y}_a + \underline{y}_a + \underline{y}_a} = \frac{U_A(-jb) + \left(0{,}5 - \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A g + \left(0{,}5 + \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A g}{\underline{jg} + g + g} =$$

$$= 0{,}63\dot{U}_A e^{j108°26'} = (-0{,}2 - j0{,}6)\dot{U}_A$$

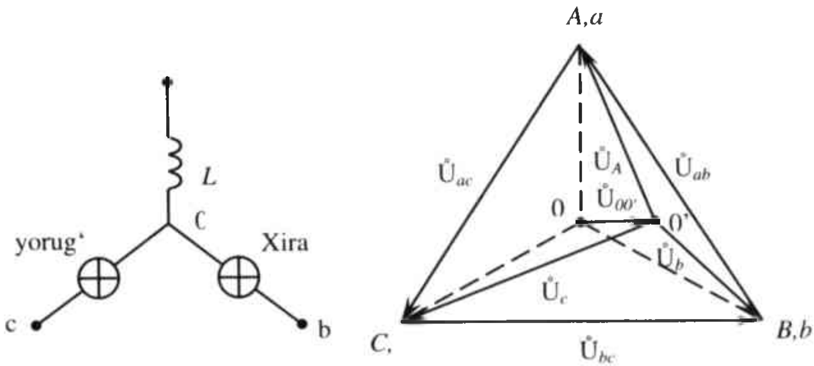
Faza kuchlanishlari:

$$\dot{U}_a = \dot{U}_A - \dot{U}_0 = \dot{U}_A - (-0{,}2 - \underline{j}0{,}6)\dot{U}_A = (1{,}2 - \underline{j}0{,}6)\dot{U}_A = 1{,}34\dot{U}_A e^{j26°34'};$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_0 = \left(-0{,}5 - \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A - (0{,}2 - \underline{j}0{,}6)\dot{U}_A = 0{,}4\dot{U}_A e^{j138°20'};$$

$$\dot{U}_C = \dot{U}_C - \dot{U}_0 = \left(-0{,}5 + \underline{j}\frac{\sqrt{3}}{2}\right)\dot{U}_A - (-0{,}2 - \underline{j}0{,}6)\dot{U}_A = (0{,}3 + \underline{j}1{,}47\dot{U}_A) = 1{,}5\dot{U}_A e^{j101°53'};$$

2.

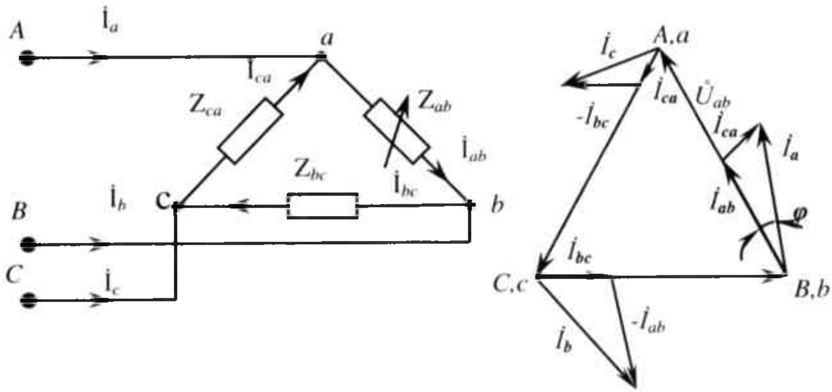


3. Uchburchak shaklida ulangan uch fazali elektr zanjir.

a) Simmetrik holat:

Simmetrik uchburchak shakilda ulangan elektr zanjirni hisoblashda bir fazali elektr zanjirni hisoblash usulidan foydalaniladi.

b) Nosimmetrik holat: ($\underline{Z}_{ab} = \frac{R}{2}$; $\underline{Z}_{bc} = \underline{Z}_{ca} = R = const$)



Fazadagi tokni aniqlaymiz:

$$\dot{I}_{ab} = \frac{\dot{U}_{ab}}{\underline{Z}_{ab}} = 2\frac{\dot{U}_{ab}}{R};$$

$$\dot{I}_{bc} = \frac{\dot{U}_{bc}}{\underline{Z}_{bc}} = 2\frac{\dot{U}_{ab}}{R}e^{-j120^\circ} = \left(-0,5 - j\frac{\sqrt{3}}{2}\right)\frac{\dot{U}_{ab}}{R}$$

$$\dot{I}_{ca}=\frac{\dot{U}_{ca}}{\underline{Z}_{ca}}=\frac{\dot{U}_{ca}}{\underline{Z}_{ca}}e^{-j120^\circ}=\left(-0{,}5+j\frac{\sqrt{3}}{2}\right)\frac{\dot{U}_{ab}}{R};$$

Liniyadagi tok:

$$\dot{I}_a=\dot{I}_{ab}-\dot{I}_{ca}=\left(2{,}5-j\frac{\sqrt{3}}{2}\right)\frac{\dot{U}_{ab}}{2}=2{,}65\frac{\dot{U}_{ab}}{R}e^{-j19^\circ}$$

$$\dot{I}_b=\dot{I}_{bc}-\dot{I}_{ab}=\left(-2{,}5-j\frac{\sqrt{3}}{2}\right)\frac{\dot{U}_{ab}}{R}=2{,}65\frac{\dot{U}_{ab}}{R}e^{-j161^\circ};$$

$$\dot{I}_c=\dot{I}_{ca}-\dot{I}_{bc}=j\sqrt{3}\frac{\dot{U}_{ab}}{2}=1{,}73\frac{\dot{U}_{ab}}{R}e^{-j90^\circ};$$

d) birinchi A fazada qisqa tutashuv:

$\underline{Z}_{ab}=0$; $\underline{Z}_{bc}=\underline{Z}_{ca}=R=const$;

Qisqa tutashuvda $\dot{I}_{ab}=\infty$ bo‘lib $\dot{I}_{ab}$ faza simi (saqlagich) uzilishi mumkin yoki $Z_{ab}=\infty$; $\underline{Z}_{bc}=\underline{Z}_{ca}=R=const$;

Bunda fazadagi tok: $\dot{I}_{ab}=\dfrac{\dot{U}_{ab}}{\underline{Z}_{ab}}=0$;

$$\dot{I}_{bc}=\frac{\dot{U}_{bc}}{\underline{Z}_{bc}}=\frac{\dot{U}_{ab}}{R}e^{-j120^\circ}=\left(-0{,}5-j\frac{\sqrt{3}}{2}\right)\frac{\dot{U}_{ab}}{R};$$

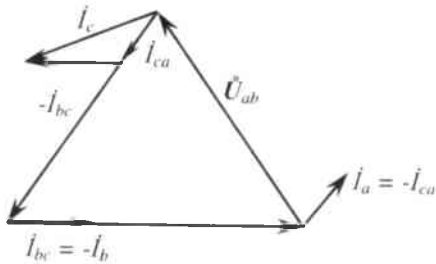
$$\dot{I}_{ca}=\frac{\dot{U}_{ca}}{\underline{Z}_{ca}}=\frac{\dot{U}_{ab}}{R}e^{j120^\circ}=\left(-0{,}5+j\frac{\sqrt{3}}{2}\right)\frac{\dot{U}_{ab}}{2};$$

Liniyadagi tok:

$\dot{I}_a=\dot{I}_{ab}-\dot{I}_{ca}=-\dot{I}_{ca}$;

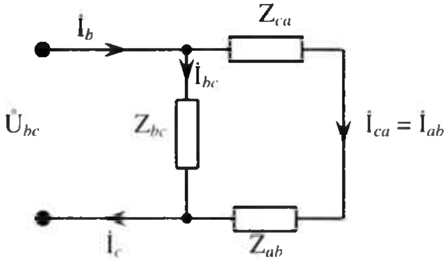
$\dot{I}_b=\dot{I}_{bc}-\dot{I}_{ab}=-\dot{I}_{bc}$;

$\dot{I}_c=\dot{I}_{ca}-\dot{I}_{bc}$;

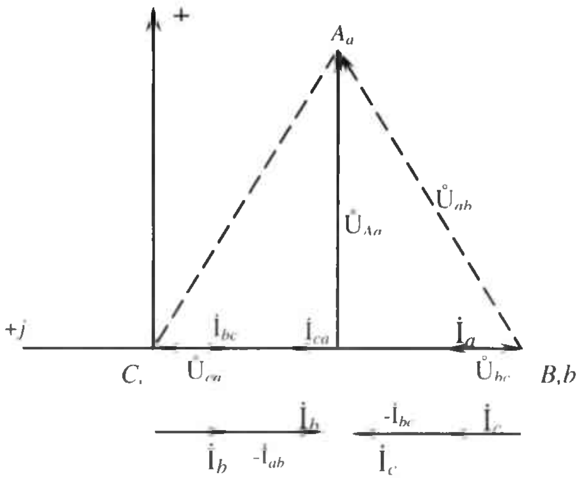


Tekshiruv: $\dot{I}_a+\dot{I}_b+\dot{I}_c=-\dot{I}_{ca}+\dot{I}_{bc}+\dot{I}_{ca}-\dot{I}_{bc}=0$;

e) birinchi A liniya simidagi uzilish:



$\underline{Z}_{ab} = \underline{Z}_{bc} = \underline{Z}_{ca} = R = const$



Ekvivalent sxemadan BC – faza kuchlanishi, liniya kuchlanishlga $\dot{U}_{bc} = \dot{U}_{Л}$ va $\underline{Z}_{ab}$, $\underline{Z}_{bc}$, qarshiliklar ketma-ket ulangan holda bo‘lib $\dot{U}_{ab} = \frac{\dot{U}_L}{2}$; $\dot{U}_{ca} = \frac{\dot{U}_L}{2}$ ga teng bo‘ladi

Bunda tok 2 marta kamayadi: $\dot{I}_{ca} = \dot{I}_{ab} = -0{,}5\dot{I}_{bc}$;

O‘z navbatida liniyadagi tok $\dot{I}_b$ va $\dot{I}_c$ kamayadi:

$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = 1{,}5\dot{I}_{bc};$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc} = -1{,}5\dot{I}_{bc};$$

Uzilgan liniya simlari orasidagi kuchlanish potensiali:

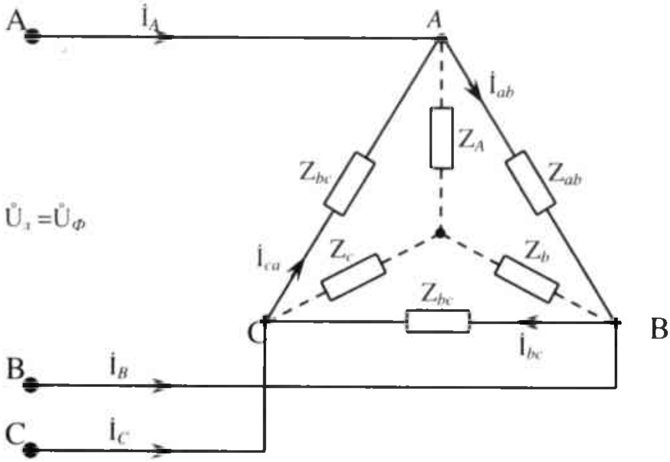
$$\dot{U}_{Aa} = \dot{U}_{AB}\cos 30^{\circ} = \frac{\sqrt{3}}{2}\dot{U}_L;$$

6.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 6.1. Uch fazali elektr zanjirga iste'molchi qarshiligi $\underline{z}_{ab} = \underline{z}_{bc} = \underline{z}_{ca} = \underline{z} = (12 + \underline{j}10)$ uchburchak shaklda biriktirilgan holatda faza va liniyadagi tokni aniqlang.

Yechish.

Uchburchak shaklda ulangan uch fazali elektr zanjirda:



$$\dot{U}_L = \dot{U}_{AB} = \dot{U}_\Phi \; 6600 \; B;$$

Fazadagi tok:

$$\dot{I}_{ab} = \frac{\dot{U}_{ab}}{\underline{z}_{ab}} = \frac{6600}{12 + \underline{j}10} = (198 - \underline{j}264) \text{ A};$$

yoki $I_{ab} = I_\Phi = \sqrt{(198)^2 + (264)^2} = 330$ A;

Liniyadagi tok $\dot{I}_L = \dot{I}_A = \sqrt{3}\dot{I}_{ab} = \sqrt{3} \cdot 330 = 571$ A;

Sistema simmetrik bo'lganligi uchun uch fazali elektr elektr zanjirning har uchala faza va liniyasidan bir xilda tok o'tadi.

Masala 6.2. Iste'molchilari yulduzcha shaklida biriktirilgan simmetrik uch fazali elektr zanjirning liniya qarshiligi $\underline{Z}_l = (1 + \underline{j}1,73)Om$ va faza qarshiligi $\underline{Z}_\Phi = (4 + \underline{j}5,34)$ Om bo'lib, liniya kuchlanishi

$\mathring{U}_l=6600\ V$ ga ulangan. Liniya va fazadagi tok hamda kuchlanishni aniqlang.

Yechish.

Liniya va iste'molchilarning umumiy qarshiligini aniqlaymiz

$Z_A = Z_{\Phi} + \underline{Z}_Л = (5 + \underline{j}7{,}07)\ Om;$

Fazadagi kuchlanish: $\dot{U}_a = \frac{\dot{U}_Л}{\sqrt{3}} = \frac{6600}{\sqrt{3}} = 3810$ V

Fazadagi tok: $\dot{I}_a = \frac{\dot{U}_a}{\underline{Z}_a} = \frac{3810}{5+\underline{j}7{,}07} = (254 - \underline{j}359)$ A;

yoki $I_a = \sqrt{(254)^2 + (359)^2} = 439$ A;

Liniya qarshiligidagi kuchianish:

$$\Delta\dot{U}_a = \dot{I}_a\underline{Z}_л = (254 - \underline{j}359)(1 + \underline{j}1{,}73) = (872 + \underline{j}80)V;$$

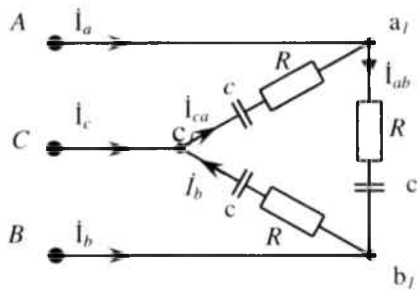
Fazadagi kuchlanish:

$$\dot{U}_A = \dot{I}_a Z_{\phi} = (254 - \underline{j}359)(4 + \underline{j}5{,}34) = (2935 + \underline{j}80)V;$$

Liniyadagi kuchlanish:

$$\dot{U}_{AB} = \dot{U}_L = \dot{U}_A - \dot{U}_B = (2935 - \underline{j}80)(1 - \underline{a}^2) =$$
$$= (2935 - \underline{j}80)(1{,}5 + \underline{j}0{,}867) = (4470 + \underline{j}2430)V;$$

Masala 6.3. Iste'molchilari uchburchak shaklida ulangan simmetrik uch fazali elektr zanjirning parametlari $R=25\ Om$, $C=100\ mkF$ bo'lib, o'zgaruvchan tok kuchlanishi $e_A = 141\sin(400t + 30°)$ ulangan. Liniya va fazadagi tokni aniqlang.



Yechish.

A fazadagi kuchlanish kompleks ifodasi: $\dot{E}_A = 100e^{j30°}$

Sig'im qarshiligi: $\underline{x}_c = \dfrac{1}{\omega C} = 25 \ \ Om$

Uchburchak shaklda ulangan uch fazali tok zanjirda: $\dot{E}_A = \dot{U}_{AB}$ bo'lib, birinchi fazadagi tok: $\dot{I}_{ab} = \dfrac{\dot{U}_{ab}}{\underline{z}} = \dfrac{100e^{j30^\circ}}{25 - j25} = 2\sqrt{2}e^{j75^\circ} \ A;$

Ikkinchi fazadagi tok – 120^0 farq qilib :

$$\dot{I}_{bc} = a^2\dot{I}_{ab} = \left(-0{,}5 - \underline{j}\frac{\sqrt{3}}{2}\right)\cdot 2\sqrt{2}e^{j75^\circ} = 2\sqrt{2}e^{j45^\circ} \ A;$$

Uchinchi fazadagi tok $+120^0$ farq qilib :

$$\dot{I}_{ca} = a\dot{I}_{ab} = \left(-0{,}5 + \underline{j}\frac{\sqrt{3}}{2}\right)\cdot 2\sqrt{2}e^{j75^\circ} = 2\sqrt{2}e^{j195^\circ} \ A$$

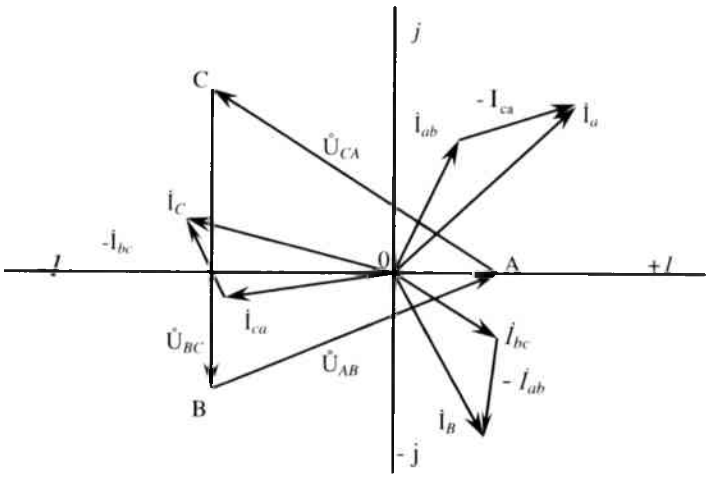
Kirxgof 1-qonuniga asosan liniyadagi tok:

$$\dot{I}_a = \dot{I}_{ab} - \dot{I}_{ca} = 2\sqrt{2}e^{j75^\circ} - 2\sqrt{2}e^{-j195^\circ} = 2\sqrt{2}\cdot\sqrt{3}e^{j45^\circ} \ A;$$

$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = 2\sqrt{2}e^{j45^\circ} - 2\sqrt{2}e^{j75^\circ} = 2\sqrt{2}\cdot\sqrt{3}e^{-j75^\circ} \ A;$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc} = 2\sqrt{2}e^{-j195^\circ} - 2\sqrt{2}e^{-j45^\circ} = 2\sqrt{2}\cdot\sqrt{3}e^{j165^\circ} \ A;$$

Kompleks tekislikda vektor ifodasini tuzamiz:



Masala 6.4. Uchburchak shaklda ulangan uch fazali tok generator liniyadagi kuchlanishlari nosimmetrik: $\dot{U}_{AB}$ *=100 V*, $\dot{U}_{BC}$*=(-50-j100) V*

va $\dot{U}_{CA}$ =(-50+j100) bo'lib, qarshiligi $\underline{Z}a=100\ Om$, $\underline{Z}b=-j100\ Om$ $\underline{Z}c=j100\ Om$ ga teng va yulduzcha shaklda biriktirilgan iste'molchiga ulangan. Fazadagi kuchlanish va liniyadagi tokni aniqlang.

Yechish.

Iste'molchilar to'la o'tkazuvchanligi aniqlanadi:

$$\underline{y}_a = \frac{1}{\underline{Z}_a} = 0{,}01\frac{1}{Om} \qquad \underline{y}_b = \frac{1}{\underline{Z}_b} = j0{,}01\frac{1}{Om} \qquad \underline{y}_c = \frac{1}{\underline{Z}_c} = j0{,}01\frac{1}{Om}$$

Fazadagi kuchianishni liniya kuchlanishlari orqali ifodalovchi tenglama:

$$\dot{U}'_A = \frac{\dot{U}_{AB}\underline{y}_b - \dot{U}_{CA}\underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = (-100 + j50)V$$

$$\dot{U}'_B = \frac{\dot{U}_{BE}\underline{y}_c - \dot{U}_{AB}\underline{y}_a}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{(-50-100j)(-j0{,}01)-100(0{,}01)}{0{,}01} = (-100 + j50)V$$

$$\dot{U}'_C = \frac{\dot{U}_{CA}\underline{y}_a - \dot{U}_{BC}\underline{y}_b}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{(-50+100j)\cdot 0{,}01-(-50-j100)\cdot j0{,}01}{0{,}01} =$$

$$= (-150 + j150)V$$

Liniyadagi tok aniqlanadi. Bunda iste'molchilar yulduzcha shaklda ulanganligi uchun $I_A = I\,\phi$

$$\dot{I}_A = \dot{U}_A' \cdot ya = (-1 + j0{,}5)A;$$

$$\dot{I}_B = \dot{U}_B' \cdot yb = (-0{,}5 - j2)A;$$

$$\dot{I}_C = \dot{U}_C' \cdot yc = (1{,}5 + j1{,}5)A;$$

Masala 6.5. Yulduzcha shaklda ulangan simmetrik uch fazali elektr zanjirda iste'molchl qarshiligi (Z=5+j5) bo'lib, fazadagi kuchlanish U=220V generatorga ulangan. Sxemaga ulangan vattmetr ko'rsatish qiymati aniqlanib, vektor ifodasi tuzilsin.

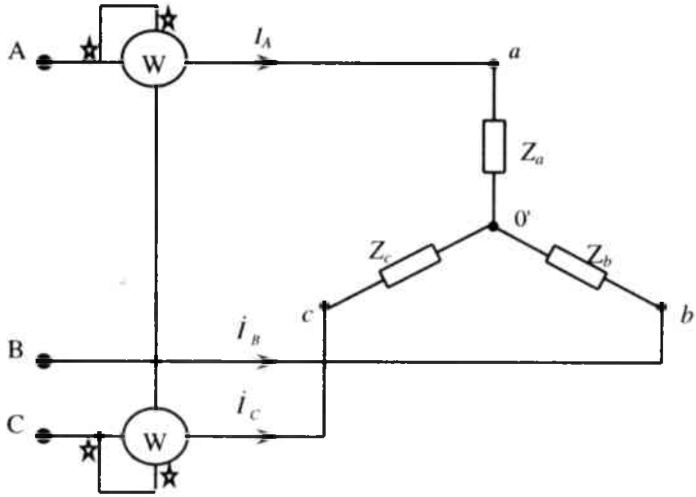
Yechish.

Birinchi fazadagi kuchlanish asosiy vektor qilib tanlanadi.

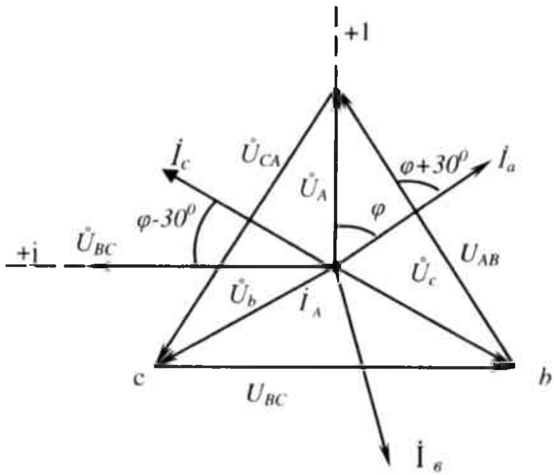
Bunda : $\dot{U}a=\dot{U}\,\phi=220\ V$,

Fazadagi tok $\dot{I}_a = \frac{\dot{U}_A}{Z} = \frac{220}{5+j5} = (22 - j22)A$

yoki $I_a = \sqrt{22^2 + 22^2} = 31{,}1A \quad tg\varphi = 1, \quad \varphi = 45^0$



Vektor ifodasi:



Bunda birinchi vattmetr quvvat tenglamasi:

$$\dot{P}_l = \dot{U}_л \cdot \dot{I}_л \cos(U_{ав} \hat{} I_a) = \dot{P}_l = \dot{U}_Л \cdot \dot{I}_Л \cos(U_{ав} \hat{} I_a) =$$

$$= \sqrt{3} \cdot 220 \cdot 31{,}1 \cos(30^\circ + \varphi) = 220\sqrt{3} \cdot 31{,}1 \cos 75^\circ = 3060 \ Vt = 3{,}06 \ kVt$$

Ikkinchi vattmetr tenglamasi:

$$\dot{P}_2 = \dot{U}_Л \cdot I_Л \cos\left(U_{CB}\hat{I}_c\right) = 220 \cdot \sqrt{3} \cdot 31{,}1\cos(30^\circ - \varphi) =$$

$$= 380 \cdot 31{,}1 \cdot \cos 15^\circ = 11460\ Vt = 1{,}146\ kVt$$

Demak: $R_{istem}=R_1+R_2=3{,}06+11{,}46=14{,}52\ kVt$

Uch fazali tok quvvat tenglamasi.

$$P=\sqrt{3}\cdot I_л \cdot U_л \cos\varphi = \sqrt{3}\cdot 31{,}1\cdot 380\frac{\sqrt{2}}{2} = 14{,}49 \approx 14{,}5kVt$$

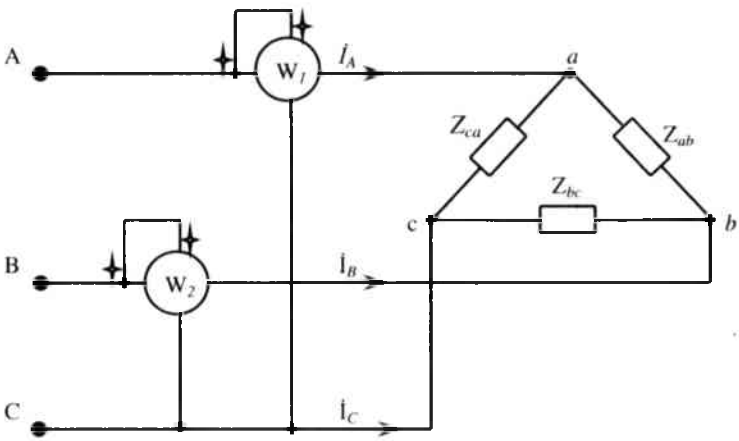
Masala 6.6. Uch fazali elektr zanjirda iste'molchi qarshiligi nosimmetrik: $Z_{ab}=38\ Om$, $Z_{bs}=38e^{j45}Om$, $Z_{ca}=38e^{-j45}\ Om$ bo'lib, uchburchak shaklda ulangan. Fazadagi kuchlamish U_{ϕ}=220v bo'lganda, sxemaga ulangan vattmetning ko'rsatish qiymatini aniqlang.

Yechish. Iste'molchi qarshiligi:

$\underline{Z}_{ab}=38(Om)$

$\underline{Z}_{bc}=38e^{j45}=(30+j30)Om$

$\underline{Z}_{ca}=38e^{-j45}=(30-j30)Om$



Fazadagi kuchlanishning vektor ifodasi:

$\dot{U}\,a=\dot{U}\,\phi=220\ V$

$\dot{U}\,b=\dot{U}\,\phi\cdot a^2=220\ e^{-j120}=(-110-j190)(v)$

$\dot{U}\,c=\dot{U}\,\phi\cdot a=220\ e^{-j120}=(-110-j190)(v)$

Liniyadagi kuchianish:

$$\dot{U}ab=\dot{U}a-\dot{U}b\ =220\left(1-a^2\right)\ =220\sqrt{3}\cdot e^{j30}=380\ e^{j30}\left(v\right)$$

$$\dot{U}bc=\dot{U}b-\dot{U}c\ =220\left(a^2-a\right)\ =220\sqrt{3}\cdot e^{-j90}=380\ e^{-j90}\left(v\right)$$

$$\dot{U}ca=\dot{U}c-\dot{U}a\ =220\left(a-1\right)\ =\sqrt{3}\cdot 220\ e^{j150}=380\ e^{j150}\left(v\right)$$

Fazadagi tok:

$$\dot{I}_{ab}=\frac{\dot{U}_{ab}}{Z_{ab}}=\frac{380e^{j30}}{38}=10e^{j30^\circ}=\left(8,67+\mathrm{j}5\right)A$$

$$\dot{I}_{bc}=\frac{\dot{U}_{bc}}{Z_{bc}}=10e^{-j135^\circ}=\left(-7-\mathrm{j}7\right)A$$

$$\dot{I}_{ca}=\frac{\dot{U}_{ca}}{Z_{ca}}=10e^{j195^\circ}=\left(9,65-\mathrm{j}2,6\right)A$$

Liniyadagi tok:

$$\dot{I}_a=\dot{I}_{ab}-\dot{I}_{ca}=(18,3+j7,6)=20e^{j22^\circ 30'}$$

$$\dot{I}_b=\dot{I}_{bc}-\dot{I}_{ab}=(-15,7+j12)=19,8e^{j217^\circ 30'}$$

$$\dot{I}_c=\dot{I}_{ca}-\dot{I}_{bc}=(-2,6+j4,5)=5e^{j120^\circ}$$

Birinchl va ikkinchi vattmetrlarning quvvat tenglamasi:

$$P_1=Re[\dot{I}_a\,\dot{U}sa]=Re[20e^{j22^\circ 30'}\cdot 380e^{j30^\circ}]=7550\ cos52^0 30'=4580(Vt)$$

$$P_2=Re[\dot{I}_v\ \dot{U}vs]=7550\ cos52^0 30'=4570(Vt)$$

Uch fazali tok to‘la quvvati

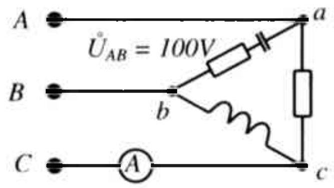
$$P=P_1+P_2=4,58+4,58=9,16(kVt)$$

Tekshiruv: Har bir iste’molchida sarf bo‘lgan quvvat yig‘indisi:

$$P=R_{ab}\,I_{ab}^{\ 2}+R_{bc}\ I^2_{bc}+R_{ca}I^2_{ca}=38\cdot 10^2+30\cdot 10^2+30\cdot 10^2\approx 9,2(kVt)$$

Masala 6.7.

Uchburchak shaklida biriktirilgan uch Z_{CA} fazali elektr zanjir iste’molchi qarshiliklari $Z_{ab}=(3\text{-}j4)\ Om$, $Z_{bc}=j10Om$. $Z_{ca}=10\ Om$ ga teng bo‘lib, liniyadagi kuchlanish $U_l=100V$ bo‘lgan generatorga ulangan. Sxemaga ulangan ampermetr qiymati va sarf bo‘ladigan quvvat amiqlansm.



Yechish.

Limiyadagi kuchlanishni aniqlaymiz:

$$\dot U_{ab} = 100\ (V)$$

$$\dot U_{bc} = 100\cdot a^2 = (-50 - j\cdot 87)(V)$$

$$\dot U_{ca} = 100\cdot a = (-50 + j\cdot 87)(V)$$

Fazadagi tok:

$$\dot I_{ab} = \frac{\dot U_{ab}}{Z_{ab}} = \frac{100}{3-j4} = \frac{100\cdot(3+j4)}{9+16} = (2+j16)A$$

$$\dot I_{bc} = \frac{\dot U_{bc}}{Z_{bc}} = \frac{(-50-j80)\cdot(-j10)}{100} = (-8,7+j5)A$$

$$\dot I_{ca} = \frac{\dot U_{ca}}{Z_{ca}} = \frac{-50+j87}{10} = (-5+j8,7)A$$

Liniyadagi tok:

$\dot I_a = \dot I_{ab} - \dot I_{bc} = 12 + j16 + 5 - j8,7 = (17 + j7,3)A$

$\dot I_b = \dot I_{bc} - \dot I_{ab} = -8,7 + j5 - 12 - j16 = (-20,7 - j11)A$

$\dot I_c = \dot I_{ca} - \dot I_{bc} = -5 + j8,7 - j5 + 8,7 = (3,7 + j3,7)A$

Tokning algebraik yig'indisi $\sum I = 0$

Ampermetr ko'rsatish qiymati: $I_c = \sqrt{(3,7)^2 + (3,7)^2} = 5,2\,A$

To'la quvvati:

$\tilde S_{ab} = \dot U_{ab}\cdot \dot I_{ab} = 100(12 - j16) = (1200 - j1600)\ (VA)$

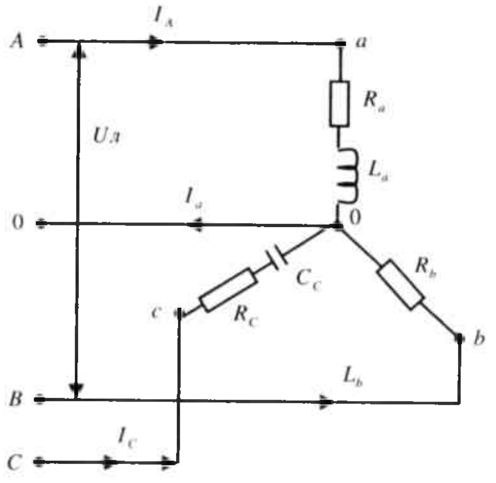
$\tilde S_{bc} = \dot U_{bc}\cdot \dot I = (-50 - j87)(-8,7 - j5) = j1000\ (VA)$

$\tilde S_{ca} = \dot U_{ca}\cdot \dot I_{ca} = (-50 - j87)(-5 - j8,7) = 1000\ (VA)$

O'rtacha aktiv quvvat:

$$P = 1200 + 1000 = 2200\ Vt$$

Masala 6.8. To'rt simli yulduzcha shaklda ulangan uch fazali elektr zanjirning parametri: $R_a=80sm$, $L_a=0,18gn$, $R_b=70sm$, $R_c=40sm$, $C_c=30mkF$ bo'lib, chastotasi $f=50$ Gs, liniyadagi kuchlanishi $U_l=380V$ bo'lgan generatorga ulangan. Tok va iste'molchidagi to'la quvvat aniqlansin.



Yechish.

Fazadagi kuchlanish: $U_F = \dfrac{380}{\sqrt{3}} = 220V$

Fazadagi to'la qarshilik:

$$Z_a = \sqrt{R_a^2 + x_{l_a}} = \sqrt{80^2 + (314 \cdot 0,18)^2} = 100 \quad Om \qquad Z_b = R_b = 70 \ Om$$

$$Z_c = \sqrt{R_c^2 + x_c^2} = \sqrt{(40)^2 + \left(\frac{1 \cdot 10^6}{314 \cdot 30}\right)^2} = 110 \ Om$$

Fazadagi tok:

$$I_a = I_a = \frac{U_a}{Z_a} = \frac{220}{100} = 2,2A \quad I_b = \frac{U_b}{Z_b} = \frac{220}{70} = 3,15A \quad I_c = \frac{U_c}{Z_c} = \frac{220}{110} = 2A$$

Aktiv quvvat:

$$P_a = I_a^2 \cdot R_a = (2,2)^2 \cdot 80 = 400 \quad Vt$$

$$P_b = I_b^2 \cdot R_b = (3,15)^2 \cdot 70 = 700 \quad Vt$$

$$P_c = I_c^2 \cdot R_c = (2)^2 \cdot 40 = 160 \quad Vt$$

Reaktiv quvvat: $R=R_a+R_v+R_s=400+700+160=1260\ Vt$

$$Q_a=I_a^2\cdot x_{l_c}=(2{,}2)^2\cdot 56{,}6=285\ \ VAR\quad Q_b=0$$

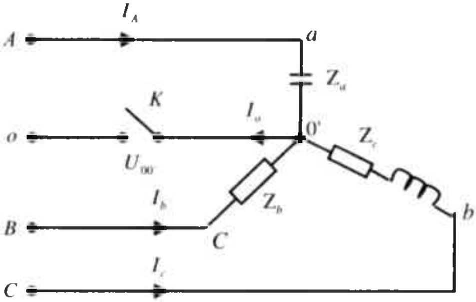
$$Q_c=-I_c^2\cdot x_c=-(2^2\cdot 106)=425\quad VAR$$

$$Q=Q_a+Q_c=285-425=-140\quad VAR$$

Sarf bo'ladigan to'la quvvat:

$$S=\sqrt{P^2+Q^2}=\sqrt{(1260)^2+(140)^2}=1280\ VA=1{,}28\ kVA$$

Masala 6.9. Yulduzcha shaklida biriktirilgan neytral simli uch fazali elektr zanjirning parametri: $Z_1=-j8\ Om;\ Z_2=10\ Om;\ Z_3=(3+j4Om.$ Liniyadagi kuchlanish simmetrik bo'lib: $U_{ab}=U_{bc}=U_{ca}=173\ (V).$ Neytral sim toki I_0, neytral sim uzilgandagi potensial kuchlanish U_{oo} va iste'molchi quvvatini aniqlang.



Yechish.

1) kalit *K* ulangan holda neytral sim yulduzcha shaklda ulangan bo'lib, fazadagi kuchlanishning kompleks ifodasi:

$$\dot U_\phi=\frac{\dot U_L}{\sqrt3}=100V;\quad \dot U_A=\dot U_\phi=100(V)$$

$$\dot U_B=\dot U_A\cdot a=(50-j87)(V);\quad \dot U_C=\dot U_A\cdot a=(-50-j87)(V)$$

Fazadagi tok:

$$\dot I_a=\frac{\dot U_a}{Z_a}=\frac{100}{-j8}=j12{,}5A$$

$$\dot I_b=\frac{\dot U_b}{Z_b}=\frac{-50-j87}{10}=(-5-j8{,}7)A$$

$$\dot I_c=\frac{\dot U_c}{Z}=\frac{-50+j87}{3+j4}=(7{,}9+j18{,}4)A$$

Neytral simdagi tok: $\dot{I}_o = \dot{I}_a + \dot{I}_b + \dot{I}_c = (2{,}9 + j22{,}2)\ A$

Effektiv yoki haqiqiy qiymat: $I_o = \sqrt{(2{,}9)^2 + (22{,}2)^2} = 22{,}4\ \ A$

Potensiallar orasidagi kuchlanish: U_{oo}'=0.

To'la quvvat:

$$\tilde{S}_a = \dot{U}_a \cdot \dot{I}_a = 100 \cdot (-j12{,}5) = -j1250\ (VA)$$

$$\tilde{S}_b = \dot{U}_b \cdot \dot{I}_b = (-50 - j87) \cdot (-5 + j8{,}7) = 100\ (VT)$$

$$\tilde{S}_c = \dot{U}_c \cdot \dot{I}_c = (-50 + j87) \cdot (7{,}9 - j18{,}4) = (1220 + j1600)\ (VA)$$

O'rtacha quvvat: $P = 1000 + 1200 = 2200\ \ (Vt) = 2{,}2\ \ kVt$

2) kalit K uzilgan holda, neytral simsiz yulduzcha shaklidagi sxema.

Yechish.

Iste'molchi o'tkazuvchanligi:

$$\underline{y}_a = \frac{1}{\underline{Z}_a} = \frac{1}{-j8} = j0{,}125\ \ \frac{1}{Om}$$

$$\underline{y}_в = \frac{1}{\underline{Z}_в} = \frac{1}{10} = 0{,}1\ \ \frac{1}{Om}$$

$$\underline{y}_c = \frac{1}{\underline{Z}_c} = \frac{3 - j4}{9 + 16} = (0{,}12 - j0{,}16)\ \ \frac{1}{Om}$$

Generator bilan iste'molchi o'rtasidagi potensial kuchlanish:

$$U_{00}' = \frac{U_a \underline{y}_a + U_b \underline{y}_b + U_c \underline{y}_c}{\underline{y}_1 + \underline{y}_2 + \underline{y}_3} = (-2{,}8 + j100)\ V$$

Fazadagi kuchlanish:

$$\dot{U}_a = \dot{U}_A - \dot{U}_{oo}' = 100 - (-2{,}8j + 100) = (102{,}8 - j100)\ V$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_{oo}' = -50 - j87 - (-2{,}8 + j100) = (-47{,}8 - j187)\ V$$

$$\dot{U}_c = \dot{U}_C - \dot{U}_{oo}' = -50 + j87 - (-2{,}8 + j100) = (-47{,}8 - j13)\ V$$

Fazadagi tok. ($\dot{I}_ф = \dot{I}_A$)

$$\dot{I}_a = \dot{U}_a \underline{y}_a = (102{,}8 - j100) \cdot j0{,}125 = (12{,}5 + j12{,}8)\ \ A$$

$$\dot{I}_b = \dot{U}_b \underline{y}_b = (-47{,}8 - j187) \cdot 0{,}1 = (-4{,}78 - j18{,}7)\ \ A$$

$$\dot{I}_c = \dot{U}_c \underline{y}_c = (-47{,}8 - j13) \cdot (0{,}12 - j0{,}16) = (-7{,}82 + j6{,}1)\ \ A$$

Tokning algebraik yig'indisi $\sum \dot{I}_q = 0$;

Liniyadagi tok: $I_Л = \sqrt{(12{,}5)^2 + (12{,}8)^2} = 17{,}8\ A.$

Neytral nuqtadagi potensiallarning effektiv qiymati:

$$\dot{U}_{oo}' = \sqrt{(-2{,}8)^2 + 100^2} = 100 \quad V$$

To'la quvvat:

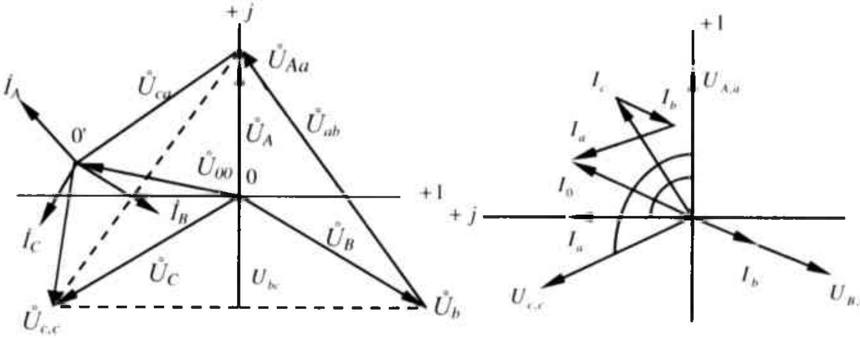
$$\tilde{S}_a = \dot{U}_a \dot{I}_a = (102{,}8 - j100)(12{,}5 - j12{,}84) = -j2560\ VA$$

$$\tilde{S}_b = \dot{U}_b \dot{I}_b = (-47{,}8 - j187)(4{,}78 - j18{,}7) = 3720\ VA$$

$$\tilde{S}_c = \dot{U}_c \dot{I}_c = (-47{,}8 - j13)(-7{,}8 - j6) = (293 + j393{,}5)\ VA$$

Iste'molchilardagi sarf bo'ladigan aktiv quvvatning o'rtacha qiymati: $P = 3720 + 293 = 4013(Vt)$

Vektor ifodasi:



Masala 6.10. Uch fazali elektr generatornmg simmetrik tashkll etuvchilari $\dot{E}_1 = 100\ V$; $\dot{E}_2 = 25 \cdot e^{j120}$; $\dot{E}_0 = 100 \cdot e^{-j\frac{\pi}{3}}$ ga teng bo'lganda, nosimmetrik EYKning analitik va vektor ifodasi aniqlansin.

Yechish.

$$\dot{E}_1 = 100(V),\ \dot{E}_2 = 25e^{j\frac{\pi}{3}} = (12{,}5 + j21{,}7)(V),$$

$$\dot{E}_0 = 100e^{-j\frac{\pi}{3}} = (50 - j86)(V)$$

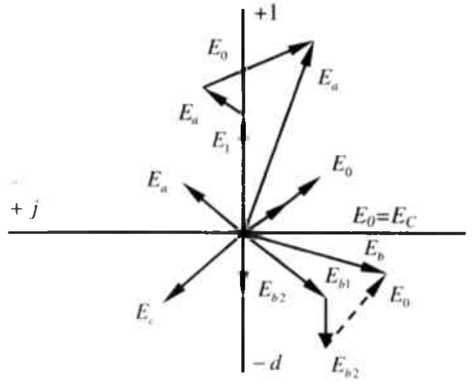
Nosimmetrik uch fazali tok sistemalarining simmetrik tashkil etuvchilarga ajratish tenglamasiga asosan:

$$\dot{E}_a = \dot{E}_o + \dot{E}_1 + \dot{E}_2 = (50 - j86) + 100 + (12{,}5 + j21{,}7) = (162{,}5 - j65)\ V$$

$$\dot{E}_b = \dot{E}_0 + a^2\dot{E}_1 + a\dot{E}_2 = (50 - j86{,}7) - 50 + (-j86{,}7 + 25) = (-25 - j173{,}4)\ V$$

$$\dot{E}_c = \dot{E}_0 + a\dot{E}_1 + a^2\dot{E}_2 = (50 - j86{,}7) + (-50 + j86{,}7) + 25 = (12{,}5 + j21{,}7)\ V$$

Vektor ifodasi:



Masala 6.11. Iste'molchi aktiv qarshlliklar nosimmetrik $R_a = 1\ Om$; $R_b = 2\ Om$; $R_c = 3\ Om$ bo'lgan neytral simsiz uch fazali elektr zanjir faza kuchlanishi $U_\varphi = 220\ V$ bo'lgan simmetrik uch fazali manbaga ulangan. Fazadagi tok va kuchlanishni aniqlang.

Yechish.

Kuchlanish $\dot{U}_2 = 0$ teng. Fazadagi tok:

$$\dot{I}_a = \dot{I}_1 + \dot{I}_2 = \frac{(1-a)Z_b + (1-a^2)Z_c}{Z_aZ_b + Z_bZ_c + Z_cZ_a} \cdot \dot{U}_1 = (150 + j17{,}3) = 151e^{j6^\circ}\ A$$

$$\dot{I}_b = a^2\dot{I}_1 + a\dot{I}_2 = \frac{(a^2-a)Z_a + (a^2-1)Z_c}{Z_aZ_b + Z_bZ_c + Z_cZ_a} \cdot \dot{U}_1 = (-90 + j86{,}6) = 125e^{j224^\circ}\ A$$

$$\dot{I}_c = a\dot{I}_1 + a^2\dot{I}_2 = \frac{(a-a^2)Z_a + (a-1)Z_b}{Z_aZ_b + Z_bZ_c + Z_cZ_a} \cdot \dot{U}_1 = (-60 + j69) = 91{,}7e^{j130^\circ 50^\circ}\ A$$

Fazadagi kuchlanish:

$$\dot{U}_a = \underline{Z}_a\dot{I}_a = 1 \cdot 151 = 151\ V;$$

$$\dot{U}_b = \underline{Z}_b\dot{I}_b = 2 \cdot 151 = 250\ V;$$

$$\dot{U}_c = \underline{Z}_c\dot{I}_c = 3 \cdot 91{,}7 = 275\ V;$$

Masala 6.12. Fazadagi kuchlanish $\dot{U}_a = 220\ V;\ \dot{U}_b = (-110 - j150)\ V;$ $\dot{U}_c = (-110 + j150)$ bo'lgan neytral simsiz uch fazali elektr zanjirning kompleks qarshiligi *Z_a=(2+j3) (Om); Z_b=(3+j2) (Om)* va *Z_c=(3-j2)(Om)*ga teng. Manbadagi kuchlanish to'g'ri, teskari va nol tashkil etuvchilari hamda faza toklari va kuchlanishlari aniqlansin.

Yechish.

Nosimmetrik kuchlanish sistemalarni simmetrik tashkil etuvchilarga ajratish tenglamasiga asosan:

$$\dot{U}_0 = \frac{1}{3}\left(\dot{U}_a + \dot{U}_b + \dot{U}_c\right) = \frac{1}{3}\left[220 + (-110 - j150) + (-110 + j150)\right] = 0;$$

$$\dot{U}_1 = \frac{1}{3}\left(\dot{U}_a + a\dot{U}_b + a^2\dot{U}_c\right) = \frac{1}{3}\left[220 + \left(-0.5 + j\frac{\sqrt{3}}{2}\right)\cdot(-110 - j150) + \right.$$

$$\left. + \left(-0.5 - j\frac{\sqrt{3}}{2}\right)\cdot(-110 + j150)\right] = 197\ V;$$

$$\dot{U}_2 = \frac{1}{3}\left(\dot{U}_a + a^2\dot{U}_b + a\dot{U}_c\right) = \frac{1}{3}\left[220 + \left(-0.5 - j\frac{\sqrt{3}}{2}\right)\cdot(110 - j150) + \right.$$

$$\left. + \left(-0.5 + j\frac{\sqrt{3}}{2}\right)\cdot(-110 + j150)\right] = 23\ V.$$

(5.31) tenglamaga asosan toklar tenglamasi:

$$\dot{I}_1 = \frac{(Z_a + Z_b + Z_c)\dot{U}_1 - (Z_a + a^2 Z_b + aZ_c)\dot{U}_2}{Z_a Z_b + Z_b Z_c + Z_c Z_a} = (50 - j15)\,A$$

$$\dot{I}_2 = \frac{(Z_a + aZ_b + a^2 Z_c)\dot{U}_1 - (Z_a + Z_b + Z_c)\dot{U}_2}{Z_a Z_b + Z_b Z_c + Z_c Z_a} = (38 + j6,4)\,A$$

(5.24) tenglamaga asosan fazadagi tok:

$$\dot{I}_a = \dot{I}_1 + \dot{I}_2 = 87{,}8 - j8{,}6 = 88{,}2e^{-j5^0}\quad A$$

$$\dot{I}_b = a^2\dot{I}_1 + a\dot{I}\ = -62{,}4 - j6{,}1 = 62{,}6e^{e^{j185^0}}\quad A$$

$$\dot{I}_c = a\dot{I}_1 + a^2\dot{I}_2 = -\left(\dot{I}_a + \dot{I}_b\right)\cdot a = -25{,}4 + j14{,}7 = 29{,}4e^{j150^0}\quad A$$

Iste'molchilardagi kuchlanish:

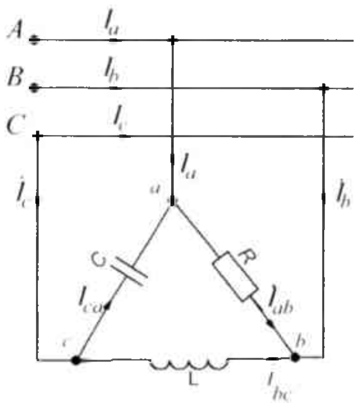
$\dot{U}_a = \underline{Z}_a\dot{I}_a = 3{,}6\cdot 88{,}4 = 318\ V;\quad \dot{U}_b = \underline{Z}_b\dot{I}_b = 3{,}6\cdot 62{,}6 = 225\ V;$

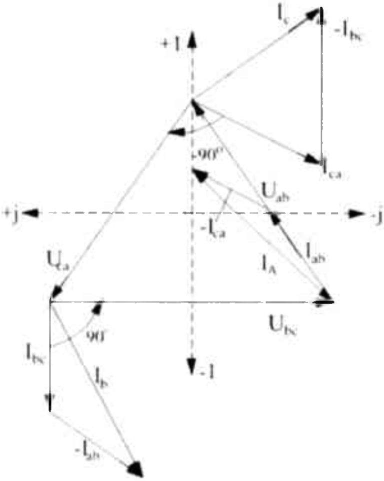
$\dot{U}_c = \underline{Z}_c\dot{I}_c = 3{,}6\cdot 29{,}4 = 106\ V;$

Masala 6.13. Uchburchak shaklda ulangan uch fazali elektr zanjirdagi kuchlanish $\dot U_n = 380V$ bo'lib faza qarshiligi $R = \dot X_L = \dot X_C = 10\ Om$ ga teng. Liniya va fazadagi tokni hisoblab, tok va kuchlanish topografik diagrammasi tuzilsin.

Yechish. Fazadagi qarshilik modullari bir xil bo'lib, argumenti bilan farqli.

$$\dot Z_{ab} = R = 10\ Om,\ \dot Z_{bc} = jx_L = j10 = 10^{j90^\circ}\ Om\quad \dot Z_{ca} = -jx_c = -j10 = 10e^{-j90}Om$$





Liniya kuchlanish kompleks ifodasi:

$$\dot U_{ab} = 380e^{j30^\circ}V;\ \dot U_{bc} = 380e^{-j90^0}V;\ \dot U_{ca} = 380e^{j150}V$$

Fazadagi tok:

$$\dot I_{ab} = \frac{380e^{j30^\circ}}{10} = 38e^{j30^0}A;\ \dot I_{bc}\ \frac{380e^{-90^\circ}}{10^{j90^\circ}} = 38e^{-j180^\circ}A;\ \dot I_{ca} = \frac{-380e^{j150}}{10e^{-j90}} = 38e^{j240^\circ}A.$$

Limiyadagi toki:

$$\dot I_a = \dot I_{ab} - \dot I_{ca} = 38e^{j30} - 38e^{j240^\circ} = 38\left[\frac{\sqrt{3}}{2} + j\frac{1}{2} - \left(-\frac{1}{2}\right) - j\left(-\frac{\sqrt{3}}{2}\right)\right] = 51,9 + j51,9 = 73,4e^{(j45^\circ)}$$

$$\dot I_b = \dot I_{bc} - \dot I_{ab} = 38e^{-j180} - 38e^{j30^0} = 38\left(-1 - j0 - \frac{\sqrt{3}}{2} - j\frac{1}{2}\right) = 70,9 - j19 = 73,4e^{j195^\circ}A$$

$$\dot I_c = \dot I_{ca} - \dot I_{bc} = 38e^{j240^\circ} - 38e^{-j180^0} = 38\left[-\frac{1}{2} - j\frac{\sqrt{3}}{2} - (-1 - j0)\right] = 19 - j32,9 = 38e^{(j300^\circ)}$$

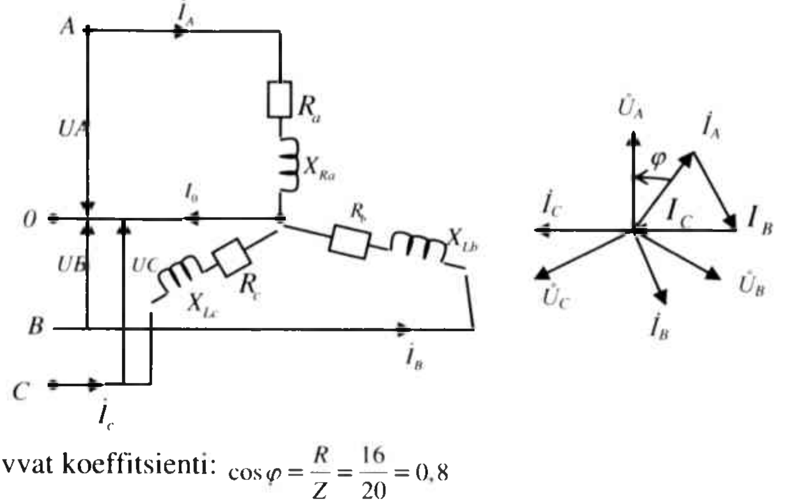
Tok va kuchlanish qiymatlari bo'yicha topografik kompleks vektor ifodasini tuzish uchun masshtab tanlanadi: $m_u = \left[\frac{B}{sm}\right]$; $m_I = \left[\frac{A}{sm}\right]$. Fazadagi tok vektorini $\dot{I}_{ab}$, $\dot{I}_{bc}$, $\dot{I}_{ca}$ liniyadagi kuchlanish vektorlariga $\dot{U}_{ab}$, $\dot{U}_{bc}$, $\dot{U}_{ca}$ nisbatan, $\varphi_{ab} = 0$; $\varphi_{bc} = 90^\circ$; $\varphi_{sa} = -90^\circ$ burchak asosida yo'naltiramiz. Endi fazadagi tok vektorini parallel ko'chirish bilan liniyadagi tok vektori $\dot{I}_a$, $\dot{I}_b$, $\dot{I}_c$ hosil qilinadi.

Masala 6.14. Yulduzcha shaklda ulangan uch fazali elektr zanjirga uchta bir xil induktiv g'altak ulangan bo'lib, aktiv qarshiligi $R = 16\,Om$, induktiv qarshilik $X_L = 12\,Om$. Bitta fazadagi aktiv quvvat: $P = 1{,}2\,kvt$ bo'lganda, faza va liniyadagi kuchlanish $U_Ф$, $U_Л$, tok hamda to'la va reaktiv quvvatini aniqlang.

Yechish.

To'la qarshilik:

$Z_Ф = \sqrt{R^2 + X_L^2} = \sqrt{16^2 + 14^2} = 20\,Om.$



Quvvat koeffitsienti: $\cos\varphi = \frac{R}{Z} = \frac{16}{20} = 0{,}8$

Fazadagi kuchlanish quvvat ifodasida:

$$P_\phi = U_\phi I_\phi \cos\varphi = U_\phi \frac{U_\phi}{I_\phi}\cos\varphi = \frac{U_\phi^2}{I_\phi}\cos\varphi$$

Bundan: $U_\phi = \sqrt{\frac{R_\phi}{\cos\varphi}} = 175V.$

Liniyadagi kuchlanish: $U_l = \sqrt{3} \cdot 175 = 305\,V$

Fazadagi tok: $I_\phi = \dfrac{U_\phi}{Z_\phi} = \dfrac{175}{20} = 8{,}8A$

Reaktiv quvvat: $Q_\phi = U_\phi I_a \sin\varphi = 175 \cdot 8{,}8 \cdot 0{,}6 = 924VAR$

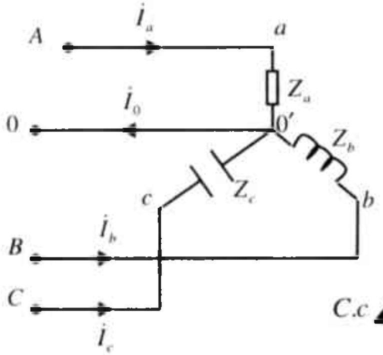
To'la quvvat: $S = U_\varphi R_\varphi = 175 \cdot 8{,}8 = 1540VA.$

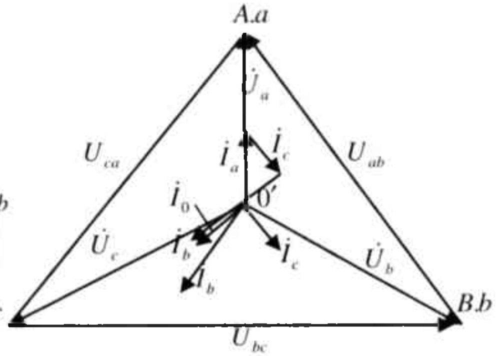
Masala 6.15. Nosimmetrik neytral simli yulduzcha sxemada ulangan uch fazali elektr zanjir faza qarshiligi yoki o'tkazuvchanligi:

$$Z_a = R;\; Z_b = jx_1 = j\frac{R}{2};\; Z_c = -jx_s = -j3R;$$

$$y_a = \frac{I}{R} = g;\; y_b = \frac{1}{j\frac{R}{2}} = -j2g;\; y_c = \frac{1}{j3R} = j0{,}033g$$

bo'lib, neytral sim qarshiligi $Z_0=0$ yoki $y = \infty$ bo'lganda fazadagi tok $\dot{I}_a, \dot{I}_b, \dot{I}_c$ va neytral sim toki I_0 topilsin.





Yechish. Neytral sim potensiali ustma-ust tushganligi uchun $U_{00'} = {}_0\dot{I}_0 = 0$ ga teng bo'lib, fazadagi tok:

$$\begin{cases} \dot{I}_a = \dfrac{\dot{U}_a}{Z_a} = \dfrac{\dot{U}_a}{R}; \\ \dot{I}_b = \dfrac{\dot{U}_b}{Z_b} = \dfrac{\left(-0{,}5 - j\sqrt{\frac{3}{2}}\right)\dot{U}_a}{j\frac{R}{R}} = (-1{,}73 + j)\dfrac{\dot{U}_a}{R} = 2\dfrac{\dot{U}_a}{R} = 2\dfrac{\dot{U}_a}{R}e^{j150} \\ \dot{I}_c = \dfrac{\dot{U}_c}{7_c} = \dfrac{\left(-0{,}5 + j\sqrt{\frac{3}{2}}\right)\dot{U}_a}{-j3R} = (-0{,}288 - j0{,}17)\dfrac{\dot{U}_a}{R} = 0{,}334\dfrac{\dot{U}_a}{R}e^{-j1490} \end{cases}$$

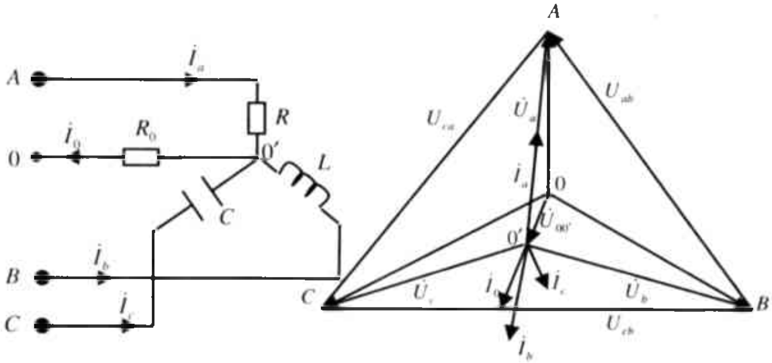
Neytral simdagi tok:

$$\dot{I}_0 = \dot{I}_a + \dot{I}_b + \dot{I}_c = (1 - 1,73 + j - 0,288 - j0,17)\frac{\dot{U}_a}{R} =$$

$$(-1,018 + j0,83)\frac{\dot{U}_a}{R} = 1,31\frac{\dot{U}_a}{R}e^{j140^0}$$

Masala 6.16. (6.15) masala shartiga asosan neytral sim qarshiligi $Z_0 = 0{,}1R$ yoki o‘tkazuvchanligi $y = 10g$ bo‘lgan fazadagi tok va neytral simdagi tok aniqlansin.

Yechish. Ushbu masala yechimi ham 6.15-masalaga o‘xshash bo‘lib, tugun potensiallar usuliga asosan neytral simni bog‘lovchi potensiallar farqi (6.5)U_{00^1}ni tenglamaga asosan topamiz.



a) b)

Neytral sim qarshiligi hisobiga tugun potensiallari orasidagi kuchlanish:

$$\dot{U}_{00^I} = \frac{\dot{U}_A y_a + \dot{U}_B y_b + \dot{U}_c y_c}{y_a + y_b + y_c + y_0} = \frac{\dot{U}_{Ag} + \left(-0,5 - j\frac{\sqrt{3}}{R}\right)\dot{U}_A(-j2g) + \left(-0,5 + j\frac{\sqrt{3}}{R}\right)\dot{U}_{Aj}0,333g}{g - j2_g + j0,333g + 10g} =$$

$$= (-0,102 + j0,06)\dot{U}_A = 0,118\dot{U}_A e^{j149^0 33^1}$$

Fazadagi kuchlanish:

$$\dot{U}_a = \dot{U}_A - \dot{U}_{00^I} = \dot{U}_A - (-0,102 + j0,06)\dot{U}_A = (1,102 - j0,06)U_A = 1,104\dot{U}_A e^{-j3^0 07^1}$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_{00^I} = \left(-0,5 - j\frac{\sqrt{3}}{R}\right)\dot{U}_A - (-0,102 + j0,06)\dot{U}_A = (-0,398 - j0,927)\dot{U}_A = 1,01\dot{U}_A e^{-113^0 14^1}$$

$$\dot{U}_c = \dot{U}_C - \dot{U}_{00'} = \left(-0,5 + j\frac{\sqrt{5}}{R}\right)\dot{U}_A - (-0,102 + j0,06)\dot{U}_A =$$

$$= (-0,398 + j0,807)\dot{U}_A = 0,9\dot{U}_A e^{j116^0 15^1}$$

Fazadagi tok:

$$\dot{I}_a = \frac{\dot{U}_a}{Z_a} = \frac{\dot{U}_a}{R} = 1,104\frac{\dot{U}_A}{R}e^{-j3^0 07^1} = (1,102 - j0,06)\frac{\dot{U}_A}{R}$$

$$\dot{I}_b = \frac{\dot{U}_b}{Z_b} = \frac{1,01\dot{U}_A e^{-j113^0}14^1}{j\frac{R}{2}} = 2,02\frac{\dot{U}_A}{R}e^{-203^0 14^1} = (-1,853 + j0,794)\frac{\dot{U}_A}{R}$$

$$\dot{I}_c = \frac{\dot{U}}{Z_c} = \frac{0,9\dot{U}_A e^{j116^0 15^1}}{-j3R} = 0,3\frac{\dot{U}_A}{R}e^{j206^0 15^1} = (-0,269 - j0,134)\frac{\dot{U}_A}{R}$$

Neytral simdagi tok:

$$\dot{I}_0 = \frac{\dot{U}_{00'}}{Z_0} = \frac{0,118\dot{U}_A e^{j149^0 33^1}}{0,1R} = 1,18\frac{\dot{U}_A}{R}e^{j149^0 33^1} = (-1,02 + j0,6)\frac{\dot{U}_A}{R}$$

Tekshirish:

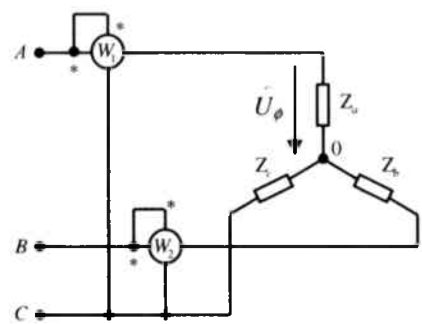
$$\dot{I}_0 + \dot{I}_b + \dot{I}_c = \dot{I}_0 = (1,102 - j0,0b - 1,853 + j0,794 - 0,269 - j0,134) =$$

$$= (1,02 - j0_1 b)\frac{\dot{U}_A}{R} = 0$$

Neytral sim qarshiligini hisobga olganda tugun potensiallari orasidagi siljish hisobiga $\dot{U}_{00'}$ kuchlanish hosil bo‘ladi.

6.3. Mustaqil yechish uchun masalalar

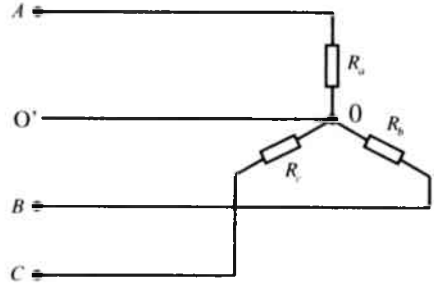
Masala 6.1. Yulduzcha shaklida ulangan uch fazali elektr zanjirning fazadagi kuchlanishi $U_\varphi = 127$ V bo‘lib, kompleks qarshiligi $Z_a = Z\varphi = 10 + j10$ bo‘lgan simmetrik iste’molchiga ulangan. Sxemada ko‘rsatilgan ulanish bo‘yicha vattmetr qiymati va uch fazali tok quvvati aniqlanib, vektor ifodasi tuzilsin.



Javob: $P_1 = 805,8$ Vt; $P_2 = 805,8$ Vt; $P = 2417,4$ Vt.

Masala 6.2. To'rt simli yulduzcha shaklda ulangan uch fazali elektr zanjirnimg liniyadagi kuchianishi $U_l=380$ V, iste'molchi aktiv qarshiligi $R=100$ Om. Fazadagi tok va sarf bo'ladigan quvvat amiqlansin.

Javob: $I=2{,}2$ A; $P=1452$ Vt.



Masala 6.3. To'rt simli yulduzcha shakldagi fazaga $P_a=40$ Vt, $P_B=100$ Vt, $P_C=60$ Vt quvvatga ega bo'lgan lampochka ulangan. Liniya kuchianishi $U_L=220$ V bo'lganda fazadagi toklar amiqlamib, vektor ifodasi tuzilsin.

Javob: $I_a=0{,}3$ A; $I_b=0{,}75$ A; $I_c=0{,}45$ A; $\overline{I_0}=\overline{I_a}+\overline{I_b}+\overline{I_c}\approx 0{,}38$ A.

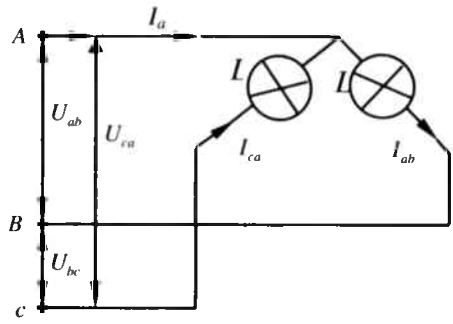
Masala 6.4. Liniyadagi kuchlanish $U_L=220$ V bo'lgan neytral simsiz yulduzcha shaklida ulangan uch fazali elektr zanjirning iste'molchi qarshiligi $R_a=40$ Om; $R_b=50$ Om; $R_c=20$ Om. Aktiv quvvati $P_a=40$ Vt; $P_v=100$ Vt; $P_s=60$ Vt. Fazadagi tok va kuchlanishi aniqlanib, vektor ifodasi tuzilsin.

Javob: $I_a=1$ A; $\dot{I}_b=1.41$ A; $I_c=1.73$ A. $U_a'=401$ V; $U_b'=70.5$ V; $U_c'=34.6$ V.

Masala 6.5. Berilgan sxemada A va B fazaga $P=40$ Vt bo'lgan 21 dona lampa, C va A fazaga $P=60$ Vt 10 dona lampa ulangan bo'lib, liniya kuchlanishi $U_L=120$ V. liniyadagi va fazadagi tok aniqlanib, vektor ifodasi tuzilsin.

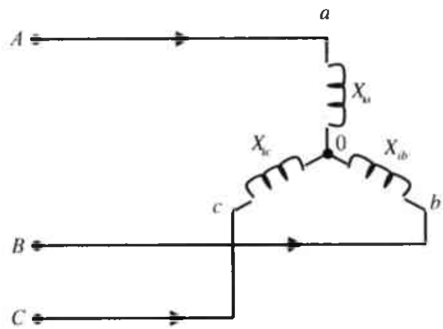
Javob:

$\dot{I}_{ab}=7$ A; $I_{bc}=5A$; $I_A=I_L=2$ A.



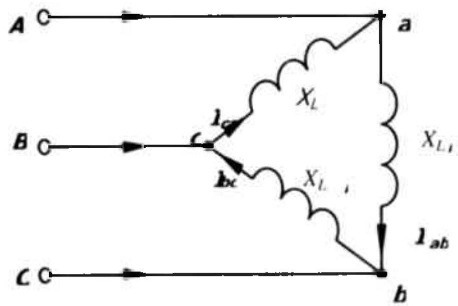
Masala 6.6. Induktivligi $L_1=L_2=L_3=126$ *mGn* bo'lgan uch fazali asimxron dvigatel chastotasi $f=50$ *Gs*, faza kuchlanishl $U_A=120$ *V* simmetrik generatorga ulangan. Fazadagi tok to'la quvvati aniqlansin.

Javob: $I_\varphi=3$ *A*; $P=0$; $S=Q=1076$ *VA*.

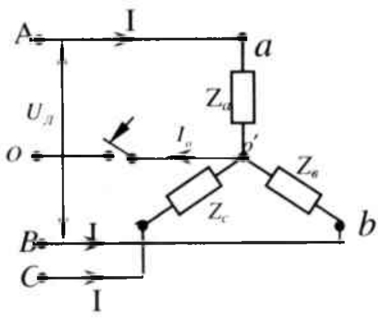


Masala 6.7. Uchburchak shaklida biriktirilgan elektr zanjir iste'molchi qarshiligi $X_L=22$ *Om* bo'lib $\dot{U}_A=220e^{j45^0}$ *V* kuchlanishga ulangan. Faza va limiyadagi tok aniqlamib, kompleks topografik diagrammasi tuzilsin.

Javob: $I_\phi=10e^{-j45}$; $I_L=17{,}3\ ye^{-j45}$.



Masala 6.8. Yulduzcha shaklida birlashtirilgan 4 ta simli uch fazali elektr zanjir iste'molchl kompleks qarshiliklari: $Z_a=(40+j30)$ *Om*; $Z_b=50$ *Om*, $Z_c=(25\text{-}j25)$*Om ga* teng bo'lib, $U=380$ *V* limiya kuchlanishi ulangan. Kalit ulangan yoki uzilgan holatlar uchun liniya va neytral



simdagi tok hamda neytral nuqtalar orasidagi $\mathring{U}_{00'}$ kuchlanish aniqlanib, vektor ifodasi tuzilsin.

Javob: a) kalit ulanganda:

$$\dot{I}_a = 3,52 - j2,64\ A,\quad \dot{I}_b = -2,2 - j3,78\ A;\quad \dot{I}_c = -2,75 - j0,56\ A;$$

$$\dot{I}_0 = \dot{I}_a + \dot{I}_b + \dot{I}_c = -2,71 - j0,56\quad \mathring{U}_{00'} = 0$$

b) kalit uzilganda:

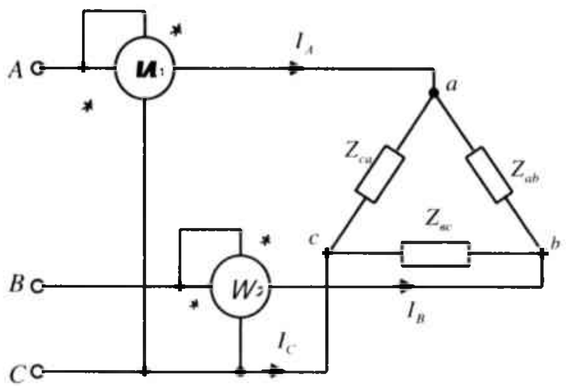
$$\mathring{U}_0 = -35 - j175\,B,\quad \dot{I}_a = 6,18 - j0,26\ A,$$

$$\dot{I}_a = 1,5 - j0,3\ A;\quad \dot{I}_a = 4,68 - j0,56\ A$$

Masala 6.9. Yulduzcha sxemada ulangan uch fazali elektr zanjirga parametri $R = 7\ Om$, $X_L = 24\ Om$ bo'lgan uchta bir xil g'altak ulangan (6.8-masala). Liniya kuchlanishi $U_n = 220V$. OA fazasidagi g'altak qisqa tutashganda tok qiymati aniqlanib, vektor ifodasi chizilsin.

Javob: $I_A = 15A$, $I_B = I_C = 8,8A$.

Masala 6.10. Uchburchak shaklda ulangan uch fazali elektr zanjir iste'molchilari: $Z_{ab}=20+j20\ Om$; $Z_{bc}=50\ Om$, $Z_{ca}=-j40\ Om$ teng bo'lib, $U_L=200\ V$ liniya kuchlanishiga ulangan. Liniyadagi tok va iste'molchllarda sarf bo'ladigan elektr quvvatni aniqlang.



Javob: $\dot{I}_a = 9,33 - j2,5\ A$, $\dot{I}_b = -7 + j1,54\ A$;

$\dot{I}_c = -2,33 + j0,96\ A$;

$P = P_1 + P_2 = 1366 + 434 = 1800\ Vt.$

Masala 6.11. Uchburchak shaklda biriktirilgan uch fazali elektr zanjir iste'molchilari simmetrik ulangan bo'lib $I=1\ A$ tok o'tadi. Liniya simi I_a va faza simi I_{ab} uzilgan holda liniyadagi tok qiymatini aniqlang.

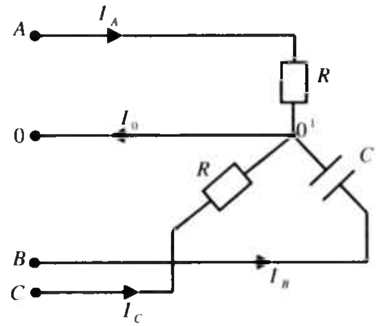
Javob: $I_Л = \sqrt{3}A$; $I_\varphi = \sqrt{3}A$; $I_b = \sqrt{3}A$; $I_c = \sqrt{3}A$

Masala 6.12. Yulduzcha shaklda ulangan uchta simli uch fazali elektr zanjirning liniyadagi kuchlanishi $380V$, iste'molchi qarshiligi $R_a = X_b = 10\ Om$, $X_C = -10\ Om$ bo'lganda, fazadagi tok aniqlanib, tok va kuchlanish topografik vektor diagrammasi tuzilsin.

Javob: $\dot{I}_a = 16A$, $\dot{I}_b = 16e^{-210^\circ}A$, $I_c = 16e^{j210^\circ}A$.

Masala 6.13. Yulduzcha shaklda ulangan elektr zanjir: liniyadagi tok $I_A = I_B = I_c = 3\ A$ bo'lganda topografik vektor ifodasini tuzish yordamida I_0 neytral tokni aniqlang.

Javob: $I_0 = 4{,}24\ A$

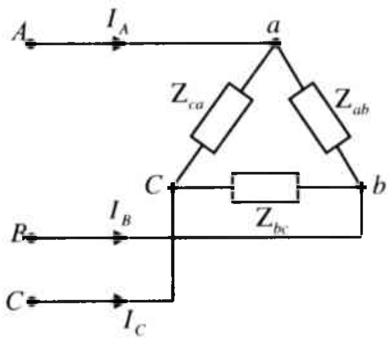


Masala 6.14. a) uchburchak shaklda ulangan simmetrik uch fazali elektr zanjir faza qarshiligi: $Z_{ab} = Z_{bc} = Z_{ca} = -j\frac{1}{\omega c}$ bo'lib, $\dot{I}_{ca} = 8\ A$ ga teng. Z_{bc} faza uzilgan holatda liniyadagi tok $\dot{I}_A$, I_B va fazadagi $\dot{I}_{ca}$ tokni aniqlang.

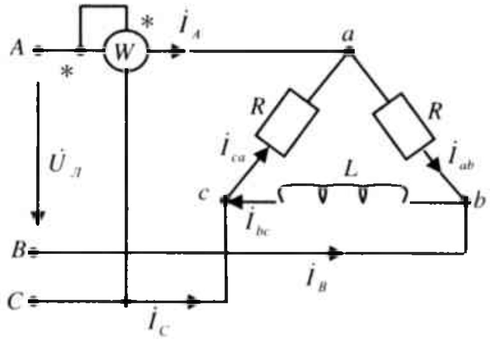
Javob: $\dot{I}_A = 8\ A$, $\dot{I}_Л = 13{,}8\ A$, $\dot{I}_{ca} = 13{,}8\ A$.

b) C liniya simi uzilgan holatda. I_B liniyadagi tok va I_{ca} fazadagi tokni aniqlang:

Javob: $I_B = 12\ A$, $I_{ca} = 4\ A$



Masala 6.15. Uchburchak shaklda ulangan uch fazali tok parametri: $Z_{ab} = Z_{ca} = R$, $Z_{bc} = j\omega L$ bo'lib, simmetrik $\dot{U}_Л = 220\, V$ kuchlanishga ulangan. Fazadagi tok $\dot{I}_{ab} = 1\, A$ va $\dot{I}_{bc} = \frac{\sqrt{3}}{2}\, A$ bo'lganda, tok va kuchlanish topografik diagrammasini tuzish bilan vattmetr ko'rsatish qiymati aniqlansin.



Javob: $P = 330\, VT$.

6.4. Nazorat savollari

1. Uch fazali smusoidal o'zgaruvchan tok deb nimaga aytiladi?
2. Uch fazali tok sistemalarining bir fazali sinusoidal o'zgaruvchan tokga nisbatan qanday afzalliklari bor?
3. Uch fazali tok qanday hosil qllinadi va manbai nima? Sinxron generatorning tuzilishi va ishiash prinsipini bilasizmi?
4. Uch fazali generator statoriga joylashtirilgan chulg'am o'qlari qanday burchakda joylashtiriladi va qutblar soni nimaga teng?
5. Uch fazali tok chastotasi f = 50 Gs, qutblar soni 2r = 6 ga teng bo'lganda, magnit maydon aylanish tezligi n_0 nimaga teng?
6. Uch fazali tok grafigi va vektor ifodasini chizing. Analitik, kompleks ifodalarni yozmg.
7. Uch fazali tok sistemalarining ulanish sxemalarini bilasizmi?
8. Ulanish sxemalariga qarab liniya, fazalardagi kuchlanish va tokning nisbiy bog'lanish tenglamasini yozing.
9. Agar yulduzcha shaklida ulangan iste'molchining simmetrik fazalari uchburchak shaklida ulansa, liniya va fazadagi tok qanday o'zgaradi?

10. 4 simli, uch fazali elektr zanjirda neytral simning vazifasi nimadan iborat?
11. Uch fazali tok sistemasi qaysi holatlarda nosimmetrik bo'ladi?
12. Uch fazali tokda aktiv, reaktiv va to'la quvvat ifodalarini yozing.
13. Uch fazali simmetrik va nosimmetrik elektr zanjirlarda aktiv quvvat o'lchash sxemasini chizing.
14. Neytral simli yulduzcha shaklda ulangan uch fazali tok iste'molchi qarshiliklari, aktiv, induktiv va sig'imdan iborat bo'lgan holat uchun vektor ifodasini tuzing.
15. Neytral simsiz yulduzcha shaklda ulangan elektr zanjirning faza simi uzilgan yoki qisqa tutashtirilgan holatda liniya va fazada tok qanday o'zgaradi?
16. Uch fazali tok vektorlarini operator «a» orqali «to'g'ri» va «teskari» ketma-ketlik ifodalanish tenglamasini yozing. Fazalar ketma-ketligini izohlab bering.
17. Nosimmetrik uch fazali elektr zanjirlarni simmetrik tashkil etuvchilarga ajratib hisoblash usulini izohlab bering. «To'g'ri», «teskari» va «nol» ketma-ketliklar bir-biridan qanday farq qiladi?
18. Nima uchun simmetrik tashkil etuvchilarga ajratib hisoblash usuli faqatgina chiziqli elektr zanjirni hisoblashda ishlatiladi?
19. Uch fazali tok hosil qiluvchi fazaviy aylanuvchi magnit maydon hosil bo'lishini tushuntirib bering.
20. Uch fazali tok asinxron dvigatelining tuzilishi va ishlash prinsipini bilasizmi?
21. Yulduzcha shaklda biriktirilgan uch fazali tok iste'molchilarda qaysi holatda neytral nuqtali siljish yuzaga keladi va aksincha?
22. Simmetrik uch fazada tok aktiv quvvatini ikkita vattmetr yordamida o'lchanganda, tok bilan kuchlanish orasida burchakning qanday qiymatida bir xilda ko'rsatadi?
23. Neytral simsiz yulduzcha shaklda ulangan uch fazali elektr zanjir neytral tugun orasidagi $U_{00'}$ kuchlanish qanday ifodalanadi.
24. Quvvat koeffitsienti 0.8, umumiy quvvat 5.4 *kVt* bo'lgan elektrodvigatel 220 *V* kuchlanishga ulangan bo'lsa, tok qiymati qancha bo'ladi?
25. Neytral simli yulduzcha shaklida ulangan zanjir faza kuchlanishi $U_{\Phi} = 220V$ bo'lib, har bir fazaga 150 *VT* li 90 ta lampochka ulangan. Liniyadagi tok va sarf bo'ladigan quvvatni aniqlang.

VII. NOSINUSOIDAL ELEKTR ZANJIR

7.1. Asosiy nazariy tushunchalar

1. Davriy o'zgaruvchan funksiyalarni garmonik (Furye) qatorga yoyish.

Matematika kursidan ma'lumki, Dirixle shartini qanoatlantiruvchi har qanday uzluksiz davriy funksiya $f(t)$ni Furye qatoriga yoyish mumkin:

$$f(t) = A_0 + A_1 Sin(\omega t + \varphi_1) + A_2 Sin(2\omega t + \varphi_2) + ... + A_k Sin(k\omega t + \varphi_k)$$

A_0 – o'zgarmas tashkil etuvchi.

$A_1 Sin(\omega t + \varphi_1)$ – asosiy yoki birinchi garmonika.

$A_k Sin(k\omega t + \varphi_k)$ – «k» tartibli yuqori garmonika.

A_k va φ_k – yuqori garmonika amplituda va boshlang'ich fazasi.

Amalda elektrotexnika, elektronika, elektromagnit zanjirda uchraydigan nosinusoidal signallar miqdori (funksiyalar) Dirixle shartini qanoatlantiradi.

Furye qatorining koeffitsientini aniqlash uchun $f(t)$ funksiyani quyidagicha yozamiz:

$$f(\omega t) = A_0 + B_1 Sin\,\omega t + B_2 Sin 2\omega t + ... + B_k Sink\,\omega t + ... + C_1 Cos\,\omega t +$$
$$+ C_2 Cos 2\omega t + ... C_k Cosk\,\omega t$$

Bu shartning koeffitsientini analitik, grafik usulda hisoblash bilan yoki elektrotexnik o'lchov asboblari yordamida aniqlanadi.

Analitik usulda quyidagi ifodadan foydalaniladi:

$$A_0 = \frac{1}{T}\int_0^T f(\alpha)d\alpha \qquad B_k = \frac{1}{T}\int_0^T f(\alpha) Sink\alpha\, d\alpha$$

$$C_k = \frac{1}{T}\int_0^T f(\alpha) Cosk\,\alpha\, d\alpha$$

Ushbu koeffitsientning qiymatini aniqlagach, «k» yuqori garmonika amplitudasi va fazasini aniqlash mumkin:

$$A_k = \sqrt{B_k^2 + C_k^2}\,; \qquad tg\varphi_k = \frac{C_k}{B_k}\,; \qquad \varphi_k = arctg\frac{B_k}{C_k}\,;$$

yoki: $B_k = A_k Cos\varphi_k \quad C_k = A_k Sin\varphi_k$.

Agar davriy o'zgaruvchan nosinusoidal funksiya grafik ko'rinishda berilgan bo'lsa, koeffitsientni aniqlashda grafik usuldan (Chebishev usuli) foydalaniladi.

2. Nosinusoidal elektr zanjirni hlsoblash.

Chiziqli nosinusoidal elektr zanjirlarni hisoblashda ustma-ustlik (superpozitsiya) usuli tatbiq etilib, har bir garmonikaning zanjir parametriga ta'siri alohida aniqlanadi va ularning oniy qiymatlari yig'indisi belgilanadi. Masalan, kuchlanish ifodasi:

$u = u_0 + u_1 + u_2 + ... + u_k$ bunda: $u_k = U_{km} Sin(k\omega t + \varphi_k)$

tok: $i = I_0 + i_1 + i_2 + ... + i_k$ $i_k = I_{km} \sin(k\omega t + \varphi_{ik} - \varphi_{uk})$

Ketma-ket ulangan oddiy R,L,C zanjir uchun «k» garmonika tok amplitudasi:

$$I_{km} = \frac{U_{km}}{\sqrt{R^2 + \left(k\omega L - \frac{1}{k\omega C}\right)^2}}$$

«k» garmonika faza burchagi:

$$tg\varphi_k = \frac{k\omega L - \frac{1}{k\omega C}}{R}$$

Murakkab nosinusoidal elektr tok zanjirni hisoblashda mavjud bo'lgan elektr zanjirni hisoblash usullari (kompleks usuldan tashqari) tatbiq etilib, har bir garmonika qiymati alohida hisoblanib topiladi. Shuni takidlash kerak: k yuqori garmonika induktiv qarshillgi «k» martaga katta ($X_L = k\omega L$), sig'im qarshiligi «k» marta kamayadi ($X_C = 1/k\omega\ C$). Aktiv qarshilik chastotaga bog'liq emas va o'zgarmas bo'ladi (Zanjir chastotasi juda ham yuqori bo'lganda inobatga olinadi).

3. Nosinusoidal tok, kuchlanish va quvvatning haqiqiy yoki effektiv qiymati.

Nosinusoidal funksiya f(ωt) effektiv qiymati:

$$A = \sqrt{1/T \int_0^T f^2(\omega t) dt}$$

Tokning effektiv qiymati: I= $\sqrt{I_0^2 + I_1^2 + I_2^2 + ... + I_k^2}$

Kuchlanish effektiv qiymati: U= $\sqrt{U_0^2 + U_1^2 + U_2^2 + ...U_k^2}$

EYK effektiv qiymati: Ye= $\sqrt{E_0^2 + E_1^2 + E_2^2 + ... + E_k^2}$

Nosinusoidal tok quvvati har bir yuqori garmonika uchun aniqlangan o'rtacha quvvatlar yig'indisiga teng. Nosinusoidal tok aktiv quvvati (o'rtacha quvvat).

$P = P_0 + P_1 + ... + P_k = U_0I_0 + U_1I_1\cos\varphi_1 + U_2I_2\cos\varphi_2 + ...+ U_kI_k\cos\varphi_k$

Reaktiv quvvat:

$Q = Q_1 + Q_2 + ... + Q_k = U_1I_1\sin\varphi_1 + U_2I_2\sin\varphi_2 + ... + U_kI_k\sin\varphi_k$

To'la quvvat:

$S = UI = S_0 + S_1 + S_2 + ... + S_k$

Nosinusoidal tok aktiv quvvatning to'la quvvatga nisbati quvvat koeffitsienti deyiladi:

$$\alpha = \frac{P}{S} = \frac{P_o + P_1 + P_2 + ... + P_k}{\sqrt{U_0^2 + U_1^2 + U_2^2 + ... + U_k^2 + ... + U_k^2} \cdot \sqrt{I_0^2 + I_1^2 + I_2^2 + ... + I_k^2}}$$

Nosinusoidal elektr zanjirda quvvat koeffitsienti $\alpha = \frac{P}{UI} < 1$.

4. O'zgaruvchan tok kuchlanish formalarining zanjir parametrga bog'liqligi.

Yuqori garmonika formasi silliqlanish yoki buzilish $\frac{A_k}{A_1}$ nisbati bilan xarakterlanib, bu nisbat qancha katta bo'lsa, shunchalik nosinusoidal funksiya sinusoidal formadan farqli bo'ladi.

O'zgaruvchan elektr zanjirga kiruvchi yuqori garmonikali nosinusoidal tok nisbatini quyidagi ko'rinishda ifodalash mumkin:

$$\frac{I_{km}}{I_{1m}} = \frac{Z_1}{Z_k} \cdot \frac{U_{km}}{U_{1m}}$$

a) agar elektr tok zanjiri aktiv qarshilikga ega bo'lsa: $Z_k = Z_1 = R$

$$\frac{I_{km}}{I_{1m}} = \frac{U_{km}}{U_{1m}}$$

tok va kuchlanish nosinusoidal formalari o'xshash bo'ladi.

b) agar elektr zanjir induktiv qarshillkga ega bo'lsa:

$$Z_k = k\omega L; \; Z_l = \omega L;$$

Bunda: $\frac{I_{km}}{I_{1m}} \frac{1}{k} \frac{U_{km}}{U_{1m}}$

Tok garmonikasi kuchlanish garmonikasi amplutudaga nisbatan past bo'lib, induktivlik yuqori garmonikalarni so'ndiradi va tok formasini tekislaydi (silliqlaydi).

d) agar elektr zanjir sig'im qarshiligiga ega bo'lsa:

$$Z_k = 1 / k\omega C; \qquad Z_1 = 1 / \omega C$$

Bunda: $\frac{I_{km}}{I_m} = k\frac{U_{km}}{U_{1m}}$

Tok garmonikalari kuchlanish garmonikalariga nisbatan katta bo'lib, sig'im tok garmonikalari buziladi, kuchianish garmonikalari tekislanadi.

Reaktiv elementning bu xususiyati elektrotexnikada nosinusoidal formadagi tok va kuchlanishni filtrlash yoki silliqlashda keng foydalaniladi.

Reaktiv elementlardan tarkib topgan murakkab elektr zanjirning tarmoq yoki konturida ma'lum bir «k» garmonikali chastotada rezonans holat yuzaga kelishi mumkin.

5. Uch fazall elektr zanjirda yuqori garmonik tashkil etuvchllar.

Uch fazali elektr zanjir EYK va kuchlanishi nosinusoidal va bir xil formaga ega bo'lganda yuqori garmonikalar fazalar ketma-ketligi hosil bo'lib, 3n + 1, (butun son yoki nol) uch fazali tok sistemasida faza to'g'ri, ketma-ketligi (1, 7, 13... garmonikalar). 3n-1 bo'lganda uch fazali tok sistemasida fazalar teskari ketma-ketligi (5, 11, 17... garmonikalar) va n=0 bo'lganda «nol» fazalar ketma-ketligi (3, 9, 15...garmonikalar) ni hosil qiladi.

Uch fazali elektr zanjirda yuqori garmonikalarning bunday xususiyatlarini inobatga olgan holda:

a) generator chulg'amlari uchburchak shaklda ulangan bo'lsa:

$$I_\Delta = \sqrt{I_3^2 + I_9^2 + I_{15}^2 + \ldots}$$

Bunda: I_3, I_9, I_{15} yuqori 3, 9, 15 garmonikali tok bo'lib, generator chulg'amlari hosil qiluvchi konturdagi tok $I_3 = \frac{E_3}{z_3}$; $I_9 = \frac{E_9}{z_9}$ ga teng.

b) generator chulg'amlari yulduzcha va uchburchak shaklda ulanganda, liniyadagi kuchlanish:

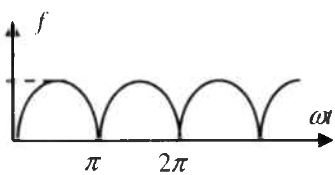
$$U_{Л} = \sqrt{U_{Л1}^2 + U_{Л5}^2 + U_{Л7}^2 + U_{Л11}^2} < \sqrt{3}U_{ф}.$$

d) neytral simsiz simmetrik uch fazali tok sistemalarining EYK simmetrik bo‘lganda 0 va 0' nuqta potensial kuchlanishi $U_{00'} \neq 0$ bo‘lib:

$$U_{00'} = \sqrt{E_3^2 + E_9^2 + E_{15}^2 + \dots}$$

e) neytral simli iste’molchilar qarshiligi teng bo‘lganda ham: $I_0 \neq 0$ teng bo‘lmasdan: $I_0 = 3\sqrt{I_3^2 + I_9^2 + I_{15}^2}$

7.2. Masalalar yechish va uslubiy ko‘rsatmalar



Masala 7.1. Amplituda kuchlanishi $U_m = 100\ V$ bo‘lgan to‘g‘rilagich (viprya-mitel) hosil qiladigan $f = (\omega t)$ funksiyasini $U = 100\ V$ Furye qatoriga yoyish bilan o‘zgarmas, birinchi va U_{m2} ikkmchi yuqori garmonika tarkibi aniqlansin.

Yechish.

Kuchlanish funksiyasinimg ifodasi: $U_{\omega t} = U_m(\sin\omega t) = 100(\mathrm{sim}\,\omega t)$

Furye qatoriga yoyishda berilgan nosinusoidal funksiyaning ordinata o‘qiga simmetrik ekanligini inobatga olamiz. Bunda kuchlanish o‘rtacha qiymati:

$$U_0 = \frac{1}{T}\int_0^T U_m(\sin\omega t)d\omega t = \frac{1}{\pi}\int_0^T U_m \sin\omega t d\omega t = \frac{2U_m}{\pi}$$

yoki $U_0 = \dfrac{2 \cdot 100}{3{,}14} = 63{,}6\ V$

Birinchi garmonika koeffitsienti:

$U_1 = \dfrac{1}{\pi}\displaystyle\int_0^T U_m(\sin\omega t)\cos\omega t d\omega t = 0$ – ya’ni, yarim davrdagi integrali nolga teng.

Ikkinchi garmonika koeffitsienti:

$$U_2=\frac{1}{\pi}\int_0^{2\pi}U_m(\sin\omega t)\cos 2\omega t d\omega t=\frac{U_m}{\pi}\left[\int_0^{\pi}\sin\omega t\cos 2\omega t d\omega t-\int_{\pi}^{2\pi}\sin\omega t\cos\omega t d\omega t\right]=$$

$$=\frac{U_m}{\pi}\left[\left(-\frac{1}{3}\cos 3\omega t+\cos\omega t\right)\Bigg|_0^{\pi}-\left(-\frac{1}{3}\cos 3\omega t+\cos\omega t\right)\Bigg|_{\pi}^{2\pi}\right]=$$

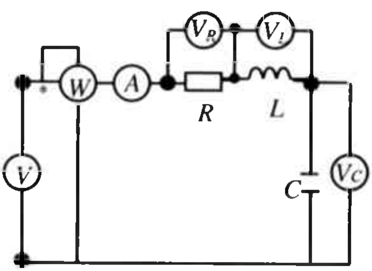
$$=\frac{U_m}{\pi}\left[\left(\frac{1}{3}+\frac{1}{3}-1-1\right)-\left(-\frac{1}{3}-\frac{1}{3}+1+1\right)\right]=-\frac{4U_m}{3\pi}(V)$$

yoki: $U_2=\dfrac{4\cdot 100}{3\cdot 3{,}14}=-42{,}4\ V$

Kuchlanish oniy qiymati:

$$U_{(\omega t)}=\frac{2U_m}{\pi}-\frac{4U_m}{3\pi}\cos 2\omega t+...=63{,}6-42{,}4\cos 2\omega t$$

Masala 7.2. Ketma-ket sxemada ulangan elektr zanjir parametri: *R=3 Om, L=636mGn, C=31,8 mkf* bo‘lib, 1, 3, 5 yuqori garmonikalardan tarkib topgan nosinusoidal kuchlanish nisbatlari $\frac{U_5}{U_1}=0{,}2$, $\frac{U_3}{U_1}=0{,}3$ ga teng. Sxemaga ulangan voltmetr ko‘rsatish qiymati *U=128 V*. Barcha elektr o‘lchov asbohlarining ko‘rsatish qiymati aniqlansin.



Yechish.

Elektrodinamik o‘lchov asbob tok va kuchlanish effektiv qiymatini ko‘rsatadi: $U=\sqrt{U_1^2+U_3^2+U_5^2}=U_1\sqrt{1^2+0{,}3^2+0{,}2^2}=U_1\cdot 1{,}06$

Bundan: $U_1=\dfrac{128}{1{,}06}=120\ V$; $U_3=0{,}3\cdot 120=36{,}6\ \ V$; $U_5=0{,}2\cdot 120=24\ \ V$

Birinchi garmonikaga nisbatan zanjir reaktiv qarshiligini aniqlaymiz:

$$\omega=2\pi\cdot 500=3140\frac{1}{sek}\qquad X_{L_1}=\omega_1 L=3140\cdot 0{,}636\cdot 10^{-3}=2\ Om$$

$$X_{C_1}=\frac{1}{\omega_1 C}=\frac{10^6}{3140\cdot 31{,}8}=10\ Om\qquad X_1=X_{L_1}-X_{C_1}=2-10=-8\ Om$$

Umumiy qarshiligi: $Z_1 = \sqrt{R^2 + X_1^2} = \sqrt{9 + 64} = 8{,}5\ Om$

Yuqori uchini garmonika uchun:

$$X_3 = 3\omega_1 L - \frac{1}{3\omega_1 C} = 3 \cdot 2 - \frac{10}{3} = 2{,}7\ Om$$

To‘la qarshihk: $Z_3 = \sqrt{R^2 + X_3^2} = 4\ Om$

Beshinchi yuqori garmonika uchun: $X_5 = 5\omega_1 L - \frac{1}{5\omega_1 C} = 10 - 2 = 8\ Om$

To‘la qarshilik: $Z_5 = \sqrt{R + X_5} = 8{,}5\ Om$

Har bir garmonik tok effektiv qiymati:

$$I_1 = \frac{U_1}{Z_1} = 14\ A\ ; \quad I_3 = \frac{U_3}{Z_3} = 9\ A\ ; \quad I_5 = \frac{U_5}{Z_5} = 2{,}8\ A$$

yoki $I = \sqrt{I_1^2 + I_3^2 + I_5^2} = 17\ A$

Vattmetr ko‘rsatgan quvvat: $P = RI^2 = 3 \cdot 17^2 = 867\ Vt$

Induktivlik va sig‘im qarshiliklarida har bir yuqori garmonikalar hosil qiladigan kuchlanishlar qiymati :

$$U_{L_1} = \omega_1 L I_3 = 14 \cdot 2 = 28\ \ V \qquad U_{L_3} = 3\omega_1 L I_3 = 9 \cdot \frac{10}{3} = 30\ \ V$$

$$U_{L_5} = 5\omega_1 L I_5 = 28\ \ V \qquad U_{C_1} = \frac{1}{\omega_1 C} I_1 = 14 \cdot 10 = 140\ \ V$$

$$U_{C_3} = \frac{1}{3\omega_1 C} I_3 = 9 \cdot \frac{10}{3} = 30\ \ V \qquad U_{C_5} = \frac{1}{5\omega_1 C} I_5 = 5{,}6\ \ V$$

Demak, mduktivlikga ulangan voltmetr ko‘rsatishi:

$$U_L = \sqrt{U_{L_1}^2 + U_{L_3}^2 + U_{L_5}^2} = \sqrt{28^2 + 30^2 + 28^2} = 676\ \ V$$

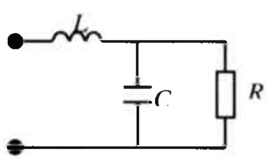
Sig‘imga ulangan voltmetr ko‘rsatishi:

$$U_C = \sqrt{U_{C_1}^2 + U_{C_3}^2 + U_{C_5}^2} = 144\ \ V$$

Aktiv qarshilikka ulangan voltmetr ko‘rsatishi:

$$U_R = R \cdot I = 17 \cdot 3 = 51\ \ V$$

Masala 7.3. Sxemada keltirilgan elektr zanjirlar parametri: *L=0,5 Gn,C=4 mkf, R=300 Om* ga teng, hamda chastotasi *f=100Gs* bo‘lib, $U = 100 \sin^3 \omega t$ nosinusoidal kuchianishga ulangan. Tarmoq toklari oniy qiymati o‘rganilib, buzilish koeffitsienti aniqlansin.



Yechish. Kuchianish ifodasini Furye qatoriga yoyamiz:

$$\sin^3 \omega t = \sin \omega t \cdot \frac{1-\cos 2\omega t}{2} = \frac{1}{2}(\sin \omega t - \sin \omega t \cos 2\omega t) = \frac{3}{4}\sin \omega t - \frac{1}{4}\sin 3\omega t;$$

Bunda zanjir kuchlanishining oniy qiymati:

$$U = 75\sin \omega t - 25\sin 3\omega t = 75\sin \omega t + 25\sin(3\omega t + \pi)$$

Birinchi garmonika uchun zanjir qarshiligi:

$$\underline{Z}_{L_1} = j\omega L_1 = j628 \cdot 0,05 = j3,14Om; \quad \underline{Z}_{C_1} = \frac{1}{j\omega C} = -j398Om$$

Bunda: $\omega = 2\pi f = 628 \frac{1}{sek}$

Zanjirning kompleks to'la qarshiligi:

$$\underline{Z}_1 = \underline{Z}_{L_1} + \frac{R \cdot \underline{Z}_{C_1}}{R + \underline{Z}_{C_1}} = j31.4 + \frac{300(-j398)}{300 - j398} = 192 - j112.6 = 220e^{-j30^0}$$

Tarmoqdagi tok kompleks ifodasi:

$$\dot{I}_{L_1} = \frac{75}{\sqrt{2} \cdot 220e^{-j30^0}} = 0,24e^{j30^0} \quad \dot{I}_{C_1} = \frac{\dot{I}_{L_1} R}{R + \underline{Z}_{C_1}} = \frac{0,24e^{j30^0} \cdot 300}{300 - j398} = 0,145e^{j83^0}$$

$$\dot{I}_{R_1} = \frac{\dot{I}_{L_1} \underline{Z}_{C_1}}{R + \underline{Z}_{C_1}} = \frac{0,24e^{j30} \cdot 398e^{-j90^0}}{300 + j398} = 0,19e^{-j6^0 40'}$$

Tokning oniy qiymati:

$$i_{L_1} = 0.24\sqrt{2}\sin(\omega t + 30^0) \qquad (A)$$

$$i_{C_1} = 0.145\sqrt{2}\sin(\omega t + 83^0 20') \qquad (A)$$

$$i_{R_1} = 0.19\sqrt{2}\sin(\omega t - 6^0 40') \qquad (A)$$

Uchinchi yuqori garmonika uchun reaktiv qarshilik:

$$\underline{Z}_{L_3} = j3\omega L = j94\ Om \qquad \underline{Z}_{C_3} = -j\frac{10^6}{3 \cdot 628 \cdot 4} = -j133\,Om$$

To'la kompleks qarshilik:

$$\underline{Z}_3 = \underline{Z}_{L_3} + \frac{R\underline{Z}_{C_3}}{R + \underline{Z}_{C_3}} = j94 + \frac{300(-j133)}{300 - j133} = 49.6e^{-19^0}$$

Uchinchi garmonika tarmoqdagi tok kompleks ifodasi:

$$\dot{I}_{L_3} = \frac{25e^{j180^0}}{\sqrt{2}49,6e^{-j19^0}} = 0,36e^{j19^0} \quad \dot{I}_{C_3} = \frac{0,356e^{j199^0}}{300 - j179} = 0,144e^{j133^0}$$

$$\dot{I}_{R_3} = \frac{0,356e^{j199^0}}{300 - j179} = 0,144e^{j133^0}$$

Tokning oniy qiymati:

$$i_{L_3} = 0,356\sqrt{2}\sin(3\omega t + 191°) \ (A) \quad i_{C_3} = 0,325\sqrt{2}\sin(3\omega t + 223^0) \ (A)$$

$$i_{R_3} = 0,144\sqrt{2}\sin(3\omega t + 132^0) \ (A)$$

Tarmoqdagi tokning effektiv qiymati:

$$I_L = \sqrt{I_{L_1}^2 + I_{L_3}^2} = \sqrt{0,24^2 + 0,356^2} = 0,43\ A \quad I_C = \sqrt{I_{C_1}^2 + I_{C_3}^2} = 0,373\ A$$

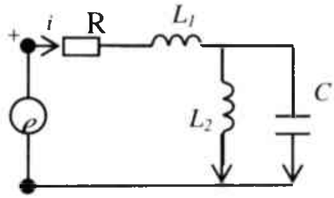
$$I_R = \sqrt{I_{R_1} + I_{R_3}} = 0,24\ A$$

Buzilish koeffitsienti:

$$k_L = \frac{I_{L_3}}{I_{L_1}} = \frac{0,356}{0.43} = 0,83 \quad k_C = \frac{I_{C_1}}{I_{C_3}} = \frac{0,325}{0,373} = 0,87 \quad k_R = \frac{I_{R_1}}{I_{R_3}} = \frac{0,144}{0,240} = 0,33$$

Demak, sig'imdan o'tuvchi tok formasi ko'proq buzilar ekan.

Masala 7.4. Nosinusoidal elektr zanjirning parametri *R=300 Om, L_1=0.25 Gn, L_2=0.1 Gn, C=3,3 mkf* va chastota *ω=1000 rad/sek* bo'lib, *E=60+250sinωt+100sin3ωt* garmonikalardan tarkib topgan manbaga ulangan. Birinchi tarmoqdagi tokning oniy, effektiv qiymati va aktiv quvvati aniqlansin.



Yechish. O'zgarmas tok kondensatordan oqib o'tmasligi *(I_C=0)* va induktiv qarshilik nolga tengligini *(L=0)* hisobga olsak:

$$I_0 = \frac{E_0}{R_1} = \frac{60}{300} = 0,2\,A$$

Masalani kompleks usul bilan yechamiz. Bunda birinchi garmonika uchun kompleks tok amplitudasi:

$$\dot{I}_{m_1} = \frac{\dot{E}_{m_1} e^{j0^0}}{\underline{Z}_1}$$

Reaktiv qarshiliklarni aniqlaymiz:

$$X_1 = \omega L_1 = 1000 \cdot 0,25 = 250 Om$$

$$X_2 = \omega L_2 = 1000 \cdot 0,1 = 100 Om$$

Sig'imdagi qarshilik: $X_C = \frac{1}{\omega C} = \frac{1}{1000 \cdot 3,3 \cdot 10^{-6}} = 300\,Om$

Birinchi garmonikadagi kompleks to'la qarshilik:

$$\underline{Z}_1 = R_1 + j\,\omega L_1 + \frac{j\,\omega L_2\left(-j\,\dfrac{1}{\omega C}\right)}{j\,\omega L_2 - j\,\dfrac{1}{\omega C}} = 300 + j\,400 = 500e^{\,j\,53^0}$$

Tok amplituda qiymati:

$$\dot{I}_{m_1} = \frac{250e^{\,j0^0}}{500\cdot e^{\,j\,53^0}} = 0{,}5e^{-j53^0} \quad (A)$$

Tok oniy qiymati:

$$i_1 = 0.5\sin\left(\omega t - 53^0\right) \qquad (A)$$

Uchinchi garmonikadagi tokni aniqlaymiz. Manba kuchlanishi:

$$e_3 = 100\ \sin\ \omega t = \dot{E}_{m_3} \cdot 100\, e^{\,j\,0^0}$$

Uchinchi garmonika uchun reaktiv qarshilik:

$$X_{L1} = 3\omega L_1 = 250\ Om, \qquad X_{L_2} = 3\omega L_2 = 300\ Om, \qquad X_C = \frac{1}{3\omega C_3} = 100\ Om$$

Umumiy kompleks qarshilik:

$$\underline{Z}_{(3)} = R_1 + jX_{L_1} + \frac{jX_{L_2}\left(\dfrac{-1}{jX_C}\right)}{jX_{L_2} - \dfrac{1}{jX_C}} = 300 + j750 + \frac{j300(-j100)}{j300 - j100} = 300 + j600 = 675e^{j63^0}\,Om$$

Uchinchi garmonika tok amplitudasming kompleks ifodasi:

$$\dot{I}_{m_3} = \frac{\dot{E}_{m_3}}{\underline{Z}_{(3)}} = \frac{100}{671\cdot e^{\,j\,63^0}} = 0{,}15\cdot e^{-j\,63^0}$$

Tok oniy qiymati:

$$i_3 = 0{,}15\ \sin\left(3\omega t - 63^0\right)$$

Zanjirga kiruvchi tok oniy qiymati :

$$i_1 = 0{,}2 + 0{,}5\sin\left(\omega t - 53^0\right) + 0{,}15\sin\left(3\omega t - 63^0\right) \qquad A$$

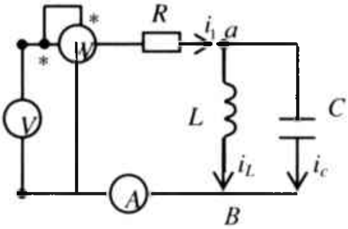
Tok effektiv qiymati:

$$I = \sqrt{0{,}2^2 + \left(\frac{0{,}5}{\sqrt{2}}\right)^2 + \left(\frac{0{,}15}{\sqrt{2}}\right)^2} = 0{,}42 \quad A$$

Zanjir aktiv quvvati har bir garmonika tok va kuchlanish oniy qiymati ifodasidan:

$$P = P_0 + P_1 + P_3 = 60\cdot 0.2 + \frac{250}{\sqrt{2}}\cdot\frac{0.5}{\sqrt{2}}\cos 53^0 + \frac{100}{\sqrt{2}}\cdot\frac{0.15}{\sqrt{2}}\cos 63^0 = 52.8\,Vt$$

Masala 7.5. Berilgan elektr zanjirning induktivlikdagi nosinusoidal tok



$i_L = 4+8\sin\omega t+6\sin(2\omega t+90°)$

bo‘lib, qarshilik parametri

$R=\omega L=5\ Om,\ \frac{1}{\omega C}=20\,Om$ ga teng. Elektr o‘lchov asboblari – ampermetr, voltmetr va vattmetrning ko‘rsatish qiymati aniqlansin.

Yechish. Induktivlikdagi tok ma’lum bo‘lganligi sababli har bir garmonika uchun parallel ulangan tarmoq kuchlanishini aniqlaymiz.

$$U_{Lm_1} = I_{Lm_1} \cdot X_{L_1} = 8 \cdot 5 = 40\ V$$

$$U_{Lm_2} = I_{Lm_2} \cdot X_{L_2} = 6 \cdot 10 = 60\ V$$

Sig‘im va induktivlikdagi kuchlanish ohiy qiymati:

$$U_C = U_L = 40\sin(\omega t + 90^0) + 60\sin(2\omega t + 180^0) = 40\sin(\omega t + 90^0) - 60\sin 2\omega t$$

Birinchi garmonika uchun parallel ulangan L, C kompleks reaktiv qarshilik:

$$\underline{Z}_{ab_1} = X_{ab_1} = \frac{jX_{L_1} \cdot jX_{C_1}}{jX_{L_1} + jX_{C_1}} = -j\frac{20 \cdot 5}{5-20} = -j6,67\ Om$$

Birinchi garmonika tok amplitudasi: $I_{m_1} = \frac{U_{Lm_1}}{Z_{ab_1}} = \frac{40}{6.67} = 6\ A$

Ikkinchi garmonika uchun: $\underline{Z}_{ab_2} = \dfrac{j2\omega L \cdot \dfrac{1}{j2\omega C}}{j\left(2\omega L - \dfrac{1}{2\omega C}\right)} = \infty$

Demak parallel ulangan reaktiv elementlarda tok rezonansi yuzaga kelib, birinchi tarmoqda ikkinchi garmonika tok ($I_{2m}=0$) nolga teng. Tok oniy qiymati:

$$i = I_0 + I_{m_1}\sin(\omega t + \varphi_u - \varphi) = 4 + 6\sin(\omega t + 90^0 - 90^0) = 4 + 6\sin\omega t$$

Ampermetrdagi tok: $I = \sqrt{4^2 + \left(\frac{6}{\sqrt{2}}\right)^2} = 5,8\ A$

Har bir yuqori garmonika uchun zanjirning umumiy qarshiligini aniqlaymiz. Nolinchi va birinchi garmonika uchun aktiv qarshilik: $R_0 = R = 5\ Om$

Birinchi garmonika to‘la qarshiligi:

$$Z_1=\sqrt{R^2+\left(X_{ab_1}\right)^2}=\sqrt{5^2+(6.7)^2}=8{,}3\,Om$$

Ikkinchi garmonikada $Z_2=\infty$

Nar bir garmonika uchun kuchlanishni topamiz:

$$U_0=I_0R_0=4\cdot 5=20\,V\quad U_{m_1}=I_{m_1}\cdot Z_1=6\cdot 8{,}3=50\,V\quad U_{m_2}=U_{Lm_2}=60\,V$$

Faza burchagi $\varphi_1=arctg=\dfrac{X_{ab_1}}{R}=\dfrac{6.67}{5}=53^0$

Zanjirning umumiy kuchlanish oniy qiymati:

$$U=U_0+U_1+U_2=U_0+Um_1\sin(\omega t+\varphi_1)+Um_2\sin 2\omega t=$$
$$=20+50\sin(\omega t+53^0)-60\sin 2\omega t$$

Voltmetr ko‘rsatishi bo‘yicha:

$$U=\sqrt{U_0^2+U_1^2+U_2^{-2}}=\sqrt{20^2+(\frac{50}{\sqrt{2}})^2+(\frac{60}{\sqrt{2}})^2}=58{,}6\,V$$

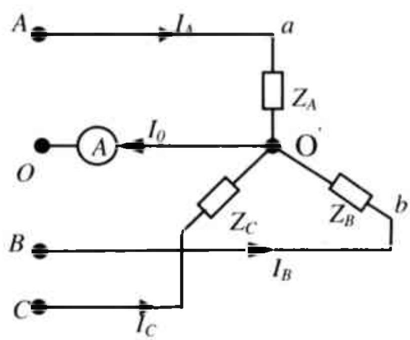
O‘rtacha quvvat yoki voltmetr ko‘rsatishi:

$$P=U_0I_0+U_1I_1\cos\varphi_1+U_2I_2\cos\varphi_2=170\ Vt.$$

Masala 7.6. Yulduzcha shaklda ulangan tok zanjirining iste’molchi kompleks qarshiligi:

$$\underline{Z}_1=\underline{Z}_2=\underline{Z}_3=(3+j6)Om$$

$U_\Phi=141\sin\omega t+42{,}5\sin 3\omega t+5\sin 5\omega t B$ bo‘lib, faza kuchlanishi generatorga ulangan. Neytral sim toki I_0 fazadagi tokning oniy qiymati va uch fazali tok quvvati aniqlansin.



Yechish.

Birinchi garmonika uchun iste’molchi faza kuchianishlari $\dot{U}_1=100\,V$; $\dot{U}_2=100e^{-j120^0}\,V$; $\dot{U}_3=100e^{j120^0}\,V$. Tokmng effektiv qiymati:

$$I_{\phi_1}=\frac{U}{\underline{Z}}=\frac{100}{\sqrt{3^2+6^2}}=15\,A$$

Faza burchagi: $\varphi=arctg\,\dfrac{X_L}{R}=63^0 30'$

Neytral simda birinchi garmonika bo‘lmaydi. ($I_0=0$)

Uchinchi garmonika fazadagi kuchlanish:

$$\dot{U}_1 = 30\,V, \qquad \dot{U}_2 = 30e^{-j3120^0} = 30\,V, \qquad \dot{U}_3 = 30^{j3120^0} = 30\,V.$$

Kuchlanish effektiv qiymati: $U=30\ V$

Faza tok effektiv qiymati: $I_{\phi_3} = \frac{U}{Z} = \frac{30}{\sqrt{3^2+18^2}} = 1{,}65\ A$

Farqi: $\varphi_3 = arctg\,\frac{X_{L_3}}{R} = \frac{3\omega L}{R} = 80^0 30'$

Neytral simda uchinchi garmonikadagi tok fazadagi tokdan uch barobar katta:

$$I_0 = 3I_{\phi_3} = 3\cdot 1.65 = 5\ A$$

Liniya kuchlanishlari tarkibida uchinchi garmonika yo'q. ($U_{l(3)}=0$).

Beshinchi garmonika uchun fazadagi kuchianish:

$$\dot{U}_1 = 3{,}54\,V; \quad \dot{U}_2 = 3{,}54e^{-j5(120^0)} = 3{,}54e^{j120^0}\,V; \quad \dot{U}_3 = 3{,}54e^{j5(120^0)} = 3{,}54e^{-j120^0}\,V$$

Kuchianish effektiv qiymati: $U=3{,}54\ V$

Fazadagi tok: $I_{\phi_5} = \frac{U}{\sqrt{R^2+(5\omega L)^2}} = \frac{3{,}54}{\sqrt{3^2+30^2}} = 0{,}117\ A$

Faza farqi: $\varphi_5 = arctg\,\frac{5\omega L}{R} = 84^0$

Neytral simda beshinchi garmonikadagi tok nolga teng. ($I_{0(5)}=0$)

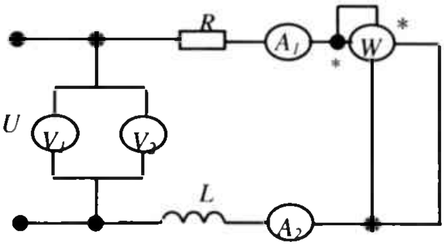
Birinchi fazadagi tok oniy qiymati:

$$i_1 = i_\phi = 15\sqrt{2}\sin(\omega t - 63°30') + 1{,}65\sqrt{2}\sin(3\omega t - 80°30') +$$
$$+0{,}117\sqrt{2}\sin(5\omega t - 84°15')$$

Iste'molchilarda sarf bo'ladigan uch fazali tok o'rtacha quvvati:

$$P = 3\left(U_1 I_1 \cos\varphi_1 + U_3 I_3 \cos\varphi_3 + U_5 I_5 \cos\varphi_5\right) \approx 9980\ Vt$$

Masala 7.7. Sxemada berilgan induktiv g'altak kuchianishi $U = U_0 + U_1 \sin\omega t\,(V)$ bo'lib, zanjirga ulangan elektr o'lchov asboblari: A_1 va V_1–magnitoelektrik, A_2,V_2 va W – elektrodinamik. Bu o'lchov asboblari ko'rsatishi: $I_1=4A$, $I_2=5A$, $U_1=30V$, $U_2=90V$, $P=190Vt$ bo'lganda, quvvat koeffitsienti g'altak parametrlari va aktiv qarshilikning o'zgarmas tokga nisbatan qiymati aniqlansin.



Yechish.

Magnitoelektrik sistemali elektr o‘lchov asboblari o‘zgarmas tok yoki kuchlanish qiymatini o‘lchaydi. (I_0 , U_0)

Elektrodinamik sistemali elektr o‘lchov asboblari esa tok va kuchlanishning effektiv qiymatini ko‘rsatadi. (I_I , U_I)

Shunga asosan: $U_1 = \sqrt{U_2^2 - U_1^2} = \sqrt{90^2 - 30^2} = 85V$

$I_1 = \sqrt{I_2^2 - I_0^2} = \sqrt{5^2 - 4^2} = 3\ A$

Nol garmonika quvvati: $P_0 = U_1 I_1 = 30 \cdot 4 = 120\,Vt$

Birinchi garmonika quvvati: $P_1 = P_2 - P_0 = 190 - 120 = 70\,Vt$

Sinusoidal o‘zgaruvchan birinchl garmonikadagi to‘la qarshilik:

$$Z_{(1)} = \frac{U_1}{I_1} = \frac{80}{3} = 26{,}6\,Om$$

Aktiv qarshilik: $R_{(1)} = \frac{P_1}{I_1^2} = \frac{70}{3^2} = 7{,}78\,Om$

Induktiv qarshilik: $X_L = \sqrt{Z_1^2 - R_1^2} = 25{,}5\,Om$

O‘zgarmas tokga nisbatan aktiv qarshilik: $R_0 = \frac{U_1}{I_1} = \frac{30}{4} = 7.5\,Om$

Siljish koeffitsienti: $k = \frac{R_{(1)}}{R_0} = \frac{7.78}{7.5} = 1.036$

Masala 7.8. Ikki qutbli nosinusoidal zanjir kuchianishi:

$$U = 100 + 50\sin\omega t - 20\sin\left(3\omega t + \frac{\pi}{6}\right) + 10\sin\left(5\omega t - \frac{\pi}{3}\right)$$

$i = 2 + 10\sin\left(3\omega t - \frac{\pi}{3}\right) + 4\sin 5\omega t$ ulangan.

Kuchlanish va tok haqiqiy qiymati, aktiv, reaktiv, to‘la quvvat, siljish va quvvat koeffitsenti aniqlansin.

Yechish. Kuchlanish va tok haqiqiy qiymati:

$$U=\sqrt{U_0^2+\frac{U_{1m}^2}{2}+\frac{U_{3m}^2}{2}+\frac{U_{5m}^2}{2}}=\sqrt{1000+\frac{2500}{2}+\frac{400}{2}+\frac{100}{2}}=\sqrt{11500}==107,2V$$

$$I=\sqrt{4+\frac{100}{2}+\frac{16}{2}}=\sqrt{62}=7,87A$$

Aktiv quvvat yuqori garmonika algebraik yig'indisidan iborat bo'lib:

$$P=U_0I+U_3\dot{I}_3\cos\varphi_3+U_5\dot{I}_5\cos\varphi_5=100\cdot 2+\frac{20}{\sqrt{2}}\cos\varphi_3+U_5I_5\cos\varphi_5=$$

$$=100\cdot 2+\frac{20}{\sqrt{2}}\cdot\frac{10}{\sqrt{2}}\cos\left(-90^{\circ}\right)+\frac{10}{\sqrt{2}}\cdot\frac{4}{\sqrt{2}}\cos(-60^{\circ})=200+0+20\frac{1}{2}=210Vt$$

Bu yerda: $\left(\varphi_3=\varphi_{u3}-\varphi_{i3}=\frac{\pi}{6}-\pi+\frac{\pi}{3}=\frac{\pi}{2}\right)\quad \varphi_5=\varphi_{u5}-\varphi_{i5}=-\frac{\pi}{3}$

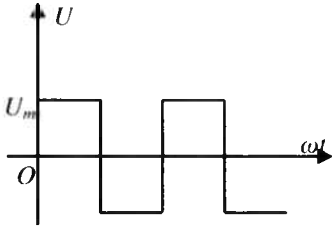
Reaktiv quvvat:

$$Q=U_3I_3\sin\varphi_3+U_5I_5\sin\varphi_5=\frac{20}{\sqrt{3}}\cdot\frac{10}{\sqrt{3}}\sin\left(-90^{\circ}\right)+\frac{10}{\sqrt{2}}\cdot\frac{4}{\sqrt{2}}\sin\left(-60^{\circ}\right)=-173,3VAR$$

To'la quvvat: $S=UI=107,2\cdot 7,87=855VA$.

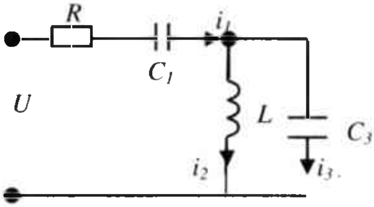
7.3. Mustaqil yechish uchun masalalar

Masala 7.1. Kuchlanish amplituda qiymati U_m=*100 B* bo'lgan funksiyani Furye qatoriga yoyish bilan 1,2,3 garmonikalar ifodasi yoki kuchlanish oniy qiymati aniqlansin .



Javob: $U=127,3\sin\omega t+42,4\sin 3\omega t+25,5\sin\omega t(V)$

Masala 7.2. Berilgan sxemaning qarshilik parametri: R_l=*100Om*, $X_{L_1}=100\,Om$, $X_{C_1}=X_{C_3}=200\quad Om$ bo'lib, nosinusoidal manba kuchlanishl $U = 100 + 500\sin\omega t + 200\sin\omega t$ ga ulangan. Tarmoqdagi tok oniy qiymati aniqlansin.



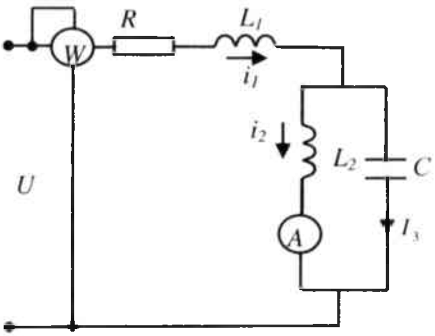
Javob:

$i_1 = 3,54\sin(\omega t - 45°) + 0,743\sin(2\omega t + 68°)A$

$i_2 = 7,08\sin(\omega t - 45°) + 0,743\sin(2\omega t + 12°)A$

$i_3 = 3,54\sin(\omega t + 135°) + 1,5\sin(2\omega t + 68°)A$

Masala 7.3. Berilgan sxema bo‘yicha parametrlar *R=20 Om, L_1=20 mGn, L_2=60 mGn, C=16.6 mkf, ω=1000 rad/sek* bo‘lib, nosinusoidal kuchlanishga $U = 40 + 120\sin\omega t + 60\sin 2\omega t$ ulangan. Birinchi tarmoqdagi tok i_1 va elektr o‘lchov asbobining ko‘rsatish qiymatini aniqlang.

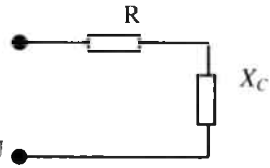


Javob: $i_1 = 2 + 1,06\sin(\omega t + 45°)A$

$I_2 = 2.47 \quad A, \quad P = 102.5 \quad Vt$

Masala 7.4. Elektr zanjir qarshilik parametri $R_1 = 10\,Om$, $X_C = \dfrac{1}{\omega C} = 27\,Om$ bo‘lib, nosinusoidal kuchianish

$U = 100 + 200\sin\omega t + 30\sin(3\omega t - 90°) + 50\sin(5\omega t + 45°)$ ga ulangan. Tokning oniy qiymati, kuchlanishi va quvvati aniqlansin.

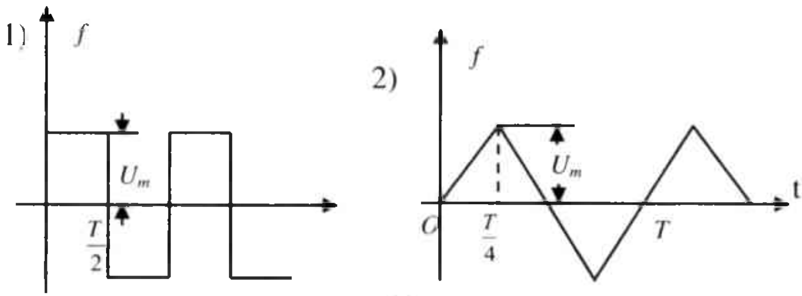


Javob:

$$i = 0,74\sin(\omega t + 88°) + 0,33\sin(3\omega t - 6°30') + 0,97\sin(5\omega t + 124°30')$$

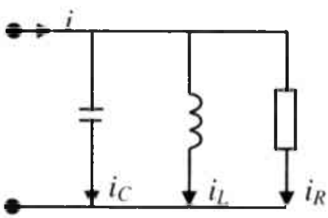
$$U = 178\ V, \qquad I = 0.863\ A, \qquad P = 7.47\ Vt$$

Masala 7.5. Grafikda keltirilgan kuchlanish funksiyasi uchun amplituda k_a, forma k_f va siljish k_{sil} koeffitsienti aniqlansin.



Javob: $1)\ k_a = k_\phi = 1;\quad k_{sil} = \frac{2\sqrt{2}}{\pi}\qquad 2)\ k_a = \sqrt{3};\quad k_\phi = \frac{2}{\sqrt{3}};\quad k_{sil} = \frac{4\sqrt{6}}{\pi^2}$

Masala 7.6. Berilgan sxema parametri: $R = \frac{1}{\omega C} = \omega L = 10\ Om$ bo'lib, $u = (200\sin\omega t + 60\sin 3\omega t + 30\sin 5\omega t)\ (V)$ kuchlanishga ulangan. Tokning oniy qiymati, effektiv qiymat va quvvati P aniqlansin.



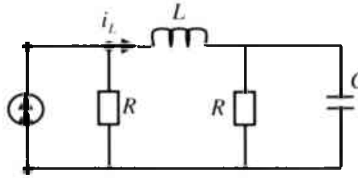
Javob: $i = 20\sin\omega t + 17{,}4\sin(3\omega t + 67°) + 14{,}7\sin(5\omega t + 178°)$

$I = 32\ A, \qquad P = 4450\ Vt$

Masala 7.7. (7.6) masaladagi parallel zanjir parametri $\omega = 1000\frac{1}{sek}$ $C = 10\ mkf$, $L = 0{,}1gn$, $g = \frac{1}{R} = 0{,}01sim$ bo'lib, nosinusoidal $u = 100\sin(\omega t + 30°) + 30\sin 3\omega t + 10\sin(5\omega t - 135°)$ kuchlanishga ulangan. Tarmoq toklari oniy $i_{R(t)}$, $i_{L(t)}$, $i_{c(t)}$ va kuchlanish effektiv qiymati aniqlanib, vaqtga nisbatan o'zgaruvchan diagrammasi chlzilsin.

Javob: $U = 70\ V$, $I_R = 0{,}71A$, $I_L = 0{,}74A$, $I_c = 1{,}02A$.

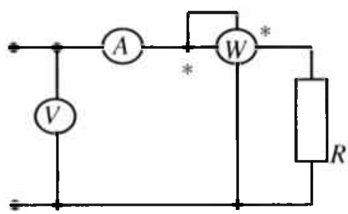
Masala 7.8: Nosinusoidal elektr zanjir parametri: $R = 1\ Om$, $X_C = 1\ Om$, $X_L = 0{,}5\ Om$. $i = 10 + 30\sqrt{2}\sin\omega t + 15\sqrt{2}\sin 2\omega t$ tok manbaiga ulangan. Induktivlikdagi tok oniy va haqiqiy qiymati aniqlansin.



Javob: $i_L = 5 + 28{,}2\sin\omega t + 15{,}8\sin(2\omega t - 26°)$;

$I_L = 23{,}4\ A$

Masala 7.9. Elektr zanjir $U = 220 + 180\sin 314t$ nosinusoidal kuchlanishga ulangan bo'lib, $R = 10\ Om$ qarshiligiga ega. Elektromagnit o'lchov asboblari: ampermetr, voltmetr va vattmetr ko'rsatish qiymatini aniqlang.

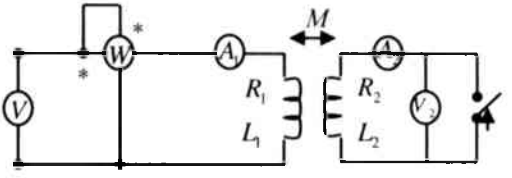


Javob: $U = 254\ V$, $I = 25{,}4\ A$, $P = 6450\ VT$.

Masala 7.10. 7.3 masaladagi aralash sxemada ulangan nosinusoidal elektr zanjir parametri: $L_1 = 2{,}5\ mgn$, $L_2 = 20\ mgn$ $C = 50\ mkf$, $R = 50\ Om$ bo'lib, $U = 50 + 60\sqrt{2}\sin 1000t + 200\sqrt{2}\sin 3000t$ kuchlanishga ulangan. Tarmoqlarga ulangan *elektrodinamik turdagi ampermetr ko'rsatish* tok qiymatini aniqlang:

Javob: $I_1 = 4{,}12\ A$, $I_2 = 3{,}24$, $I_3 = 5{,}4\ A$.

Masala 7.11. Havo transformatori (o'zaksiz) $U_1 = 60 + 113\sin 2000t$ kuchlanishga ulangan bo'lib parametri: $R_1=R_2=6$ *Om*, $L_1=L_2=4$ *mgn*, $M=1$ *mgn*. Qisqa tutashuv holat *elektromagnit turdagi o'lchov asboblar* qiymatini aniqlang.



Javob: $I_1 = 12{,}8\,A$; $I_2 = 1{,}6\,A$; $U_1 = 100\,V$; $U_2 = 0$.

7.4. Nazorat savollari

1. Nosinusoidal o'zgaruvchan tok va kuchianishlarni izohlab bering.
2. Elektr zanjirda nosinusoidal tok, kuchlanish va EYK qanday hosil bo'ladi?
3. Nosinusoidal o'zgaruvchan funksiyalarni Furye qatoriga yoyish manosini tushuntiring.
4. Nosinusoidal tok funksiyasining trigonometrik qatoriga yoyilgandagi umumiy ifodasini yozing.
5. Nosinusoidal funksiyaning asosiy garmonikasi yoki yuqori garmonikasi deganda nimani tushunasiz?
6. Obsitsa, ordinata va koordinata boshiga simmetrik bo'lgan sinusoidal funksiya grafigini chizib ko'rsating.
7. Trapetsiadal ko'rinishdagi nosinusoidal funksiyani analitik usulda trigonometrik qatorga yoying.
8. Nosinusoidal funksiyaning grafo-analitik usulda hisoblash qanday bajariladi?
9. Nosinusoidal funksiyaning koeffitsienti va boshiang'ich fazalarini aniqlash formulasini yozing.
10. Nosinusoidal tok kuchlanish va EYKning haqiqiy o'rtacha qiymatini ifodalovchi formulasini yozing.
11. Nosinusoidal tok quvvatini ifodalovchi tenglamani yozing.
12. Nosinusoidal funksiya amplituda, forma siljish koeffitsienti qanday ifodalanadi?

13. Nosinusoidal elektr zanjirni hisoblashda ustma-ustlik usulidan qanday foydalaniladi?
14. Induktivlik yoki sig'im parametri yuqori garmonika tok, kuchlanishlarning birinchi garmonikaga nisbatan ifodalanuvchi tenglamasini yozing.
15. Nima sababdan iste'molchi induktiv xarakterga ega bo'lganda nosinusoidal tok formasi silliqlanib, kuchlanish buziladi?
16. Nima sababdan iste'molchi sig'im xarakterga ega bo'lganda nosinusoidal kuchlanish formasi tekislanib, tok formasi buziladi?
17. Uch fazali sistema uchun asosiy va yuqori garmonikali kuchlanish ifodalovchi formulasini yozing.
18. Uch fazali tok sistemalarida qaysi garmonikalar «to'g'ri», «teskari» va «nol» ketma-ketlikni hosil qiladi?
19. Nima sababdan simmetrik uch fazali tok sistemasida nosinusoidal kuchlanish ulanganda neytral simdagi tok nolga teng emas?
20. Nima sababdan generator chulg'amlari uchburchak shaklda ulanganda liniya va faza kuchlanishlarida uch karrali garmonikalar yo'qoladi?
21. R, L, C parametrning nosinusoidal tok va kuchlanish formulalariga qanday ta'sir ko'rsatishini tushuntiring.
22. Elektr filtri nima va qanday maqsadda foydalaniladi?
23. Nosinusoidal elektr zanjirda rezonansli filtrlarning xususiyatlarini izohlab bering.
24. Uch fazali generator liniyalarida yuqori garmonika hosil bo'lishi sababi nimada va qanday xususiyatga ega?
25. $i = 5 + 3\sin(\omega_1 t + 30^0) + 2\sin(3\omega_1 t - 45^0) + 4\sin(5\omega_1 t - 30^0)(A)$ tok haqiqiy (effektiv) qiymatini toping.
26. Ketma-ket R, L, C zanjir nosinusoidal $U = U_0 + U_{1m}\sin(\omega_1 t + \varphi_{U_1}) +$ $+U_{5m}\sin(5\omega_1 t + \varphi_{U_5})$ kuchlanishga ulanganda, tok qiymati ifodasini yozing.
27. Pulsatsiya, modulatsiyalangan tebranish amplitudaviy modulatsiya qanday hosil bo'ladi?
28. Nosinusoidal elektr zanjiriga ulangan ampermetr, voltmetr, vattmetr ko'rsatishiga yuqori chastotali garmonikalar ta'sir o'tkazadimi yoki yo'qmi?

29. Magnitoelektrik elektr o‘lchov asbobi nosinusoidal tok va kuchlanishning qaysi qiymatini o‘lchaydi?

30. Induksion, elektromagnit, elektrodinamik issiqlik elektr o‘lchov asboblari nosinusoidal tok va kuchlanishlarning qanday qiymatlarini o‘lchaydi?

31. Vattmetr nosinusoidal quvvatning qaysi qiymatini o‘lchaydi?

32. Zanjirga ketma-ket uchta ampermetr: elektromagnit, induksion va issiqlik turdagi tok o‘lchov asbobi ulangan. Agar magnitoelektrik asbob ko‘rsatishi $I_1 = 6A,$ induksion ampermetr $I_2 = 8A$ bo‘lsa, issiqlik ampermetr I_3 qiymati nimaga teng?

VIII. TO‘RT QUTBLI ZANJIR

8.1. Asosiy nazariy tushunchalar

Ikkita kirish (1-1') va ikkita chiqish (2-2') qutblari bo‘lgan har qanday elektr zanjirga to‘rt qutbli zanjir deyiladi. Odatda kirish qismi manbaga U_1, chiqish qismiga esa iste’molchi qarshiligi Z_2 ulanadi.

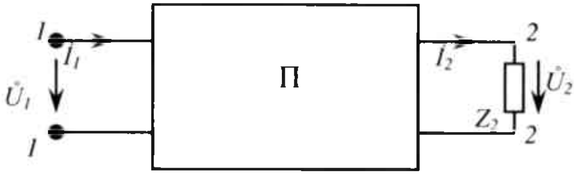
To‘rt qutbli (ko‘p qutbli) ko‘rinishdagi murakkab elektr zanjirni o‘rganishdan asosiy maqsad, to‘rt qutbli ichki tuzilishidan qati nazar, zanjirning kirish va chiqish qismidagi funksional bog‘lanish aniqlanadi. Ya’ni, to‘rt qutbli kirish qismidagi tok va kuchlanish U_1 va I_1 ma’lum bo‘lsa, chiqishdagi U_2 va I_2 ni aniqlash qonuniyati va bog‘lanishini topish kerak.

To‘rt qutbli ichki parametr tavsiyalariga ko‘ra, kirish va chiqish qismlarini bog‘lovchi tenglama chiziqli yoki nochiziqli bo‘lishi mumkin.

Ichki tarmoqlarida EYK va tok manbai bo‘lmasa to‘rt qutbli passiv bo‘ladi (liniya simlari, transformator, to‘g‘rilash sxemasi, to‘g‘rilagich filtr va hokazolar)

Agarda to‘rt qutbli ichida juda bo‘lmaganda bitta energiya manbai bo‘lsa, u *aktiv* bo‘ladi.

1. Chiziqli passiv to‘rt qutbli asosiy xususiyatini tahlil qilish.



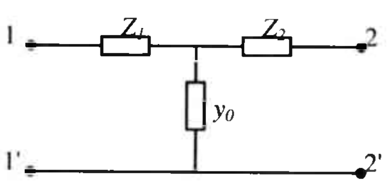
Passiv to‘rt qutbli kirish $\dot{I}_1$, $\dot{U}_1$ va chiqish qismlaridagi $\dot{I}_2$, $\dot{U}_2$ tok va kuchlanish chiziqli bo‘lgan ikkita tenglama bilan ifodalanadi:

$$\left.\begin{aligned} \dot{U}_1 &= A\dot{U}_2 + B\dot{I}_2 \\ \dot{I}_1 &= C\dot{U}_2 + D\dot{I}_2 \end{aligned}\right\} \qquad (8.1)$$

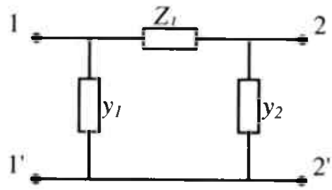
A, B, C, D – to‘rt qutbli doimiy koeffitsientga ega bo‘lib, bularning bog‘lanishi:

$$AD - BC = 1 \qquad (8.2)$$

Agarda to‘rt qutbli kirish qismi chiqish qismi bilan almashtirilsa (8.1) tenglamadan A va D koeffitsientining o‘rni almashadi:



T – sxema



П – схема

$$\left.\begin{aligned} \dot U_1 &= D\dot U_2 + A\dot I_2 \\ \dot I_1 &+ C\dot U_2 + A\dot I_2 \end{aligned}\right\} \qquad (8.3)$$

To‘rt qutbli koeffitsienti: A=D (8. 4) bo‘lsa simmetrik deyiladi.

To‘rt qutblilar doimiy koeffitsient zanjir parametr bilan bog‘langan bo‘lib, quyidagicha ifodalanadi:

$$A = \frac{\Delta_{2,2}}{\Delta_{1,2}};\quad B = \frac{\Delta}{\Delta_{1,2}}(om);\quad C = \frac{\Delta_{1,1}\cdot\Delta_{2,2} - \Delta^2_{1,2}}{\Delta\cdot\Delta_{1,2}}\left(\frac{1}{ом}\right);\quad D = \frac{\Delta_{1,1}}{\Delta_{1,2}} \qquad (8.\ 5)$$

Bunda Δ kontur uchun tuzilgan tenglama sistemasi asosiy xususiy qarshilik determinanti.

$\Delta_{1,1}$, $\Delta_{1,2}$ va $\Delta_{2,2}$ algebraik to‘ldiruvchi tenglama tizimi determinanti.

2. Passiv to‘rt qutbli almashinish sxemasi bo‘yicha parametrini aniqlash.

T – sxemasi parametri $\underline{Z}_1 = \frac{A-1}{C};\ \underline{Z}_2 = \frac{D-1}{C};\underline{Y}_0 = C;$ (8. 6)

Doimiy koeffitsient parametr orqali:

$$\left.\begin{aligned} A &= 1 + \underline{z}\underline{y}_0; \\ B &= \underline{z}_1 + \underline{z}_2 + \underline{z}_1\underline{z}_2\underline{y}_0; \\ C &= \underline{y}_0; \\ D &= 1 + \underline{z}_2\underline{y}_0; \end{aligned}\right\} \qquad (8.\ 7)$$

П – sxema parametri: $\underline{Z}_0 = B;\ \underline{Y}_1 = \frac{D-1}{B};\ \underline{Y}_2 = \frac{A-1}{B};$ (8. 8)

yoki koeffitsient parametri orqali:

$$\left.\begin{aligned} A &= 1 + \underline{y}_2 \underline{z}_0; \\ B &= \underline{z}_0; \\ C &= \underline{y}_1 + \underline{y}_2 + \underline{y}_1 \underline{y}_2 \underline{z}_0 \\ D &= 1 + \underline{y}_1 \underline{z}_0; \end{aligned}\right\} \qquad (8.\ 9)$$

3. To'rt qutbli parametrni tajriba asosida aniqlash.

Tajriba asosida to'rt qutbli doimiy koeffitsientni aniqlashda kirish va chiqish qismidan ikki marta salt va qisqa tutashuv tajribasi o'tkaziladi. Natijada chiqish qismida qisqa tutashuv bo'lganda (8.1) tenglamadan:

$$\underline{Z}_{1k} = \frac{B}{D}; \qquad (8.\ 10)$$

chiqish qismida salt holat tajribasiga asosan: $\underline{Y}_{1,0} = \frac{C}{A};$; (8. 11)

Endi to'rt qutbli kirish va chiqish qismlari o'rni almashtirilib, tajriba o'tkazilganda:

$$\underline{Z}_{2k} = \frac{A}{B}; \quad \underline{Y}_{2,0} = \frac{C}{D}; \qquad (8.\ 12)$$

To'rt qutbli parametri o'xshashligidan: $\underline{Z}_{1k} \underline{Y}_{1,0} = \underline{Z}_{2k} \underline{Y}_{2,0}$ (8.13)

$$A = \sqrt{Z_{1k} \cdot Z_{10} / Z_{20} \left(Z_{10} - Z_{1k} \right)} \qquad (8.13a)$$

4. Simmetrik to'rt qutbli uzatuvchanlik funksiya va tavsifiy (operator) qarshiligi.

Tavsifiy qarshilik: $\underline{Z}_C = \frac{\dot{U}_2}{\dot{I}_2} = \frac{\dot{U}_1}{\dot{I}_1} = \sqrt{\frac{B}{C}};$ (8.14)

Bunda uzatish koeffitsienti:

$$\left.\begin{aligned} &\bar{g} = \bar{a} + j\bar{b} = \ln \frac{\dot{I}_1}{\dot{I}_2} = ln\left(A + \sqrt{A^2 + 1} \right) = \ln\left(A + \sqrt{BC} \right) \\ &\text{So'nish koeffitsienti}: \bar{a} = \operatorname{Re} g = \ln \frac{\dot{U}_1}{\dot{U}_2} = \ln \frac{\dot{I}_1}{\dot{I}_2} \\ &\text{Faza koeffitsienti}: \bar{b} = \ln g = \bar{\varphi}_1 - \bar{\varphi}_2 = \bar{\varphi}_1' - \bar{\varphi}_2' \left(rad / sek \right) \end{aligned}\right\} \qquad (8.15)$$

Bu tenglamalardan to'rt qutbli kirish qismidagi tok va kuchlanish:

$$\dot{U} = \dot{U}_1 e^{j\varphi}; \quad \dot{I}_1 = \dot{I}_1 e^{j\varphi_1'}; \qquad (8.\ 16)$$

Chiqish qismidagi tok va kuchlanish ifodalari (Z_2 – qarshilik ulanganda):

$$\dot{U}_2 = \dot{U}_2 e^{j\varphi_2}; \ \dot{I}_2 = \dot{I}_2 e^{j\varphi_2} \quad (8.17)$$

Tavsifiy qarshilik (Z_c) bilan to‘rt qutbli koeffitsient bog‘lanish tenglamasi:

$$A = D = chg; \quad B = \underline{Z}_2 shg; \quad C = \frac{1}{\underline{Z}_2} shg; \quad (8.18)$$

Aniqlangan qiymatni (8.1) tenglamaga qo‘yamiz:

$$\left.\begin{aligned} \dot{U}_1 &= \dot{U}_2 \mathrm{chg} + Z_c \dot{I}_2 \mathrm{shg}; \\ \dot{I}_1 &= \dot{U}_2 \frac{\mathrm{shg}}{Z_c} + \dot{I}_2 \mathrm{chg} \end{aligned}\right\} \quad (8.19)$$

8.19 tavsifiy qarshilik va uzatish koeffitsienti tajriba asosida salt holatda: $I_2 = 0; \ Z_0 = \frac{\dot{U}_{10}}{\dot{I}_{10}} = \frac{Z_c}{\mathrm{thg}}$ yoki qisqa tutashuvga asosan:

$$Z_q = \frac{\dot{U}_{1q}}{\dot{I}_{1q}} = Z_c \mathrm{thg}$$

Bundan: $Z_s = \sqrt{Z_0 Z_q}$; $\mathrm{thg} = \sqrt{\frac{Z_q}{Z_0}}$

5. To‘rt qutbli har xil turda ifodalash tenglamalari.

To‘rt qutbli ulanish sxemasiga qarab turli xil ko‘rinishdagi tenglamalardan foydalanish mumkin:

Ifoda [z] $$\begin{aligned} \dot{U}_1 &= \underline{z}_{11}\dot{I}_1 + \underline{z}_{12}\dot{I}_2 \\ \dot{U}_2 &= \underline{z}_{21}\dot{I}_1 + \underline{z}_{22}\dot{I}_2 \end{aligned}; \quad (8.20)$$

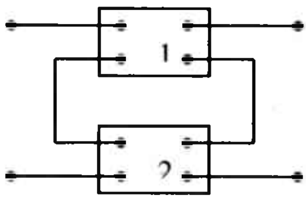
Ifoda [y] $$\begin{aligned} \dot{I}_1 &= \underline{y}_{11}\dot{U}_1 + \underline{y}_{12}\dot{U}_2 \\ \dot{I}_2 &= \underline{y}_{21}\dot{U}_1 + \underline{y}_{22}\dot{U}_2 \end{aligned}; \quad (8.21)$$

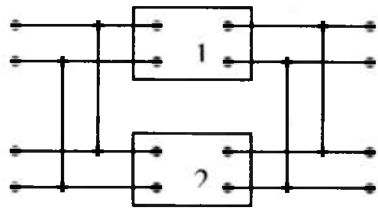
Ifoda [g] $$\begin{aligned} \dot{I}_1 &= \underline{g}_{11}\dot{U}_1 + \underline{g}_{12}\dot{I}_2 \\ \dot{U}_2 &= \underline{g}_{21}\dot{U}_1 + \underline{g}_{22}\dot{I}_2 \end{aligned}; \quad (8.22)$$

Ifoda [h] $$\begin{aligned} \dot{U}_1 &= \underline{h}_{11}\dot{I}_1 + \underline{h}_{12}\dot{U}_2 \\ \dot{I}_2 &= \underline{h}_{21}\dot{I}_1 + \underline{h}_{22}\dot{U}_2 \end{aligned}; \quad (8.23)$$

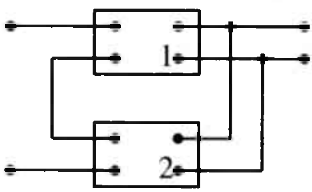
6. To‘rt qutbli ulanishi sxemasi.

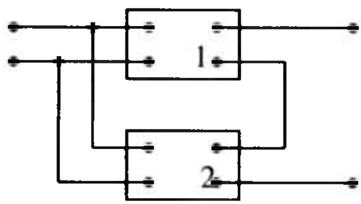
To‘rt qutbli elektr zanjirni analiz qilishdan maqsad ekvivalent doimiy koeffitsientini aniqlashdan iborat bo‘lib, ketma-ket ulangan to‘rt qutbli doimiy koeffitsientini aniqlashida (z) tenglamasidan foydalaniladi.





Parallel ulangan to‘rt qutbli (y) formadagi tenglamadan foydalaniladi.





To‘rt qutbli ketma-ket va parallel sxemada ulanganda (h) tenglamasidan, parallel va ketma-ket sxemada ulanishda (g) tenglamasidan foydalangan qulay.

Kaskad sxemada ulangan bo‘lsa (a) (8.1) tenglamadan foydalaniladi.

8.2. Masala yechish va uslubiy ko‘rsatmalar

Masala 8.1. Simmetrik to‘rt qutbli zanjirning doimiy koeffitsienti: $A = 2 + j3$ va $B = (1 + j)$ *Om* ga teng bo‘lganda, C – koeffitsienti aniqlansin.

Yechish. (8. 2) va (8. 4) tenglamadan

$$C=\frac{A^2-1}{B}=\frac{(2+j3)^2-1}{(1+j)}=3+j9\ \frac{1}{Om}$$

Masala 8.2. To'rt qutbli qisqa tutashuv va salt holat tajribalari o'tkazilib tok va kuchlanishning quyidagi qiymati aniqlangan.

a) qisqa tutashuv: $\dot{U}_2=0$; $\dot{I}_{2k}=0{,}05e^{j93^\circ}$ (A);

$\dot{U}_k=100$ (V); $\dot{I}_{1k}=0{,}04e^{j87^\circ}$ (A);

b) salt holatda: $\dot{I}_{20}=0$; $\dot{U}_{20}=180e^{j15^\circ}$ (V);

$\dot{U}_{10}=100$ (V); $\dot{I}_{10}=0{,}055e^{-j57^\circ}$ (A);

To'rt qutbli doimiy koeffitsienti hisoblab topilsin.

Yechish. (8. 1) tenglamaga asosan qisqa tutashganda $(\dot{U}_2=0)$:

$\dot{U}_{1k}=B\dot{I}_{2k}$; $\dot{I}_{1k}=D\dot{I}_{2k}$;

Bundan: $B=\dfrac{\dot{U}_{1k}}{\dot{I}_{2k}}=2000e^{-j93^\circ}\ (Om)$; $D=\dfrac{\dot{I}_{1k}}{\dot{I}_{2k}}=0{,}8e^{-j16^\circ}$;

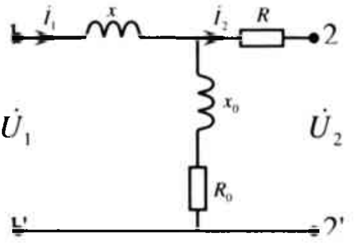
Salt holatda: $\dot{I}_2=0$; bo'lib (8. 1) dan: $\dot{U}_{10}=A\dot{U}_{20}$; $\dot{I}_{10}=C\dot{U}_{20}$;

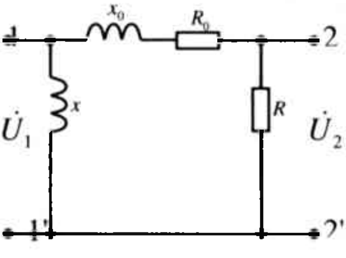
Bundan: $A=\dfrac{\dot{U}_{10}}{\dot{U}_{20}}=0{,}555e^{-j15^\circ}$; $C=\dfrac{\dot{I}_{10}}{\dot{U}_{20}}=3{,}06\cdot10^{-4}e^{-j72^\circ}\left(\dfrac{1}{Om}\right)$;

Tekshiramiz:

AD – BC$=0{,}555e^{-j15}\cdot0{,}8e^{-j16}-2000e^{-j93^0}\cdot3{,}06\cdot10^{-4}e^{j72}\approx1$

Masala 8.3. Parametri *R=10 (Om), x=10 (Om), x_0=5 (Om), R_0=5 (Om)* bo'lgan, *T* va *П* shaklda ulangan to'rt qutbli doimiy *A, B, C, D* koeffitsienti aniqlansin:





Yechish. (8. 7) tenglamaga asosan T sxema uchun:

$$A = 1 + \underline{z}_1 \underline{y}_0 = 1 + \frac{\underline{x}}{R_0 + \underline{x}_0} = 1 + \frac{j10}{5 + \underline{j}5} = 1 + \frac{10^{j90^\circ}}{5\sqrt{2}e^{j45^\circ}} = 1 + \sqrt{2}e^{j45^\circ} = 1 + 1 + \underline{j} = 2 + \underline{j};$$

$$B = \underline{z}_1\underline{z}_2 + \underline{z}_1\underline{z}_2\underline{y}_0 = \underline{x} + R + \frac{\underline{x}R}{R_0 + \underline{x}_0} = \underline{j}10 + 10 + \frac{\underline{j}10 \cdot 10}{5 + \underline{j}5} = \underline{j}10 + 10 + 10\sqrt{2}e^{j45^\circ} =$$

$$= \underline{j}10 + 10 + 10 + j10 = 20 + \underline{j}20\ Om$$

$$C = \underline{y}_0 = \frac{1}{R_0 + \underline{x}_0} = \frac{1}{5\sqrt{2}e^{j45^\circ}} = \frac{\sqrt{2}e^{-j45^\circ}}{10} = \frac{\sqrt{2}e^{j45^\circ}}{10} = 0{,}1 + \underline{j}0{,}1\ \left(\frac{1}{Om}\right);$$

$$D = 1 + \underline{z}_2 \underline{y}_0 = 1 + \frac{10}{5\sqrt{2}e^{j45^\circ}} = 1 + \sqrt{2}e^{-j45^\circ} = 1 + 1 - \underline{j} = 2 - \underline{j};$$

(8. 9) tenglamaga asosan *П* sxema uchun:

$$A = 1 + \underline{z}_0 \underline{y}_2 = 1 + \frac{\underline{x}_0 + \underline{z}_0}{R_3} = 1 + \frac{5\sqrt{2}e^{j45^\circ}}{10} = 1 + 0{,}5 + \underline{j}0{,}5 = 1{,}5 + \underline{j}0{,}5;$$

$$B = \underline{z}_0 = x_0 + R_0 = 5 + \underline{j}5\ Om;$$

$$C = \underline{y}_1 + \underline{y}_2 + \underline{y}_1\underline{y}_2\underline{z}_0 = -\underline{j}0{,}1 + 0{,}1 + \frac{5\sqrt{2}e^{j45^\circ}}{10 \cdot 10e^{j90^\circ}} = -\underline{j}0{,}1 + 0{,}1 + 0{,}05\sqrt{2}e^{j45^\circ} =$$

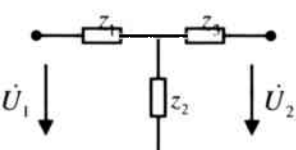
$$= -\underline{j}0{,}1 + 0{,}1 + 0{,}05 - j0{,}05 = 0{,}15 - j0{,}15\left(\frac{1}{Om}\right);$$

$$D = 1 + \underline{z}_0 \underline{y}_1 = 1 + \frac{R_0 + \underline{x}_0}{\underline{x}} = 1 + \frac{5\sqrt{2}e^{j45^\circ}}{10e^{j90^\circ}} = 1 + 0{,}5 - \underline{j}0{,}5 = 1{,}5 + \underline{j}0{,}5;$$

Masala 8.4. To'rt qutbli doimiy koeffitsienti: $A = 1 - \underline{j}3$, $B = -3 - j30$, $C = -j0{,}1$, $D = -1$ bo'lib, ekvivalent T va П shakldagi sxema tuzilsin.

Yechish. (8. 6) tenglamaga asosan T sxema tuzish uchun parametr aniqlanadi.

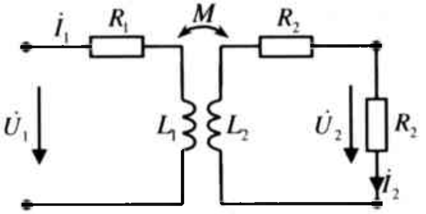
$$\underline{z}_1 = \frac{A-1}{C} = \frac{1 - \underline{j}3 - 1}{-\underline{j}0{,}1} = 30(Om); \quad \underline{z}_2 = \frac{1}{C} = \underline{j}10(Om); \quad \underline{z}_3 = \frac{D-1}{C} = \frac{-1-1}{-\underline{j}0{,}1} = -\underline{j}20(Om);$$



(8.8) Tenglamaga asosan П sxema tuzish uchun parametr aniqlanadi:

$\underline{z}_0 = B = -3 - \underline{j}30$ teng П – shakldagi sxemani tuzish mumkin emas, sababi aktiv qarshilik qiymati minus ishora bilan berilgan.

Masala 8.5. Transformatorning ikkilamchi chulg'amidagi tok $\dot{I}_2 = 1\ A$, kuchlanishi $\dot{U}_2 = 20\,V$ bo'lib, aktiv qarshilik ulangan. Transformatorning parametr qarshiligi $R_1 = R_2 = 1\,Om$, $\underline{X}_{L_1} = \underline{X}_{L_2} = 25\ Om$, o'zaro induksiya $\underline{x}_M = \omega M = 20 Om$ bo'lganda, kirish qismidagi birlamchi chulg'amdagi tok $\dot{I}_1$ va kuchlanish $\dot{U}_1$ aniqlansin.



Yechish.

Transformator ekvivalent sxemasi T sxemaga mos keladi, shuning uchun T sxema parametrini aniqlaymiz.

$$\underline{Z}_1 = \underline{Z}_2 = R + j\omega\left(L_1 - M\right) = 1 + j25 - j20 = 1 + \underline{j}5\ Om;$$

$$\underline{y}_0 = \frac{1}{j\omega M} = \frac{1}{j20} = -j0{,}05\left(\frac{1}{Om}\right);$$

(8.7) tenglamaga asosan to'rt qutbli doimiy koeffitsientni aniqlaymiz. Bunda $\underline{z}_1 = \underline{z}_2$ bo'lganligi uchun: $A = D$

$$A = D = 1 + \underline{z}_1\,\underline{y}_0 = 1 + (1 + j5)\cdot(-\underline{j}0{,}05) = 1{,}25 - \underline{j}0{,}05;$$

$$B = \underline{z}_1 + \underline{z}_2 + \underline{z}_1\underline{z}_2\underline{y}_0 = 2\left(1 + \underline{j}5\right) + \left(1 + \underline{j}5\right)\cdot\left(-\underline{j}0{,}05\right) = 2{,}5 + j11{,}2\ Om;$$

$$C = \underline{y}_0 = -j0{,}05\left(\frac{1}{Om}\right);$$

Transformator ulangan iste'molchi qarshiligi aktiv bo'lganligi uchun:

$\dot{U}_2 = U_2 = 20(\text{V})$; tok $\dot{I}_2 = I_2 = 1(A)$ teng ushbu qiymatlarini (8. 1) tenglamaga qo'yamiz:

$$\dot{U}_1 = A\dot{U}_2 + B\dot{I}_2 = (1,25 - j0,05)\cdot 20 + (2,5 + j11,2)\cdot 1 = (27,1 + j10,2)$$
$$\dot{I}_1 = C\dot{U}_2 + D\dot{I}_2 = (-j0,05)\cdot 20 + (1,25 - j0,05)\cdot 1 = (1,25 - j1,05)$$
Demak: $U_1 = \sqrt{27,5^2 + 10,2^2} = 28,5V$; $I_1 = \sqrt{1,25^2 + 1,05^2} = 1,6A$;

Masala 8.6. To'rt qutbli simmetrik bo'lib, koeffitsienti: $\underline{A} = 1 + j2$ va $\underline{B} = -80 + j240$ ga teng. Qisqa tutashuv va salt holat to'la kompleks qarshilikni hisoblang.

Yechish.

To'rt qutbli simmetrik bo'lganligi uchun: $A = D = 1 + j2$; (8.2)

tenglamadan C koeffitsientni topamiz: $C = \dfrac{AD - 1}{B} = \dfrac{A^2 - 1}{B}$; (8.1)

tenglamadan to'rt qutbli salt holati uchun: $\dot{U}_{10} = A\dot{U}_2$; $\dot{I}_{10} = C\dot{U}_2$;

yoki $\dfrac{\dot{U}_{10}}{\dot{I}_{10}} = \dfrac{A}{C}$;

Bunda: $\underline{Z}_{10} = \dfrac{AB}{A^2 - 1} = \dfrac{(1 + j2)\cdot(-80 + j240)}{(1 + j2)^2 - 1} = 80 + j60 = 100e^{j36^\circ 45'}(Om)$;

Qisqa tutashuv holatdagi tenglama: $\dot{U}_{1k} = B\dot{I}_2$; $\dot{I}_{1k} = D\dot{I}_2$; yoki $\dfrac{\dot{U}_{1k}}{\dot{I}_{1k}} = \dfrac{B}{D}$;

$$\underline{Z}_{1k} = \frac{-80 + j240}{1 + j2} = \frac{253e^{j108^\circ}}{2,24e^{j63^\circ}} = 112^{j45^\circ} = 78 + j80,7\ Om;$$

Masala 8.7. To'rt qutbli zanjr kirish qismida qisqa tutashuv va salt holat, chiqish qismida salt holat tajribasi o'tkazilib o'lchov asbobi yordamida quyidagi qiymatlar aniqlangan:

$\dot{U}_{10} = 158\ B$; $\dot{I}_{10} = 10A$; $P_{10} = 500\,\text{Vt}$; $\varphi_{10} > 0$;

$\dot{U}_{1k} = 126,5B$; $\dot{I}_{1k} = 10A$; $P_{1k} = 400\,\text{Vt}$; $\varphi_{1k} > 0$;

$\dot{U}_{20} = 158\ B$; $\dot{I}_{20} = 10\ A$; $P_0 = 1500\ \text{Vt}$; $\varphi_{20} > 0$;

To'rt qutbli zanjir doimiy koeffitsienti aniqlansin.

Yechish.

O'lchov asboblari ko'rsatish qiymatiga asosan to'rt qutbli salt holat uchun kirish qismidagi to'la qarshilik: $\underline{Z}_{10} = \dfrac{\dot{U}_{10}}{\dot{I}_{10}} = \dfrac{158}{10} = 15,8\ Om$

Quvvat koeffitsienti: $\cos\varphi_{10} = \dfrac{P_{10}}{\dot{U}_{10}\cdot \dot{I}_{10}} = \dfrac{500}{158\cdot 10} = 0{,}316$; $\varphi_{10} = 71^\circ 30'$

yoki: $\underline{Z}_{10} = 15{,}8e^{j71^\circ 30'} = 5 + j15$

Qisqa tutashuv holatda to‘la qarshilik: $Z_{1k} = \dfrac{\dot{U}_{1k}}{\dot{I}_{1k}} = \dfrac{126{,}5}{10} = 12{,}65\ Om$;

Quvvat koeffitsienti:

$$\cos\varphi_{1k} = \frac{P_{1k}}{\dot{U}_{1k}\cdot \dot{I}_{1k}} = \frac{400}{126{,}5\cdot 10} = 0{,}31; \quad \varphi_{1k} = 71^\circ 30',$$

yoki: $\underline{z}_{1k} = 12{,}65e^{71^\circ 30'} = 12{,}6 + j4{,}3$

To‘rt qutbli chiqish qismidagi salt holat to‘la qarshiligi:

$$\underline{z}_{20} = \frac{\dot{U}_{20}}{\dot{I}_{20}} = 15{,}81(Om);$$

Quvvat koeffitsienti: $\cos\varphi_{20} = \dfrac{P_{20}}{\dot{U}_{20}\cdot \dot{I}_{20}} = \dfrac{1500}{158\cdot 10} = \dfrac{1500}{1580} = 0{,}94$; $\varphi_{20} = 19^\circ$,

yoki: $\underline{Z}_{20} = 15{,}81e^{j19^\circ} = 15 + j5$

To‘rt qutbli (8.10), (8.11), (8.12) tenglamasiga asosan koeffitsientni aniqlaymiz:

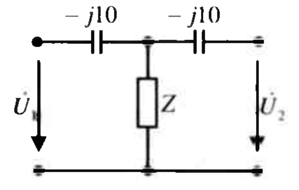
$$A = \frac{\underline{z}_{10}}{\sqrt{\underline{z}_{20}\cdot \underline{z}_{10}\cdot \underline{z}_{1k}}} = \frac{5 + j15}{\sqrt{(15 + j5)\cdot(5 + j15)\cdot(12{,}6 + j4{,}3)}} = 1{,}023e^{j26^\circ}$$

$$C = \frac{1}{\underline{Z}_{10}} = \frac{1}{5 + j5} = 0{,}064e^{-j45^\circ};$$

$$D = C\cdot \underline{Z}_{10} = 0{,}064e^{j45^\circ}\cdot 15{,}8e^{j71^\circ 30'} = 1{,}02e^{j25^\circ 30'};$$

$$B = D\cdot \underline{Z}_{1k} = 1{,}02e^{j25}\cdot 12{,}65e^{j71^\circ 30'} = 13e^{j96^\circ 30'}.$$

Masala 8.8. Simmetrik T sxema parametri $\underline{x}_1 = -j10\ Om$, $\underline{x}_2 = -j10\ Om$, $\underline{z} = 100\ Om$ ga teng bo‘lib, xarakteristik qarshiligi $(\underline{z}_C)$ va uzatish koeffitsienti (g) aniqlansin.



Yechish.

To‘rt qutbli koeffitsientni aniqlaymiz:

$$A = D = 1 + \underline{Z}_1\underline{Y}_0 = 1 + \frac{-j10}{100} = 1 - j0{,}1 = 1e^{j5^\circ 30'};$$

$$C = \underline{Y}_0 = \frac{1}{100} = 0{,}01\left(\frac{1}{Om}\right);$$

$$B = \frac{1}{C}\left(A^2 - 1\right) = -1 - \underline{j}20 = 20e^{-j93^\circ};$$

(8.14) tenglamaga asosan to‘rt qutbli xarakteristik qarshiligi:

$$\underline{Z}_C = \sqrt{\frac{B}{C}} = 44{,}7e^{-j46^\circ 30'};$$

Uzatish koeffitsienti (8. 15) tenglamadan:

$$g = \ln\left(\sqrt{A^2} + \sqrt{BC}\right) = \ln\left(A + \sqrt{BC}\right)$$

Bundan: $A + \sqrt{BC} = 1{,}31 - \underline{j}0{,}42 = 1{,}38e^{j18^\circ 20'}$

$$g = \ln 1{,}38e^{j18^\circ 20'} = \ln 1{,}38 - \underline{j}18^\circ 20' = 0{,}322 - \underline{j}0{,}32$$

So‘nish koeffitsienti: $a = 0{,}322$ nep. Faza koeffitsienti: $b = -0{,}32\ rad/sek$.

Masala 8.9. To‘rt qutbli zanjir doimiy koeffitsient qiymati $A = 0{,}56e^{-j15^\circ}$, $B = 2000e^{-j93^\circ}\ (Om)$, $C = 3{,}06 \cdot 10^{-4} e^{j72^\circ}\left(\frac{1}{Om}\right)$, $D = 0{,}8e^{-j6^\circ}$ bo‘lib, [z] forma tenglamasi koeffitsienti aniqlasin.

Yechish.

To‘rt qutbli [a] forma tenglamasi:

$$\left.\begin{aligned} \dot{U}_1 &= A\dot{U}_2 + B\dot{I}_2 \\ \dot{I}_1 &= C\dot{U}_2 + D\dot{I}_2 \end{aligned}\right\}$$

Bu tenglamada kompleks kuchlanishni chap tomonga o‘tkazamiz:

$$\left.\begin{aligned} \dot{U}_1 - A\dot{U}_2 &= B\dot{I}_2 \\ C\dot{U}_2 &= \dot{I}_1 - D\dot{I}_2 \end{aligned}\right\}$$

Ikkinchi tenglamadan: $\dot{U}_2 = \frac{1}{C}\dot{I}_1 - \frac{D}{C}\dot{I}_2$;

Ushbu tenglamani [a] tenglamaning birinchi ifodasidagi $\dot{U}_2$ o‘rniga qo‘yamiz:

$$\dot{U}_1 = B\dot{I}_2 + A\left(\frac{1}{C}\dot{I}_1 + \frac{D}{C}\dot{I}_2\right) = \frac{A}{C}\dot{I}_1 - \frac{1}{C}\dot{I}_2;$$

[z] ifodali (6.19) tenglamadan doimiy koeffitsient kompleks qarshiligi:

$$\underline{z}_{11}=\frac{A}{C}=\frac{0{,}56e^{-j15^\circ}}{3{,}06\cdot10^{-4}e^{j72^\circ}}=1830e^{j57^\circ};$$

$$\underline{z}_{12}=-\frac{1}{C}=-\frac{1\cdot10^{4}}{3{,}06\cdot e^{j72^\circ}}=3260e^{-j108^\circ}$$

$$\underline{z}_{21}=+\frac{1}{C}=\frac{1\cdot10^{4}}{3{,}06\cdot e^{j72^\circ}}=3260e^{-j72^\circ}$$

$$\underline{z}_{22}=-\frac{D}{C}=-\frac{0{,}8\cdot e^{-j6^\circ}}{3{,}06\cdot e^{j72^\circ}}=2600e^{-j114^\circ}$$

Masala 8.10. To'rt qutbli doimiy A, B, C, D koeffitsientlari 8.9-masalada berilgan qiymatlar bo'yicha [y] forma tenglamadagi doimiy koeffitsient aniqlansin.

Yechish.

To'rt qutbli (8.1) tenglamadagi tok $\dot{I}_1$ va $\dot{I}_2$ ifodalarini chap tomonga o'tkazamiz:

$$\left.\begin{aligned} B\dot{I}_2&=\dot{U}_1-A\dot{U}_2\\ \dot{I}_1-D\dot{I}_2&=C\dot{U}_2\end{aligned}\right\}$$

Bundan $\dot{I}_1$ va $\dot{I}_2$ tokni topamiz. Ya'ni $\dot{I}_1=\frac{\Delta_1}{\Delta}$ va $\dot{I}_2=\frac{\Delta_2}{\Delta}$

$$\Delta=\begin{vmatrix}0 & B\\ 1 & -D\end{vmatrix}=-B;$$

$$\Delta_1=\begin{vmatrix}\dot{U}_1-A\dot{U}_2 & B\\ C\dot{U}_2 & -D\end{vmatrix}=-\dot{U}_1D+AD\dot{U}_2-BC\dot{U}_2=-D\dot{U}_1+\dot{U}_2;$$

$$\Delta_2=\begin{vmatrix}0 & \dot{U}_1-A\dot{U}_2\\ 1 & C\dot{U}_2\end{vmatrix}=-\dot{U}_1+A\dot{U}_2;$$

yoki:

$$\left.\begin{aligned}\dot{I}_1&=\frac{D}{B}\dot{U}_1-\frac{1}{B}\dot{U}_2\\ \dot{I}_2&=\frac{D}{B}\dot{U}_1-\frac{1}{B}\dot{U}_2\end{aligned}\right|$$

Bu toklar tenglamasi [y] formadagi (8.21) tenglamaga o'x-shashligi sababli doimiy koeffitsientini ifodalovchi parametrni topamiz:

$$\underline{y}_{11}=\frac{D}{B};\ \underline{y}_{12}=-\frac{1}{B};\ \underline{y}_{21}=\frac{1}{B};\ \underline{y}_{22}=-\frac{A}{B}$$

A, B, C, D koeffitsient qiymatini qo'ysak:

$$\underline{y}_{11}=\frac{0,8e^{-j6^\circ}}{2000e^{-j93^\circ}}=10^{-4}\left(0,21+\underline{j}4\right)\left(\frac{1}{Om}\right);$$

$$\underline{y}_{12}=\frac{1}{2000e^{-j93^\circ}}=10^{-4}\left(0,26-\underline{j}5\right)\left(\frac{1}{Om}\right);$$

$$\underline{y}_{21}=-\underline{y}_{12}=10^{-4}\left(0,26+\underline{j}5\right)\left(\frac{1}{Om}\right);$$

$$\underline{y}_{22}=\frac{0,5e^{-j15^\circ}}{2000e^{-j93^\circ}}=10^{-4}\left(-0,58-\underline{j}2,74\right)\left(\frac{1}{Om}\right);$$

Masala 8.11. To'rt qutbli doimiy koeffitsienti 8.9-masalada berilgan qiymatlar bo'yicha [g] forma tenglamasidagi doimiy koeffitsient qiymati hisoblab topilisin.

Yechish.

To'rt qutbli asosiy [a] forma tenglamasidagi (8.3) tok $\dot{I}_1$ va kuchlanish $\dot{U}_2$ ga nisbatan yechamiz:

bunda $\dot{U}_2=\frac{1}{A}\left(\dot{U}_1-B\dot{I}_2\right)=\frac{1}{A}\dot{U}_1-\frac{B}{A}\dot{I}_2$;

Bu tenglamani (8.3) tenglamadagi $\dot{U}_2$ kuchlanish o'rniga qo'yamiz:

$$\dot{I}_1=\frac{C}{A}\left(\dot{U}_1-B\dot{I}_2\right)+D\dot{I}_2=\frac{C}{A}\dot{U}_1-\frac{1}{A}\dot{I}_2;$$

Bu ikkala tenglamaning to'rt qutbli [g] formadagi (8.22) o'xshashligidan doimiy koeffitsient parametrini aniqlaymiz:

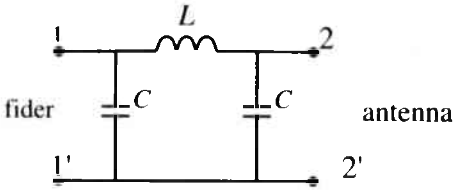
$$\underline{g}_{11}=\frac{C}{A}=\frac{3,06\cdot 10^{-4}e^{-j72^\circ}}{0,56e^{-j15^\circ}}=5,46\cdot 10^{-4}e^{-j57^\circ}\left(\frac{1}{Om}\right);$$

$$\underline{g}_{12}=\frac{1}{A}=\frac{1}{0{,}56e^{-j15^\circ}}=1{,}78e^{j15^\circ}\left(\frac{1}{Om}\right);$$

$$\underline{g}_{21}=-\frac{1}{A}=-\frac{1}{0{,}56e^{-j15^\circ}}=1{,}78e^{j15^\circ}\left(\frac{1}{Om}\right);$$

$$\underline{g}_{22}=-\frac{B}{A}=-\frac{2000e^{-j93^\circ}}{0{,}56e^{-j15^\circ}}=3570e^{j102^\circ}\left(\frac{1}{Om}\right);$$

Masala 8.12. To'lqin qarshilik $\underline{z}_0=125(Om)$ $C_0=5\cdot10^5\left(\frac{1}{sek}\right)$ bo'lgan П shaklidagi to'rt qutbli fiderga antennani rostlash uchun $R_A=500\,(Om)$ aktiv qarshilik ulangan. To'rt qutbli parametri L, C ni hisoblab toping.



Yechish.

To'rt qutbli [a] tenglamasini (8.1) va (8.4) dan kuchlanish ifodasini tokga bo'lamiz hamda to'rt qutbli kirish qismida fider Z_F to'la qarshilik antenna bilan rostlanishini inobatga olamiz.

Bunda: $\underline{Z}_F=\dfrac{A\dot{U}_2+B\dot{I}_2}{C\dot{U}_2+A\dot{I}_2}=\dfrac{A\underline{Z}_a+B}{C\underline{Z}_a+A};$

Xuddi shunga o'xshash to'rt qutbli chiqish qismidagi antenna to'la qarshilikka: $\underline{Z}_a=\dfrac{A_{Z_\phi}+B}{C_{Z_\phi}+A}.$

Bu ikkita tenglamaga ($\underline{Z}_F,\underline{Z}_a$) to'rt qutbli (8.2) tenglamami qo'shib hisobga olgan holda, uchta noma'lum tenglama sistemasini A, B, C, D koeffitsientga nisbatan yechamiz.

Berilgan qiymat qo'shilganda quyidagicha tenglama hosil bo'ladi:

$$\left.\begin{aligned}&375A+B+250^2C=0;\\&-375A+B-250^2C=0;\\&A^2-BC=1;\end{aligned}\right\}$$

Birinchi tenglamadan ikkinchisini ayirsak: $A=0;$

Hamda: $\frac{B}{C}=250^2;\ BC=-1;$

Bu qiymatni tenglama sistemasiga qo'shish bilan:

$$B=j250(Om)$$

$$C=j4\cdot10^{-3}\left(\frac{1}{Om}\right)$$

П shaklda sxemaning Z va Y parametrlarini (8.8) tenglamaga asosan topamiz:

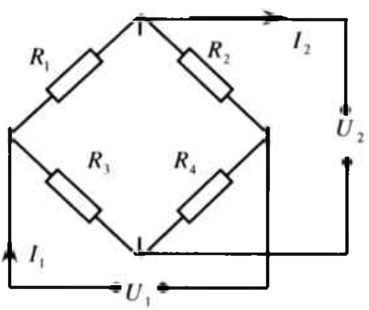
$$\underline{Z}_0=B=j250\ Om$$

$$\underline{Y}=\frac{A-1}{B}=-\frac{1}{B}=-\frac{1}{j250}=4\cdot10^{-3}\left(\frac{1}{Om}\right)$$

Bundan induktivlik: $L=\frac{\underline{Z}_0}{\omega}=\frac{250}{5\cdot10^5}=5\cdot10^{-4}(Gn)=0,5(mGn)$

Sig'im parametri: $C=\frac{\underline{Y}}{\omega}=\frac{4\cdot10^{-3}}{5\cdot10^5}=0,8\cdot10^{-8}(F)=8(mgF)$

Masala 8.13. Ko'prik sxemada ulangan to'rt qutbli elektr zanjirning parametri: $R_1=1\ Ом$, $R_2=3\ Ом$, $R_3=R_4=2\ Ом$ ga teng. To'rt qutbli elektr zanjir doimiy koeffitsienti A,B,C,D ni aniqlang.



Yechish. To'rt qutbli zanjir doimiy koeffitsientini aniqlash uchun salt ishlash va qisqa tutashuv tajribasidan foydalanamiz:

yoki : $A=\sqrt{\frac{R_{10}}{R_{20}-R_{2K}}}$ bundan:

$$R_{10}=\frac{(R_1+R_2)(R_3+R_4)}{R_1+R_2+R_3+R_4}=\frac{(1+3)(2+2)}{1+3+2+2}=\frac{16}{8}=2\ \ Om$$

$$R_{20}=\frac{(R_1+R_3)(R_3+R_4)}{R_1+R_2+R_3+R_4}=\frac{3\cdot 5}{1+3+2+2}=\frac{15}{8}\ Om$$

$$R_{2K}=\frac{R_1R_2}{R_1+R_2}+\frac{R_3R_4}{R_3+R_4}=\frac{3}{4}+1=\frac{7}{4}\ \ Om$$

demak: $A=\sqrt{\dfrac{2}{\dfrac{15}{8}-\dfrac{7}{4}}}=4$

(8.10), (8.11), (8.12) tenglamaga asosan

$$C=\frac{A}{R_{0X}}=\frac{4}{2}=2\frac{1}{Om}\quad B=R_{2X}=4\cdot\frac{7}{4}=7Om$$

$$D=CR_{2K}=2\cdot\frac{15}{8}=3{,}75Om$$

Tekshirib ko'ramiz: $AD-BC=4\cdot 3{,}75-7\cdot 2=1$

Masala 8.14. T sxema to'rt qutbli parametri $Z_1=j2Om$, $Z_2=j2Om$, $Z_3=2Om$ bo'lganda, (b) formadagi koeffitsientini toping.

Yechish. (b) ko'rinishda ifodalanuvchi to'rt qutbll tenglamaga asosan:

$\dot{I}_1=0$ bo'lganda $B_{11}=\dfrac{\dot{U}_1}{\dot{U}_2}=\dfrac{Z_2+Z_3}{Z_3}=1-j1$

$\dot{U}_1=0$ bo'lganda $B_{12}=\dfrac{\dot{U}_2}{\dot{I}_1}=Z_1+Z_2+\dfrac{Z_1Z_2}{Z_3}=2Om$

$\dot{I}_1=0$ bo'lganda $B_{21}=\dfrac{\dot{I}_2}{\dot{U}_1}=\dfrac{1}{Z_3}=0{,}5\dfrac{1}{Om}$

$\dot{U}_1=0$ bo'lganda $B_{22}=\dfrac{\dot{I}_2}{\dot{I}_1}=\dfrac{Z_1+Z_3}{Z_3}=1+j1$

Yechimini tekshlramiz: $B_{11}\cdot B_{22}-B_{12}B_{21}=\dfrac{Z_3^2}{Z_3^2}=1$

Masala 8.15: П sxemadagi to'rt qutbli elektr zanjirga $Z_2=5+j5$ iste'molchi ulangan bo'lib, $\dot{U}_1=100$ V kuchianish qo'yilgan. Tok $\dot{I}_1$ va iste'molchi kuchlanishi $\dot{U}_2$ qiymati aniqlansin.

Yechish. (8.1) tenglamadan iste'molchi kuchianishini $\dot{U}_2 = \dot{Z}_2\dot{I}_2$ inobatga olgan holda: $\dot{U}_1 = \left(A + \frac{B}{Z_n}\right)\dot{U}_2$; $\dot{I}_1 = \left(C + \frac{D}{Z_2}\right)\dot{U}_2$

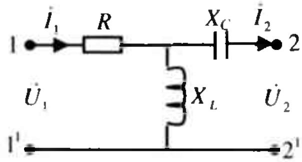
yoki:

$$\dot{U}_2 = \dot{U}_1\left(A + \frac{B}{Z_2}\right)^{-1} = 100\left(1 - j + \frac{10}{5\sqrt{2}e^{j45^\circ}}\right)^{-1} = 100(1 - j + 1 - j)^{-1} =$$

$$= 100(2 - j)^{-2} = \frac{100}{2\sqrt{2}e^{j45^\circ}} = \frac{50}{\sqrt{2}}e^{j45^\circ}\ B.$$

$$\dot{I}_1 = \dot{U}_2\left(C + \frac{D}{Z_2}\right) = \frac{50e^{j45^\circ}}{\sqrt{2}}\left(0{,}1 + \frac{\sqrt{2}e^{45^\circ}}{5\sqrt{2}e^{j45^\circ}}\right) = \frac{50}{\sqrt{2}}e^{j45^\circ}(0{,}1 + 0{,}2) = \frac{15}{\sqrt{2}}e^{j45^\circ}\ A$$

Masala 8.16. T sxemada ulangan to'rt qutbli elektr zanjr parametri $R = X_L = 10\ Om,\ \ X_c = 20\ Om$ ga teng. Salt holat va qisqa tutashuv tajriba va xarakteristik tenglamasi asosida A, B, C, koeffitsienti aniqlansin.



Yechish. a) to'rt qutbli elektr zanjirga U_I kuchlanish ulahib, chiqish qismida salt holat bo'lganda (8.1) tenglamadan:

$$A = \frac{\dot{U}_1}{\dot{U}_{20}} = \frac{\dot{U}_1}{\frac{\dot{U}_1}{R + jx_L}jx_L} = \frac{R + jx_L}{jx_L} = \frac{10 + j10}{j10} = \frac{\sqrt{2}10e^{j45^\circ}}{10e^{j90^\circ}} = \sqrt{2}e^{-j45^\circ}$$

$$C = \frac{\dot{I}_{10}}{\dot{U}_{20}} = \frac{\dot{I}_{10}}{\dot{I}_{10}\cdot jx_L} = \frac{1}{jx_L} = \frac{1}{j10} = -j0{,}1 = 0{,}1e^{-j90^\circ}\left(\frac{1}{Om}\right)$$

Chiqishda qisqa tutashuv bo'lganda :

$$B = \frac{\dot{U}_1}{\dot{I}_{2q}} = \frac{\dot{U}_1}{\frac{\dot{U}_1 / R}{\left(\frac{1}{R} + \frac{1}{jx_L} - \frac{1}{jx_c}\right)(-jx_c)}} = -jx_cR\left(\frac{1}{R} + \frac{1}{jx_L} - \frac{1}{jx_c}\right) =$$

$$= -j200(0{,}1 - j0{,}1 + j0{,}05) = 22{,}4e^{-j116^\circ}\ Om.$$

$$D=\frac{\dot I_{1k}}{\dot I_{2k}}=\frac{\dot I_{1k}}{\frac{\dot I_{1k}jx_L}{jx_L-jx_c}}=\frac{j(X_L-X_c)}{jx_L}=\frac{-j10}{j10}=-1$$

Masalaning yechimini tekshlramiz:

$$AD-BC=\sqrt{2}e^{-j45}(-1)-22,4e^{-j116^\circ}\cdot 0,1e^{-j90^\circ}=$$

$$=-(1-j)+j0,1(-10+j20)=-1+j-j+2=1.$$

b) endi xarakteristik tenglama orqali to'rt qutbli koeffitsientni aniqlaymiz.

Salt ishlash tajribasida, kirish qismida xarakteristik qarshiligi:

$$Z_{10}=R+jx_L=10+j10=\sqrt{2}\cdot 10e^{j45^\circ}\,Om$$

qisqa tutashuvda esa:

$$Z_{1k}=\frac{R+jx_L(-jx_c)}{j(X_L-X_C)}=\frac{10+j10(-j20)}{-j10}=10+j20=22,8e^{j}63^\circ\,Om$$

Kirishda qisqa tutashtirilgan holda, chiqishdagi xarakterstik qarshilik:

$$Z_{2k}=\frac{-jx_c+R_jX_L}{R+jx_L}=\frac{-j20+10\cdot j10}{\sqrt{2}e^{j45^\circ}}=-j20+\frac{10}{\sqrt{2}}e^{j45^\circ}=$$

$$=-j20+5+j5=5-j15=15,8e^{-j71,5^\circ}\,Om.$$

$(8.10,\div 8.13a)$ tenglamaga asosan to'rt qutbli koefitsientni topamiz:

$$A=\sqrt{\frac{\left(22,8e^{j63^\circ}\right)\cdot\left(10\sqrt{2}e^{j45^\circ}\right)}{\left(15,8e^{-j71,5^\circ}\right)(10+j10-10-j20)}}=\sqrt{\frac{322e^{j108^\circ}}{15,8e^{-j71,5^\circ}\cdot 10e^{-j90^\circ}}}=$$

$$=\sqrt{2\cdot e^{j270^\circ}}=1,41e^{j135^\circ}$$

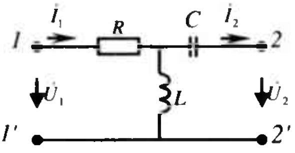
$$C=\frac{A}{Z_{10}}=\frac{\sqrt{2}e^{-j45^\circ}}{10\sqrt{2}e^{j45}}=-j0,1\left(\frac{1}{Om}\right);\ B=A\cdot Z_{2k}=$$

$$=\sqrt{2}e^{-j45^\circ}\cdot 15,8e^{j71,5^\circ}=22,3e^{-j116,5^\circ}\,Om$$

$$D=\frac{B}{Z_{1k}}=\frac{22,3e^{-j116,5^\circ}}{22,36e^{j63,5}}=-1$$

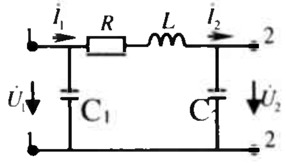
8.3. Mustaqil yechish uchun masalalar

Masala 8.1. T sxema shaklidagi to'rt qutbli elektr zanjir qarshiligi $R = x_L = x_c = 10(Om)$ A, B, C, D doimiy koeffitsientni aniqlang:



Javob: $\sqrt{2}e^{-j45}$, $10e^{-j90}(Om)$, $0,1e^{-90}\left(\frac{1}{Om}\right)$.

Masala 8.2. П sxema shaklidagi to'rt qutbli elektr zanjir parametri $\underline{Z} = (10 + j20)\ Om$, $\underline{Y}_1 = j0,1\left(\frac{1}{Om}\right)$, $\underline{Y}_2 = j0,25\left(\frac{1}{Om}\right)$ doimiy A, B, C, D doimiy koeffitsientlari aniqlansin.



Javob: $A = -4 + j2,5$, $B = 10(1 + j2)(Om)$,

$C = -0,05(5 + j3)\left(\frac{1}{Om}\right)$, $D = -1 + j$

Masala 8.3. n sxemadagi to'rt qutbli elektr zanjir doimiy koeffitsienti A=–4+j2,5, B=10(1+j2) (Om), $C = -0,05(5 + j3)\left(\frac{1}{Om}\right)$, $D = -1 + j$ bo'lganda, parametrini aniqlang.

Javob: $\underline{Z}_0 = 10(1 + j2)(Om)$, $\underline{y}_1 = j0,1\left(\frac{1}{Om}\right)$, $\underline{y}_2 = j0,25\left(\frac{1}{Om}\right)$

Masala 8.4. (8. 1) masaladagi T sxema bo'yicha to'rt qutbli parametri $R = \underline{x}_2 = 10\ (Om)$, $\underline{x}_c = 20\ (Om)$ to'rt qutbli kirish (1 – 1') va chiqish (2 – 2') qismlarida qisqa tutashuv va salt holat tajribalari asosida doimiy koeffitsienti aniqlansin.

Javob: $A=\sqrt{2}e^{-j45°}$, $C=0,1e^{-j90°}\left(\frac{1}{Om}\right)$, $B=22,4e^{-j116°}Om$, $D=-1$

Masala 8.5. T sxema shaklidagi to'rt qutbli parametri $\underline{Z}_1=10$ *(Om)*, $\underline{Z}_2=-j10$ *(Om)*, $\underline{y}_0=0,1\left(\frac{1}{Om}\right)$ bo'lib, $\underline{Z}_{ist}=5-j5$ iste'molchi qarshiligi ulangan to'rt qutbli kirish qismidagi kuchlanish $\dot{U}_1=100\,(V)$ ga teng bo'lganda $\dot{I}_1$ va $\dot{I}_C$ tok aniqlansin.

Javob: $\dot{I}_1=35\sqrt{2}e^{-j45°}(A)$, $\dot{I}_2=5(A)$

Masala 8.6. Doimiy koeffitsienti $A_2=2$, $B=j10$ ga teng simmetrik to'rt qutbli kirish qismidagi kuchlanish $\dot{U}_1=100\,(V)$ bo'lib xarakteristik qarshilikga ulangan. Xarakteristik qarshilik, uzatish koeffitsienti va $\dot{U}_2$ kuchlanishni aniqlang.

Javob: $\dot{U}_2=268\,(V)$, $g=1,32\,(Np)$, $a=0$, $b=j5,77$ *(rad)*

Masala 8.7. Xarakteristik qarshiligi $\underline{z}_c=100(O\text{м})$, $a=0$, $b=0,785$ *(rad)* bo'lgan simmetrik to'rt qutblik $\underline{z}_{ист}=100+j100(O\text{м})$ iste'molchi qarshiligiga ulangan. To'rt qutbli kirish qismidagi kuchlanish $\dot{U}_1=100\,(V)$ bo'lganda, ekvivalent umumiy qarshilik $\underline{z}_{ум1}$ va $\dot{I}_2$ tok hisoblab topilsin.

Javob: $\underline{z}_{ум1}=223,6e^{-j26°}$ *(Om)*, $\dot{I}_2=0,632e^{-j63°}(A)$

Masala 8.8. Simmetrik to'rt qutblida o'tqazilgan qisqa tutashuv va salt holat tajribalari asosida quyidagilar aniqlansin:

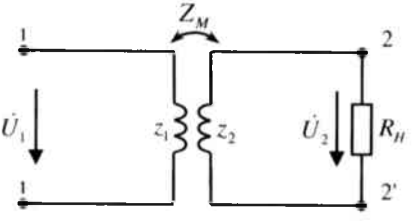
$\dot{U}_{10}=10\,(V)$, $\dot{I}_2=1(A)$, $P_{10}=10(Vt)$,

$\dot{U}_{1k}=10(V)$, $\dot{I}_{1k}=0,8(A)$, $P_{1k}=8(Vt)$

To'tr qutbli doimiy koeffitsient aniqlanib, T shakldagi sxemasi tuzilsin.

Javob: $A=j2$, $B=25e^{j90°}Om$; $C=0,2e^{j90°}\left(\frac{1}{Om}\right)$

Masala 8.9. Qarshilik parametri $x_1 = x_2 = R_1 = R_2 = 10(Om)$ induktiv bog'lanish koeffitsienti $K = 0{,}5$ ga teng, transformator R=10(Om) aktiv qarshilikga ulangan bo'lib, birlamchi chulg'am kuchlanishi $\dot{U}_1 = 184(V)$. To'rt qutbli doimiy koeffitsienti A, B, C, D, $\dot{U}_2$ kuchlanish va kirish qismidagi $\underline{Z}_{um}$ qarshilik aniqlanib, T ekvivalent sxemasi tuzilsin.

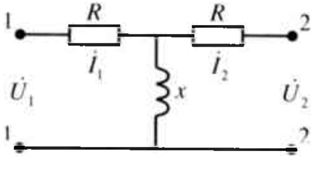


Javob: $A = 2 - j2$, $B = 40 - j5(Om), C = -0{,}2\left(\frac{1}{Om}\right) D = 2 - j2$,

$Z_{um} = 14{,}6e^{-j14^\circ}\ (Om)$, $\dot{U} = 28{,}4(V)$

Masala 8.10. To'rt qutbli transformator $A = \frac{1}{3}(-5 + j)$, $B = -\frac{1}{3}(10 + j15)\ (Om)$, $C = \frac{j}{3}\left(\frac{1}{Om}\right)$ teng va $f = 50 \cdot 10^3\,(Gs)$ bo'lganda transformatorning parametrlari: R_1, R_2, L_1, L_2, M aniqlansin: (Gn)
Javob: $R_1 = R_2 = 1(Om)$, $L_1 = L_2 = -10^{-4}(Gn)$, $M = 0{,}6 \cdot 10^{-4}(Gn)$

Masala 8.11. To'rt qutblining parametri $R_{12} = x = 1(Om)$ bo'lib, salt holat va qisqa tutashuv tajribalari asosida quyidagilar aniqlangan:



1) $\dot{U}_2 = 1\ (V)$; $\dot{I}_2 = 5(A)$; $\cos\varphi_2 = 0{,}8$; $\varphi_2 > 0$;
2) $\dot{U}_2 = 10\ (V)$; $\dot{I}_2 = 10(A)$; $\cos\varphi_2 = 0{,}8$; $\varphi_2 < 0$;

3) $\dot{U}_2 = 5\,(V)$; $\dot{I}_2 = 1(A)$; $\cos\varphi_2 = 1$; $\varphi_2 < 0$;

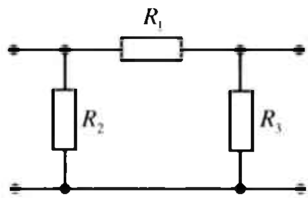
To‘rt qutbli kirish qismidagi tok $\dot{I}_1$ va kuchlanish $\dot{U}_2$ aniqlansin.

Javob:

1) $\dot{U}_1 = 12{,}5(V)$; $\dot{I}_1 = 8{,}05(A)$; 2) $\dot{U}_1 = 32{,}5(V)$; $\dot{I}_1 = 18{,}4(A)$;

3) $\dot{U}_1 = 8{,}05(V)$; $\dot{I}_1 = 6{,}08(A)$;

Masala 8.12. П sxemada ulangan to‘rt qutbli parametri $R_1 = 450\,Om$, $R_2 = 1800\,Om$, $R_3 = 900\,Om$ bo‘lganda, doimiy koeffitsienti aniqlansin.



Javob: $A = 1{,}5$, $B = 450\,Om$, $C = 1{,}95 \cdot 10^{-3}\frac{1}{Om}$, $D = 1{,}25$

Masala 8.13. Nosimmetrik to‘rt qutbli koeffitsienti $A = 1$; $B = 2{,}83e^{j45^\circ}\,Om$, $C = j0{,}5\,sm$, $D = j1$ ga teng. Xarakteristik qarshiligi va uzatish koeffitsienti aniqlansin.

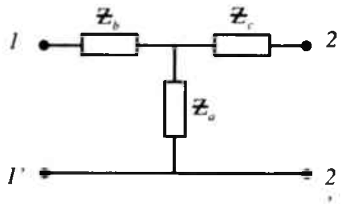
Javob: $_{s_1} = \pm 2{,}38e^{-j67{,}5}Om$; $_{s_2} = \pm 2{,}38e^{j22{,}5}Om$,

$g = 0{,}765 + j1{,}0$ $(\alpha = 0{,}765\,NP,\ \beta = 1rad)$

Masala 8.14. Simmetrik to‘rt quthli zanjir $\dot{U}_1 = 100V$ kuchlanishga ulangan. Ikkilamchi parametri $Z_s = 100\,Om$, $\alpha = 0$; $\beta = 0{,}785 rad$ bo‘lib, $Z_2 = 100 + j \cdot 100\,Om$ qarshilikga ulanganda, kirish qismidagi qarshilik $_1$ va I_2 tok qiymati aniqlansin:

Javob: $Z_1 = 223{,}6e^{-j26{,}6^\circ}\,Om$; $\dot{I}_2 = 0{,}632e^{-j63{,}5^\circ}$

Masala 8.15. T sxemada ulangan to‘rt qutbli elektr zanjir parametri: $Z_a = 30 - j40\,Om$, $Z_b = Z_c = 12 + j16\,Om$. So‘nish koeffitsienti a va faza koeffitsienti b aniqlansin.



Javob: $a = 0{,}562\, nep, \quad b = 0{,}703\, rad.$

8.4. Nazorat savollari

1. To‘rt qutbli elektr zanjir mma? Asoslab bering.
2. Elektr zanjirni to‘rt qutbli ko‘rinishida ifodalash bilan qanday masalalar yechiladi?
3. To‘rt qutbli elektr zanjir doimiy koeffitsienti nechta?
4. Aktiv va passiv to‘rt qutbli nima? Amalda qanday elektrotexnik uskuna va sxemalar misol bo‘la oladi?
5. Elektr energiyasi uzatish liniyasi to‘rt qutblimi?
6. Passiv to‘rt qutbli kirish ($\dot{I}_1, \dot{U}_1$) va chiqish ($\dot{I}_2, \dot{U}_2$) qismidagi tok va kuchlanish bog‘lanishini ifodalovchi tenglamani yozing.
7. To‘rt qutbli A, B, C, D koeffitsientlar bog‘lanish tenglamasini yozing.
8. To‘rt qutbli qanday holatda simmetrik bo‘ladi?
9. To‘rt qutbli almashinish (ekvivalent) sxemasi bo‘yicha parametrini aniqlash tenglamasimi yozing.
10. To‘rt qutbli parametri qanday aniqlanadi?
11. To‘rt qutbli qanday sxemada ulanadi va qaysi turdagi (formadagi) tenglamadan foydalaniladi?
12. To‘rt qutbli elektr zanjirning chiqish qismidagi to‘la qarshiligi uzatish va tutashtiruv tajribasiga asosan ($\underline{Z}_{20}$, $\underline{Z}_{2K}$) doimiy koeffitsientlari bilan bog‘lanish tenglamasini yozing.
13. To‘rt qutbli elelktr zanjirining kirish qismidagi to‘la qarshilik uzilgan va qisqa tutashtirilgan tajribasiga o‘tqazilganda ($\underline{Z}_{10}$, $\underline{Z}_{1K}$) doimiy koeffitsient bilan ifodalanish tenglamasini yozmg.
14. Parametri T, П, Г shaklda ulangan to‘rt qutbli sxemani chizmg va doimiy koeffitsient bilan bog‘lanish tenglamasini yozmg.

15. Simmetrik to‘rt qutblida tajriba o‘tqazish (salt holat, qisqa tutashtirish) natijasida kirish qismidagi kompleks qarshilik: $\underline{Z}_{10}=10e^{-j90}$ *Om*, $\underline{Z}_{1K}=10e^{-j30}$ *Om* bo‘lganda, A – doimiy koeffitsient qiymati nimaga teng? (Javob: $A=e^{-j30}$)
16. Differensialiovchi yoki integrallovchi to‘rt qutbli sxemani chlzing va ta’riflab bering.
17. Chastotaviy elektr filtr nima va qaysi maqsadda foydalaniladi?
18. Aktiv to‘rt qutbli elektr zanjirinmg kirish qismidagi R_1 aktiv quvvatga nisbatan, chiqish qismidagi R_2 aktiv quvvat katta bo‘lishi mumkinmi?
19. П shaklida ulangan to‘rt qutbli elektr zanjir parametri: $R_1=450$ *Om*, $R_2=1800$ *Om*, $R_3=900$ *Om* ga teng. Doimiy koeffitsient qiymati nimaga teng? (Javob: A=1,5, B=450 *Om*, $C=1{,}95\cdot10^{-3}\,\frac{1}{Om}$, D=1,25)
20. П shaklida ulangan to‘rt qutbli elektr zanjir kirish qismidagi kuchlamsh $U_1=60\,(V)$ bo‘lib, $R_2=1000\ Om$ iste’molchiga ulangan. Chiqish qismidagi U_2 kuchlanish va I_2 tok aniqlansin. Javob: $U_2=35{,}3V$, $I_2=35{,}3\ mA$
21. Simmetrik to‘rt qutbli tavsifiy tenglamasi uzatish koeffitsienti ifodalari ma’nosini tushuntiring.
22. To‘rt qutbli uzatish koeffitsienti qanday ifodalanadi?

IX. ELEKTR FILTR

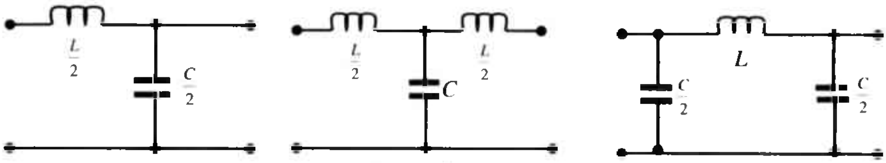
9.1. Asosiy nazariy tushunchalar

Reaktiv elementlardan tarkib topgan to‘rt qutbli zanjirsimon chastota ajratuvchi elektr filtr radiotexnika, aloqa, avtomatika va boshqa sohalarda keng foydalamladi. Elektr filtrlarining turlicha elektr signallarini kuchaytirish, pasaytirish, tekislash yoki chegaralash xususiyatlariga ega bo‘lishi induktivlikning past chastotaga qarshiligi kichik, sig‘imda esa qarshiligi yuqori yoki aksincha ekanligi sabab bo‘ladi.

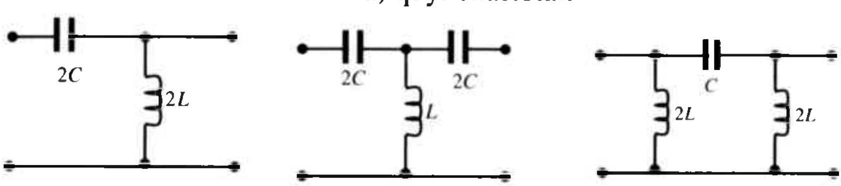
Chastota ajratuvchi filtrlarnmg ishiash prinsipi L va C qarshilikning (o‘tkazuvchanliklari) signal chastotasi ω ga bog‘liq holda o‘zgarishga asoslangan bo‘lib, turli xildagi – Г, Т, П sxemalarda ulash bilan signallar maqsadli filtrlanadi.

Shuni ta’kidlash kerakki, chastota ajratuvchi filtrlarmng reaktiv elementlar L, C dan tuzilishiga asosiy sabab aktiv energiya isrofi minimal bo‘lishidadir.

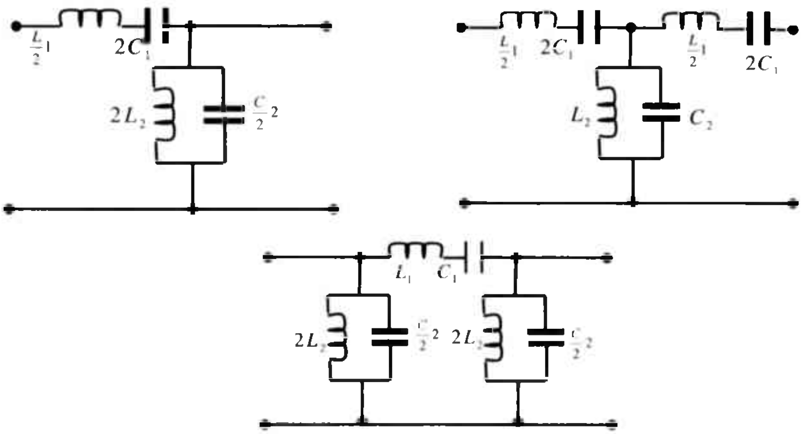
Elektr filtr vazifasi va sxemasinmg tuzilishi jihatdan quyi chastotali, yuqori chastotali, hududli (chastotalararo) va to‘suvchi filtrlarga bo‘linadi:



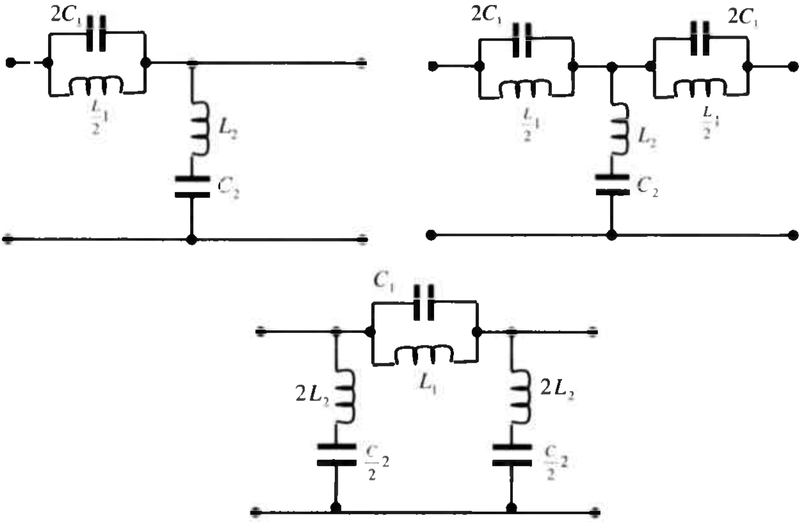
a) quyi chastotali



b) yuqori chastotali



d) hududli



e) to‘suvchi.

Past chastotali filtrlar tok chastotasini

$$0 \div f_0 \text{ gacha } \left(0 \le f \le \frac{1}{\pi(LS)}\right).$$

Yuqori chastotali filtr $f_0 \div \infty$ gacha $\left(\frac{1}{4\pi\sqrt{LC}} \le f \le 0\right)$ o‘tkazadi.

Hududiy filtrlar esa: $f_1 \div f_2$ gacha $f_{1,2} = \frac{1}{2\pi}\left(\sqrt{\frac{1}{L_1C_2}+\frac{1}{L_1C_1}} \mp \frac{1}{\sqrt{L_1C_2}}\right)$ tok chastotasini oraliqda chegaralaydi.

To‘sib qoluvchi filtr $0 \div f_1$ va $f_2 \div \infty$ gacha $f_{1,2} = \frac{1}{8\pi}\left(\sqrt{\frac{1}{L_2C_1}+\frac{16}{L_1C_2}} \mp \frac{1}{\sqrt{L_2C_1}}\right)$ bo‘lgan tok chastotasini o‘tkazadi.

Odatda hududiy yoki to‘suvchi elektr filtrda $L_1C_1 = L_2C_2$ shart bajarilishi kerak. Elektr filtr kaskadli zanjirsimon to‘rt qutbli reaktiv elementlardan tuzilgan sxemalar bo‘lib, chiqish yoki keyingi filtrga kiruvchi tavsifiy qarshilik Z_S ga teng bo‘ladi.

Bunda filtrdan chiquvchi tok va kuchlanish kompleks ifodasi $e^{ng} = e^{na} \cdot e^{jnb}$ bo‘lib, moduli kirishdagi signalga nisbatan e^{na} marta kichik bo‘ladi.

n – zanjirsimon sxemada ulangan filtrlar soni, α – chastotaga bog‘liq to‘rt qutbli so‘nish koeffitsienti bo‘lib, (8.8) tenglamaga asosan:

$$A = chg = ch(\alpha + jb) \tag{9.1}$$

T – sxema uchun: $$A = 1 + \frac{y_T Z}{2} \tag{9.2}$$

П – sxema uchun: $$A = 1 + \frac{y_0 Z}{2} \tag{9.3}$$

(9.2), (9.3) y, z mavhum son bo‘lib, A koeffitsient mavhum son bo‘la olmaydi, shunga asosan:

$$A = ch(a + jb) = cha\cos b + j\, sha\sin b. \tag{9.4}$$

ya’ni: $$sha\ sin\ b = 0 \tag{9.5}$$

$$cha\cos\cos b = A = 1 + \frac{yZ}{2} \tag{9.6}$$

Bu tenglamadan chastota o‘zgarishi bilan – y, z parametr ikki holatda bo‘ladi.

a) agar $sha = 0$ bo‘lganda, $\alpha = 0$ bo‘lib, $cha = 1$.

Shunga asosan: $$\cos b = A + \frac{yZ}{2} \tag{9.7}$$

Tenglamada y, z qiymatlar bir xil mavhum son bo‘lib, chastotaviy chegarasi:

$-1 \leq 1 + \frac{y}{2} \leq +1$, unda chastota o'tkazish chegaralari:

$$\begin{matrix} -y= \\ -y= \end{matrix}\begin{cases} 0 \\ 4. \end{cases} \qquad (9.7a)$$

Agarda: $\frac{Z}{2}+\frac{2}{y}=0$ bo'lsa, bundan $yz+4=0$ bo'lib, filtr rezonans holatda bo'ladi.

Tavsifiy qarshilik tenglama ham chastotaga bog'liq bo'lib, to'rt qutbli koeffitsientlar orqali quyidagicha bog'langan:

T – sxema bo'lganda: $Z_{st} = \sqrt{\frac{B}{C}} = \sqrt{\frac{A^2-1}{C^2}}$;

П – sxema uchun: $Z_{sn} = \sqrt{\frac{B}{C}} = \sqrt{\frac{B^2}{A^2-1}}$

yoki: $_{st}\, va\, _{sp}$ tavsifiy qarshilikni to'rt qutbli koeffitsient orqali ifodalash bilan (9.2), (9.3) tenglamaga asosan:

$$Z_{st} = \sqrt{\frac{A^2-1}{y_T^2}} = \sqrt{\frac{Z}{y}}\sqrt{1+\frac{yZ}{4}}; \qquad (9.8)$$

$$Z_{sp} = \sqrt{\frac{Z_p^2}{A^2-1}} = \sqrt{\frac{Z}{y}};\sqrt{1+\frac{yZ}{4}} \qquad (9.9)$$

(9.8), (9.9) formuladan chegaraviy hududlari: $0 \leq -y \leq 4$

Chastotaviy chegara T sxema uchun: $0 \div Z_s = \sqrt{\frac{Z}{y}} = \sqrt{\frac{B}{C}}$

П sxema uchun: $Z_s \div \infty$ gacha bo'lib $Z_s = R$.

Elektr filtr chastotani chegaralashda, chastota o'zgarishiga nisbatan faza koeffitsienti ham o'zgaradi. (5.7) tenglamani (8.18) tenglamaga qo'yish bilan

$$sh = sh(a+jb) = CZ_c = \frac{B}{Z_c}$$

Bunda: $b=0$: $j\sin b = Cz_c = y_T Z_{cT}$; yoki $j\sin b = \frac{B}{Z_c} = \frac{Z_p}{Z_{sp}}$.

Faza koeffitsienti ishorasi o'tkazuvchanlik parametri bilan bog'liq ekan.

b) endi (9.5) tenglamadan $sha\sin b=0$, $\sin b=0$, bo'lganda, $sha\geq 1$ bo'lib, $\cos b=-1$. Unda (9.6) dan $cha=-A=-\left(1+\frac{yZ}{2}\right)$ (9.10)

So'nish koeffitsienti b = 0, signalni filtrlash chegarasi:

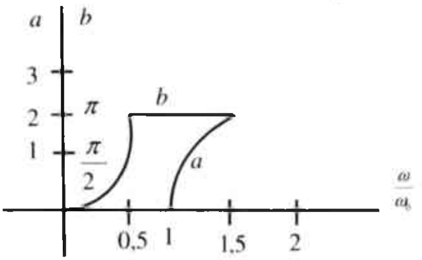
$$\left.\begin{array}{c} 1\leq-\left(1+\frac{yZ}{2}\right)\leq\infty \\ -yZ=4 \\ yoki \quad -yZ=\infty \end{array}\right\}$$

Bu esa filtr sxemasining R = 0; y = ∞ ekanligini belgilaydi.

Bu holda: $A^2-1=ch^2a-1\geq 0$ bo'lib, (9.8), (9.9) tenglamaga asosan so'nish chegarasida tavsifiy qarshilik mavhum son bo'lib, T va П filtr sxema uchun ishorasi har xil bo'ladi.

Tahlil qilingan elektr filtr xususiyatiga asosan:

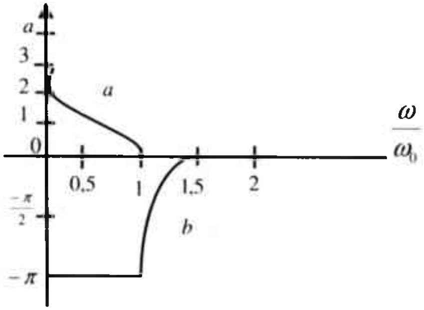
a) quyi chastotali filtr: T sxemadan $z=j\omega L$, $y=j\omega c$ bo'lganda, filtrlash chegarasi (9.7a) asosan $-yZ=\omega^2LC=\begin{cases}0\\4\end{cases}$



Demak: $\omega_1=0; \omega=\frac{2}{\sqrt{LC}}=\omega_0$

b) yuqori chastotali filtr: (b) T sxema reaktiv qarshilik parametri $Z=\frac{1}{j\omega c}$; $Y=\frac{1}{j\omega L}$ bo'lib, $-yZ=\frac{1}{\omega^2LC}=\begin{cases}0\\4\end{cases}$ filtrlash chegarasi

$\omega_1=\frac{1}{2\sqrt{LC}}=\omega_0$ va $\omega_2=\infty$ gacha bo'ladi.



d) hududiy filtr: Yuqorida keltirilgan shartga asosan: $L_1C_1 = L_2C_2$ bo‘lib,

$$\omega_0 = \frac{1}{\sqrt{L_1C_1}} = \frac{1}{\sqrt{L_2C_2}}$$

yoki: $Z = j\omega L_1 + \frac{1}{j\omega c_1} = \frac{1}{j\omega c_1}\left(1-\omega^2 L_1 C_1\right) = \frac{1}{j\omega c_1}\left(1-\frac{\omega^2}{\omega_0^2}\right)$

$$y = j\omega c_2 + \frac{1}{j\omega L_2} = \frac{1}{j\omega L_2}\left(1-\frac{\omega^2}{\omega_0^2}\right)$$

Keltirilgan tenglamalar quyidagi chegarada ifodalanadi

$$-ZY = \frac{\left(1-\frac{\omega^2}{\omega_0^2}\right)^2}{\omega^2 L_2 C_1} = \begin{cases} 0 \\ 4 \end{cases}$$

bundan: $\omega^2 \pm 2\omega\omega_0^2\sqrt{L_2C_1} - \omega_0^2 = 0$

$\omega_1 = \omega_0\left(\sqrt{k^2+1}-k\right)$; $\omega_2 = \omega_0\left(\sqrt{k^2+1}+k\right)$; $k = \omega_0\sqrt{L_2C_1} = \sqrt{\frac{L_2}{L_1}}$

Demak filtr chastotani $\omega_1 \div \omega_2$ oraliqda chegaralaydi. ω_0 esa oraliq chastotani ifodalaydi, ya’ni: $\omega_1\omega_2 = \omega_0^2$

e) to‘suvchi filtr:

Bu filtr sxemasidan yuqoridagi shartga asosan:

$$L_1C_1 = L_2C_2 \text{ va } \omega_0 = \frac{1}{\sqrt{L_1C_1}} = \frac{1}{\sqrt{L_2C_2}}.$$

$$Z = \frac{1}{j\omega c_1 + \frac{1}{j\omega L_1}} = \frac{j\omega L_1}{1-\frac{\omega^2}{\omega_0^2}};\; y = \frac{1}{j\omega L_2 + \frac{1}{j\omega c_2}} = \frac{j\omega c_2}{1-\frac{\omega^2}{\omega_0^2}}$$

Chastotani to'sish chegarasi esa:

$$-ZY = \frac{\omega^2 L_1 C_1}{\left(1-\frac{\omega^2}{\omega_0^2}\right)^2} = 0; \qquad -YZ = \frac{\omega^2 L_1 C_2}{\left(1-\frac{\omega^2}{\omega_0^2}\right)^2} = 4$$

Birinchi tenglama ikkita qiymat beradi: $\omega_1 = 0; \omega_4 = \infty$. Ikkinchisi: $\omega_2 = \omega_0\left(\sqrt{k^2+1}-k\right)$; uchinchisi: $\omega_3 = \omega_0\left(\sqrt{k^2+1}+k\right)$

Bunda: $k = \frac{\omega_0\sqrt{L_1C_2}}{4} = \frac{1}{4}\sqrt{\frac{L_1}{L_2}}$

Demak filtr chastotani $0 \div \omega_2$ va $\omega_3 \div \infty$ o'tkazib, chastotani to'sish chegarasi: $\omega_2 \div \omega_3$ ga teng yoki: ω_0 – chegara ichida bo'lib: $\omega_0^2 = \omega_2\omega_3$.

9.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 9.1. T sxemadagi filtr parametrlari $L = 20\, mgn,\ C = 20\, mkf$ bo'lganda chastota o'tkazish chegaralari aniqlanib, $\omega = 2000\, {}^{rad}/_{sek}$ va tok $I_2 = 0{,}1\, A$ bo'lganda so'nish koeffitsient a topilsin.

Yechish. T sxema uchun (9.2) ifodaga asosan:

$$A = 1 + \frac{Z_1}{Z_3} = 1 + j\omega L \cdot j\omega c = 1 - \omega^2 LC$$

Agarda $A = 1$; bo'lsa $\omega_1 = 0$; yoki $A = -1$ bo'lganda;

$-1 = 1 - \omega^2 LC;$ (1)

Bundan: $\omega_2 = \sqrt{\frac{2}{LC}} = 2235\, {}^{rad}/_{sek}$ Chastotani filtrlash chegarasi: $b = \arccos A = \arccos(1 - \omega^2 LC)$.

Chastota $\omega = 2000\, {}^{rad}/_{sek}$ bo'lganda, tavsifiy qarshilik:

$$Z_c = \sqrt{\frac{2L}{C} - \omega^2 L^2} = 80\, om.$$

filtr tavsifiy qarshiligi 80 *Om* bo'lganda chiqishdagi kuchlanishl:

$$U_2 = I_{2s} = 0{,}1 \cdot 80 = 8\, V.$$

So'nish koeffitsient a chastotaga nisbatan o'zgarishini topish uchun (9.1) tenglamadan $cha = -A = \omega^2 LC - 1$

Bundan $\omega = 2\omega_2 = 2 \cdot 2235 = 4470\, {}^{rad}/_{sek}$ teng bo'lganda:

$cha = (4470) \cdot 20 \cdot 10^{-3} \cdot 20 \cdot 10 - 1 = 8,$ $\qquad a = 2{,}8\, nep.$

Masala 9.2. K turdagi quyi chastotali filtr yuqori chegaralash chastotasi $f_0 = 0{,}5\,kgts$ bo‘lib, $R = 500\,Om$ iste’molchi qarshiligiga ulangan.

a) filtr parametri L, C, b) $f_1 = 1\,kgts$ bo‘lgan so‘nish koeffitsienti *a* kirish va chiqishdagi kuchianishga nisbatan qiymatlari *nep, detsb* o‘lchamlari topilsin; b) ekvivalent sxemasi tuzilsin.

Yechish. K turdagi quyi chastotali filtrlarning yuqori chastota chegarasi quyidagicha ifodalanadi .

$L = \frac{R}{\pi f_0} = 0{,}317\,gn,\quad C = \frac{1}{\pi f_0 R} = 1{,}27\,mkf.$

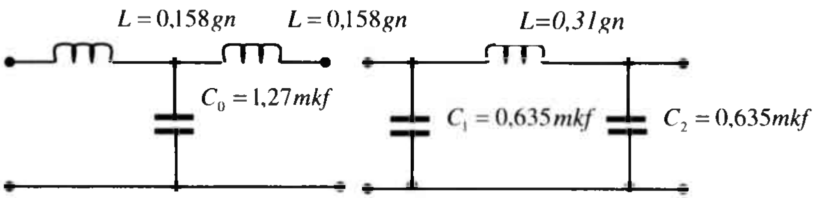
So‘nish koeffitsienti $f_1 = 1\,kgts$ bo‘lganda $ch\mathrm{L} = 2\eta_1^2 - 1;$

Bundan $\eta = \frac{\omega_1}{\omega_0} = \frac{f_1}{f_0} = 2:$

Demak: $ch\alpha = 7,\ \ \alpha = 2{,}64\ \text{nep} = 22{,}9\ \text{dtsb}.$

Bundan: $\alpha = \ell n\frac{U_1}{U_2}$ yoki $\frac{U_1}{U_1} = e^{\alpha} = 14$

Ekvivalent sxema T yoki П ko‘rinishda bo‘ladi:



Masala 9.3. T sxemada filtr parametri $C_3 = 0{,}08\,mkf$ va $L_2 = 0{,}02\,gn$ bo‘lganda, filtrlash chegarasi aniqlanib, iste’molchi qarshilik R_2ning qaysi chastota formasi buzilmasligi va chastotaning $f_1 = 0;\ f_2 = \frac{f_s}{2};\ f_3 = 0;\ f_4 = 2f_s\ (f_s - rezonans\ chastota)$ qiymatida tavsifiy qarshiligi Z_C va so‘nish koeffitsienti a aniqlansin.

Yechish. Masalaning shartiga ko‘ra T sxema quyi chastotali filtr bo‘lib, filtrlash oralig‘i tenglamaga asosan: $-1 \le \frac{1}{y_2} \le 0$

Bunda: $Z_1 = j\omega L\ va\ Z_2 = \frac{1}{j\omega c}.$

Shunga asosan quyi chegarasi $f_1 = 0$ dan yuqori chegarasi $f_s = \frac{1}{\pi\sqrt{LC}} = 8000\ gs$ oralig‘ida chastota filtrlanadi.

T sxema uchun tavsifiy qarshilik tenglamasi:

$$Z_C = \sqrt{Z_1Z_2\left(1+\frac{Z_1}{YZ_2}\right)} = R_0\sqrt{1-\left(\frac{f}{f_c}\right)^2}.$$

Bunda: $R_C = \sqrt{\frac{L}{C}}$ filtrlarning tavsifiy qarshilik tenglamasi.

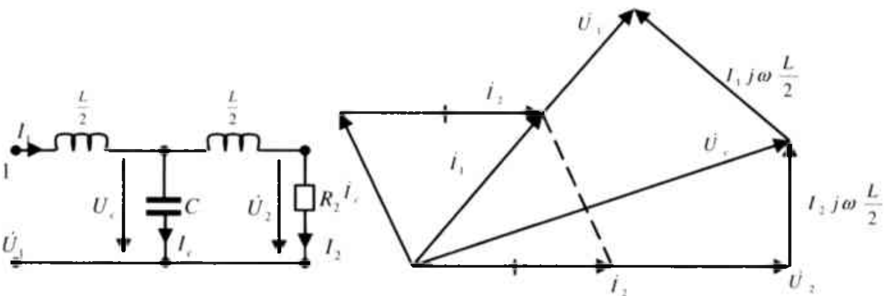
Filtr so'nishini ifodalovchi tenglama: $ch\frac{a}{2} = \sqrt{\frac{x_1}{4x_2}} = \sqrt{\frac{\omega^2 LC}{4}} = \frac{f}{f_c}$

Qiymatlarini tablitsa asosida keltiramiz.

$f(gs)$	0	$f_s/_2$	f_s	$2f_s$
$Z_C Om$	500	433	0	$j865$
$a.(пер.)$	0	0	0	2,64

Shuni ta'kidlash kerakki, filtrnmg $f = 0$ dan $f = f_c$ filtrlash chegaralarida tavsifiy qarshilik qiymati haqiqiy, so'nish chegarasida esa mavhum son qiymatiga ega. Demak T shakldagi quyi chastota filtrlash hususiyati xarakteristik tenglamaning $Z_c = R_0\, dan\, Z_s = 0$ oralig'ida bo'lar ekan.

Masala 9.4. T sxema shaklidagi quyi chastotali xarakteristik parametri $L = 0{,}02$ gn, $C = 8\,mkf$ bo'lib, R_2 qarshiligiga $U_2 = 13\,B$ kuchlanish ulangan. Chastota filtrlash chegarasi $\omega_1 = \frac{\omega_0}{2}$, va so'nish $\omega_2 = 2\omega_0$ bo'lganda tok va kuchlanish qiymati aniqlanib, vektor ifodasi tuzilsin:



Yechish. Rezonans holatda burchak chastota:

$\omega_0 = \frac{2}{\sqrt{LC}} = \frac{2}{\sqrt{0{,}02\cdot 8\cdot 10^{-6}}} = 500\, {}^{rad}/_{sek}$

Demak: $\omega_1 = 2500\, {}^{rad}/_{sek};\quad \omega_2 = 10^4\, {}^{rad}/_{sek}$

Salt yoki qisqa tutashuv tajribasiga asosan xarakteristik qarshilikni topamiz:

$$Z_{1x} = j\omega_1 \frac{L}{2} + \frac{1}{j\omega_1 c} = j25 - j50 = -j25Om;$$

$$Z_{1k} = jx_L + \frac{jx_L \cdot jx_c}{j(x_L - x_c)} = j25 + \frac{j25(-j50)}{j25 - j50} = j75Om.$$

Tavsifiy qarshiligi: $R_2 = Z_0 = \sqrt{Z_{1x} \cdot Z_{1k}} = 25\sqrt{3}\ Om.$

Tok: $\dot{I}_2 = \frac{\dot{U}_2}{R_2} = \frac{13}{25\sqrt{3}} = 0,3A.$

Filtr sxemasidan: $\dot{U}_c = \dot{U}_2 + j\omega \frac{L}{2} \dot{I}_2 = (13 + j7,5)V$

$\dot{I}_c = \frac{\dot{U}_c}{-jx_c} = \frac{13+j7,5}{-j50} = (-0,15 + j0,26)\ A$

Kirish qismidagi tok:

$\dot{I}_1 = \dot{I}_2 + \dot{I}_c = 0,3 - 0,15 + j0,26 = 0,15 + j0,26 = = 0,3e^{j60^\circ}\ A$

Kuchlanish:

$$\dot{U}_1 = U_c + j\omega_1 \frac{L}{2} I_1 = 13 + j7,5 + j25(0,15 + j0,26) = 6,5 + j11,25 = 13e^{j60^\circ}\ V$$

So‘nish chegarasi $\omega_2 = 10^4\ rad/_{sek}$ bo‘lganda, tok va kuchianish qiymatini topamiz.

$$\dot{U}_c = \dot{U}_2 + j\omega_2 \frac{L}{2} \dot{I}_2 = 13 + j100 \cdot 0,3 = (13 + j30)\ V$$

$$\dot{I}_c = \frac{\dot{U}_c}{jx_c} = \frac{13 + j30}{-j12,5} = (-2,4 + j1,04)\ A$$

$$\dot{I}_1 = \dot{I}_2 + \dot{I}_c = 0,3 - 2,4 + j1,04 = -2,1 + j1,04 \approx 2,34e^{j153^\circ}\ A$$

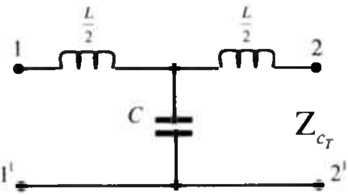
$$\dot{U}_1 = \dot{U}_c + j\omega_2 \frac{L}{2} \dot{I}_1 = 13 + j30 - j210 - 104 = -91 - j180 \approx 202, e^{j117^\circ}\ V$$

Masala 9.5. Quyi chastotali (K turdagi) T va П sxemadan iborat bo‘lgan elektr filtr burchak chastotasi $\omega_0 = 3,14 \cdot 10^{-3}\ \frac{1}{sek}$ bo‘lib, $R_c = R_2 = 0,5 \cdot 10^{-3}\ Om$ tavsifiy aktiv qarshilikga ulangan.

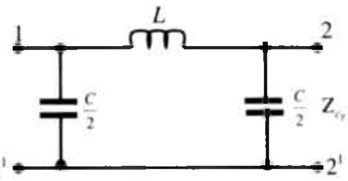
a) elektr filtr parametrlari L, C.

b) chastotani filtrlash chegarasi $\omega = 0,5 \cdot \omega_0$ bo‘lganda, tavsifiy qarshiligi Z_{st}, Z_{sp} faza koeffitsienti $b/2$.

d) $\omega = 1,5\omega_0$ bo‘lganda (chastotani to‘sishda) so‘nish koeffitsienti $b/2$ qiymati aniqlansin.



a)



b)

Yechish.

a) quyi chastotali T shakldagi elektr filtr parametri yuqori chegarasini aniqlaymiz:

$$L=\frac{2R}{\omega_0}=\frac{2\cdot 0,5\cdot 10^3}{3,14\cdot 10^3}=0,318gn, C=\frac{2}{\omega_{0R}}=\frac{2}{3,14\cdot 10^3\cdot 0,5\cdot 10^3}=1,274\cdot 10^{-6}f$$

b) K turdagi elektr filtr tavsifiy qarshiligi:

$$K=Z_c=\sqrt{\frac{L}{C}}=\sqrt{\frac{0,318}{1,27\cdot 10^{-6}}}=0,5\cdot 10^3\ Om.$$

d) filtr chastotasi $\omega = 0,5\omega_0 = 1,57\cdot 10^3\frac{1}{sek}$ bo‘lganda, filtr reaktiv qarshiligini aniqlaymiz:

$$X_L=\omega\left(\frac{L}{2}\right)=1,57\cdot 10^3\cdot\frac{0,318}{2}=250\ Om;$$

$$X_c=\frac{1}{\omega\left(\frac{c}{2}\right)}=\frac{1}{1,57\cdot 10^3\cdot\frac{1}{2}\cdot 1,27\cdot 10^{-6}}=1000\ Om$$

e) endi $\omega = 0,5\omega_0$ bo‘lganda quyi chastotani filtrlar tenglamasiga asosan T, П sxema tavsifiy qarshiligini aniqlaymiz:

$$Z_{CT}=K\sqrt{1-\left(\frac{\omega}{\omega_0}\right)^2}=0,5\cdot 10^3\cdot\sqrt{1-\left(\frac{0,5\cdot\omega_0}{\omega_0}\right)^2}=0,433\cdot 10^3 Om;$$

$$Z_{C\Pi}=\frac{K}{\sqrt{1-\left(\frac{\omega}{\omega_0}\right)^2}}=\frac{0,5\cdot 10^3}{\sqrt{1-\left(\frac{0,5\omega_0}{\omega_0}\right)^2}}=0,577\cdot 10^3 Om.$$

f) chastota o‘tkazish chegarasi $\omega = 0,5\,\omega_0\frac{1}{sek}$ bo‘lganda, so‘nish koeffitsienti $\frac{a}{2} = 0$ bo‘lib, faza koeffitsienti:

$$\frac{b}{2} = arc\sin\frac{\omega}{\omega_0} = arc\sin 0,5 = 30^\circ$$

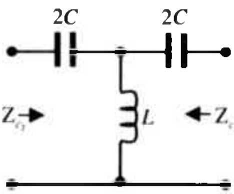
g) $\omega = 1{,}5\,\omega_0 = 4{,}77 \cdot 10^3 \frac{1}{sek}$, chastotani to'sish chegarasida, so'nish koeffitsienti: $\frac{a}{2} = arcch\frac{\omega}{\omega_0} = arcch1{,}5 = 0{,}963\ NP = 8{,}345\ Db$. ($1\ NP = 8{,}686\ Db$)

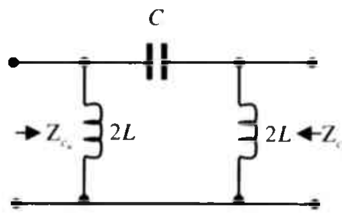
Faza koeffitsienti: $\frac{b}{2} = 90^\circ$.

Masala 9.6. (9.5) masala shartiga asosan yuqori chastotali K turdagi filtr parametri L, C va tavsifiy qarshiligi Z_c va $a/2$, $b/2$ koeffitsienti aniqlansin:

Masala 9.7. K turdagi yuqori chastotali filtr burchak chastotasi $\omega = 3{,}14 \cdot 10^3 \frac{1}{sek}$ bo'lib, $R = Z_c = 2 \cdot 10^3\ Om$, $\left(R = K = \sqrt{\frac{L}{C}}\right)$ tavsifiy qarshiligi ulangan.

Filtr o'tkazish chegarasi $\omega = 1{,}5\,\omega_0$ bo'lganda, tavsifiy qarshilik qiymati $Z_{CT}, Z_{C\Pi}$ va faza koeffitsienti $b/2$ hamda to'sish chegarasi va $\omega = 0{,}5\,\omega_0$ bo'lganda so'nish koeffitsienti $a/2$ qiymati aniqlansin.





Yechish.

a) yuqori chastotali filtr parametrini (9.10) ifodaga asosan:

$$L = \frac{R}{2\omega_0} = \frac{2 \cdot 10^3}{2 \cdot 3{,}14 \cdot 10^3} = 0{,}318gn;$$

$$C = \frac{1}{2\omega_0 R} = \frac{1}{2 \cdot 3{,}14 \cdot 10^3 \cdot 2 \cdot 10^3} = 0{,}0795 \cdot 10^{-6} f.$$

b) K turdagi yuqori chastotali filtr tavsifiy qarshiligi:

$$K = Z_c = \sqrt{\frac{L}{C}} = \sqrt{\frac{0{,}318}{0{,}08 \cdot 10^{-6}}} = 2 \cdot 10^3 Om.$$

d) $\omega = 1{,}5\omega_0 = 1{,}5 \cdot 3{,}14 \cdot 10^3 = 4{,}7 \cdot 10^3 \frac{1}{sek}$ bo'lganda filtr reaktiv qarshiligini topamiz:

$$X_c = \frac{1}{\omega(2c)} = \frac{1}{4,7\cdot 10^3\cdot 2\cdot 0,08\cdot 10^{-6}} = 1335Om;$$

$$X_L = \omega(2L) = 4,7\cdot 10^3\cdot 2\cdot 0,3 = 3000Om.$$

e) П sxemadagi filtr chastota o'tkazish chegarasidagi tavsifiy qarshilik qiymatini (ω = 1,5ω_0) aniqlaymiz:

$$Z_{CT} = K\cdot\sqrt{1-\left(\frac{\omega_0}{\omega}\right)^2} = 2\cdot 10^3\sqrt{1-\frac{\omega_0}{1,5\omega_0}} = 1,5\cdot 10^3 Om.$$

$$Z_{C\Pi} = \frac{K}{\sqrt{1-\left(\frac{\omega_0}{\omega}\right)}} = \frac{2\cdot 10^3}{\sqrt{1-\left(\frac{\omega_0}{1,5\omega_0}\right)^2}} = 2,7\cdot 10^3 Om.$$

f) chastota o'tkazish chegarasi:

$\omega = 1,5\omega_0 = 4,7\cdot 10^3\frac{1}{sek}$ bo'lganda, so'nish koeffitsienti $a/2 = 0$, faza koeffitsienti:

$$b/2 = arc\sin\left(-\frac{\omega_0}{\omega}\right) = arc\sin\left(\frac{1}{1,5}\right) = -42^{\circ}.$$

Chastotani to'sish chegarasi: $\omega = 0,5\omega s = 1,57\cdot 10^3\frac{1}{sek}$

g) so'nish koeffitsienti:

$$\frac{a}{2} = arch\frac{\omega_c}{\omega} = arch\frac{1}{0,5} = Arch = 2 = 1,32NP = 11,45Db;$$

Faza koeffitsienti: $b = -90°$

Masala 9.8. K turdagi hududiy filtr burchak chastotasi $\omega_{01} = 62,8\cdot 10^3\frac{1}{sek}$; $\omega_{02} = 75,4\cdot 10^3\frac{1}{sek}$ bo'lib, tavsifiy qarshiligi

$$R = R_c = 10\cdot 10^3 Om\ \left(R_{yuk} = K = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}}\right).$$

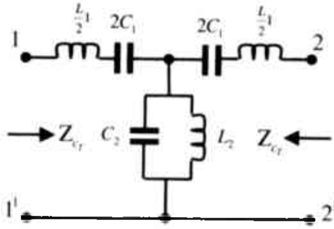
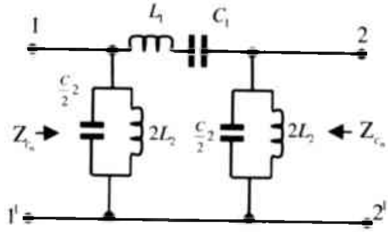
a) filtr parametrlari: L_1, C_1, L_2, C_2.

b) $\omega = 0,5\cdot(\omega_{01}+\omega_{02})$ chastota o'tkazish chegarasida Z_{st}, Z_{sp} tavsifiy qarshiligi va faza koeffitsienti $b/2$

d) filtr chap tomonida to'sish chastotasi $\omega = 0,5\omega_{01}$ bo'lganda, so'nish koeffitsienti $a/2$ qiymatni aniqlang.

Yechish.

a) hududiy filtr signallarini o'tkazish ifodasiga yoki chegaralanish ifodasiga asosan:

$$L_1 = \frac{2R}{\omega_{02} - \omega_{01}} = \frac{2 \cdot 10 \cdot 10^3}{75,4 \cdot 10^3 - 62,8 \cdot 10^3} = 1,59 gn$$

$$C_1 = \frac{\omega_{02} - \omega_{01}}{2R\omega_{02} \cdot \omega_{01}} = \frac{75,4 \cdot 10^3 - 62,8 \cdot 10^3}{2 \cdot 10 \cdot 10^3 \cdot 75,4 \cdot 10^3 \cdot 62,8 \cdot 10^3} =$$

$$= 0,133 \cdot 10^{-9} = 0,133 nf.$$

$$L_2 = \frac{R(\omega_{02} - \omega_{01})}{2\omega_{02} \cdot \omega_{01}} = \frac{10 \cdot 10^9 (75,4 \cdot 10^3 - 62,8 \cdot 10^3)}{2 \cdot 75,4 \cdot 10^3 \cdot 62,8 \cdot 10^3} = 0,0133 gn$$

$$C_2 = \frac{2}{R(\omega_{02} - \omega_{01})} = \frac{2}{10 \cdot 10^3 (75,4 \cdot 10^3 - 62,8 \cdot 10^3)} =$$

$$= 15,88 \cdot 10^{-9} f = 15,9 nf$$

b) K turdagi hududiy filtr tavsifiy qarshiligi:

$$Z_s = K = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{1,59}{15,9 \cdot 10^{-9}}} = 10 \cdot 10^3 om;$$

$$Z_c = K = \sqrt{\frac{L_2}{C_1}} = \sqrt{\frac{0,0133}{0,133 \cdot 10^{-9}}} = 10 \cdot 10^3 f.$$

d) filtrning ketma-ket yoki parallel ulangan konturlardagi rezonans chastotasini topamiz:

$$\omega_0 = \frac{1}{\sqrt{\frac{L_1}{2} \cdot 2C_1}} = \frac{1}{\sqrt{1,59 \cdot 0,133 \cdot 10^{-9}}} = 68,8 \cdot 10^3 \frac{1}{sek}$$

yoki: $\omega_0 = \dfrac{1}{\sqrt{2L_2 \dfrac{C_2}{2}}} = \dfrac{1}{\sqrt{0{,}0133 \cdot 1{,}59 \cdot 10^{-9}}} = 68{,}8 \cdot 10^3 \dfrac{1}{sek}$.

Filtrnimg chastota o'tkazish chegaralanish qiymatini aniqlaymiz:

$$\omega = 0{,}5(\omega_{01} + \omega_{02}) = 0{,}5(62{,}8 \cdot 10^3 + 75{,}4 \cdot 10^3) = 69{,}1 \cdot 10^3 \frac{1}{sek}$$

Chap tomondagi to'sish chastotasi:

$$\omega = 0{,}5\omega_{01} = 0{,}5 \cdot 62{,}8 \cdot 10^3 = 31{,}4 \cdot 10^3 \frac{1}{sek}$$

e) T, П shakldagi hududiy filtrning $\omega = 0{,}5(\omega_{01} + \omega_{02}) = 69 \cdot 10^3 \dfrac{1}{sek}$ qiymatidagi tavsifiy qarshiligini topamiz:

$$Z_{CT} = K \cdot \sqrt{1 - \left[\frac{\omega^2 - \omega_0^2}{\omega_0(\omega_{02} - \omega_{01})}\right]^2} =$$

$$= 10 \cdot 10^3 \sqrt{1 - \left[\frac{(69 \cdot 10^3)^2 - (68{,}8 \cdot 10^3)^2}{69 \cdot 10^3 \cdot (75{,}4 \cdot 10^3 - 62{,}8 \cdot 10^3)}\right]^2} = 9{,}99 \cdot 10^3 Om$$

$$Z_{C\Pi} = \frac{K}{\sqrt{1 - \left[\dfrac{\omega^2 - \omega_0^2}{\omega_0(\omega_{02} - \omega_{01})}\right]^2}} = \frac{10 \cdot 10^3}{\sqrt{1 - \left[\dfrac{(69 \cdot 10^3)^2 - (68{,}8 \cdot 10^3)^2}{69 \cdot 10^3 \cdot (75{,}4 \cdot 10^3 - 62{,}8 \cdot 10^3)}\right]^2}} =$$

$$= 10 \cdot 10^3 Om$$

Chastotaning filtrlash chegarasi:

f) $\omega = 0{,}5 \cdot (\omega_{01} + \omega_{02}) = 69 \cdot 10^3 \dfrac{1}{sek}$ bo'lganda so'nish koeffitsienti *a/2* va faza koeffitsienti *b/2* qiymatlarini aniqlaymiz:

So'nishi: $a/2 = 0$; faza koeffitsienti

$$b/2 = arc\sin\frac{\omega^2 - \omega_0^2}{\omega(\omega_{02} - \omega_{01})} = arc\sin 0{,}0382 = 2^{\circ}11'$$

g) chap tomon filtr to'sish chastotasi: $\omega = 0{,}5 \cdot \omega_{01} = 31{,}4 \cdot 10^3 \dfrac{1}{sek}$ bo'lganda, so'nish va faza koeffitsienti:

$$a/2 = \text{Arch}\left[\frac{\omega^2-\omega_0^2}{\omega\left(\omega_{02}-\omega_{01}\right)}\right]\text{arch}9,45 = 2,934NP = 25,5Db$$

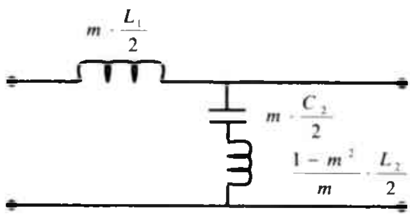
$b/2 = -90^{\circ}$.«minus» ishora filtr chap tomon to'sish chegarasini ifodalaydi.

Masala 9.9. m turkumidagi quyi chastotali G shaklidagi differensiallovchi filtr burchak chastotasi $\omega_0 = 6,28\cdot10^3\frac{1}{sek}$; m=0,6 bo'lib, $R = Z_c = 0,5\cdot10^3 Om$ aktiv tavsifiy qarshilik yuklangan.

a) Г shakldagi quyi chastotall filtr, K turkumidagi o'xshashligiga asoslanib L, C parametri;

b) T turdagi differensial filtr L_1, C_2, L_2 parametri;

d) $\omega_0 = \infty$ bo'lgandagi (ketma-ket ulangan rezonansli kontur) so'nish chastota qiymati hisoblab topilsin.



Yechish. Avval K turkumidagi Г sxema uchun L, C parametrlarni topamiz:

$$L = \frac{2R}{\omega_0} = \frac{2\cdot0,5\cdot10^3}{6,28\cdot10^3} = 0,16gn;\quad C = \frac{2}{\omega_0 R_n} = \frac{2}{6,28\cdot10^3\cdot0,5\cdot10^3} = 0,637\cdot10^{-6}f.$$

Endi Г shakldagi m turkumli quyi chastotali filtr doimiy koeffitsienti m = 0,6 bo'lganda parametrini aniqlaymiz:

$$L_1 = m\frac{L}{2} = 0,6\cdot\frac{0,16}{2} = 0,0477gn = 47,7mgn.$$

$$C_2 = m\frac{c}{2} = 0,6\cdot\frac{0,637\cdot10^{-6}}{2} = 0,19\cdot10^{-6}f = 0,191mkf$$

$$L_2 = \frac{1-\text{m}^2}{\text{m}}\cdot\frac{\text{L}}{2} = \frac{1-06^2}{0,6}\cdot\frac{0,16}{2} = 0,085gn = 85mgn.$$

m turkumidagi differensiallovchi quyi chastotali filtr: $\omega_\infty = \omega_0$ da so'nish chastotasi:

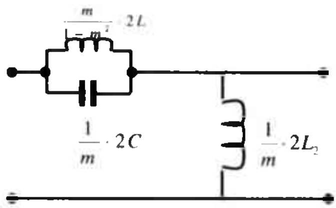
$$\omega_\infty = \omega_0 \cdot \frac{1}{\sqrt{1-m^2}} = 6,28 \cdot 10^3 \cdot \frac{1}{\sqrt{1-0,6^2}} = 7,85 \cdot 10^3 \frac{1}{sek.}$$

Masala 9.10. Γ shakldagi m turkum yuqori chastotali filtr burchak chastotasi $\omega_0 = 31,4 \cdot 10^3 \frac{1}{sek}$; $m = 0,6$ bo'lib, $R = Z_c = 25 \cdot 10^3 Om$ aktiv tavsifiy qarshilik ulangan $\left(R = K = \sqrt{\frac{L}{C}}\right)$.

a) K turdagi yuqori chastotali filtr parametri;

b) m turkumidagi Γ shakldagi differensiallovchi filtr parametri L_1, C_1, L_2;

d) parallel sxemadagi rezonansli kontur xususiyatiga asosan m turkumdagi differensiallovchi filtr $\omega = \infty$ so'nish chastota qiymati hisoblab topilsin.



Yechish.

a) R aktiv qarshilikga yuklangan K turkumda filtr parametrini aniqlaymiz:

$$L = \frac{R}{2\omega_0} = \frac{25 \cdot 10^3}{2 \cdot 31,4 \cdot 10^3} = 0,4 gn;$$

$$C = \frac{1}{2\omega_0 R} = \frac{1}{2 \cdot 31,4 \cdot 10^3 \cdot 25 \cdot 10^3} = 0,637 \cdot 10^{-9} f = 0,637 nf.$$

b) endi $m = 0,6$ ga teng bo'lgandagi differensiallovchi yuqori chastotali filtr parametrini topamiz:

$$L_1 = \frac{\mathrm{m}}{1-\mathrm{m}^2} 2L = \frac{0,6}{1-0,6^2} \cdot 2 \cdot 0,4 = 0,747 gn.$$

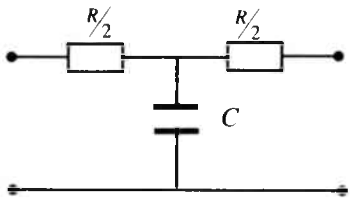
$$C_1 = \frac{1}{m} 2C = \frac{1}{0,6} \cdot 2 \cdot 0,637 \cdot 10^{-9} = 0,764 \cdot 10^{-9} f = 0,764 nf.$$

$$L_2 = \frac{1}{m} 2L = \frac{1}{0,6} \cdot 2 \cdot 0,4 = 0,478 gn.$$

d) cheksiz so'nish chastota qiymati:

$$\omega_\infty = \omega_0\sqrt{1-m^2} = 31,4\cdot10^3\sqrt{1-0,6^2} = 25,1\cdot10^3\frac{1}{sek}$$

Masala 9.11. T sxemadagi induktivsiz quyi chastotali R, C parametri: $R = 2\cdot10^3 Om$; $C = 0,5\cdot10^{-9} f = 0,5nf$ bo'lganda, chastota o'tkazish chegarasi aniqlanib, filtr tavsifiy qarshiligi hisoblab topilsin.



Yechish. a) quyi chastotali R, C filtr, chastota o'tkazish chegarasi chap va o'ng tarmoq aktiv qarshilik bilan ularni bog'lovchi tarmoqdagi sig'im reaktiv qarshilik tomon tengligidan topamiz:

$$\frac{R}{2} = \frac{1}{\omega_0\frac{C}{2}};\quad \text{bundan: } \omega_0 = \frac{4}{RC} = \frac{4}{2\cdot10^3\cdot0,5\cdot10^{-9}} = 4\cdot10^6\frac{1}{sek}$$

yoki: $(f_0 = 637\cdot10^3 gts)$

b) $\omega = \omega_0$ shart uchun tavsifiy qarshilik Z_C ni salt yoki qisqa tutashuv tajriba asosida aniqlaymiz. Filtr chiqish qismida salt holatda bo'lganda:

$$Z_0 = \frac{R}{2} - j\frac{1}{\omega_0 c} = \frac{2\cdot10^3}{2} - j\frac{1}{4\cdot10^6\cdot0,5\cdot10^{-9}} = 1,11\cdot10^3 e^{-j26^\circ34^1} Om$$

$\omega = \omega_0$ shartga asosan chiqishda qisqa tutashtirish bilan:

$$Z_k = \frac{R}{2} + \frac{\frac{R}{2}\cdot\left(-j\frac{1}{\omega_0 c}\right)}{\frac{R}{2} - j\frac{1}{\omega_0 c}} = \frac{2\cdot10^3}{2} + \frac{\frac{2\cdot10^3}{2}\cdot\left(-j\frac{1}{4\cdot10^6\cdot0,5\cdot10^{-9}}\right)}{\frac{2\cdot10^3}{2} - j\frac{1}{4\cdot10^6\cdot0,5\cdot10^{-9}}} = 1,26\cdot10^3 e^{-j18^\circ}\ (Om)$$

T shakldagi filtr chastotani o'tkazishda chegaralanish tavsifiy qarshiligi $(\omega = \omega_0)$:

$$Z_c = \sqrt{Z_0\cdot Z_k} = \sqrt{1,11\cdot10^3 e^{-j26^\circ34^1}\cdot1,26\cdot10^{j3}\cdot e^{j18^\circ}} = 1,2\cdot e^{-j22^\circ30^1}\ (Om)$$

9.3. Mustaqil yechish uchun masalalar

Masala 9.1. Parametri L_1 = 0,02 *gn* C = 0,08 *mkf* bo'lgan T sxemadagi filtrning salt, qisqa tutasbuv va tavsifiy qarshiligi hamda chastota filtrlash chegarasi aniqlansin.

Javob: $Z_0 = j\left(0{,}01\omega - 125\cdot 10^5\right)Om;$

$$Z_q = j\left(0{,}01\omega + \frac{125\cdot 10^3\omega}{125\cdot 10^5 - 0{,}01\omega^2}\right)Om.\quad Z_s = \sqrt{Z_0 Z_k} = \sqrt{2{,}5\cdot 10^5 - 10^{-4}\omega^2}\,Om.$$

Bundan $0 \le \omega \le 5\cdot 10^4$

Masala 9.2. П sxemadagi filtr parametri C=0,08 *mkf*, L=0,02 *gn* bo'lganda, chastota o'tkazish chegarasi aniqlanib, xarakteristik qarshilik va faza koeffitsienti toplIsin.

Javob: Chastota $12{,}5\cdot 10^3 \le \omega \le \infty$ oraliqda chegaralaydi.

$$Z_{sn} = \sqrt{\frac{Z_1 Z_2}{1 + \frac{Z_1}{4Z_2}}} = \frac{500}{\sqrt{1 - \frac{156\cdot 10^6}{\omega^2}}}\,om.\quad 500 \le Z_s \le \infty,\quad -\pi \le b \le 0;\quad 500 \div \infty$$

Masala 9.3. 9.1-masalada T sxema kesish chastotasi $\omega_C = 10^{-4}\frac{1}{sek}$ va tavsifiy qarshiligi R=60 *Om* bo'lib, chastotasi $\omega = 0{,}5\omega_C$ ga teng bo'lganda filtr parametrlari L, C qiymatlari aniqlansin:

Javob: $L = 69{,}3mgn,\ \ C = 0{,}289mkf$.

Masala 9.4. T sxemada filtr parametri L_1=100 *mgn*, L_2=100 *mgn*, C=0,005 *mkf* bo'lganda, chastota o'tkazish chegarasi aniqlansin.

Javob: $2\cdot 10^4\frac{1}{sek} \le \omega \le 4{,}47\cdot 10^4\frac{1}{sek.}$

Masala 9.5. K tartibli quyi chastotali filtr chastota chegarasi $f_0 = 8kgts$ bo'lganda, so'nish koeffitsienti $f_1 = 12kgts$, $f_2 = 4kgs$ ga teng. Faza koeffitsientini aniqlang.

Javob: $\alpha = 1{,}93nep,\ \ \beta = \frac{\pi}{3}.$

Masala 9.6. Quyi chastotali filtr chastota chegarasi $f_0 = 8\,kgs$ bo'lganda, chastotaning qanday qiymatida faza koeffitsienti 60° ga teng bo'ladi.

Javob: $f_0 = 7{,}12\,kgs$.

Masala 9.7. K turdagi yuqori chastotali filtr chastota chegarasi $f = 250gs \div \infty$ ga teng bo'lganda: 1) so'nish koeffitsienti α: faza koeffitsienti β chastotaning $f_1 = 125gs\,da$, $f_2 = 200gs$ va $f_3 = 500gs$ qiymatida aniqlansin.

Javob: 1) $\alpha = 2{,}64nep$; $\beta_2 = \pi$; $\beta_3 = -\dfrac{\pi}{3}$

Masala 9.8. Quyi chastotali filtr chastotalar chegarasi $f = 1000gs$, xarakteristik qarshiligi $Z_c = 100om(f_0 = 0)$ ga teng, filtr parametri aniqlansin.

Javob: $L = 31{,}8\,mgn$, $C = 3{,}18\,mkf$.

Masala 9.9. T shakldagi sxema parametri L=0,4 gn, C=0,1 mkf bo'lib, R=1000 Om qarshilikga ulangan. ω chastotaning qanday qiymatida kirishdagi to'la qarshilik $Z_1 = \dfrac{\dot{U}_1}{\dot{I}_1}$ haqiqiy qiymatga erishadi va Z_2 qiymati nimaga teng.

Javob: $\omega_1 = 5000\dfrac{1}{sek}; \omega_2 = 6620\dfrac{1}{sek}; Z = 4000\ Om; Z_2 = 1000\ Om.$

9.4. Nazorat savollari

1. K turdagi filtrga qaysi filtr kiradi?
2. Chastotaviy elektr filtr nima va qaysi maqsadda foydalaniladi?
3. So'nish koeffitsienti α, faza koeffitsienti β, uzatish koeffitsienti b nimani ifodalaydi va qanday birlikda ulanadi?
4. Filtr xarakteristik tenglama ifodasini yozing.
5. Filtr uzatish funksiyasi $H_u(j\omega)$ixtiyoriy Z_2 yoki induktivlik L va sig'im C parametr bilan qanday bog'lanishga ega?

6. Ko'prik sxemada ulangan to'rt qutblik filtr signallarni o'tkazish chegarasi qanday aniqlanadi?

7. So'nish koeffitsienti $\alpha(\omega)$ bilan $Ln\left[\frac{1}{H(\omega)}\right]$ qiymat farqi nimada?

8. Filtrdan o'tuvchi signal formasi buzilmasligi uchun kompleks kuchlanish uzatish funksiyasi qanday shartga asoslanishi zarur?

9. Filtrdan o'tuvchi signal buzilmasligi uchun so'nish koeffitsienti α va faza koeffitsienti β chastota ω o'zgarishiga nisbatan qanday o'zgarishi kerak?

10. Aktiv qarshiligini hisobga olmaganda har qanday filtr ideal bo'lishi mumkinmi?

11. Zanjirsimon sxemada ulangan filtr xususiyatini ta'riflang.

12. Simmetrik passiv to'rt qutbli elektr zanjir so'nish koeffitsienti α – manfiy bo'ladimi?

13. Nosimmetrik filtrning xarakteristik qarshiligi salt yoki qisqa tutashuv tajribalari orqali qanday aniqlanadi?

14. Xarakteristik qarshilik chastotaga bog'liq bo'lganda filtrlarning chastotaviy chegarasi qanday amqlanadi?

15. Filtr tavsifiy qarshiligi $Z_C = \sqrt{\frac{B}{C}}$ chastota o'zgarishi bilan qanday bog'liqligini tushuntiring.

16. Filtrlarning chastotani filtrlash yoki so'nish chegarasida xarakteristik qarshilik qiymati qanday xarakterga ega bo'ladi?

17. Turlicha xildagi filtr elektr sxemasini chizmg va chastota chegaralash xususiyatihi tushuntiring.

18. Elektr filtr uzatish funksiyasi tenglamasini yozmg va mohiyatini tushuntiring.

19. Filtr faza koeffitsienti b nmg fizik ma'nosmi tushuntiring.

X. CHIZIQLI ELEKTR ZANJIRLARDA O‘TKINCHI JARAYON

10.1. Asosiy nazariy tushunchalar

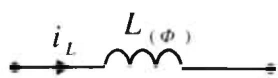
Elektr zanjirning bitta turg‘unlashgan holatdan boshqasiga o‘tishni ifodalovchi jarayon **o‘tkinchi jarayon** deyiladi.

Elektr zanjirda o‘tkinchi jarayon elektr zanjirning manbaga ulanish, uzilish tarmoqlardagi parametrning o‘zgarishi, qisqa tutashuv kabi holatlarda yuzaga kelib, bu jarayon bir necha millisekund bir necha sekundgacha davom etishi mumkin. Elektr zanjir holatini o‘zgarishiga olib keluvchi barcha sabablarga **kommutatsion jarayon** deyiladi.

Elektr zanjirda o‘tkinchi jarayon hosil bo‘lishiga asosiy sabab reaktiv elementlardagi *(L,C)* elektromagnit maydon energiyasining energiya saqlanish qonuniga asosan sakrab (bordan yo‘q, yo‘qdan bor bo‘laolmasligi sababli) o‘zgaraolmasligi, yani vaqt o‘tishi bilan asta-sekin kamayib yoki ko‘payib borishi sabab bo‘ladi.

Induktivligi *L,* sig‘imi *C* elementlarning bunday xususiyatlaridan ikkita o‘tkinchi jarayon qonuni – **kommutatsiya qonuni** kelib chiqadi.

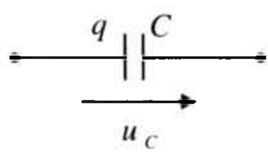
a) kommutatsiya birinchi qonuni:



Har qanday induktivlikga ega bo‘lgan tarmoqdagi tok – i yoki magnit oqimi Ф (kommutatsiya vaqtida $t=0$) kommutatsiyaga bo‘lgan qiymati, kommutatsiyadan keyingi qiymatga teng bo‘lib, **tok sakrab o‘zgara olmaydi.**

$$i_{L(0^+)} = i_{L(0^-)} \left[\Phi_{(0^+)} = \Phi_{(0^-)} \right]$$

b) kommutatsiya ikkinchi qonuni:



Har qanday tarmoqda sig‘im kuchlanishi – U va zaryad – q (kommutatsiya vaqtida $t=0$) kommutatsiyaga bo‘lgan kuchlanish qiymati, kommutatsiyadan keyingi kuchlanish qiymatiga teng bo‘lib, **kuchlanish sakrab o‘zgarolmaydi.**

$$u_{C(0^+)} = u_{C(0^-)}, \left[q_{(0^+)} = q_{(0^-)} \right]$$

Chiziqli elektr zanjiridagi o'tkinchi jarayonni tahlil qilish uchun klassik usul, operator usuli Dyuamel integrali (formulalarini ustma-ustlash usuli) va Furye integralidan (chastotali usul) foydalaniladi.

1. Klassik usulga asosan elektr zanjir uchun tuzilgan chiziqli differensial tenglamani yechish bilan bajariladi:

Masalan: koeffitsienti o'zgarmas chiziqli differensial tenglama:

$$A_0\frac{d^n i_K}{dt^n}+A_1\frac{d^{n-1}i_K}{dt^{n-1}}+.......+A_{n-1}\frac{di_K}{dt}+A_n i_K=F_{K(+)}$$

Bunday differensial tenglama yechimi yoki integrali xususiy va umumiy yechimdan iborat bo'lib:

$$i_{K(t)}=i'_{K(t)}+i''_{K(t)} \qquad (10.1)$$

$i'_{K(t)}$ differensial tenglamaming xususiy yechimi bo'lib, elektr zanjirining kommutatsiyadan keyingi turg'un holatini ifodalaydi.

$i_{K(t)}$ differensial tenglamaning umumiy yechimi bo'lib, o'tkinchi jarayon vaqtidagi erkin holatdagi tok va kuchlanishni ifodalaydi:

$$A_0\frac{d^n i''_K}{dt^n}+A_1\frac{d^{n-1}i''_K}{dt^{n-1}}+.......+A_{n-1}\frac{di''_K}{dt}+A_n i''_K=0$$

Ya'ni, fizik manoda kommutatsiyadan keyin reaktiv elementlarda to'plangan elektromagnit maydon energiyasi erkin kamayishi va ko'payishini ifodalaydi va vaqtga nisbatan so'nuvchan yoki kamayuvchan bo'ladi:

Ya'ni: $i''_K=A_1e^{\alpha_1 t}+A_2e^{\alpha_2 t}+.......A_ne^{\alpha_n t}=\sum_{K=1}^{n}A_Ke^{\alpha_k t}$

(9.1) tenglamadan: $i_{K(t)}=i'_{K(t)}+\sum_{K=1}^{n}A_Ke^{\alpha_k t}$ (10.2)

Bunda A doimiy integrallash koeffitsienti bo'lib, boshiang'ich shartdan yoki kommutatsiya qonuniga asosan topiladi.

α_K differensial tenglama ildizi bo'lib, xarakteristik tenglamadan topiladi.

a) **R, L zanjirida o'tkinchi jarayon:**

Bunday zanjir tenglamasi birinchi tartibli differensial tenglama bilan ifodalanadi: $L\frac{di}{dt}+iR=U$ (10.3)

Xarakteristik tenglamasi: $LP + R = 0$; Bundan: $p = -\frac{R}{L} = -\frac{1}{\tau}\left(\frac{1}{sek}\right)$

O'tkmchi jarayondagi tok $\quad i_t = i' + Ae^{-\frac{t}{\tau}}$ (10.4)

τ – o'tkinchi jarayondagi vaqti sekundda ifodalanadi.

b) **R, C zanjirida o'tkinchi jarayon:**

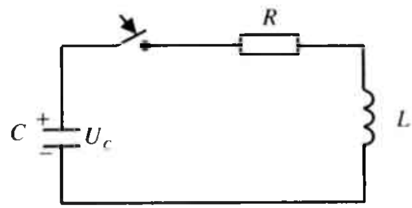
Bunday zanjirning differensial tenglamasi:

$$RC\frac{dU_C}{dt} + U_C = U \qquad (10.5)$$

Yechimi quyidagicha bo'ladi:

$$\begin{cases} U_C = U'_C + Ae^{-\frac{t}{\tau}} \\ i = i' - \frac{A}{R}e^{-\frac{t}{\tau}} \\ \tau = RC(sek) \end{cases} \qquad (10.6)$$

A doimiy integrallash koeffitsienti boshlang'ich shartdan, ya'ni kommutatsiya qonuniga asosan aniqlanadi.



d) **R, L, C zanjirning razryadlanishi:**

Bu zanjirning differensial tenglamasi:

$$\left.\begin{array}{l} L\frac{di}{dt} + Ri + \frac{q}{C} = 0 \\ L\frac{d^2i}{dt^2} + R\frac{di}{dt} + \frac{1}{C}i = 0 \end{array}\right| \qquad (10.7)$$

Ushbu tenglamaning yechimi:

$$i_{(t)} = i' + i'' = A_1e^{P_1t} + A_2e^{P_2t} \qquad (10.8)$$

R$_1$ va R$_2$ ildiz koeffitsienti xarakteristik tenglamadan aniqlanadi:

$$LP^2 + RP + \frac{1}{C} = 0 \qquad (10.9)$$

Bundan: $P_{1.2} = -\delta \pm \sqrt{\delta^2 - \omega_0^2}$ yoki: $\delta = \frac{R}{2L}$; $\omega_0^2 = \frac{1}{LC}$ (10.10)

A_1 va A_2 – koeffitsient boshlang'ich shart, ya'ni kommutatsiya qonuniga asosan aniqlanadi.

Ushbu *R, L, C* zanjirda uch xil holat yuzaga kelishi mumkin:

a) aperiodik zaryadsizlanish: $\delta^2 > \omega_0^2;\ R > 2\sqrt{\dfrac{L}{C}}$

Bunda $i_{(t)}$ tok o‘zgarishi: $i_{(t)} = \dfrac{U_0}{2L\gamma}(e^{\alpha_2 t} - e^{\alpha_1 t})$ bunda $\gamma = (P_1 - P_2)$

b) tebranuvchan zaryadsizlanish: $\delta^2 < \omega_0^2;\ R =< 2\sqrt{\dfrac{L}{C}}$

Bunda $i_{(t)}$ tok: $i_{(t)} = -I_0 e^{-\delta t}\sin\omega t = -\dfrac{U_0}{\omega L}e^{-\delta t}\sin\omega t$

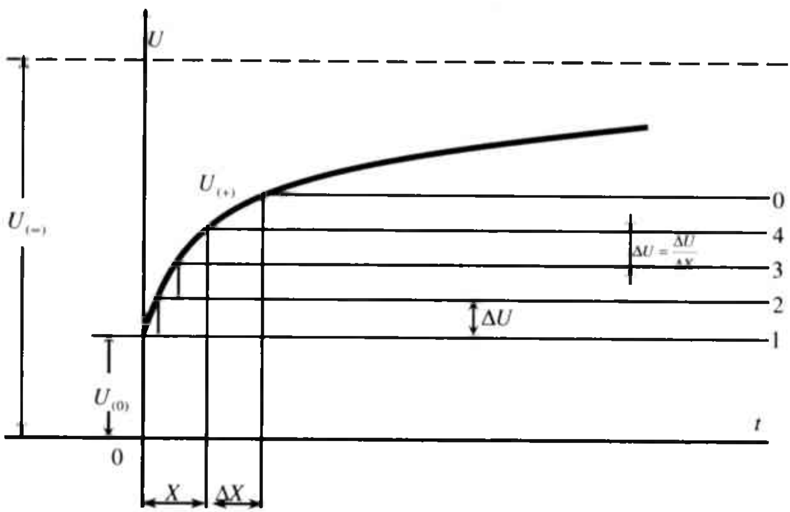
U_0 – kondensatordagi boshlang‘ich kuchlanish

d) kritik holat: $\delta^2 = \omega_0^2;\ R = 2\sqrt{\dfrac{L}{C}}$. Bunda: $i_{(t)} = \dfrac{U_0}{L}te^{-\delta t}$

10.2. Ixtiyoriy shakldagi kuchlanish ta’sir etgan zanjirdagi o‘tkinchi jarayonni hisoblash (Dyuamel integrali)

Strukturasi ma’lum bo‘lgan passiv zanjirga kuchlanishi vaqtga nisbatan ixtiyoriy qonunga (funksiyaga) asosan o‘zgaruvchan bo‘lsa, o‘tkinchi jarayon masalasi quyidagicha hal qilinadi.

Masalan: elektr zanjir $t=0$ vaqtda qandaydir o‘zgarmas U_0 kuchlanishga ulangan deb faraz qilaylik. Zanjir iste’mol qiladigan



o'tkinchi tok shu kuchianishnimg o'tkinchi o'tkazuvchanligi deb ataladigan $y_{(t)}$ ga ko'paytmasini ifodalovchi funksiya bo'ladi.

$$i_{(t)} = y_{(t)}U_0 \qquad (10.11)$$

Funksiya $y_{(t)}$ faqat zanjirning strukturasiga bog'liq bo'lib, berilgan kuchianish U_0 ning miqdoriga bog'liq emas.

Masalan, ketma-ket ulangan R, L zanjirida:

$$i_{(t)} = U_0 y_{(t)} = \frac{U_0}{R}\left(1 - e^{-\frac{t}{\tau}}\right) \qquad (10.12)$$

bo'lib, tok $i_{(t)}$ ning o'zgarish qonuni ushbu zanjir o'tkmchi jarayon o'tkazuvchanligining o'zgarish qonuni $y_{(t)} = \frac{1}{R}(1 - e^{-\frac{t}{\tau}})$ da aks ettirilgan.

Shunga o'xshash berilgan egri chiziqli kuchlanish funksiyasini ΔU bo'lakchalarga bo'lib, har birining ta'siridan aniqlangan tokning yig'indisi o'tkmchi jarayon tokni ifodalaydi. Bunga Dyuamel mtegrali deyilib, oltita formula ko'rinishida ifodalanadi:

$$\left.\begin{aligned}
&1.\quad i_{(t)} = U_{(0)}y_{(t)} + \int_{x=0}^{x=t} y(y-x)U'_{(t)}dx \\
&2.\quad i_{(t)} = U_{(0)}y_{(t)} + \int_{x=0}^{x=t} y(t)U'_{(t-x)}d \\
&3.\quad i_{(t)} = U_{(t)}y_{(0)} + \int_{x=0}^{x=t} U(x)\frac{d}{dx}y(t-x)dx \\
&4.\quad i_{(t)} = U_{(t)}y_{(0)} + \frac{d}{dx}\int_{x=0}^{x=t} y(x)U_{(t-x)}dx \\
&5.\quad i_{(t)} = \frac{d}{dt}\int_{x=0}^{x=t} y(t-x)U_{(t)}dx \\
&6.\quad i_{(t)} = \frac{d}{dt}\int_{x=0}^{x=t} y(x)U_{(t-x)}dx
\end{aligned}\right| \qquad (10.13)$$

3. Operator usuli.

Original deb ataluvchi har qanday vaqt funksiyasi $f(t)$ ni unga ekvivalent bo'lgan kompleks o'zgaruvchan $p = S + j\omega$ argumentli $F(p)$ funksiyasi bilan almashtirish mumkin.

Matematik ko'rinishda:

$$f(x) \doteq F(p) \text{ yoki } F(p) = f(t) \qquad (10.14)$$

Berilgan funksiya $f(t)$ tasviri $F(p)$ «Laplas almashtirishi» deb ataladigan formulaga asosan:

$$F(p) = \int_0^\infty e^{-Pt} f(t)dt \qquad (10.15)$$

Bu integral birmuncha chegaralangan bo'lganligi uchun, original $f(t)$ dan uning tasviri $F(p)$ ga o'tish uchun «Karson-Xevidsayd almashtirishi» deb ataluvchi formuladan foydalaniladi:

$$F(p) = p\int_0^\infty e^{-Pt} f(t)dt$$

Bu formula operator R ga ko'paytirish bilan farq qiladi. Funksiya hosilasi va integralining Laplas bo'yicha tasviri:

$$f'(t) \doteq p\left[F(p) - f_{(0)}\right] \qquad (10.16)$$

Bunda, $f_{(0)}$ funksiyasining $t = 0$ bo'lgandagi qiymati.

Integrali:

$$\int_0^t f(t)dt = \frac{1}{p}F(p) \qquad (10.17)$$

Om qonuni operator ifodasi:

$$I_{(P)} = \frac{U_{(P)}}{Z_{(P)}} \qquad (10.18)$$

Kirxgof qonuni operator ifodasi:

$$\sum E_{K(P)} = \sum\left[I_{K(P)}Z_{K(P)} - PL_K i_{K(0)} + U_{CK(0)}\right] \qquad (10.19)$$

Bunda: $i_{K(0)}$ - $t = 0$ da L_K – induktivlikdagi tok:

$U_{CK(0)}$ - $t = 0$ da Ck – sig'imdagi kuchlanish:

$PL_K i_{K(0)}$ va $U_{CK(0)}$ – boshlang'ich shartga asosan hosil bo'ladigan tok va kuchlanishni ichki manba bilan almashtirilgan ifodasi.

O'tkinchi jarayon boshlang'ich shartlarini ichki manba bilan almashtirish natijasida ustma-ustlash usuliga asosan masalani yechish mumkin, natijada operator formada tok tenglamasini quyidagicha ifodalaymiz:

$$I_{(P)} = P\frac{G_{(P)}}{H_{(P)}} \qquad (10.20)$$

$G_{(P)}$ va $H_{(P)}$ ko'rsatkichli funksiya butun sonlar m va n polinomlari bunda $(m \leq n)$

Keltirilgan tenglamadagi (yoyish teoremasi) $H_{(P)} = 0$ deyilib ildiz operatori $R_1, R_2, R_3, ...R_n$ topiladi.

Barcha ildizlar R_K aniqlangandan keyin tok funksiyasi $i_{(t)}$ (original) quyidagicha ifodalanadi:

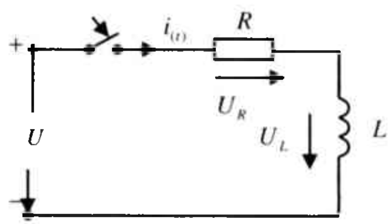
$$i_{(t)} = \sum_{K=1}^{n} \frac{G_{(P)}}{H'_{(P)}} e^{P_K t} \qquad (10.21)$$

Bunda $H', \frac{dH}{dP}$ - olingan hosila. Agarda elektr zanjir sinusoidal o'zgaruvchan kuchlanishga ulangan bo'lsa, $U = U_m \sin(\omega t + \varphi)$ kompleks ifodasiga o'tilib, keyin operator ko'rinishida yoziladi:

$$\dot{U}_m e^{j\omega t} \dot{=} \frac{\dot{U}_m P}{P - j\omega} \qquad (10.22)$$

10.2. Masalalar yechish va uslubiy ko'rsatmalar (klassik usul)

Masala 10.1. Ketma-ket ulangan elektr zanjirnmg aktiv va mduktiv parametri $R=10$ Om, $L=40$ MGn bo'lib, o'zgarmas kuchianishga $U=100$ V ulanganda o'tkinchi tok $i_{(t)}$ aniqlanib, grafigi chizilsin.



Yechish.

Kalit zanjirga ulangan paytda induktivlikda o‘zinduksiya hodisasiga asosan elektr yurituvchi kuch induksiyalanadi $e_L = -L\frac{di}{dt}$

Kirxgof 2-qonuniga asosan differensial tenglamasi:

$$U = iR + L\frac{di}{dt}$$

Bu birinchi tartibli differensial tenglama bo‘lib, o‘tkinchi tok quyidagicha ifodalanadi:

$$i_{(t)} = i' + i'' = i' + Ae^{Pt}$$

$i_{(t)}$ – o‘tkinchi jarayondagi tok.

i' – differensial tenglamaning xususiy yechimi bo‘lib, kommutatsiyadan keyingi turg‘un holatdagi tok.

i'' – differensial tenglamaning umumiy yechimini ifodalovchi (kommutatsiya vaqtidagi) erkin tok. Kommutatsiya birinchi qonuniga asosan aniqlanadi.

A – doimiy integrallash koeffitsienti boshiang‘ich shart yoki kommutatsiya qonuniga asosan aniqlanadi.

P – xarakteristik tenglama ildizi.

Kommutatsiyadan keyin zanjirdan o‘tuvchi turg‘un tok.

$$i' = \frac{U}{R} = \frac{100}{10} = 10\,A$$

Erkin holatdagi tok i'' topish uchun tenglamani quyidagicha ifodalaymiz:

$$L\frac{di''}{dt} + Ri'' = 0$$

Bu differensial tenglamaning yechimi: $i'' = Ae^{Pt}$

Xarakteristik tenglamadan ildizni topamiz: $LP + R = 0$

Bunda: $P = -\frac{R}{L} = \frac{10}{40 \cdot 10^{-3}} = -0{,}25 \cdot 10^{3} = 250 \quad \left(\frac{1}{sek}\right)$

Zanjirdagi o‘tkinchi tok ifodasi:

$$i_{(+)} = 10 + Ae^{-250t}$$

A – integrallash koeffitsienti kommutatsiya birinchi qonuniga asosan t=0 bo‘lganda:

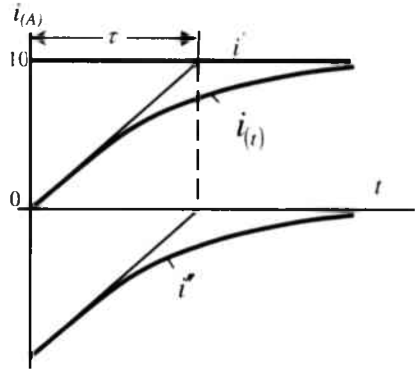
$$i_{(0)} = i_{(0^-)} = 10 + A; \quad A = -10$$

Demak, o'tkinchi jarayon tok ifodasi:

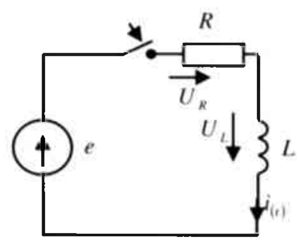
$$i_{(+)} = 10 - 10e^{-250t} = 10\left(1 - e^{-250t}\right)\ (A)$$

Bunda: $P = -\dfrac{1}{\tau}$ yoki $\tau = 40 \cdot 10^{-3}$ *сек* o'tkinchi jarayon vaqti

yoki R, L janjir uchun: $\tau = \dfrac{L}{R}$ (sek)



Masala 10.2. Induktiv g'altakning aktiv qarshiligi R=10 Om, induktivligi $L = 0{,}01\ Гн$ bo'lib, $e = 100\sqrt{2}\sin(1000t + 15^0)\ B$ kuchlanishga ulanganda o'tkinchi jarayon tok $i_{(t)}$ aniqlansin.



Yechish.

Zanjirning differensial tenglamasi :

$$L\frac{di}{dt} + Ri = e_{(t)}$$

Tenglamaning yechimi:

$$i_{(t)} = i' + i'' = i' + Ae^{Pt}$$

Xarakteristik tenglamadan: $LP + R = 0$

$$P = -\frac{R}{L} = -\frac{10}{0{,}01} = -10^3\left(\frac{1}{sek}\right)$$

Bunda kommutatsiyagacha bo‘lgan tok nolga teng $\left(i_{(0^-)}=0\right)$.

Kommutatsiyadan keyingi turg‘un holatdagi tokni topamiz.

$$I'_m=\frac{\dot{E}}{\underline{z}}=\frac{100\sqrt{2}e^{j15^0}}{10+j10}=10e^{-j30^0}=10\sin(\omega t-30^0)$$

Kommutatsiya vaqtida t=0;

$$i'_{(0)}=10\sin\left(-30^0\right)=-5\,A$$

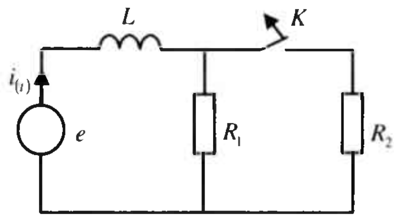
Kommutatsiya qonuniga asosan $i_{L(0^-)}=i_{L(0^+)}$

O‘tkinchi jarayondagi tok t=0 bo‘lganda:

$i''_{(0)}=i_{(0^-)}-i'_{np}=0+5=5\ \ A$

Demak: $i_{(t)}=i'+i''=10\sin\left(\omega t-30^0\right)+5e^{-10^3t}$

Masala 10.3. Elektr zanjiri parametri $R_1=R_2=5\ Om,\ L=10mGn$ bo‘lib, chastotasi $f=50\ Gs,\ U=220\sin(\omega t+90^0)$ kuchlanishga ulangan. Kalit uzilgan holatidagi $i_{(t)}$ o‘tkinchi jarayondagi tok aniqlansin.



1. Kommutatsiyagacha bo‘lgan tokni topamiz:

$$\dot{I}_{(0^-)}=\frac{220\sqrt{2}e^{j90^0}}{\underline{z}}=\frac{220\sqrt{2}e^{j90^0}}{j\omega L+\dfrac{R_1\cdot R_2}{R_1+R_2}}=\frac{220\sqrt{2}e^{j90^0}}{2{,}5+j314\cdot 0{,}01}=\frac{220\sqrt{2}e^{j90^0}}{4e^{j51^030'}}=77{,}5e^{j38^030'}\ \ A$$

2. Kommutatsiyadan keyingi turg‘un holatdagi tokni topamiz:

$$\dot{I}'=\frac{220\sqrt{2}e^{j90^0}}{\underline{z}}=\frac{220\sqrt{2}e^{j90^0}}{5+j3{,}14}=\frac{220\sqrt{2}e^{j90^0}}{5{,}89e^{j32^010'}}=52{,}6e^{j57^050'}\ \ A$$

Bunda doimiy vaqt koeffitsienti: $\tau=\dfrac{L}{R_1}=\dfrac{0{,}01}{5}=0{,}002\ (сек)$

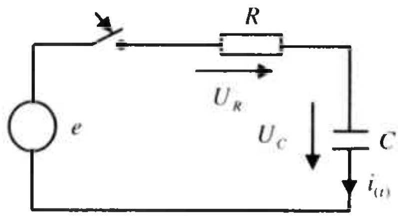
O‘tkinchi jarayondagi tok: $i_{(t)}=i'_{(+)}+i''_{(+)}=52{,}6\sin\left(\omega t+57^030'\right)+Ae^{-\frac{t}{\tau}}$

bundan t=0 bo'lgandagi boshlang'ich shartdan, ya'ni kommutatsiya birinchi qonuniga asosan $\left(i_{L(0^-)} = i_{L(0^+)}\right)$ A – koeffitsientni aniqlaymiz: $i_{(0)} = 52{,}6\sin\left(57^0 30'\right) + A = 77{,}5\sin(38^0 30')$ yoki: $A = 48{,}3 - 44{,}3 = 4\ A$.

Kommutatsiyadan keyingi umumiy tok ifodasi:

$$i_{(t)} = 52{,}6\sin\left(\omega t + 57°30'\right) + 4e^{-\frac{t}{0{,}002}}$$

Masala 10.4. Ketma-ket ulangan aktiv qarshiligi $R = 100\ Om$ va sig'imi $C = 10^{-5}$ Φ bo'lgan elektr zanjir sinusoidal o'zgaruvchan EYK $e = 100\sin(10^3 t - 90^0)$ B ulangandan keyingi o'tkinchi jarayon (sig'im) $U_{C(t)}$ kuchlanishi va tok $i_{(t)}$ aniqlansin.



Yechish.

1. R, C zanjir uchun differensial tenglamani tuzamiz:

$$e = iR + U_C = RC\frac{dU_C}{dt} + U_C \qquad (1)$$

differensial tenglamaning yechimi quyidagicha ifodalanadi:

$$U_{C(t)} = U'_C + U''_C = U'_C + Ae^{Pt} \qquad (2)$$

2. (1) dan xarakteristik tenglamaga asosan ildizni amiqlaymiz:

$$Z_{(P)} = 0; \qquad RC\rho + 1 = 0$$

Bundan: $P = -\frac{1}{RC} = \frac{1}{100\cdot 10^{-5}} = -10^3\left(\frac{1}{sek}\right)$

O'tkinchi jarayon vaqti: $\tau = \frac{1}{P} = RC = 10^{-3}(sek)$

3. Ushbu zanjirda kommutatsiyagacha bo'lgan tok $i_{(0^-)} = 0$, $U_{C(0^-)} = 0$ bo'lib, kommutatsiya ikkinchi qonuniga asosan:

$$u_{C(0^-)} = u_{C(0^+)} = 0$$

4. Kommutatsiyadan keyingi sig'im turg'un holat kuchlanishini aniqlaymiz:

$$U'_C = \frac{100e^{-j90^0}}{100e^{-j100^0}}(-j100) = \frac{100}{\sqrt{2}}e^{-j135^0} \qquad U'_{C(t)} = \frac{100}{\sqrt{2}}\sin(\omega t - 135°)$$

yoki t=0 da $U'_{C(0)} = \frac{100}{\sqrt{2}}\sin(-135^0) = \frac{100}{\sqrt{2}}\cdot\frac{\sqrt{2}}{2} = -50\ (V)$

(2) tenglamadan t=0 bo'lganda $U_{C(0)} = U'_{C(0)} + A$ yoki $0 = -50 + A$; $A = 50$. Sinusoidal o'tkinchi jarayon kuchlanish ifodasi:

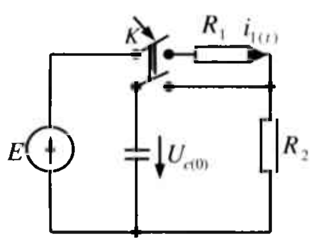
$$U_{C(t)} = \frac{100}{\sqrt{2}}\sin(\omega t - 135°) + 50e^{-10^3 t}(V)$$

O'tkinchi jarayon tok ifodasini aniqlash uchun quyidagi tenglamadan foydalanamiz:

$$i_{C(t)} = C\frac{dU_C}{dt} = \frac{100}{\sqrt{2}}10^{-5}10^3 10^{-5}\cos(\omega t - 135^0) + 50 10^{-5}10^3 e^{-10^3 t} =$$

$$= \frac{1}{\sqrt{2}}\sin(\omega t - 45^0) + 0{,}5e^{-10^3 t}\ A$$

Masala 10.5. Elektr zanjir parametri R_1=4*Om*, R_2=2*Om*, *C*=300(*mkF*) va manba kuchlanishi *E*=12 *V* bo'lib, kommutatsiyagacha sig'im kuchlanishi $U_{C(0^-)}$=6 *V* kuchlanishga ega. Kalit ulangandan keyin R_1 qarshilikdan o'tuvchi $i_{1(t)}$ o'tkinchi jarayondagi tok aniqlansin.



Yechish.

1) kommutatsiyagacha bo'lgan tok nolga teng $i_{(0^-)} = 0$.

O'tkinchi jarayondagi tok: $i_{(t)} = i'_{(t)} + i''_{(t)} = i' + Ae^{pt}$ (1)

2) kommutatsiyadan keyingi turg'un holatdagi tok:

$$i' = \frac{E}{R_1 + R_2} = \frac{12}{6} = 2A$$

O'tkinchi jarayon vaqti: $\tau = \frac{R_1 \cdot R_2}{R_1 + R_2}\cdot C = 4\cdot 10^{-4}\ (sek)$

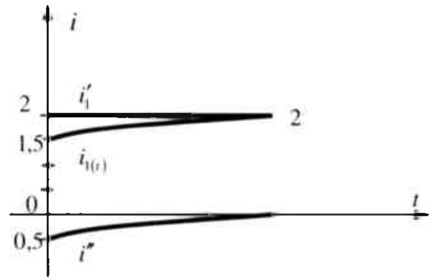
3) Kirxgof qonuniga asosan t = 0 bo'lgan holat tenglamasini tuzamiz va kommutatsiya ikkinchi qonuniga asosan $U_{C(0^-)} = U_{C(0^+)}$ ekanligini hisobga olsak: $i_{1(0)}R_1 + U_{C(0)} = E \quad i_{2(0)}R_2 - U_{C(0)} = 0$

Bundan: $i_{2(0)} = \dfrac{U_{C(0)}}{R_2} = \dfrac{6}{2} = 3A \qquad i_{1(0)} = \dfrac{E - U_{C(0)}}{R_1} = \dfrac{12-6}{4} = 1{,}5A$

(1) tenglamadan $z=0$ bo'lganda: $i_{1(0)} = i'_{1(0)} + i''_{1(0)} = i'_{1(0)} + A$

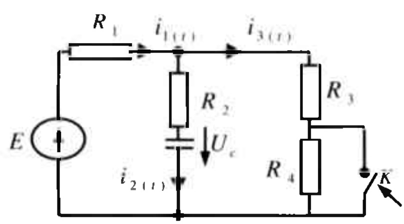
Bundan: $A = i''_{1(0)} - i'_{1(0)} = 1{,}5 - 2 = -0{,}5A$

O'tkinchi jarayon toki: $i_{(t)} = 2 - 0{,}5e^{-2,5\cdot 10^3 t}$



Masala 10.6. Parametri: $R_1= R_2= R_3= R_4=10$ *Om*, C=1 va EYK E = 60 V ga teng bo'lgan elektr zanjirda kalit ulangandan keyingi o'tkinchi jarayondagi $i_{1(+)}$ tok aniqlansin.

Yechish.



1. Kommutatsiyagacha bo'lgan tarmoqdagi tokni aniqlaymiz:

$$i_{1(0^-)} = i_{3(0^-)} = \frac{E}{R_1 + R_1 + R_1} = \frac{60}{30} = 2(A)$$

Sig'imdan o'zgarmas tok o'tmasligi sabib: $i_{2(0^-)} = 0$

Sig'imdagi kuchlahish: $u_{C(0^-)} = i_{3(0^-)}(R_3 + R_4) = 2 \cdot 20 = 40\ (V)$

Kommutatsiya qonuniga asosan: $u_{C(0^-)} = u_{C(0^+)} = 40\,(V)$

2. Kommutatsiyadan keyingi elektr tokni aniqlash uchun Kirxgof qonuniga asosan tenglama tuzamiz:

$$\begin{cases} i_{1(0^+)}R_1 + i_{2(0^+)}R_2 + u_{1(0^+)} = E \\ i_{1(0^+)}R_1 + i_{3(0^+)} = E \\ i_{1(0^+)} = i_{2(0^+)} + i_{3(0^+)} \end{cases} \qquad (1)$$

Tok qiymatini topamiz:

$$i_{2(0^+)} = \frac{E - u_{C(0^+)} - i_{1(0^+)}R}{R_2}; \quad i_{3(0^+)} = \frac{E - i_{1(0^+)}R_1}{R_3}$$

$$i_{1(0^+)} = \frac{E_1 - u_{C(0^+)} - i_{1(0^+)}R_1 + E - i_{1(0^+)}R_1}{R} = \frac{2E - u_{C(0^+)} - 2i_{1(0^+)}R_1}{R}$$

Bundan: $i_{1(0^+)} = \dfrac{2E - u_{C(0^+)}}{3R_1} = \dfrac{120 - 40}{30} = 2{,}66A$

3. O'tkmchi jarayondagi tok ifodasi:

$$i_{1(t)} = i_1' + i_1'' = i_1' + Ae^{pt} \qquad (2)$$

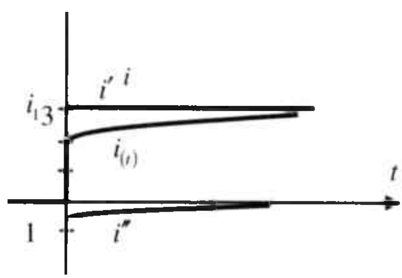
Turg'un holatdagi tok: $i_1' = \dfrac{E}{2R} = \dfrac{60}{20} = 3(A)$

(2) tenglamadan t=0 bo'lganda:

$i''_{1(0)} = i_{1(0^+)} - i'_{1(0)} = 2{,}66 - 3 = -0{,}33(A)$ yoki: $i''_{1(0)} = A = -0{,}33(A)$

4. Zanjirning xarakteristik tenglamasiga asosan ildiz P ni aniqlaymiz: $Z(p) = 0$

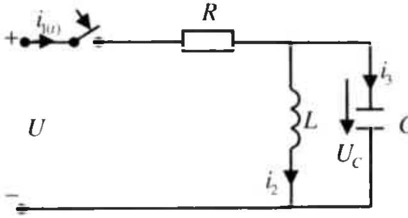
$$Z(p) = R + \frac{R\left(R + \dfrac{1}{pc}\right)}{R + R + \dfrac{1}{pc}} = 0$$



yoki: $3R^2Cp+2R=0;\ p=-\dfrac{2R}{3R^2C}=-\dfrac{2}{3\cdot 10\cdot 10^{-6}}=-6{,}66\cdot 10^4\left(\dfrac{1}{sek}\right)$

O'tkmchi jarayondagi tok: $i_{1(t)}=i_1'+i_1''=3-0{,}33e^{6{,}66*10^4 t}$

Masala 10.7._Tarmoqlangan elektr zanjir parametri R, L, C bo'lib, o'zgarmas kuchlanishga ulangandan keyingi o'tkinchi jarayondagi tok $i_{2(t)}$ va sig'im $U_{C(t)}$ ifodalari aniqlansin.



Yechish.

1. Kirxgof qonuniga asosan differensial tenglama tuzamiz:

$$\begin{cases} u=i_{1(0^+)}R+L\dfrac{di_{2(t)}}{dt} \\ u_{C(t)}=L\dfrac{di_{2(t)}}{dt} \\ i_{1(t)}=i_{2(t)}+i_{3(t)}=i_{2(t)}+C\dfrac{du_{C(t)}}{dt} \end{cases} \qquad (1)$$

Ushbu tenglamaning $i_{2(t)}$ nisbatan differensial tenglamasini yechamiz:

$$\frac{di_{2(t)}}{dt^2}+\frac{1}{RC}\frac{di_{2(t)}}{dt}+\frac{1}{LC}i_{2(t)}=\frac{U_{(t)}}{RLC} \qquad (2)$$

Differensial tenglama bo'lib quyidagicha ifodalanadi:

$$i_{2(t)}=i_{2(t)}'+i_{2(t)}''=i_{2(t)}'+A_1e^{p_1t}+A_2e^{p_2t} \qquad (3)$$

(2) tenglamaga asosan xarakteristik tenglama ildizini aniqlaymiz:

$$p^2+\frac{1}{RCL}p+\frac{1}{CL}=0$$

Ildizlari:
$$p_{12}=-\frac{1}{2RC}\pm\sqrt{\frac{1}{4R^2C^2}-\frac{1}{LC}} \qquad (4)$$

Elektr zanjirda kommutatsiyagacha bo'lgan tok va $i_{(0^-)} = 0, u_{C(0^-)} = 0$

Kommutatsiya qonuniga asosan t = 0 bo'lganda:

$$i_{2(0)} = i_{2(0^-)} = i_{2(0^+)} = 0$$
$$u_{C(0)} = u_{C(0^-)} = u_{C(0^+)} = 0 \qquad (5)$$

Kommutatsiyadan keyingi turg'un holatdagi tok:

$$i_2' = \frac{U}{R} \qquad (6)$$

(3) tenglamadan t = 0 bo'lganda:

$$i_{2(0)} = i_{2(0)}' + A_1 + A_2 = \frac{U}{R} + A_1 + A_2 = 0 \qquad (7)$$

(1) tenglamalar sistemasidagi: $u_{L(t)} = L\dfrac{di_{2(t)}}{dt}$ ga (3) tenglamadagi $i_{2(t)}$ tok hosilasini (1) tenglamaga qo'yamiz:

Bunda: $u_{L(t)} = L(A_1 P_1 e^{p_1 t} + A_2 P_2 e^{p_2 t})$

yoki t = 0 bo'lganda: $u_{L(0)} = A_1 P_1 + A_2 P_2 = 0$ (8)

(7) va (8) tenglamalar sistemasini yechish bilan integrallash koeffitsienti A_1 va A_2 aniqlanadi:

$$\begin{cases} A_1 + A_2 + \dfrac{v}{R} = 0 \\ A_1 P + A_2 P = 0 \end{cases}$$

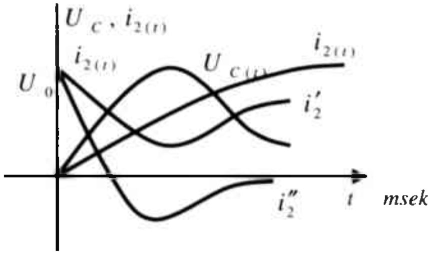
Bundan: $A_1 = \dfrac{UP_2}{R(P_1 - P_2)}$; $A_2 = \dfrac{UP_1}{R(P_1 - P_2)}$

Topilgan barcha qiymatni (3) tenglamada qo'yish bilan o'tkinchi jarayondagi tokni $i_{2(t)}$ topamiz:

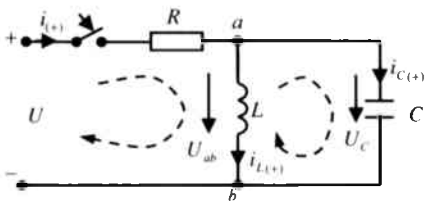
$$i_{2(t)} = \frac{U}{R} + \frac{U}{R(p_1 - p_2)}(p_2 e^{p_1 t} - p_1 e^{p_2 t})$$

$$u_{C(t)} = L\frac{di_2}{dt} = \frac{ULp_1 p_2}{R(p_1 - p_2)}(e^{p_1 t} - e^{p_2 t})$$

Agarda: $p_1 = p_2 = \dfrac{1}{LC}$ bo'lsa $u_{C(t)} = \dfrac{U}{RC(p_1 - p_2)}(p_1 e^{p_1 t} - p_2 e^{p_2 t})$ aperiodik zaryadsizlanish holati yuzaga keladi.



Masala 10.8. Aralash sxemada birlashtirilgan elektr zanjir parametri: *R=50Om, L=300(mGn) C=100(mkF)* bo'lib, $u=1000\sin 314t$ (V) sinusoidal o'zgaruvchan kuchlanishga ulanganda, $i_{(t)}$ o'tkimchi jarayondagi tok aniqlansin.



Yechish.

1. Bu elektr zanjirda kommutatsiyagacha bo'lgan tarmoqdagi tok nolga teng:

$$i_{(0^-)}=0, \qquad i_{L(0^-)}=0, \qquad i_{C(0^-)}=0$$

2. Kalit ulangandan keyin turg'un holatdagi tokni aniqlaymiz:

Umumiy tarmoqdagi tok:

$$\dot{I}'_m=\frac{\dot{U}_m e^{j0}}{\underline{Z}}=\frac{1000}{R+\dfrac{jx_L(-jx_C)}{jx_L-jx_C}}=\frac{1000}{10+\dfrac{31{,}8e^{j90^0}\cdot 34e^{-j90^0}}{j31{,}8-j34}}=14{,}4e^{j44^0}$$

Tok oniy qiymati: $i'=14{,}4\sin(314t+44^0)$

Bunda: *t=0* bo'lganda $i'_{(0)}=14{,}4\sin 44^0=10A$

Induktivlik: $\dot{I}'_{mL}=\dfrac{\dot{U}_{ab}}{Z_{ab}}=\dot{I}'_m\dfrac{jx_C}{jx_L-jx_C}=14{,}4e^{j44^0}*\dfrac{-j34}{j31{,}8-j34}=-7{,}22e^{j44^0}$

yoki: $i'_L=-7{,}22\sin(314t+44^0)$

Bunda: *t=0* bo'lganda $i'_{L(0)}=-7{,}22\sin 44^0=-5{,}1A$

Sig'imdagi tok: $i'_{mC} = i'_m \frac{jx_L}{jx_L - jx_C} = 14{,}4e^{j44^0} * \frac{-j31{,}8}{j31{,}8 - j34} = 21{,}66e^{j44^0}$ yoki

$i'_C = 21{,}66\sin(314t + 44^0)$ Bunda $t=0$ bo'lganda

$i'_{C(0)} = 21{,}66\sin 44^0 = 15{,}1A$

3. Xarakteristik tenglama tuzib, ildizni aniqlaymiz: $Z_{(P)} = 0$

Bunda: $R + \dfrac{PL\cdot\dfrac{1}{PC}}{PL + \dfrac{1}{PC}} = 0$ yoki: $P^2 + \frac{1}{RC}P + \frac{1}{CL} = 0$

$$P_{12} = -\frac{1}{2RC} \pm \sqrt{\frac{111}{4R^2C^2} - \frac{1}{LC}}$$

$$\frac{RP^2CL + R + RL}{PC} = 0$$

$$P_1 = -100 + j153\cdot\left(\frac{1}{sek}\right) \text{ yoki } P_2 = -100 - j153\left(\frac{1}{sek}\right)$$

4. Ushbu zanjirda o'tkmchi jarayonni ifodalovchi (2) differensial tenglama yechimi quyidagicha ifodalanadi:

$$i_{(t)} = i_{(t)} + Ae^{P1t} + Ae^{P2t} \qquad (1)$$

Hosilasi:
$$\frac{di''_{(t)}}{dt} = A_1P_1e^{P1t} + A_2P_2e^{P2t} \qquad (2)$$

yoki $t = 0$ bo'lganda:
$$\left.\begin{aligned} i''_{(0)} &= A_1 + A_2 \\ \frac{di''_{(0)}}{dt} &= A_1P_1 + A_2P_2 \end{aligned}\right\} \qquad (3)$$

Bu tenglamani yechish uchun kommutatsiya qonuniga asosan erkin tok qiymatini aniqlaymiz, yoki t = 0 bo'lganda

$$i''_{(0)} = i' + A_1 + A_2 = i_{(0^-)} = 0$$

yoki: $i''_{(0)} = 0 - 10 = -10$ Bundan: $A_1 + A_2 = -10;\qquad A_2 = -A_1 - 10$

(2) tenglamadan $\frac{di''_{(0)}}{dt}$ aniqlash uchun Kirxgof qonuniga asosan elektr zanjir differensial tenglamasini tuzamiz:

$$\left.\begin{aligned} i'' &= i''_L + i''_C && (*) \\ 0 &= Ri'' + L\frac{di''_L}{dt} && (**) \\ L\frac{di''_L}{dt} &= \frac{1}{C}\int i''_C dt && (***) \end{aligned}\right\}$$

(**) tenglamadan: $i''=-\frac{L}{R}\frac{di''_L}{dt}$. Hosilasi: $\frac{di''}{dt}=-\frac{L}{R}\frac{di''^2_L}{dt^2}$ (4)

(***) tenglama hosilasi: $\frac{di''^2_L}{dt^2}=\frac{1}{LC}i''_C$

Bu ifodani (4) tenglamaga qo'ysak: $\frac{di''}{dt}=-\frac{1}{RC}i''_C$ (5)

Bundan $t=0$ bo'lganda induktivlikdagi tok kommutatsiya qonuniga asosan $i_{L(0^-)}=i_{L(0^+)}=0$. Hamda:

$i''_{C(0)}=-i''_{L(0)}-i''_{(0)}=-10-5{,}1=-15{,}1$ A

Topilgan qiymatni (5) tenglamaga qo'ysak: $\frac{di''}{dt}=-\frac{1}{RC}(-15{,}1)=3020$

Barcha aniqlangan qiymatni (3) tenglama sistemasiga qo'yib tenglamani yechamiz:

$$\left.\begin{aligned}&A_2=-A_1-10\\&A_1P_1+A_2P_2=A_1(-100+j153)+(A_1+10)\cdot(100+j153)=3020\end{aligned}\right\}$$

yoki: $A_1=\frac{2020-j1530}{j306}=-5-j6{,}6=-8{,}3e^{j53^0}$

Bunda: $A_2=-5-j6{,}6-10=-5+j6{,}6=-8{,}3e^{-j53^0}$

Integrallash koeffitsienti A_1 va A_2 qiymatni (1) tenglamaga qo'yamiz:

$$i''=A_1e^{P_1t}+A_2e^{P_2t}=-8{,}3e^{j53^\circ}\cdot e^{(-100+j153)t}-8{,}3e^{j53^\circ}\cdot e^{(-100-j153)t}=$$

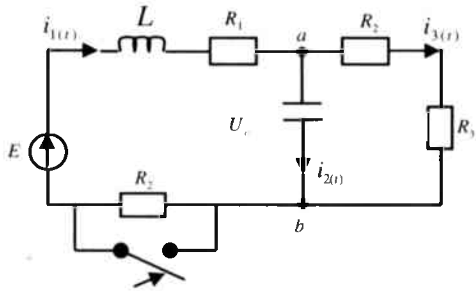
$$=-8{,}3e^{-100t}\cdot\left[e^{j(153t+53^\circ)}+e^{-j(153t+53^\circ)}\right]=-8{,}3e^{-100t}\cdot 2\cos(153t+53^\circ)=$$

$$=-16{,}6e^{-100t}\cos[90^\circ-(37^\circ-153t)]=-16{,}6e^{-100t}\cdot\sin(153t+37^\circ)$$

o'tkmchi jarayondagi tok $i_{(t)}$:

$$i_{(t)}=14{,}4\sin(314t+44^0)-16{,}6e^{-100t}\sin(153t-37^0)\,A$$

Masala 10.9. Elektr zanjir parametri: L=1MGN=10^{-3}GN; C=1500MkF=1,5 $\cdot10^{-3}$$\Phi$, R_1=2 Om, R_2=13 Om, R_3=1 Om, R_4=4 Om bo'lib, E=50 V o'zgarmas kuchlanishga ulangan. R_2 qarshllik qisqa tutashtirilgan holat uchun $i_{1(t)}$ o'tkmchi jarayondagi tok va induktivlik, sig'im qarshiligidagi kuchlanish $u_{(t)}$ o'tkmchi jarayon klassik usulida hisoblansin.



Yechish. a) kommutatsiyagacha bo'lgan tok qiymatini topamiz:
Sig'imdan o'zgarmas tok o'tmasligi sababli: $i_{2(0)}=0$.

Om qonuniga asosan:

$$i_{1(0^-)}=i_{2(0^-)}=\frac{E}{R_1+R_2+R_3+R_4}=\frac{50}{20}=2.5A$$

Sig'imdagi kuchlanish: $U_{c(0^-)}=i_{3(0^-)}\times(R_2+R_3)=2.5\times5=12.5V$

b) kommutatsiyadan keyingi turg'un holatdagi tok va sig'imdagi kuchlanishni aniqlaymiz.

Bu holatda: $i'_{2(0^+)}=0$;

Birinchi tarmoqdagi tok: $i'_{1(0^+)}i'_{2(0^+)}=\frac{E}{R_1+R_3+R_4}=\frac{50}{7}=7.1$A

Sig'imdagi kuchlanish $U'_c=i'_3(R_3+R_4)=7,1\cdot5=35,5V$

Xarakteristik tenglama ildizlarini topamiz:

$$z_{(p)}=PL+R_1+\frac{\frac{1}{PC}(R_3+R_4)}{\frac{1}{PC}+R_3+R_4}=PL+R_1+\frac{\frac{R_3+R_4}{PC}}{\frac{1+PCR_3+PCR_4}{PC}}=$$

$$=\frac{PL+R_1+P^2LCR_3+PCR_1R_3+P^2LCR_4+R_3+R_4}{1+PCR_3+PCR_4}=0$$

Ushbu tenglamada surat nolga teng

$$P^2\cdot6\cdot10^{-6}+18\cdot10^{-3}P+7=0$$

Bundan:

$$P_{12}=\frac{-9\cdot10^{-3}\pm\sqrt{(9\cdot10^{-3})^2-7\cdot6\cdot10^{-6}}}{6\cdot10^{-6}}=\frac{-9\cdot10^{-3}\pm\sqrt{39\cdot10^{-6}}}{6\cdot10^{-6}}$$

$$P_{12} = \frac{-9\cdot10^{-3} \pm \sqrt{(9\cdot10^{-3})^2 - 7\cdot6\cdot10^{-6}}}{6\cdot10^{-6}} = \frac{-9\cdot10^{-3} \pm \sqrt{39\cdot10^{-6}}}{6\cdot10^{-6}}$$

$$P_1 = \frac{-2800}{6} = -470\frac{1}{sek};\ P_2 = \frac{-15200}{6} = -2530\frac{1}{sek};$$

Xarakteristik tenglama ildizi $P_1 \neq P_2$ ga teng emas, haqiqiy sonlar bo'lganligi uchun o'tkinchi jarayon ifodasi: (*)

$$(*)\begin{cases} i_1^{"} = A_1e^{P_1t} + A_2e^{P_2t} \\ \dfrac{di_1^{"}}{dt} = P_1Ae^{P_1t} + P_2A_2e^{P_2t} \end{cases}$$

yoki t=0 bo'lganda: $(**)\begin{cases} i_{1(0)}^{"}A_1 + A_2 \\ \dfrac{di_{1(0)}}{dt} = P_1A_1 + P_2A_2 \end{cases}$

Kalit ulangandagi o'tkinchi jarayon: $i_{1(t)} = i_1^{'} + i_1^{"} = i_1^{'} + A_1e^{P_1t} + A_2e^{P_2t}$

Kommutatsiya qonuniga asosan: t=0 da $i_{1(0)} = i_{1(0^-)} = i_{1(0)} = 2,5A$

Sig'imdagi kuchlanishi: $U_{c(0^-)} = U_{c(0^+)} = U_{c(0)} = 12,5V$.

Shunga asosan: o'tkinchi jarayondagi tok va sig'imdagi kuchlanish:

$$i_1^{"} = i_{1(0)} - i_{1(0^+)} = 2,5 - 7,5 = -5A$$

$$U_c^{"} = U_{c(0)} - U_{c(0^+)} = 12,5 - 35,5 = 23V$$

(*) tenglamada $\dfrac{di_1^{"}}{dt}|t=0$ qiymatni topish uchun Kirxgof qonuniga asosan tenglama tuzamiz:

$$(***)\begin{cases} i_{1(0)}^{"} = i_{2(0)}^{"} + i_{3(0)}^{"}(1) \\ \left(L\dfrac{di_1^{"}}{dt}\right)_{t=0} + i_{1(0)}^{"}R_1 + U_{c(0)}^{"} = 0(2) \\ -U_{c(0)}^{"} - i_{3(0)}^{"}(R_1 + R_4) = 0(3) \end{cases}$$

(2) tenglamadan: $\dfrac{di_{1(0)}^{"}}{dt} = \dfrac{-i_{(0)}^{"}R - U_{c(0)}^{"}}{L} = \dfrac{10+23}{10^{-3}} = 33\cdot10^3\dfrac{a}{cek}$

Aniqlangan qiymatni (**) tenglamaga qo'yish bilan integrallash koeffitsienti A_1 va A_2 ni topamiz:

$$\begin{cases} -5 = A_1 + A_2; \\ 33\cdot 10^3 = -470A_1 + 2530A_2 \end{cases}$$

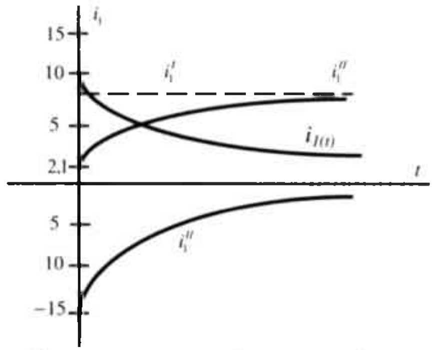
Tenglama yechimi: $33\cdot 10^3 = 470A_2 + 2350 - 2530A_2$

Bundan: $A_2 = \frac{-300}{20} = -15, A_1 = -5 - A_2 = -5 + 15 = 10$

O'tkinchi jarayon: $i_{(t)}$ tok:

$i_{1(t)} = i_1' + A_1 e^{p_1 t} + A_2 e^{p_2 t} = 7,1 + 10e^{-470t} - 15e^{-2530t}$ (A)

O'tkinchi jarayon grafigi:



Induktivlikda o'tkinchi jarayondagi kuchlanishi:

$$U_L = L\frac{di_{1(t)}}{dt} = 10^{-3}\left(-470\cdot 10e^{-470t} + 2530\cdot 15e^{-2530t}\right) = -4.7e^{-470} + 38e^{-2530t}$$

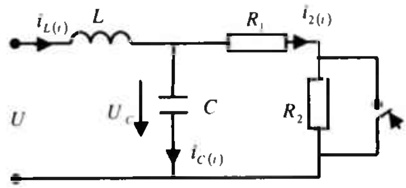
Sig'imdagi o'tkinchi jarayondagi kuchlanish:

$$U_C = \frac{1}{c}\int_{2(t)} dti = \frac{10^3}{1,5}\left(\frac{1}{-470}e^{-470t} - \frac{10.6}{-2530}e^{-2530t}\right) = -1,7e^{-470t} + 3e^{-2530t}$$

Masala 10.10. Elektr zanjir parametri $R_1 = 30\ Om$, $R_2 = 10\ Om$, $C = 5\ 10^{-5} F$ bo'lib, chastotasi $f = 50\ Gs$ bo'lgan sinusoidal o'zgaruvchan kuchlanish $U = 220\ V$ ga ulangan. Zanjirning R_2 qarshiligi qisqa tutashtirilganda (kalit ulanganda) o'tkinchi jarayondagi tok $i_{L(t)}$ va kuchlanish $U_{C(t)}$ aniqlansin.

Yechish. 1. Kommutatsiyagacha bo'lgan tok va kuchlanish qiymatini topamiz.

Umumiy qarshilik:



$$\underline{Z} = j\omega L - \frac{j\dfrac{R}{\omega C}}{R - j\dfrac{1}{\omega C}} = j1,5 + 33,8e^{-j33^\circ} = 28,6 + j133 = 136e^{j77^\circ}$$

Induktivlikdagi tok: $\dot{I}_{L(0^-)} = \dfrac{\dot{U}}{\underline{Z}} = \dfrac{220}{136e^{j77^0}} = 1,62e^{-j77^0}$

Tok oniy qiymati: $i_{L(0^-)} = 2,3\sin(314t - 77^0)$; yoki: *t=0* bo'lganda: $i_{L(0^-)} = -2,24 \;\; A$

Sig'imdagi kuchlanish:

$$\dot{U}_{C_{(0^-)}} = \dot{I}_L - \frac{j\dfrac{R}{\omega C}}{R - j\dfrac{1}{\omega C}} = 1,62e^{-j77^\circ}33,8e^{j33^\circ} = 54,8e^{j110^\circ}$$

Kuchlanish oniy qiymati: $u_{C_{(0^-)}} = 54,8\sin(314t - j10^0)$ yoki: *t=0* bo'lganda: $U_{L(0^-)} = -73,5 \; (V)$

Aktiv qarshllikdagi tok: $\dot{I}_{2(0^-)} = \dfrac{\dot{U}_{C(0^-)}}{R_1 + R_2} = \dfrac{54,8e^{-j110^0}}{40} = 1,37e^{-j110^0}$

Oniy qiymati: $i_{2(0^-)} = 1,37\sin(314t - 110^0)$ yoki: *t=0* bo'lganda: $i_{2(0^-)} = -1,25 \;\; A$

2. Kommutatsiyadan keyingi turg'un holatdagi tok va kuchlanishni aniqlaymiz.

To'la kompleks qarshilik: $\underline{Z} = j\omega L - \dfrac{j\dfrac{R}{\omega C}}{R - j\dfrac{1}{\omega C}} = 142e^{j80^\circ}$

Induktivlikdagi tok: $\dot{I}_{L(0^+)} = \dfrac{\dot{U}}{\underline{Z}} = \dfrac{220}{142e^{j80^\circ}} = 1,65e^{j80^\circ}$

yoki: $i'_{L(0^-)} = 1,65\sin(314t - 80^0)$; *t=0* bo'lganda: $i'_{L(0^-)} = -2,16 \;\; A$

Sig'imdagi tok: $\dot{I}'_C = \dot{I}'_L \dfrac{R_1}{R_1 - j\dfrac{1}{\omega C}} = 0{,}66e^{-j15^0}$

Oniy qiymat: $i'_C = 0{,}66\sin(314 + 15^0)$ yoki: $t=0$ bo'lganda: $i'_{C(0^+)} = -0{,}6\ A$

Tok: $\dot{I}'_2 = \dot{I}'_1 \cdot \dfrac{-j\dfrac{1}{\omega C}}{R_1 - \dfrac{1}{j\omega C}} = 1{,}4e^{-j105^0}$

Oniy qiymat: $i'_2 = 1{,}4\sin(314 + 105^0)$ yoki: $t=0$ bo'lganda: $i'_{2(0^+)} = -1{,}3\ A$

Sig'imdagi kuchlanish: $U'_C = I_2 \cdot R_1 = 1{,}4e^{-j105^\circ} 30 = 42e^{-j105^\circ}$.

Oniy qiymat: $U'_C = 42\sin(314t - 105^\circ)$ yoki: $t=0$ bo'lganda: $U_{C(0^+)} = -56{,}5\ (V)$

3. Kommutatsiyadan keyingi o'tkinchi jarayon erkin tok va kuchlanishni aniqlash uchun (kommutatsiya qonunini inobatga olgan holda) Kirxgof qonuniga asosan tenglama tuzamiz:

$$\left.\begin{aligned} & i''_L = i''_C + i''_2 \qquad (1) \\ & L\frac{di''_L}{dt} + i''_2 R_1 = 0\ (2) \\ & L\frac{di''_L}{dt} + \frac{1}{C}\int i''_C dt = 0\ \ (3) \end{aligned}\right| \qquad (1)$$

(1) tenglamadan: $i''_2 = i''_L + i''_C$

Buni (2) tenglamadagi i''_2 o'rniga qo'yamiz:

$$L\frac{di''_L}{dt} + i''_L R_1 - i''_C R_1 = 0$$

Bundan: $$i''_C = \frac{1}{R_1}\left(L\frac{di''_L}{dt} + i''_L R_1\right) = \frac{L}{R_1}\frac{di''_L}{dt} + i''_L \qquad (2)$$

Ushbu ifodani (3) tenglamaga qo'yib differensiallaymiz:

$$L\frac{d^2 i''_L}{dt^2} + \frac{1}{C}i_C = L\frac{d^2 i''_L}{dt^2} + \frac{1}{C}\left(\frac{L}{R_1}\frac{di''_L}{dt} + i''_L\right) = L\frac{d^2 i''_L}{dt^2} + \frac{L}{CR_1}\frac{di''_L}{dt} + \frac{1}{C}i''_L = 0 \quad (3)$$

Bundan: $$\frac{d^2 i''_L}{dt^2}+\frac{L}{CR_1}\frac{di''_L}{dt}+\frac{1}{LC}i''_L=0 \qquad (4)$$

4. Differensial tenglama yechimi:

$$\left.\begin{aligned} i''_L &= A_1e^{P_1t}+A_2e^{P_2t} \\ \frac{di''_L}{dt} &= P_1A_1e^{P_1t}+P_2A_2e^{P_2t} \end{aligned}\right\} \qquad (5)$$

Xarakteristik tenglama (4) dan ildizlari P_1 va P_2 ni topamiz:
Ya'ni: $$P^2+\frac{1}{R_1C}P+\frac{1}{LC}=0$$

$$P_{1,2}=\frac{-L\pm\sqrt{L(R_1-4R^2{}_1C)}}{2R_1CL}=\frac{-0{,}48\pm0{,}38}{144\cdot10^{-5}} \qquad P_1=-69{,}5; \qquad P_2=-596$$

Induktivlikdagi tok ; $i''_L=A_1e^{-69,5t}+A_2e^{-596t}$

Sig'imdan o'tuvchi tok (2) tenglamadan:

$$i''_C=\frac{L}{R_1}(-69{,}5)A_1e^{-69,5t}+\frac{L}{R_1}(-596)A_2e^{-596t}+A_1e^{-69,5t}+A_2e^{-596t}$$

Endi sig'imdagi kuchianishni aniqlash uchun i''_C tokni integrallaymiz:

$$U''_C=\frac{1}{C}\int i''_C dt=\frac{1}{C}[(\frac{0{,}11}{69{,}5}A_1e^{-69,5t}+\frac{8{,}65}{596}A_2e^{-596t})]=316A_1e^{-69,5t}+290A_2e^{-596t}$$

Kommutatsiya birinchi qonuniga asosan induktivlikda: $i_{L_{(0^-)}}=i_{L_{(0^+)}}=-2{,}24\ A$

Kommutatsiya ikkinchi qonuniga asosan sig'imdagi kuchianish: $U_{C_{(0^-)}}=U_{C_{(0^+)}}=-73{,}5\ B$

Demak $t=0$ bo'lganda (5) tenglamadan:

$$\left.\begin{aligned} -2{,}24 &= -2{,}16+A_1+A_2 \\ -73{,}5 &= -53{,}5+316A_1+290A_2 \end{aligned}\right\} \quad \text{yoki:} \quad \left.\begin{aligned} -0{,}08 &= A_1+A_2 \\ -17 &= 316A_1+290A_2 \end{aligned}\right\}$$

Bundan: $A_2=-0{,}08-A_1 \quad -17=316A_1-23{,}2-290A_1$

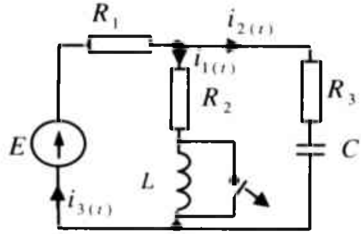
yoki: $A_1=\frac{6{,}2}{26}=0{,}258; \quad A_2=-0{,}338$

Demak: $i_{L(t)}=i'+i''=2{,}24\sin(314t-80^0)+0{,}258e^{-69,5t}-0{,}338e^{-596t}$

$$U_{C(t)}=U'_C+U''_C=42\sin(314t-105^0)+316\cdot0{,}258e^{-69,5t}-290\cdot0{,}338e^{-596t}=$$
$$=42\sin(314t-105^0)+81e^{-69,5t}-98e^{-596t}$$

Demak, tok va kuchlanish tenglamasida o‘tkinchi jarayon aperiodik qonunga asosan o‘zgarar ekan.

Masala 10.11. Elektr zanjir parametri: $R_1 = 8{,}5\ Om$, $R_2 = 11\ Om$, $R_3 = 197{,}4\ Om$, $L_1 = 11\ Gn$, $C=1\ mkF$ bo‘lib, E=24 B o‘zgarmas tok manbaiga ulangan. Induktivlikdagi kalit uzilgan holatda o‘tkinchi tok $i_{1(t)}$ va $U_{L(t)}$ aniqlansin.



Yechish.

1. Kommutatsiyagacha bo‘lgan tok va kuchianishni aniqlaymiz:

$$i_{1(0^-)} = \frac{E}{R_3 + R_1} = \frac{24}{197{,}4 + 8{,}5} = 0{,}116\ A$$

Sig‘imdan o‘zgarmas tok o‘tmasligi sababli:

$$i_{2(0^-)} = 0$$

$$i_{3(0^-)} = i_{1(0^-)} = 0{,}116\ \ A$$

Sig‘imdagi kuchlanish:

$$U_{C_{2(0^-)}} = \frac{E}{R_3 + R_1} R_1 = i_{1(0^-)} R_1 = 0{,}116 \cdot 8{,}5 = 1\ V$$

2. Kommutatsiyadan keyingi turg‘un holatdagi tok va kuchlanish kommutatsiyagacha bo‘lgan tokga teng bo‘ladi:

$$i_1' = \frac{E}{R_3 + R_1} = 0{,}116\ A$$

$$i_2' = 0 \quad i_3' = i_1' = 0{,}116\ A$$

Sig‘imdagi kuchlanish:

$$U_C' = i_1' R_1 = 1\ V$$

3. O‘tkinchi jarayon tok kuchlanishini aniqlash uchun Kirxgof qonuniga asosan elektr zanjir uchun differensial tenglama tuzamiz:

$$\left.\begin{aligned} &-i_{1(t)} - i_{2(t)} + i_{3(t)} = 0 && (1)\\ &i_{1(t)}R_1 + L\frac{di_{1(t)}}{dt} + i_{3(t)}R_3 = E && (2)\\ &i_{2(t)}R + \frac{1}{C_2}\int i_{2(t)}dt - L\frac{di_{1(t)}}{dt} + i_{1(t)}R_1 = 0 && (3)\end{aligned}\right\}$$

Bunda (2) tenglamadan: $\frac{di_{1(t)}}{dt} = \frac{E - i_{1(t)}R_1 - i_{3(t)}R_3}{L}$ (4)

4. Xarakteristik tenglama ildizini aniqlash uchun $Z_{(P)} = 0$ bo'lganda:

$$Z_{(P)} = R_1 + PL_1 + \frac{R_3(R_2 + \frac{1}{PC_2})}{R_3 + R_2 + \frac{1}{PC_2}} = 0$$

$$P^2 + P\frac{R_3R_1 + R_3R_2 + R_2R_1 + \frac{L}{C}}{(R_2 + R_3)L} + \frac{R_3 + R_1}{(R_2 + R_3)LC} = 0$$

Bundan: $P^2 + P46{,}8\cdot10^3 + 5972\cdot10^6 = 0$

yoki: $P_{1,2} = -\frac{46{,}8\cdot10^3}{2} \pm \sqrt{(\frac{46{,}8\cdot10^3}{2})^2 - 5972\cdot10^6} = -23\cdot10^3 \pm j73\cdot10^3$ (5)

5. (2) differensial tenglama yechimi:

$$\left.\begin{aligned} &i_{1(t)} = i'_{1(t)} + i''_{1(t)} = i'_{1(t)} + A_1e^{P_1t} + A_2e^{P_2t}\\ &\frac{di''_{1(t)}}{dt} = A_1P_1e^{P_1t} + A_2P_2e^{P_2t}\end{aligned}\right\} \quad (6)$$

Integrallash koeffitsienti A_1 va A_2 boshlang'ich shartga binoan kommutatsiya birinchi qonunida, $t=0$ bo'lganda: $i_{1(0^-)} = 0{,}116\ A$

(4) tenglamadan:

$$\frac{di_{1(0)}}{dt} = \frac{E - i_{1(0)}R_1 - i_{3(0)}R_3}{L_1} = \frac{24 - 0{,}116\cdot197{,}4}{807\cdot10^{-6}} = 2{,}8\cdot10^3\ \left(\frac{A}{sek}\right)$$

Ushbu qiymatni (6) tenglamaga qo'ysak ($t=0$):

$$\left.\begin{aligned} &0{,}116 = 0{,}116 + A_1 + A_2\\ &2{,}8\cdot10^3 = A_1(-23\cdot10^{-3} + j73\cdot10^3) + A_2(-23\cdot10^{-3} - j73\cdot10^3)\end{aligned}\right\} \quad (7)$$

(7) tenglamani yechish natijasida:

$$A_1 = 0{,}058e^{-j179^0};\ A_2 = 0{,}058e^{j179^0};$$

Aniqlangan barcha qiymatni (6) tenglamaga qo'ysak, o'tkinchi jarayondagi $i_{1(t)}$ tok ifodasi:

$$i_{1(t)} = i'_{1(t)} + i''_{1(t)} = 0{,}116 + A_1e^{P_1t} + A_2e^{P_2t} =$$

$$= 0{,}116 + 0{,}058e^{-j179^\circ}\cdot e^{(-23{,}4\cdot10^{-3}+j73{,}6\cdot10^3)t} + 0{,}058e^{(-23{,}4\cdot10^{-3}+j73{,}6\cdot10^3)t} =$$

$$= 0{,}116 + 0{,}116e^{-23{,}4\cdot10^3t}\sin(73{,}6\cdot10^3t - 89^\circ)A$$

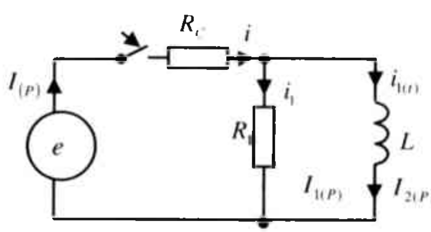
Induktivlikdagi o'tkinchi kuchlanish:

$$U_{L(t)} = L_1\frac{di_{1(t)}}{dt} = 807\cdot10^6\cdot0{,}058e^{-23{,}4\cdot10^3t}\cdot\begin{bmatrix}-23{,}4\cdot10^3t\sin(73\cdot10^3t-89^\circ)+\\+73\cdot10^3t\cos(73\cdot10^3t-89^\circ)\end{bmatrix}=$$

$$= 3{,}6\sin(73\cdot10^3t + 89^\circ)$$

Elektr zanjirida o'tkinchi jarayonni operator usulida hisoblash

Masala 10.12. Aktiv qarshiligi $R=R_l=50$ *Om*, induktivligi $L = 0{,}033$ *Гн* bo'lgan elektr zanjir $U_m = 200\sqrt{2}\sin(\omega t + 90^0)$ sinusoidal kuchlanishga ulanganda hosil bo'ladigan $i_{2(t)}$ o'tkinchi jarayondagi tok operator usulida topilsin.



Yechish.

Umumiy operator qarshiligini aniqlaymiz

$$Z_{(P)} = R + \frac{R_1PL}{R_1 + PL} = \frac{RR_1 + PL(R + R_1)}{R_1 + PL}$$

Induktivlikdan o'tuvchi $I_{2(P)}$ tokning operator ifodasi Om qonuniga asosan:

$$I_{2(P)} = I_{(P)}\frac{R_1}{R_1 + PL}$$

yoki:

$$I_{2(P)} = \frac{U_{(P)}}{Z_{(P)}}\cdot\frac{R_1}{R_1 + PL} = \frac{U_{(P)}(R_1 + PL)R_1}{[RR_1 + PL(R + R_1)](R_1 + PL)} = \frac{U_{(P)}R_1}{RR_1 + PL(R + R_1)} = \frac{U_{(P)}}{Z_{2(P)}}$$

Bundan: $Z_{2(P)} = \dfrac{RR_1 + PL(R + R_1)}{R_1}$

Tenglama ildizi $Z_{2(P)} = 0$ asosan: $PL(R + R_1) + RR_1 = 0$

$$P = -\frac{RR_1}{L(R + R_1)} = -\frac{25}{10L} = -78{,}2 \quad \frac{1}{сек}$$

$i_{2(t)}$ o'tkinchi jarayondagi tokni operator ifodasida aniqlash uchun (9.22) tenglamaga asoslanadi:

$$i_{2(t)} \doteq M\left[\frac{U_m e^{j(\omega t+\psi)}}{Z_{2(j\omega)}} + \sum_{K=0}^{n}\frac{U_m e^{j\varphi}e^{P_K t}}{(P_K - j\omega)Z'_{2(P)}}\right] \qquad (1)$$

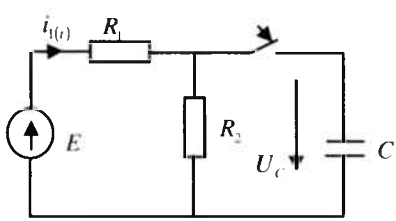
Bundan: $Z'_{2(P)} = \dfrac{L(R + R_1)}{R_1} = 0{,}064$

Aniqlangan qiymat (1) tenglamaga qo'yiladi:

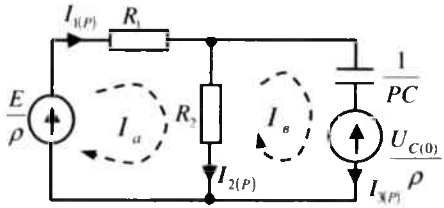
$$i_{2(t)} = \left[\frac{310e^{j(\omega t+90^\circ)}}{20{,}55e^{j76^\circ}} + \frac{310e^{-90^\circ}ee^{-78{,}2^\circ t}}{322e^{-j104}0{,}064}\right] =$$

$$= 15\sin(\omega t - 166^\circ) + 15\sin 14^\circ ee^{-78.2t} = 15\sin(\omega t - 166^\circ) + 3{,}74e^{-78.2t}$$

Masala 10.13. Parametri $R_1 = R_2 = 10$ *Om*, C = 1 mkF bo'lgan elektr zanjirning o'zgarmas manbai E = 10 V bo'lib, sig'im ulanganda hosil bo'ladigan $i_1(t)$ o'tkinchi jarayon tok operator usuliga asosan aniqlansin.



Yechish. Kommutatsiyadan keyingi operator sxemasini tuzamiz:



Konturli tok usuliga asosan tenglama yozamiz:

$$\begin{cases} I_{a(p)}(R_1+R_2)-I_{b(p)}R_2=\dfrac{E}{p} \\ -I_{a(p)}R_2+I_{b(p)}(R_2+\dfrac{1}{PC})=-\dfrac{U_{C(P)}}{p} \end{cases}$$

Son qiymatini qo'yamiz:

$$\begin{cases} I_{a(p)}20-10I_{b(p)}=\dfrac{10}{p} \\ -I_{a(p)}10+(\dfrac{10^6}{P}+10)I_{b(p)}=-\dfrac{U_{C(0)}}{p} \end{cases}$$

Bundan:

$$I_{a(p)}=I_{1(p)}=\frac{10^7+100P-U_{C(0)}10P}{100P^2+2\cdot10^7P}=\frac{10P-U_{C(0)}10P+10^6}{10P(P+2\cdot10^5)}=\frac{F_1(p)}{F_2(p)}$$

Tenglamadan ildiz P ni topamiz: $Z(p)=0$

$$Z(p)=P+2\cdot10^5=0; P=-2\cdot10^5\left(\frac{1}{sek}\right)$$

Yoyish teoremasiga asosan ushbu operator tenglamani kasr tenglamalar yig'indisi ko'rinishida yozamiz:

$$I_{1(p)}=\frac{10P}{10P(P+2\cdot10^5)}-\frac{U_{C(0)}P\cdot10}{10P(P+2\cdot10^5)}+\frac{10^6}{10P(P+2\cdot10^5)}=$$

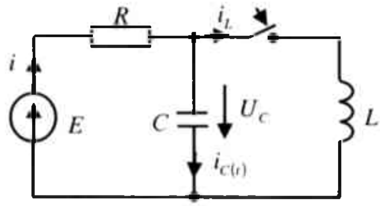
$$=\frac{1}{P+2\cdot10^5}-\frac{U_{C(0)}}{P+2\cdot10^5}+\frac{10^5}{P(P+2\cdot10^5)}$$

O'tkinchi jarayondagi tok $i_1(t)$ haqiqiy ifodasini aniqlashda o'tish jadvalidan foydalanamiz.

Bunda:

$$i_1(t)=e^{-2\cdot10^5t}-\frac{U_{C(0)}}{}e^{-2\cdot10^5t}+\frac{1}{2}(1-e^{-2\cdot10^5t})=\frac{1}{2}(1+e^{-2\cdot10^5t})-\frac{U_{C(0)}}{10}e^{-2\cdot10^5t}$$

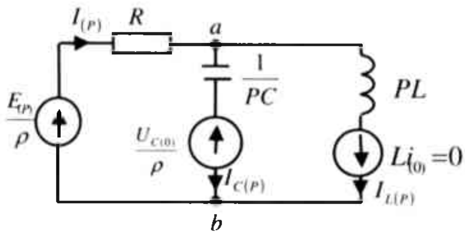
Masala 10.14. Elektr zanjir parametri $R = 10Om$, $C = 100mkF$, $L = 29{,}4mGn$ bo‘lib, o‘zgarmas $E = 100V$ manbaga ulangan. Zanjirga induktivlik ulanganda sig‘imdan o‘tuvchi $i_C(t)$ o‘tkinchi jarayondagi tok operator usulda aniqlansin.



Yechish.

Operator sxemasini tuzamiz:

Bunda: $U_{C(0)} = 100$ (V) bo‘lib, induktivlikdagi tok kommutatsiya birinchi qonuniga asosan $t = 0$ $i_{(0^-)} = i_{(0^+)} = i_{(0)} = 0$, yoki $Li_{(0)} = 0$



$I_{C(P)}$ tokni topish uchun ushbu sxemani ekvivalent sxemaga almashtiramiz:

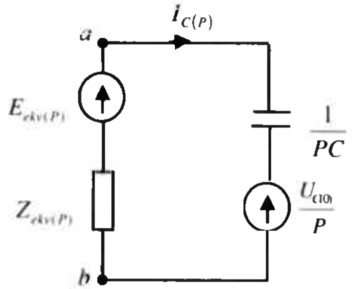
Bunda:

$$U_{ab} = E_{ekv(P)} = \frac{\frac{E_{(P)}}{p}Y_1 - Li_{(0)}Y_2}{Y_1 + Y_2} = \frac{\frac{E_{(3)}}{p}\cdot\frac{1}{R} - Li_{(0)}\frac{1}{RL}}{\frac{1}{R} + \frac{1}{PL}} =$$

$$= \frac{10\cdot 10P\cdot 29{,}4}{P\left(P29{,}4 + 10^4\right)} = \frac{29{,}4}{p2{,}94 + 10}$$

Bunda: $Z_{ekv} = \frac{1}{Y_{ekv}} = \frac{29{,}4}{2{,}94P + 10^3}$

Ekvivalent sxema tuzamiz:



Bundan:

$$I_{C(P)}=\frac{E_{ekv(P)}-\frac{U_{C(0)}}{P}}{Z_{ekv(P)}+\frac{1}{PC}}=\frac{294P-294P-10^5}{29{,}4P^2+10^4\cdot 2{,}94P+10^7}=\frac{-10^5}{29{,}4P^2+29{,}4\cdot 10^3P+10^7}=\frac{F_1(P)}{F_2(P)}$$

Umumiy operator qarshilikdan $Z_{ekv}=0(F_2(P)=0)$ ildizni aniqlaymiz: $29{,}4P^2+29{,}4\cdot 10^3P+10^7=0$ yoki:

$$P_{12}=\frac{-29{,}4\cdot 10^3\pm\sqrt{(29{,}4)^2\cdot 10^6-4{,}29\cdot 4\cdot 10^7}}{58{,}8}=\frac{-29{,}4\cdot 10^3\pm 17{,}8\cdot 10^3}{58{,}8}$$

$$P_1=(-500+j300)\frac{1}{sek};P_2=(-500-j300)\frac{1}{sek}$$

Yoyish teoremasiga asosan operator ifodadan haqiqiy tok $i_{C(t)}$ o'tish formulasidan: $i_{(t)}\doteq 2\,\mathrm{Re}\sum_{k=1}^{n}\frac{F_1(P_K)}{F_2'(P_K)}\cdot e^{P_Kt}$

Bundan: $F_1(P_K)=-10^5$

$$F_2(P_K)=\left(58{,}8P+29{,}4\cdot 10^3\right)=58{,}8\left(-500+j300\right)+29{,}4\cdot 10^3=$$

$$=-29{,}4\cdot 10^3+17{,}6\cdot 10^3j+29{,}4\cdot 10^3=j17{,}6\cdot 10^3$$

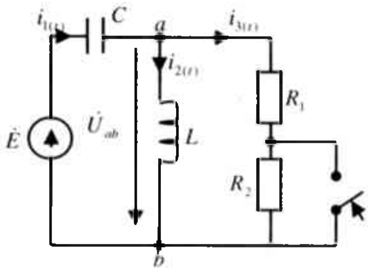
Aniqlangan son qiymatini yoyish tenglamasiga qo'yib $i_{C(t)}$ o'tkinchi jarayondagi tokni aniqlaymiz:

$$i_C(t)\doteq 2\,\mathrm{Re}\left[\frac{-10^5}{j17{,}6}e^{-500t}e^{j300t}\right]=2\,\mathrm{Re}\left[\frac{-10^5}{j17{,}6\cdot 10^3}e^{-500t}\left(cos300t+j\sin 300t\right)\right]=$$

$$=2\,\mathrm{Re}\left[\frac{-10^2}{j17{,}6}\cos 300t+\frac{j\sin 300t(-10^2)}{j17{,}6}\right]e^{-500t}=2(-5{,}6\sin 300t\cdot e^{-500t})=$$

$$=11{,}3e^{-500t}\sin 300t$$

Masala 10.15. Elektr zanjir parametri: $I_1 = R_1 = 5\ Om, L = 4\cdot10^{-2}GN$, $C = 2\cdot10^{-4}$ bo'lib, $e = 100\sin(1000t + 120°)$ sinusoidal kuchlamishga ulangan. R_2 qarshllik kalit uzilgan holatda o'tkinchi jarayondagi tok $i_{3(t)}$ klassik va operator usulga asosan yechilsin.



Yechish.

1. Klassik usul.

a) xarakteristik tenglama ildizini topamiz:

$$z_p = \frac{1}{PC} + \frac{PL(R_1 + R_2)}{PL + R_1 + R_2} = \frac{PL + R_1 + R_2 + PC\left[PL(R_1 + R_2)\right]}{PC(PL + R_1 + R_2)} = 0$$

Bundan: $PL + R_1 + R_2 + PC\left[PL(R_1 + R_2)\right] = 0$

yoki: $8\cdot10^{-5}P^2 + 4\cdot10^{-2} + 10 = 0$

Tenglama yechimi:

$$P_{12} = \frac{-4\cdot10^{-2} \pm \sqrt{16\cdot10^{-4} - 4\cdot80\cdot10^{-6}\cdot10}}{2\cdot80\cdot10^{-6}} = \frac{-4\cdot10^{-2} \pm j4\cdot10^{-2}}{160\cdot10^{-6}} =$$

$$= \frac{5.65e^{j135}}{160\cdot10^{-4}} = 0.0354\cdot10^{-4}e^{j135}$$

Ildizini aniqlaymiz: $P_1 = -250 + j250; P_1 = -250 - j250$

Demak, ildiz kompleks son bo'lganligi uchun, o'tkinchi jarayondagi tok quyidagicha ifodalanadi:

$$i^{'} = Ae^{-t}\sin(\omega_0 t + \gamma) = e^{+250t}\sin(250t - 8)$$

$$\left.\begin{aligned} &\text{yoki;} \qquad t = 0 \text{ bo'lganligi } \ e^{'}_{(0)} = Asin\gamma \\ &\text{Hosilasi:} \qquad \frac{di^{'}}{dt}\Big|_{t=0} = -\delta Asin\gamma + \omega_0 Acos\gamma \quad (*) \end{aligned}\right\}$$

b) kommutatsiyagacha bo‘lgan tok va sig‘imdagi kuchlanish qiymatini topish uchun ikkita tugun potensiallar usulidan foydalanamiz:

$$\dot{U}_{ab}=\frac{\dot{E}y_1}{y_1+y_2+y_3}=\frac{71e^{j120^\circ}\cdot 0,2e^{j90^\circ}}{j0,2-j0,025+0,2}=\frac{14,2e^{j210^\circ}}{0,2+j0,175}=$$

$$=\frac{14,2e^{j210^\circ}}{0,260e^{j42^\circ}}=53,4^{j168^\circ}=-52,3+ji0,3V$$

Om qonuniga asosan tarmoqdagi tokni topamiz:

$$\dot{I}_1=\frac{\dot{I}-\dot{U}_{ab}}{x_c}=\frac{16,7+j51,2}{5e^{-j90^\circ}}=\frac{54\cdot e^{j72^\circ}}{5e^{-j90^\circ}}=10,8^{j162^\circ}=-10,25+j3,34A$$

$$\dot{I}_2=\frac{\dot{U}_{ab}}{x_L}=\frac{53,4e^{j168^\circ}}{40e^{-j90^\circ}}=1,33e^{j78^\circ}=0,258+j1,3A$$

$$\dot{I}_3=\frac{\dot{U}_{ab}}{R_1}=\frac{53,4e^{j168^\circ}}{5}=10,7e^{j168^\circ 50'}=-10,5+j2,07A$$

Oniy qiymat:

$i_1=10,8\sqrt{2}\sin(\omega t+162^\circ)=15,2\sin(\omega t+162^\circ)$

$t=0$ bo‘lganda $i_{1(0^-)}=4,7A$

$i_2=1,33\sqrt{2}\sin(\omega t+78^\circ)=1,87\sin(\omega t+78^\circ)A$

$t=0$ bo‘lganda $i_{2(0^-)}=1,83A$

$i_3=10,7\sqrt{2}\sin(\omega t+168^\circ)=15,1\sin(\omega t+168^\circ)$

$t=0$ bo‘lganda $i_{3(0^-)}=1,8A$

Sig‘imdagi kuchlanish:

$\dot{U}_c=\dot{I}_1(-jx_c)=10,8e^{j162^\circ}\cdot 5e^{j90^\circ}=54e^{j72^\circ}$

Oniy qiymati: $U_c=\sqrt{2}54\sin(\omega t+72^\circ)=76\sin(\omega t+72^\circ)$

$t=0$ bo‘lganda: $U_{c(0^-)}=72V$

d) kommutatsiyadan keyingi turg‘un holatdagi tokni topamiz:

$$\dot{U}_{ab}=\frac{E_1Y_1}{y_1+y_2+y_3}=\frac{14,2e^{j120^\circ}}{0,1+j0,175}=67,5e^{j149^\circ}=-58,4+j34V$$

Tokning kompleks ifodasi:

$$\dot{I}_1 = \frac{\dot{E}_1\dot{U}_{ab}}{x_s} = \frac{22{,}9 + j27{,}5}{5e^{-j90^\circ}} = \frac{36e^{j50^\circ}}{5e^{-90^\circ}} = 7{,}2e^{j140^\circ} = -55 + j4{,}65A$$

$$\dot{I}_2 = \frac{\dot{U}_{ab}}{x_L} = \frac{67{,}5e^{j149^\circ}}{40e^{-j90^\circ}} = 1{,}7e^{j60^\circ} = 0{,}85 + j1{,}46A$$

$$\dot{I}_3 = \frac{\dot{U}_{ab}}{R_1 + R_2} = \frac{67{,}5e^{j149^\circ}}{10} = 6{,}75e^{j149^\circ} = -5{,}85 + j3{,}4$$

Oniy qiymat: $i_1 = 7{,}2\sqrt{2}\sin\left(\omega t + 140^\circ\right) = 10{,}1\sin\left(\omega t + 140^\circ\right)$.

Bunda: $t = 0; i_{1(0^+)} = 6{,}5A$

$i_2 = 1{,}7\sqrt{2}\sin\left(\omega t + 60^\circ\right) = 2{,}38\sin\left(\omega t + 60^\circ\right)A \quad t = 0; i_{2(0^+)} = 2{,}06A$

$i_3 = 6{,}75\sqrt{2}\sin\left(\omega t + 149^\circ\right) = 9{,}5\sin\left(\omega t + 149^\circ\right)A \quad t = 0; i_{3(0^+)} = 4{,}75A$

Sig'im kuchlanishi:

$\dot{U}_c = \dot{I}_1\left(-jx_c\right) = 72e^{j140^\circ} \cdot 5e^{-j90^\circ} = 36e^{j50^\circ}$.

Oniy qiymati: $U_c = 50{,}7\sin\left(\omega t + 50^\circ\right); t = 0; U_{c(0^+)} = 38{,}8V$

e) kommutatsiya qonunini hisobga olgan holda o'tkinchi jarayon, ya'ni erkin holatdagi tok va sig'imdagi kuchlanishni topamiz:

$$i_1^{\cdot} = i_{1(0^-)} - i_{1(0^+)} = 4{,}7 - 6{,}5 = -1{,}8A$$

$$i_2^{\cdot} = i_{2(0^-)} - i_{2(0^+)} = 1{,}83 - 2{,}06 = -0{,}23A$$

$$U_c^{\cdot} = U_{c(0^-)} - U_{c(0^+)} = 33{,}2V$$

O'tkinchi jarayondagi i_3'' tokni topish uchun tenglama tuzamiz:

$$\begin{cases} i_{1(0)}^{\cdot} - i_{2(0)}^{\cdot} - i_{2(0)}^{\cdot} = 0 & (1) \\ \frac{1}{c}\int i_{1(0)}^{\cdot} dt + i_{3(0)}^{\cdot}\left(R_1 + R_2\right) = 0 & (2) \\ \frac{1}{c} i_{1(0)}^{\cdot} dt + L\frac{di_{2(0)}^{\cdot}}{dt} = 0 & (3) \end{cases}$$

O'tkinchl jarayon uchun hisoblab topilgan tok va sig'imdagi kuchlanish qiymatiga (2) tenglamadan i_3'' tokni topamiz:

$t=0 \quad U''_{c(0)} + i''_{3(0)}(R_1+R_2)=0;$ ya'ni $i''_{3(0)} = \frac{Ui''_{c(0)}}{R_1+R_2} = \frac{-33,2}{10} = -3,32A$

t=0 bo'lganda hosilasi:

$$\frac{di''_3}{dt}\Big|_{t=0} = -\frac{i''_{1(0)}}{C(R_1+R_2)} = -\frac{\left(i''_{2(0)} + i''_{3(0)}\right)}{C(R_1+R_2)} = -\frac{-0,23-3,32}{2\cdot 10^{-4}\cdot 10} =$$

$$= \frac{3,55}{2}\cdot 10^3 = 1,77\cdot 10^3 a/sek$$

f) Integrallash koeffitsientini topish uchun aniqlangan tok qiymatini (*) tenglamaga qo'yamiz:

$$\begin{cases} -3,32 = A\sin\gamma \\ 1,77\cdot 10^3 = -250A\sin\gamma + 250A\cos\gamma \end{cases}$$

Tenglamani yechish uchun:

940=250 A cos yoki: $A\cos\gamma = 3,76$

$$tg\gamma = -\frac{3,32}{3,76} = -0,885; \quad \text{yoki} \quad \gamma = -42°50'$$

$$\sin(\gamma) = -0,676$$

yoki: $A = \frac{3,32}{0,676} = 4,22$

Demak: $i''_3 = 4,492e^{-250t}\sin(250t - 42°30')$;

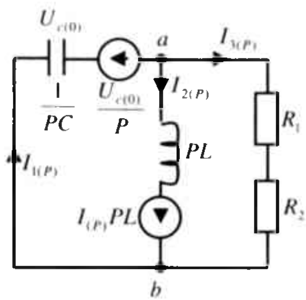
O'tkinchi jarayondagi tok:

$$i_{3(t)} = i'_3 + i''_3 = 9,5\sin(\omega t + 149°) + 4,92e^{-j250t}\sin(250t - 42°30');$$

2. Operator usul.

Ekvivalent operator sxemasini chizamiz. Bunda: $U_{c(0)} = 33,2V$

$i_{2(0)}\cdot L = -0,23\cdot 4\cdot 10^2 = -0,92\cdot 10^2$



Yechish.

Ikki tugun potensiallar usuliga asosan:

$$U_{ab(p)} = \frac{-\frac{U_{c(0)}}{P}PC - i_{2(0)}L\frac{1}{P}}{PC + \frac{1}{PL} + \frac{1}{R}} = \frac{\left[-U_{c(0)}PC + \left(-i_{2(0)}\right)\right]PLR}{P\left(P^2LCR + R + PL\right)} =$$

$$= \frac{\left[-U_{c(0)}PC - i_{2(0)}\right]\frac{LR}{RLC}}{P^2 + \frac{R}{RLC} + \frac{PL}{PLC}} = \frac{-U_{c(0)}P - \frac{i_{2(0)}}{C}}{P^2 + \frac{1}{4\cdot 10^{-2}\cdot 2\cdot 10^{-4}} + \frac{P}{10\cdot 2\cdot 10^{-4}}} =$$

$$= \frac{-33,2P + 1150}{P^2 + 500P + 12,5\cdot 10^4}$$

$$I_{3(0)} = \frac{U_{ab(p)}}{R} = \frac{-33,2 + 1150}{\left(P^2 + 500P + 12,5\cdot 10^4\right)R} = \frac{-33,2P + 1150}{P^2 + 500P + 12,5\cdot 10^4};$$

Yoyish teoremasiga asosan operator ifodadan haqiqiy tokga o'tish formulasi: $i_{3(t)} \cong 2\operatorname{Re}\sum_{k=1}^{n}\frac{F_1(P_k)}{F'_2(P_k)}\cdot e^{P_k t}$ $\qquad (*)$

Bundan:

$$F_{1(P_1)} = -3,32(-250 + j250) + 115 = 830 - j650 + 115 = 945 - j830;$$

$$F_{2(P_1)} = 2(-250 + j250) + 500 = j500;$$

Aniqlangan qiymatni $(*)$ tenglamaga qo'yamiz:

$$i_{3(t)} = 2\operatorname{Re}\sum\frac{945 - j830}{j500}e^{-250t}\cdot e^{j250t} = 2\operatorname{Re}(1,66 - j1,89)e^{-250t}\cdot e^{j250t} =$$

$$= 2\cdot 2,46e^{-250t}\operatorname{Re}\left[e^{j(250t - 227^\circ)}\right] = 4,92e^{-j250t}\sin(250t - 47^\circ)$$

$i_{3(t)}$ o'tkinchi jarayondagi tok ifodasi:

$$i_{3(t)} = i_3' + i_3'' = 9,5\sin\sin\left(\omega t + 149^\circ 50'\right) + 4,93e^{j250t}\sin(250t - 47^\circ)$$

Elektr zanjirda o'tkinchi jarayonini Dyuamel integrali usulida hisoblash

Masala 10.16. Ketma-ket ulangan R, L zanjir parametri R=10*Om*, L=40 *MGn* bo'lib, ekspotensial funksiyasi $U_{(t)} = Ue^{-\gamma t}$ bo'lgan kuchlanishga ulanganda o'tkinchi jarayondagi tok $i_{(t)}$ Dyuamel integrali usuliga asosan aniqlansin (U=100(*V*) $\gamma = 500\left(\frac{1}{sek}\right)$)

Yechish. Aktiv va induktiv zanjirni o‘zgarmas tokga ulaganda o‘tkmchi jarayondagi tok (9.12) tenglamaga asosan yechiladi:

$$i_{(t)} = \frac{U}{R}(1 - e^{-\frac{t}{\tau}})$$

Yoki o‘tkinchi o‘tkazuvchanlik ifodasi bo‘yicha:

$$y_{(t)} = \frac{1}{R}(1 - e^{-\frac{t}{\tau}}) = \frac{1}{R}(1 - e^{-\delta t})$$

Bunda: $\delta = \frac{R}{L} = \frac{10}{40 \cdot 10^{-3}} = 250 \left(\frac{1}{sek}\right)$

(9.3) tenglama Dyuamel integrali birinchi ifodasidan foydalanamiz:

$$i_{(t)} = U_{(0)} y_{(t)} + \int_0^t y(t - x) U'_{(x)} dx \qquad (1)$$

Bunda $t = 0$ bo‘lganda; $U_{(0)} = U = 100$ V

$$y_{(t-x)} = \frac{1}{R}(1 - e^{-\delta(t-x)}) = \frac{1}{R}(1 - e^{-\delta t} e^{\delta x});$$

$$U'_{(x)} = \left.\frac{dU}{dt}\right|_{t=x} = -\gamma U e^{-\gamma x}$$

Aniqlangan qiymatni (1) tenglamaga qo‘yib integrallaymiz:

$$i_{(t)} = \frac{U}{R}(1 - e^{-\delta(t)}) + \int_{x=0}^{x=t} \frac{1}{R}(1 - e^{-\delta t} e^{\delta x})(-\gamma U) e^{-\gamma x} dx =$$

$$= \frac{U}{R}(1 - e^{-\delta(t)}) - \frac{\gamma U}{R} \int_{x=0}^{x=t} (e^{-\gamma x} - e^{-\delta x} e^{(\delta - \gamma)x}) dx$$

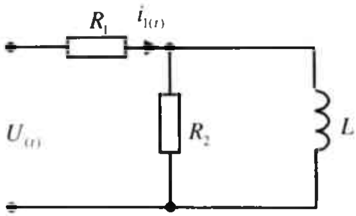
$$i_{(t)} = \frac{U}{R}(1 - e^{-\delta(t)}) - \frac{\gamma U}{R}\left(-\frac{1}{\gamma}\right) e^{-\gamma x}\Big|_0^t + \frac{\gamma U}{R} e^{-\delta x} \frac{1}{\delta - \gamma} e^{(\delta - \gamma)x}\Big|_0^t =$$

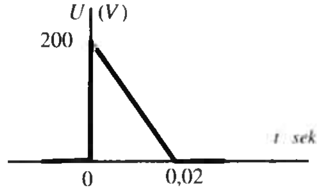
$$= \frac{\frac{U}{L}}{\delta - \gamma}(e^{-\gamma x} - e^{-\delta x})$$

Aniqlangan qiymatni tenglamaga qo‘yamiz:

$$i_{(t)} = \frac{250}{250 - 500} \frac{100}{10}(e^{-500t} - e^{-250t}) = 10(e^{-250t} - e^{-500t}) \ A$$

Masala 10.17. Parametri: $R_1=5\ Om$, $R_2=10\ Om$, $L=100\ MGn$ bo'lgan elektr zanjir arrasimon impulsli kuchlanishga ulanganda $i_{1(t)}$ o'tkinchl jarayondagi tok Dyuamel integraliga asosan aniqlansin.





Yechish.

Kuchlanish analitik ifodasi:

$U = 10^4(0{,}02 - t)$ (V)bo'lib: $t=0$ $U=200\ (V)$ va $t=0{,}02\ (sek)$ $U=0$.

Demak $t=0$ bo'lganda: $U_{(0)}=200\ (V)$ $U'_{(0)}=-10^4\ (V)$

O'tkinchi jarayondagi tok:

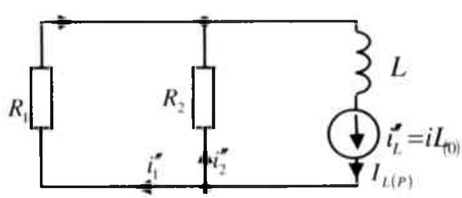
$$i_{(t)} = U \cdot y_{(t)} \text{agar } U = 1;\quad i_{(t)} = y_{(t)}$$

Umumiy $i_{1(t)}$ o'tkinchi jarayondagi tok:

$i_{1(t)} = i'_1 + i''_1$, bo'lib, qiymatini aniqlaymiz:

Bunda $$i' = \frac{U}{R_1} = \frac{1}{5} = 0{,}2\ A$$

i'' – o'tkmchi erkin hisoblanadi, tokni topish uchun operator usulidan foydalanamiz. Buning uchun operator sxemasini chizamiz:



Kirxgof qonuniga asosan tenglama tuzamiz: $\left.\begin{array}{l} R_2 i''_2 = R_1 i''_1, \\ i''_1 + i''_2 = 0{,}2 \end{array}\right\}$

Bundan: $i''_2 = 0{,}2 - i''_1$ yoki: $10(0{,}2 - i''_1) = 5 \cdot i''_1$; $\quad i''_1 = \dfrac{2}{15} = 0{,}13\ A$

Om qonuni operator ifodasiga asosan:

$$I''_{1(P)} = \frac{(i_1 L)R_2}{R_1 \cdot R_2 + R_1 PL + R_2 PL} = \frac{0{,}02 \cdot 10}{50 + 50P0{,}1 + 10P0{,}1} = \frac{0{,}2}{50 + 1{,}5P}$$

Bundan: $50 + 1{,}5P = 0;\ P = -\frac{50}{1{,}5} = -33 \cdot \left(\frac{1}{sek}\right)$

Operator ifodasining o'tish teoremasiga asosan:

$$i''_{1(t)} = \frac{F_{(P)}}{F_{2(P)}} e^{Pt} = \frac{0{,}2}{1{,}5} e^{-33t} = 0{,}13e^{-33t}$$

$$i''_{1(t)} = 0{,}13e^{-33t}$$

O'tkinchi o'tkazuvchanlik ifodasi:

$$y_{(t)} = 0{,}2 + 0{,}13e^{-33t}$$

$$y_{(t-x)} = 0{,}2 + 0{,}13e^{-33(t-x)}$$

$0<t<t_1$ Interval uchun Dyuamel integrali ifodasidan $i_{(t)}$ o'tkinchi tok:

$$i_t = U_{(0)} y_{(t)} + \int_0^t U'_{(x)} + y(t-x)dx = 200(0{,}2 + 0{,}13e^{-33t} +$$

$$+\int_0^t -10^4(0{,}2 + 0{,}13e^{-33(t-x)})dx = 40 + 26e^{-33t} - 10^4 \int_0^t (0{,}2 + 0{,}13e^{-33x} \cdot e^{-33t})dx =$$

$$= 40 + 26e^{-33t} - 10^4 \left[(0{,}2x)\Big|_0^t + \frac{0{,}13e^{-3t}}{33} e^{-33t} \Big|_0^t \right] =$$

$$= 40 + 26e^{-33t} - 10^4 \left[(0{,}2t - 0) - \frac{0{,}13e^0}{33} - \frac{0{,}13}{33} e^{-33t} \right] = 80 + 66e^{-33t} - 2000t$$

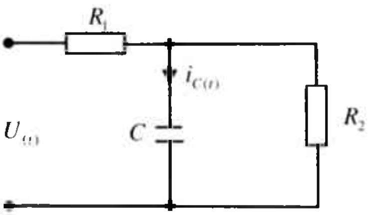
$t>t_1$ intervalda o'tkinchi jarayondagi tokni aniqlaymiz:

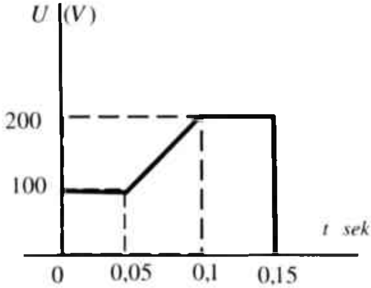
$$i_{(t)} = U_{(0)} y_{(t)} + \int_0^t U'_{(x)} y(t-x)dx - U_{(t_1)} y(t-t_1) =$$

$$= 200(0{,}2 + 0{,}13e^{-33t}) + \int_0^t -10^4(0{,}2 + 0{,}13e^{-33(t-x)})dx =$$

$$= 40 + 26^{-33t} - 2000t_1 + 40 + 40e^{-33t} = 11{,}2e^{-33{,}4t}$$

Masala 10.18. Parametri $R_1=R_2=2\cdot10^3$ Om, $C=10^{-4}$ F bo'lgan elektr zanjir $U_{(t)}$ grafikda keltirilgan impulsli kuchlanishga ulanganda, $i_{c(t)}$ o'tkinchi jarayondagi tok Dyuamel integrali usuliga asosan aniqlansin.





Yechish.

$i_{c(t)}$ tokni $0<t<0,05$, $0,05<t<0,1$, $0,1<t<0,15$ va t>0,5 sek intervallarda aniqlaymiz:

Kalitga ulanganda o'tkinchi jarayondagi o'zgaruvchanlik:

$$y_{(t)}=\frac{1}{R}e^{-Pt}$$

Bundan: $P=-\dfrac{R_1+R_2}{R_1R_2C}=\dfrac{4\cdot10^3}{4\cdot10^6\cdot10^4}=-10\left(\dfrac{1}{sek}\right)$

O'tkinchi jarayondagi tok $i_{c(t)}$: $\underline{0<t<0,05}$ intervalda:

$$\text{a) } i_{2(t)}=U_{(0)}y_{(t)}=100\left(\frac{1}{2\cdot10^3}e^{-10t}\right)=0,05e^{-10t}$$

$$i_{2(t)}=0,05e^{-10t}+\int_{0,05}^{t}y(t-x)U'_{(x)}\,dx=0,05e^{-10t}+$$

$$\text{b) } +\int_{0}^{t}2000\left(\frac{1}{2\cdot10^3}e^{-10(t-x)}\right)dx=0,05e^{-10t}+\frac{1}{10}e^{-10t}e^{-10x}\Big|_{0,05}^{t}=$$

$$=0,05e^{-10t}+0,1-0,1e^{(0,5-10t)}=0,1+0,05e^{-10t}+0,1e^{-5t}$$

d) interval: $t=0,1\div0,15$ (sek)

$$i_{2(t)}=0,05e^{-10t}+\int_{0,05}^{t}2000e^{-10(t-x)}dx+0=0,05e^{-10t}+0,1e^{-10(t-0,1)}-0,1e^{-10(t-0,05)}$$

e) interval: $t > 0{,}15\ (sek)$

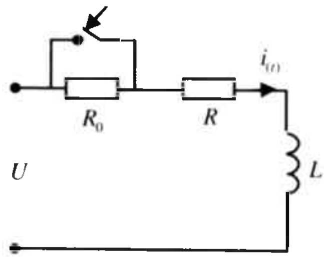
$$i_{2(t)} = 0{,}05e^{-10t} + 0{,}1e^{-10(t-0{,}1)} - 0{,}1e^{-10(t-0{,}05)} + U'_{(t_3)}y(t-t_3) =$$

$$= 0{,}05e^{-10t} + 0{,}1e^{-10(t-0{,}1)} - 0{,}1e^{-10(t-0{,}05)} - 200\frac{1}{210^3}e^{-10(t-0{,}15)} =$$

$$= 0{,}05e^{-10t} - 0{,}1e^{-10(t-0{,}15)} + 0{,}1e^{-10(t-0{,}1)} - 0{,}1e^{-10(t-0{,}05)}$$

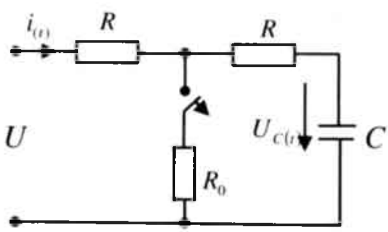
10.3. Mustaqil yechish uchun masalalar

Masala 10.1. Ketma-ket ulangan elektr zanjir parametri: $R_0=30\ Om$, $R=10Om$, $L=100\ MGn$ bo'lib, $U=120\ V$ o'zgarmas kuchlanishga ulangan. R_0 qisqa tutashtirilganda (kalit ulanganda) o'tkinchi jarayondagi $i_{(t)}$ tok klassik va operator usulda aniqlansin va grafigi chizilsin:



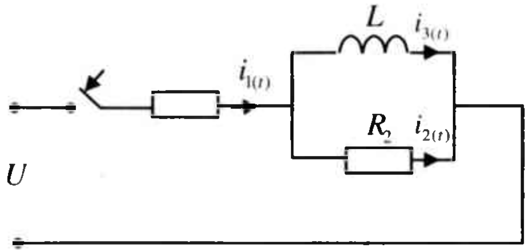
Javob: $i_{(t)} = (12 - 9e^{-100t})\ A$

Masala 10.2. Parametri: $R_0=2\ Om$, $R=20\ Om$, $C=10^{-2}\ F$ bo'lgan elektr zanjiri $U=220\ V$ o'zgarmas tok kuchlanishga ulangan bo'lib, R_0 qarshilik ulangan tarmoq uzilganda sig'imda hosil bo'lgan o'tkinchi jarayondagi $U_{C(t)}$ kuchlanish aniqlansin.



Javob: $U_{C(t)} = 220 - 200e^{-\frac{t}{2RC}}\ (V)$

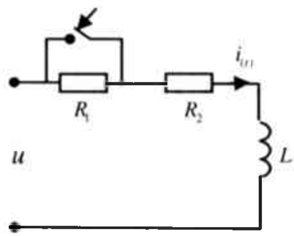
Masala 10.3. Parametri: $R_1=4\ Om$, $R_2=2\ Om$, $L=100\ MGn$ bo'lgan elektr zanjir $U=100\ V$ o'zgarmas kuchlanishga ulanganda hosil bo'ladigan o'tkinchi jarayondagi tok: $i_{1(t)}, i_{2(t)}, i_{3(t)}$ klassik va operator usulda aniqlansin.



Javob:

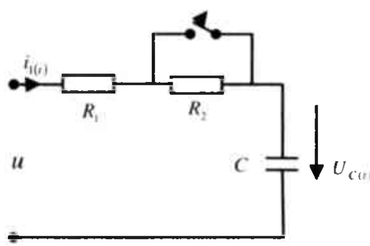
$$i_{1(t)} = 25(1-\frac{1}{3}e^{-\frac{t}{0,1}})\ (A),\ i_{2(t)} = \frac{32}{3}e^{-\frac{t}{0,1}}\quad (A),\quad i_{3(t)} = 25(1-e^{-\frac{t}{0,1}})\ (A)$$

Masala 10.4. Ketma-ket sxemada ulangan elektr zanjir parametri: $R_1=R_2=2\ Om$, $\omega L=3\ Om$ bo'lib, $f=50\ Gs$, $u=127sin(\omega t\text{-}50^0)$ V sinusoidal o'zgarmas kuchlanishga ulangan. R_1 qarshilik qisqa tutashtirilganda o'tkmchi jarayondagi tok $i_{(t)}$ klassik va operator usulida aniqlansin.



Javob: $i_{(t)} = 35\sin(314-106^0)+8{,}5e^{-210t}\ \ A$

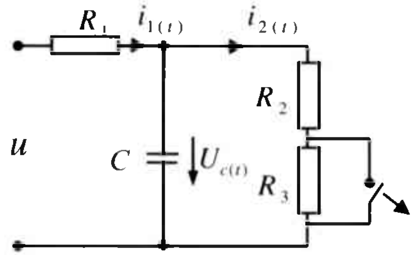
Masala 10.5. Parametri: $R_0=2Om$, $R=20$ Om, $C=10^{-2}$ F bo'lgan elektr zanjir sinusoidal kuchlanish $u=1000\sqrt{2}\sin(314t+82^0)$ V ga ulangan o'tkinchi jarayondagi $i_{(t)}$ tok va sig'imdagi $U_{C(t)}$ kuchlanish aniqlansin.



Javob: $i_{(t)} = (314t+90^0)-0{,}3e^{-\frac{t}{0,025}}\ (A)$

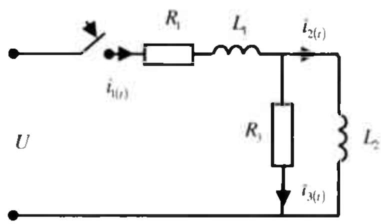
$$u_{C(t)} = 178\sin 314t + 77e^{-\frac{t}{0,025}}\ (V)$$

Masala 10.6. Parametri: R_1=50*Om*, R_2=30 *Om*, R_3=20 *Om*, C=10 *mkF* bo'lgan elektr zanjir U=80 *V* o'zgarmas kuchlanishga ulangan. R_3 qarshilik qisqa tutashtirilganda hosil bo'ladigan o'tkinchi jarayondagi $i_{2(t)}$ tok va sig'imdagi $U_{C(t)}$ kuchlanish ifodasi klassik va operator usulda aniqlansin.



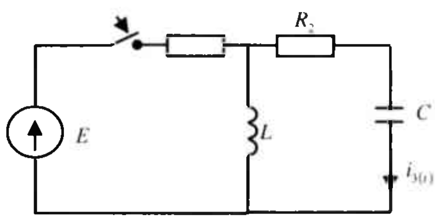
Javob: $i_{2(t)} = 0{,}8 + 0{,}2e^{-4\cdot10^4 t}$ A, $U_{C(t)} = 0{,}8 + 0{,}2e^{-4\cdot10^4 t}$ (V)

Masala 10.7. Parametri R_1=160 *Om*, R_3=90 *Om*, L=100 *MGn*, L_2=36 *MGn* bo'lgan elektr zanjir U=48 V o'zgarmas kuchlanishga ulanganda $i_{2(t)}$ o'tkinchi jarayondagi tok klassik va operator usulga asosan aniqlansin.



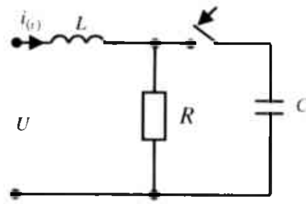
Javob: $i_{2(t)} = 0{,}3 - 0{,}4e^{-1000t} + 0{,}1e^{-4000t}$ A,

Masala 10.8. Parametri R_1=R_2=10 *Om*, L=1 *Gn*, C=1000 *mkF* bo'lgan elektr zanjir E=100 V o'zgarmas manbaga ulanganda $i_{3(t)}$ o'tkinchi jarayondagi tok klassik va operator usulida aniqlansin.



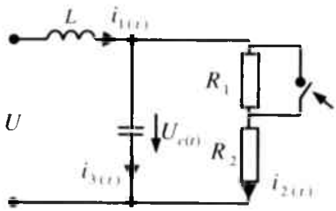
Javob: $i_{3(t)} = 6{,}81e^{-43t} - 1{,}81e^{-11t}$ A

Masala 10.9. Ketma-ket ulangan elektr zanjiri parametrlari R=100 *Om*, L=0,32 *Gn* bo‘lib, U=2000sin(314t+90^0) *V* o‘zgaruvchan kuchlanishga ulangan zanjirga C=16 *mkF* bo‘lgan sig‘ım ulanganda hosil bo‘ladigan o‘tkinchi jarayon tok $i_{(t)}$ aniqlansin.



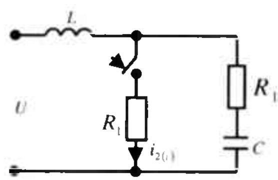
Javob: $i_{(t)} = 20\sin(314t + 58^0) + 2\sqrt{10}e^{-314t} \cdot \sin(314t - 71^0)$ *A*

Masala 10.10. Parametri R_1=R_2=10 *Om*, L=0,04 *MGn*, C=55 *mkF* bo‘lgan elektr zanjirga U=100sin(1000t+30^0) sinusoidal o‘zgaruvchan kuchlanish ulangan. R$_1$ qarshilkni qisqa tutashtirilganda hosil bo‘ladigan o‘tkinchi jarayondagi tok $i_{3(t)}$ va $U_{C(t)}$ klassik va operator usulida aniqlansin va grafigi chizilsin.



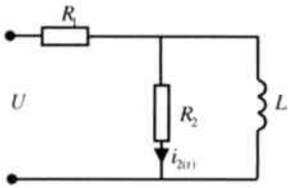
Javob: $i_{3(t)} = 1{,}825e^{-1500t} - 0{,}04e^{-300t} + 1{,}32\sin\left(1000t + 13^0\right)$

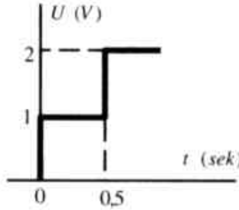
Masala 10.11. Parametri R_1=25 *Om*, R_2=50 *Om*, L=0,25 *Gn*, C=400 *mkF* bo‘lgan elektr zanjir $U = 400\sqrt{2}(314t - 90^0)$ ulangan. Zanjirga R$_2$ qarshilik ulanganda hosil bo‘ladigan o‘tkinchi jarayondagi tok $i_{2(t)}$ klassik va operator usulga asosan aniqlansin.



Javob: $i_{2(t)} = 1{,}81\sin\left(314t - 179^0\right) - 0{,}326e^{-50t}\sin(64{,}6t + 4^0)$ *A*

Masala 10.12. Elektr zanjir parametri R_1=R_2=*10 Om*, L=*5 MGn*, bo‘lib, bosqichma-bosqich o‘suvchi impulsi kuchlanishga ulangan. Dyuamel intervalidan foydalanib $i_{2(t)}$ o‘tkinchi jarayondagi tok aniqlansin.

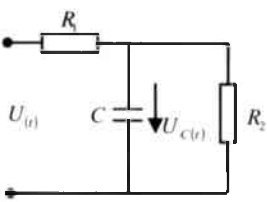


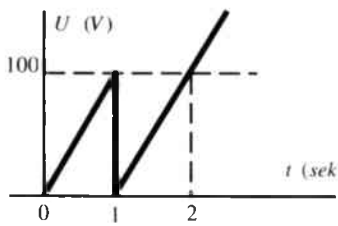


Javob: interval 0<t<0,5 msek $i_{2(t)} = 0{,}05e^{-10^3 t}$ (mA)

interval t>0,5 msek $i_{2(t)} = 0{,}132e^{-10^3 t}$ (mA)

Masala 10.13. Elektr zanjir parametri $R_1=R_2=10\ Om$, $C=200\ mkF$ bo'lib, grafik berilgan $U_{(t)}$ kuchlanishga ulangan. Dyuamel integraliga asosan $U_{C(t)}$ o'tkinchi jarayondagi tok aniqlansin.





Javob: interval 0<t<1 msek $U_{C(t)} = 50(t - 1 + e^{-t})$ (V)

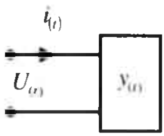
interval t>1 msek $U_{C(t)} = 50t - 100 + 186e^{-t}$ (V)

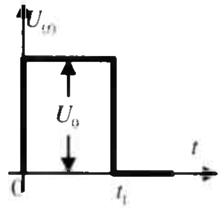
10.4. Nazorat savollari

1. Elektr zanjirda hosil bo'ladigan o'tkinchi jarayon deganda nimani tushunasiz?
2. Qachon va nima sababdan elektr zanjirlarda o'tkinchi jarayon hosil bo'ladi?
3. Nima uchun induktivlikdagi tok yoki sig'imdagi kuchlanish sakrab o'zgara olmaydi?
4. Kommutatsiya qonunining fizik ma'nosini tushuntirib bering.
5. O'tkinchi jarayon, turg'un holatdagi tok va kuchlanishning fizik ma'nosini bilasizmi?

6. Nima uchun o‘tkmchl jarayondagi tok, turg‘un holat va o‘tkinchi tok yig‘indisi ko‘rimshida ifodalanadi va chiziqli elekrt zanjir uchun ishlatiladi?
7. O‘tkinchi jarayon vaqti nima, qanday ifodalanadi?
8. RL, RC zanjir uchun o‘tkmchi jarayon vaqti nimaga teng?
9. O‘tkinchi jarayon mtegrallash koeffitsienti qanday aniqlanadi?
10. O‘tkinchi jarayon boshlang‘ich sharti deganda nimani tushunasiz va qanday aniqlanadi?
11. O‘tkinchi jarayon vaqtida elektr va magnit maydon energiyalari qanday o‘zgaradi?
12. Elektr zanjir manbaga ulanganda uzilish, qisqa tutashuv holatlarida nima uchun uchqun chiqadi?
13. Kondensator razryadlanganda elektr energiyasi qayerda sarflanadi?
14. R, L C zanjirnmg differensial tenglamasiga asosan xarakteristik tenglamasini yozmg va ildizlarini amqlang.
15. R, L C zanjirida o‘tkmchi jarayon tok yoki kuchlanish tebranuvchan, so‘nuvchan (aperiodik) hamda kritik holatda o‘zgarishiga sabab nima?
16. Qaysi vaqtda induktiv g‘altak smusoidal o‘zgaruvchan elektr zanjiriga ulanganda o‘tkinchi jarayon hosil bo‘lmaydi va aksincha?
17. O‘tkinchi jarayondagi tok yoki kuchlanish grafigidan o‘tkinchi jarayon vaqti τ qanday aniqlanadi?
18. Ketma-ket ulangan R, L zanjirning o‘zgarmas tok manbai U dan uzilgan holatdagi o‘tkinchi jarayondagi $i_{(t)}$ tok ifodasini yozing.
19. Ketma-ket R, C zanjirining o‘zgaruvchan $U_{(t)}$ kuchianishga ulanganda $U_{C(t)}$ o‘tkmchi jarayon tenglamasini yozing.
20. O‘tkinchi jarayondagi tokni operator usulida hisoblash qanday amalga oshiriladi?
21. Elektr zanjirda o‘tkinchi jarayondagi tokni hisoblashda ekvivalent operator sxemasi qanday tuziladi?
22. Om va Kirxgof qonuni operator ifodasini yozmg.
23. Operator formadan originaliga o‘tish formulasini ifodalab bering.
24. O‘tkinchi jarayondagi tokni Dyuamel mtegraliga asosan hisoblash qanday amalga oshiriladi?
25. Dyuamel integrallash formulasini yozmg.

26. Passiv ikki qutbli zanjirga o‘tkinchi jarayon o‘tqazuvchanligi $y_{(t)}$ ga impulsli formada $U_{(t)}$ kuchlanish ulangan $0 \le t \le t_1$ intervalda $i_{(t)}$ o‘tkmchi jarayondagi tok ifodasini aniqlang.





Javob: $i_{(t)} = U_0 y_{(t)}$

XI. TARQOQ PARAMETRLI ELEKTR ZANJIR

11.1. Asosiy nazariy tushunchalar

1. Bir jinsli tarqoq parametrli elektr zanjirning asosiy tenglamasi.

Bunday elektr zanjirning nisbiy uzunlikdagi birlamchi parametri: aktiv R_0, induktiv L_0, aktiv o'tqazuvchanligi g_0 va sig'im C_0 bo'ladi.

Ikkilamchi parametri: to'lqin qarshiligi $\underline{Z}_C$ va doimiy tarqalish koeffitsienti γ.

Bir jinsli liniyaning **to'lqin** yoki **tavsifiy qarshiligi** quyidagicha ifodalandi.

$$\underline{Z}_C = \sqrt{\frac{R_0 + j\omega L_0}{g_0 + j\omega C_0}} = \underline{Z}_C e^{j0} \qquad (11.1)$$

Liniyaning **tarqalish koeffitsienti:**

$$\underline{\gamma} = \sqrt{(R_0 + j\omega L_0)(g_0 + j\omega C_0)} = \alpha + j\beta \qquad (11.2)$$

Bunda α – **so'nish koeffitsienti;** β – **faza koeffitsienti.**

Odatda liniya birlamchi parametri berilgan bo'lib (11.2) tenglamadan α va β ni aniqlashda doimiy kompleks ifodasidan foydalaniladi.

$$\left.\begin{aligned} \alpha &= \mathrm{Re}(\gamma) \\ \beta &= I_m(\gamma) \end{aligned}\right\} \qquad (11.3)$$

Elektromagnit **to'lqin tarqalish tezligi:** $\theta = \dfrac{\omega}{\beta}$ (10.4)

ω – tok va kuchlanish burchak chastotasi.

To'lqin uzunligi: $\lambda = \dfrac{v}{f} = \dfrac{2\pi}{\beta}$ (11.5)

Liniyadagi tok va kuchlanish qaytish to'lqini quyidagicha ifodalanadi:

$$K_U = -K_I = \frac{\underline{Z}_2 + \underline{Z}_C}{\underline{Z}_2 + \underline{Z}_C} \qquad (11.6)$$

$\underline{Z}_2$ – liniyaning oxiriga ulangan kompleks qarshiligi.

Bu yerda: $\underline{Z}_2 = \underline{Z}_C$ bo‘lganda to‘lqin qaytmaydi.

Liniyaning salt ishlash holatida $\underline{Z}_2 = \infty$ bo‘lib to‘lqin qaytish koeffitsienti yoki kuchlanishning tushuvchi to‘lqin koeffitsienti:

$$K_U = \frac{1 - \underline{Z}_2 \underline{Z}_C}{1 - \underline{Z}_2 \underline{Z}_{yuk}} = 1 \quad \text{va} \quad K_1 = K_U = -1 \tag{11.7}$$

Biror-bir (x) masofadagi liniya boshldan hisobga olinsa tok va kuchlanish effektiv kompleks ifodasi:

$$\left.\begin{aligned} \dot{U}_X &= \dot{U}_1 ch\gamma X - \dot{I}_1 \underline{Z}_C sh\gamma X \\ \dot{I}_X &= \dot{I}_1 ch\gamma X - \frac{\dot{U}_1}{\underline{Z}_C} sh\gamma X \end{aligned}\right\} \tag{11.8}$$

$\dot{U}_1$ va $\dot{I}_1$ – liniya boshidagi tok va kuchlamish.

Agar liniya oxiridagi tok va kuchlanish qiymati berilgan bo‘lsa, biror (x) masofadagi liniya oxiriga nisbatan tenglama:

$$\left.\begin{aligned} \dot{U}_X &= \dot{U}_2 ch\gamma X - \dot{I}_2 \underline{Z}_C sh\gamma X \\ \dot{I}_X &= \dot{I}_2 ch\gamma X - \frac{\dot{U}_2}{\underline{Z}_C} sh\gamma X \end{aligned}\right\} \tag{11.9}$$

Demak, liniyanmg boshi va oxiridagi tok va kuchlanish bog‘lanish tenglamasi quyidagicha ifodalanadi:

$$\left.\begin{aligned} \dot{U}_1 &= \dot{U}_2 ch\gamma X - \dot{I}_2 \underline{Z}_C sh\gamma X \\ \dot{I}_1 &= \dot{I}_2 ch\gamma X - \frac{\dot{U}_2}{\underline{Z}_C} sh\gamma X \end{aligned}\right\} \tag{11.10}$$

Liniya boshidagi kompleks qarshilik $\underline{Z}_1 = \frac{\dot{U}_1}{\dot{I}}$ desak, (11.10) tenglamadan biror ixtiyoriy qarshilik ulangan holatdagi kompleks qarshilik:

$$\underline{Z}'_2 = \underline{Z}_C \frac{\underline{Z}_2 + \underline{Z}_C th\gamma l}{\underline{Z}_2 th\gamma l + \underline{Z}_C} \tag{11.11}$$

Liniya qarshiligi salt ishlash holatda $\underline{Z}_2 = \infty$ ($\underline{Z}_\infty$ bilan belgilaymiz) va qisqa tutashtirilganda $\underline{Z}_0 = 0$ bo‘lib ($\underline{Z}_0$ bilan belgilaymiz) (11.11) tenglamaga asosan:

$$\left.\begin{aligned} \underline{Z}_\infty &= \underline{Z}_C cth\gamma l \\ \underline{Z}_0 &= \underline{Z}_C th\gamma l \end{aligned}\right\} \qquad (11.12)$$

2. Bir jinsli liniya xususiy holatdagi ikkilamchi parametri.

a) yuqori chastotali liniya parametri:

Agar bir jinsli liniya chastotasi $\frac{\omega L_0}{R_0} \geq 5$; $\frac{\omega L_0}{g_0} \geq 5$ bo‘lsa, liniya parametri quyidagi tenglama ko‘rinishida ifodalanadi:

$$\underline{Z}_C = \sqrt{\frac{L_0}{C_0}};\ \beta = \omega\sqrt{L_0 C_0};\ \alpha = \frac{R_0}{2}\sqrt{\frac{C_0}{L_0}} + \frac{g_0}{2}\sqrt{\frac{L_0}{C_0}} \qquad (11.13)$$

b) signal shaklini buzmaydigan liniya parametri:

uzun liniyaning eng muhim parametri uzun liniya bo‘ylab energiya uzatishni ta’minlovchi elektromagnit to‘lqinlarning miqdor va sifatdosh o‘zgarishini tavsiflovchi so‘nish koeffitsienti – α, faza koeffitsienti – β va tavsifiy qarshiligi $\underline{Z}_C$ deb belgilanadi. Bular bir jinsli liniyaning ikkilamchi parametri yoki tavsifi deyiladi.

So‘nish koeffitsienti – α, to‘lqin qarishligi – $\underline{Z}_C$ va to‘lqin fazoviy tarqalish tezligi – $\theta = \frac{\omega}{\beta}$ ning burchak chastotasi – ω ga teng bo‘lmasligi uchun birlamchi parametri quyidagi nisbatda tanlanishi lozim:

$$\frac{R_0}{L_0} = \frac{g_0}{C_0}$$

Signal shaklini buzmaydigan liniyada to‘lqin qarshiligi $\underline{Z}_B$ va faza koeffitsienti β (11.1), (11.2), (11.13) tenglama asosida aniqlanadi.

So‘nish koeffitsienti esa (11.2) dan:

$$\alpha = \frac{g_0}{C_0}\sqrt{L_0 C_0} = \frac{R_0}{L_0}\sqrt{L_0 C_0} = \sqrt{R_0 g_0} \qquad (11.14)$$

Barcha yuqori chastotalar ushbu turdagi liniyada to‘lqin tarqalish tezligi quyidagicha ifodalanadi:

$$v = \frac{1}{\sqrt{L_0 C_0}} \qquad (11.15)$$

Uzatish liniyasida to‘lqin tarqalish tezligi: $v = 3\cdot10^5 km/sek$

b) isrofsiz liniya parametri.

Radiotexnikada foydalaniladigan chastotasi yuqori bo‘lgan liniyalarda aktiv qarshilik parametri $R_0 \ll \omega L_0$ dan va aktiv o‘tkazuvchanlik $g_0 \ll \omega C_0$ juda ham kichik bo‘lganligi uchun hisobga olinmaydi, shu sababli bu turdagi liniyaga isrofsiz liniya deyiladi. Bunday liniya ikkilamchi parametrli (11.13) tenglamadan aniqlanadi. Bu yerda koeffitsient α= 0.

3. Bir jinsli liniyaning turli holatda ishlashi.

a) bir jinsli liniyaga $\underline{Z}_2$ to‘la qarshilik ulangan bo‘lib, to‘lqin qarshiligiga teng: $\underline{Z}_2 = \underline{Z}_C$

Bunda (11.10) tenglamaga asosan tok $\dot{U}_2$ va $\dot{I}_2$ giperbolik funksiyasidan kompleks formada quyidagi tenglik bilan ifoda qilinadi:

$$\dot{U}_2 = \dot{U}_1 e^{-\gamma l}; \quad \dot{I}_2 = \dot{I}_1 e^{-\gamma l}; \qquad (11.16)$$

Bularning nisbati:

$$\frac{\dot{U}_2}{\dot{U}_1} = \frac{\dot{I}_2}{\dot{I}_1} = e^{-\gamma l} = \varphi_{U_1} - \varphi_{U_2} = \varphi_{i_1} - \varphi_{i_2} = \beta l \qquad (11.17)$$

(11.11) yoki (11.12) tenglamaga asosan lihiyaga kiruvchi qarshilik:

$$\overline{Z}_{kir} = \overline{Z}_C \qquad (11.18)$$

(11.17) tenglamaga asosan liniya foydali ish koeffitsienti quyidagi tenglamadan aniqlanadi:

$$h = \frac{P_2}{P_1} = e^{-2\gamma l}$$

b) liniya rostlashgan holatida maksimal quvvat uzatish mumkin bo‘ladi:

$$P_{2\max} = I_H^2 \rho = \frac{U_H^2}{\rho} \qquad (11.19)$$

Limiya juda uzun bo‘lganda ($2l \geq 1{,}5$) va $\underline{Z}_2 \neq \underline{Z}_C$.

Bu holatda yuqorida keltirilgan tenglamadan zarur bo‘lgan miqdorning barchasi hisoblab topiladi.

d) isrofsiz liniya. Isrofsiz liniya uchun (10.8) tenglamani quyidagicha yozamiz:

$$\left.\begin{aligned} \dot{U}_X &= \dot{U}_1 \cos\beta X - j\dot{I}_1 \underline{Z}_C \sin\beta X \\ \dot{I}_X &= \dot{I}_1 \cos\beta X - j\frac{\dot{U}_1}{\underline{Z}_C}\sin\beta X \end{aligned}\right\} \qquad (11.20)$$

Shunga o'xshash (10.10) tenglamani ham quyidagicha belgilab olamiz:

$$\left.\begin{aligned} \dot{U}_X &= \dot{U}_2 \cos\beta X - j\dot{I}_2 \underline{Z}_C \sin\beta X \\ \dot{I}_X &= \dot{I}_2 \cos\beta X - j\frac{\dot{U}_2}{\underline{Z}_C}\sin\beta X \end{aligned}\right\} \qquad (11.21)$$

Agar liniya masofasi x oxiridan hisoblansa (11.11) va (11.5) tenglamaga binoan:

$$\underline{Z}_{kir} = \underline{Z}_C \frac{\underline{Z}_2 - j\underline{Z}_C tg \frac{2\pi}{\lambda} l}{j\underline{Z}_C tg \frac{2\pi}{\lambda} \underline{Z}_C} \qquad (11.22)$$

4. Turg'un (qo'zg'almas) to'lqinlar.

Odatda turg'un to'lqinlar isrofsiz liniyada salt va qisqa tutashuv holatlarida yuzaga kelib, to'g'ri va teskari to'lqinlarning amplitudalari bir xil bo'lganda, ya'ni ikkita kiruvchi to'lqinni ushlashdan iborat. Bundan tashqari, liniyaga ulangan iste'molchida aktiv, reaktiv quvvat sarf bo'lmasligi kerak.

a) (11.21) tenglamaga asosan liniya salt ishlash holati:

$$\dot{I}_2 = 0, \quad \underline{Z}_2 = \infty$$

$$\dot{U}_X = \dot{U}_C \cos\beta X, \quad \dot{I}_X = j\frac{\dot{U}_X}{\underline{Z}_C}\sin\beta X \qquad (11.23)$$

Liniya qanday masofa va vaqtiga bog'liq bo'lmagan holda:

$$X = k\frac{\pi}{\beta} = k\frac{\lambda}{2}$$

Haqiqatan ham $X=0$, $\lambda/2$, λ, $3\lambda/2$ va hokazo hollarda $\cos\beta X = \pm 1$ bo'lib, $X=\lambda/4$, $3\lambda/4$, $5\lambda/4$ va hokazo bo'lganda $\cos\beta X = 0$

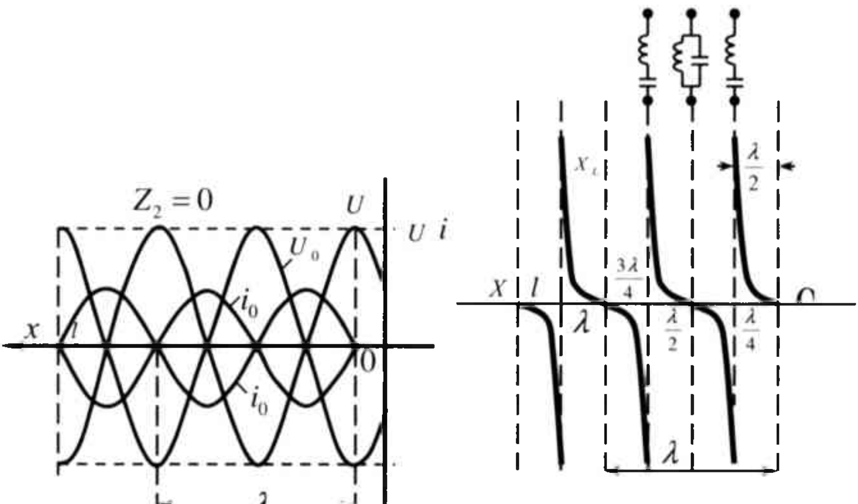
X masofada kuchlanish ham xuddi shunday qonuniyat bilan o‘zgarib $\cos\beta X = \pm 1$ da kuchlanishlar «**bo‘rtiq**»larini, $\cos\beta X = 0$ bo‘lganda kuchlanish «**tugun**» larini hosil qlladi.

Isrofsiz liniya salt ishlaganda (11.22) formulaga binoan uning kirish qarshiligi:

$$\underline{Z}_0 = \frac{\dot{U}_{10}}{\dot{I}_{10}} = \frac{\underline{Z}_C}{jtg\beta l} = -j\underline{Z}_C ctg\beta l = jXl \qquad (11.24)$$

Bunda Xl liniya tavsifiy qarshiligi, «**moduli**» shu sababli
$\theta = 0$, $\underline{Z}_C = X_C$

Liniyaga kiruvchi qarshilik sof reaktiv qarshilik bo‘lib, uning qiymati, ishorasi liniyaning uzunligi X va manba kuchlanishi bilan o‘lchanadi.



Agar liniya uzunligi $l = k\frac{\lambda}{2}$ bo‘lsa, kirish qarshiligi induktivlik xususiyatiga ega bo‘lib, o‘zini xuddi tok rezonansi rejimida ideal parallel konturdek tutadi.

Agar liniya uzunligi $l = (2k+1)\frac{\lambda}{4}$ bo‘lganda, uning kirish qarshiligi sig‘im xususiyatiga ega bo‘lib, o‘zini xuddi kuchianish rezonansi rejimidagi ideal ketma-ket tebranish konturidek tutadi.

b) isrofsiz liniyada qisqa tutashuv $\underline{Z}_2 = 0$ va $\dot{U}_2 = 0$. Bunday liniyaning kirish qarshlligi (11.22) tenglamaga asosan quyidagicha ifodalanadi:

$$\underline{Z}_K = \frac{\dot{U}_{1K}}{\dot{I}_{1K}} = j\underline{Z}_C \quad tg\beta l = jXl \tag{11.25}$$

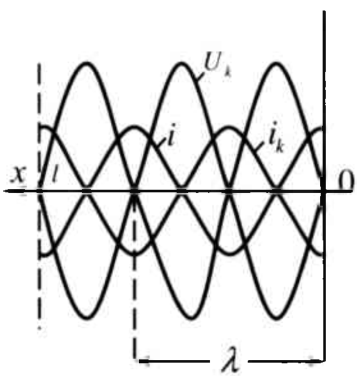
liniyaning har qanday nuqtasida tok va kuchlanish quyidagicha aniqlanadi:

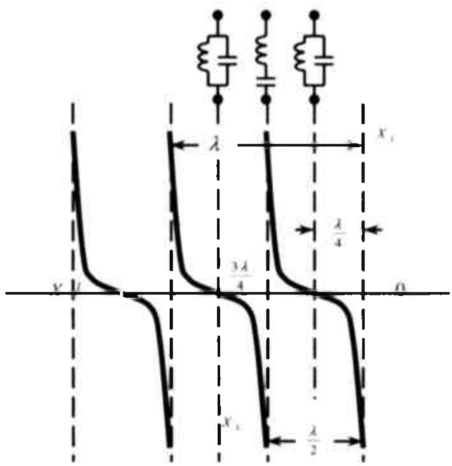
$$\dot{U}_K = j\dot{I}_{2K}\underline{Z}_C \sin\beta X, \quad \dot{I}_K = \dot{I}_{2K}\cos\beta X \tag{11.26}$$

Qisqa tutashuvda hosil bo'ladigan turg'un to'lqin hududi salt ishlash holatidek faqat fazalari jihatidan *λ/4* masofaga siljigan. Liniyaning uzunligi *l=0, λ/2,λ* va hokazo bo'lganda, liniyadagi tok bo'rtiqlari va kuchlanish tugunlarining liniya oxiridan *l= λ/4, 3λ/4, 5λ/4* va h.k. masofalardagi nuqtalarda esa kuchlanish bo'rtiqlari $\dot{U}_K$ va tok tugunlari i_K ning hosil bo'lishi kuzatiladi. Uzunligi *l=λ/2, λ, 3λ/2* va h.k bo'lib, oxirida qisqa tutashgan liniyaning kirish qarshiligi $\underline{Z}_2 = 0$ va bunday liniya o'zini xuddi kuchlanish rezonansi zanjiriday tutadi.

Uzunligi *l= λ/4, 3λ42, 5λ/4* va h.k. bo'lgan liniyaning kirish qarshiligi $\underline{Z}_K = \infty$ o'zini xuddi toklar rezonansi zanjiriday tutadi.

Bunday isrofsiz liniyaning yuqori chastotali qurilmalar uchun sof tayanch izolyatorlar yasashda foydalaniladi.





11.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 11.1. Bir jinsli liniyaning boshlang'ich parametri: R_0=2.25 *Om/km*, $L_0=2\cdot10^{-3}$*Gn/km*, $C_0=6\cdot10^{-9}$ *F/km*, $g_0=10^{-6}$ $\frac{1}{Om\cdot km}$ uzunligi l=100 *km* chastota *f*=800*Gs* ga teng, to'lqin qarshiligi – Z_C, doimiy tarqalish koeffitsienti– γ , to'lqin tarqalish tezligi – *V* va uzunligi – λ hamda $\frac{I_{2m}}{I_{1m}}=\frac{U_{2m}}{U_{1m}}$ nisbat aniqlansin.

Yechish.

Mis simdan tortilgan havo liniyasining to'lqin qarshiligi:

$$\underline{Z}_C=\sqrt{\frac{R_0+j\omega L_0}{g_0+j\omega C_0}}=\sqrt{\frac{2,25+j10}{10^{-6}(1+j30)}}=585\cdot e^{-j6^\circ5}\ Om\,;$$

Doimiy tarqalish koeffitsienti:

$$\underline{\gamma}=\sqrt{(R_0+j\omega L_0)(g_0+j\omega C_0)}=(\gamma)e^{j\omega}=17,6\cdot10^{-3}e^{j83^\circ}\left(\frac{1}{km}\right)$$

So'nish koeffitsienti: $\beta=|\gamma|\sin 82^\circ=2,44\cdot10^{-3}\left(\frac{1}{km}\right)$

Faza koeffitsienti: $\alpha=|\gamma|\sin 82^\circ=17,4\cdot10^{-3}\left(\frac{1}{km}\right)$

Liniya bo'ylab to'lqin tarqalish tezligi:

$$v=\frac{\omega}{\alpha}=\frac{2\pi\cdot800}{17,4\cdot10^{3}}=289000\left(\frac{km}{sek}\right)$$

To'lqin uzunligi: $\lambda=\frac{2\pi}{\alpha}=\frac{2\cdot3,14}{17,4\cdot10^{3}}=360km$

Liniyaning boshi va oxirida so'nuvchi to'lqin tok va kuchlanishlar amplituda nisbati:

$$\frac{I_{2m}}{I_{1m}}=\frac{U_{2m}}{U_{m}}=e^{\beta l}=\frac{1}{e^{2,44}\cdot10^{-3}\cdot100}=0,785$$

Masala 11.2. Uzunligi l=200 *m* va boshlang'ich parametrlari $L_0=2\cdot10^{-6}Gn/km$, $C_0=5,55\cdot10^{-6}mkF/m$ bo'lgan isrofsiz liniyada to'lqin uzunligi *λ=60 m* ga teng. Liniya oxiriga *L=0,01 mGn* induktivlik ulangan.

a) to‘lqin qarshiligi; b) liniyada bo‘rtiq to‘lqinlar tok va kuchlanish hosil bo‘lishini isbotlash; d) liniya oxiridan qanday X masofada tok va kuchlanish bo‘rtig‘i hosil bo‘ladi; e) tok va kuchlanishlar uchun liniya oxiridan bo‘rtiq amplituda nisbatlari; f) tok va kuchlanish uchun liniya boshida bo‘rtiq amplituda nisbati; g) liniyaga kirish qarshiligi aniqlansin.

Yechish.

To‘lqin qarshiligi: $\underline{Z}_C = \sqrt{\dfrac{L_0}{C_0}} = 600 Om$.

Faza koeffitsienti: $\alpha = \dfrac{2\pi}{\lambda} = \dfrac{6\cdot 28}{60} = 0{,}105\left(\dfrac{1}{m}\right)$

(10.20) va (10.21) liniyaning kompleks tenglamasiga binoan hamda masalaning shartiga ko‘ra: $\underline{Z}_{kir} = \underline{Z}_C$, $\gamma = j\alpha$ va tok $\dot{I}_2 = \dfrac{\dot{U}_2}{\underline{Z}_2}$

yoki: $\underline{Z}_2 = X_L = j\omega L = 2\pi f L = 314 Om$ bo‘lib, quyidagi bir jinsli liniya kompleks tenglamasini yozamiz:

$$\left.\begin{aligned} \dot{U}_X &= \dot{U}_2(\cos\alpha X - \frac{\underline{Z}_C}{\underline{Z}_2}\sin\alpha X) = \frac{\dot{U}_2}{\cos\delta}\cos(\alpha X - \delta) \\ \dot{I}_X &= \dot{I}_2(\cos\alpha X - \frac{\underline{Z}_2}{\underline{Z}_C}\sin\alpha X) = \frac{\dot{I}_2}{\sin\delta}\sin(\alpha X - \delta) \end{aligned}\right\}$$

Bunda $\delta = arctg\dfrac{\underline{Z}_C}{\underline{Z}_2} = arctg\dfrac{600}{314} = 63°20' = 1{,}1$ *rad.*

Kuchlanish boshlang‘ich fazasi φ_U=0 ekanligi inobatga olinib, tok va kuchlanishni oniy qiymat orqali ifodalaymiz:

$$\left.\begin{aligned} U_X &= \frac{\sqrt{2}U_2}{\cos\delta}\cos(\alpha X - \delta)\sin\omega t = U_{2m}\cos(\alpha X - \delta)\sin\omega t \\ I_X &= \frac{\sqrt{2}I_2}{\sin\delta}\sin(\alpha X - \delta)\cos\omega t = I_{2m}\sin(\alpha X - \delta)\cos\omega t \end{aligned}\right\}$$

Keltirilgan tenglamaga asosan liniyada turg‘un holatdagi tok yuzaga kelishi mumkun. Liniya oxiridagi bo‘rtiq kuchlanish *(cosαX₁-δ)=1*

Bundan: αX_1-δ= 0 $X_1 = \frac{\delta}{\alpha} = \frac{1,09}{0,1} = 10,5\ m$

Liniya oxirida hosil bo'lgan bo'rtiq tok masofasi:

$$X_2 = X_1 + \frac{\lambda}{4} = 10.5 + \frac{60}{4} = 25,5\ m$$

Liniya oxiridagi bo'rtiq tok va kuchlanish amplituda nisbati:

$$\frac{U_2}{\cos\delta} : U_2 = \frac{1}{\cos\delta} = 2,15 \text{ va } \frac{I_2}{\sin\delta} : I_2 = \frac{1}{\sin\delta} = 1,13$$

Liniya boshida bo'rtiq tok va kuchlanish amplituda nisbati:

$$\frac{U_2}{\cos\delta} : \frac{U_2}{\cos\delta}\cos(\alpha l - \delta) = \frac{1}{\cos(1047\cdot 10^{-4}\cdot 200 - 1,09)} = \frac{1}{\cos 57^0 30'} = 1,86$$

Tok uchun: $\frac{I_2}{\sin\delta} : \frac{I_2}{\sin\delta}\sin(\alpha l - \delta) = \frac{1}{\sin 57^0 30'} = 1,19$

Masala 11.3 Uzunligi l=2 km ga teng bir jinsli isrofsiz liniyaga $\dot{U}_2 = 120\sin 30000t$ bo'lgan o'zgaruvchan kuchlanish ulangan. Iste'molchi qarshiligi bilan to'lqin qarshiligi: $\underline{Z}_2 = \underline{Z}_C$ va $\underline{Z}_2 = 2\underline{Z}_C$ bo'lgan holat uchun liniya kirish qismidagi (boshidagi) $\dot{U}_1$ kuchlanish, $\underline{Z}_2 = 2\underline{Z}_C$ bo'lganda to'lqin qaytish hamda yuguruvchi koeffitsient aniqlansin.

Yechish.

Isrofsiz liniyada to'lqin tarqalish tezligi: $v = 3\cdot 10^5\ \left(\frac{km}{sek}\right)$. Shu

sababli (11.17) tenglamaga binoan liniya oxiridagi kuchlanish U_2 ga nisbatan boshidagi U_1 kuchlanishga hisbatan fazadagi farq:

$$\Delta\varphi = \beta l = \frac{\omega t}{v} = \frac{3\cdot 10^4\cdot 2}{3\cdot 10^5} = 0,2\ rad$$

(11.17) tenglamaga asosan $\underline{Z}_2 = \underline{Z}_C$ bo'lsa:

$$U_1 = 120\sin(30000t + 0,2) = 120\sin(30000t + 12^0)\ (V)$$

Iste'molchi $\underline{Z}_2 = 2\underline{Z}_C$ bo'lganda liniya kirish qismidagi kuchlanishni (11.21) tenglamaga binoan quyidagicha yozamiz:

$\dot{U}_1 = \dot{U}_2(\cos\beta l + \frac{1}{2} j\sin\beta l)$. Demak: $\varphi = \varphi_{U1} - \varphi_{U2} = arctg\frac{1}{2}tg\beta l$

Tangens kichlk burchagi o'zining burchagiga teng bo'lib: $\Delta\varphi$=0,1 $rad = 6°$

U_{1m} kuchlanish amplitudasi U_{2m} dan kichlk bo'lib:

$$U_{1m} = U_{2m}\cos\beta l\sqrt{1+\left(\frac{1}{2}tg\beta l\right)^2} = U_{2m}\cos 0,2\sqrt{1+0,1^2} =$$

$$= U_{2m}0,98(1+0,005) = 0,985U_{2m}$$

Liniya boshidagi kuchlanish oniy qiymati:

$U_1 = 1200{,}985\sin(30000t + 6^0) = 118\sin(30000t + 6^0)$ V

Iste'molchi qarshiligi $\underline{Z}_2 = 2\underline{Z}_C$ bo'lganda (11.6) tenglamaga asosan to'lqin qaytish koeffitsienti : $K_U = \frac{\underline{Z}_2 - \underline{Z}_C}{\underline{Z}_2 + \underline{Z}_C} = \frac{2-1}{2+1} = \frac{1}{3}$

Yuguruvchl to'lqin koeffitsienti: $K = \frac{1-K_U}{1+K_U} = \frac{1-\frac{1}{3}}{1+\frac{1}{3}} = 0{,}5$

Masala 11.4. Uzunligi l = *900 km*, uch fazali liniya chastotasi $f = 50Gs$, to'lqm tarqalish umumiy koeffitsienti $\underline{\gamma} = (0{,}1 + j1{,}07)10^{-3}\left(\frac{1}{km}\right)$

va to'lqin qarshiligi $\underline{Z}_C = 400e^{-j6^0}$ *Om*, liniya oxiridagi kuchlanishi $U_{л2} = \sqrt{3}220$, kV ga teng. Liniya boshidagi U_{lL} kuchlanish, liniya boshidagi va oxiridagi tok $\dot{I}_1$, $\dot{I}_2$, liniyadagi tok quvvati va foydali ish koeffitsienti aniqlansin.

Yechish.

Limiya sof quvvati $\underline{Z}_\Phi = \underline{Z}_C$ bo'lganda liniya oxiridagi quvvat qiymati hisoblanadi:

$$P_2 = 3\frac{(220\cdot 10^3)^2}{400}\cos 6^0 = 363\cdot 10^6 Vt = 363MVt$$

(11.16) tenglamaga asosan:

$$\dot{U}_{1L} = \dot{U}_2 e^{\gamma l} = \dot{U}_2 e^{\alpha l} \cdot e^{j\beta l} = 220 e^{0,09} \cdot e^{j0,963} = 220 \cdot 1,094 e^{j55^{\circ}} = 241 e^{j55^{\circ}} kV$$

yoki: $U_{1L} = 241\sqrt{3} = 417(kV)$

Liniya boshidagi kiruvchi tok:

$$\dot{I}_1 = \frac{\dot{U}_{1L}}{\underline{Z}c} = \frac{241 e^{j55^0} 10^3}{400 e^{-j6^0}} = 602,5 e^{j61^0} \quad (A)$$

Liniya oxiridagi tok: $\dot{I}_2 = \dfrac{\dot{U}_{2L}}{\underline{Z}c} = \dfrac{220 \cdot 10^{-3}}{400 e^{-j6^0}} = 550 e^{j6^0} \quad (A)$

Liniya foydali ish koeffitsienti tenglamasiga binoan:

$$\eta = e^{-2\alpha L} = e^{-0,18} \approx 0,83$$

Masala 11.5. Bir necha jinsli uch fazali liniya uzunligi *l=200 km*, to'lqin tarqalish koeffitsienti $\gamma = (0,59 + j1,21)10^{-3} \left(\frac{1}{km}\right)$, to'lqin qarshiligi $Z_C = 475 e^{-j26^0} (Om)$ ga teng. Liniya oxiridagi liniya kuchianishi U_L=100*KV*, $\cos\varphi = 0,8$ bo'lgan iste'molchi quvvati *P*= 10 *MVt* nimstansiyaga ulangan.

Liniya boshidagi kuchlanish $\dot{U}_{1L}$ va liniya oxiridagi kuchlanish $\dot{U}_{2L}$ va ular orasidagi fazadagi farq aniqlansin.

Yechish.

Uch fazali liniyada iste'molchi qarshiligi simmetrik bo'lganligi uchun: $\varphi = \arccos 0,8 = 37^0$ fazadagi qarshilik:

$$Z_\phi = \frac{U_{л2}^2}{P} \cos\varphi = \frac{10^{10}}{10^7} 0,8 = 800 \ Om$$

yoki: $\underline{Z}_\phi = Z_\varphi e^{j\varphi} = 800 e^{j137^{\circ}} = (640 + j480) \ Om$

(11.10) tenglamadan foydalanamiz: $\dot{U}_1 = \dot{U}_2 (ch\gamma l + \dfrac{\underline{Z}_C}{\underline{Z}_\phi} sh\gamma l)$

Giperbolik funksiya argumentini kompleks ifoda orqali yozamiz:

$$sh\gamma l = \frac{1}{2}\left(e^{\gamma l} - e^{\gamma l}\right) \quad ch\gamma l = \frac{1}{2}\left(e^{\gamma l} + e^{-\gamma l}\right)$$

Bunda: $\gamma l = (0,59 + j1,21) \cdot 10^{-3} \cdot 200 = 0,118 + j0,242$

Giperbolik funksiya kompleks ifodasidan haqiqiy argumentga o'tishda tablitsadan foydalaniladi:

$$sh\gamma l = \frac{1}{2}(e^{0.118} \cdot e^{-j0.242} - e^{-0.118} \cdot e^{-0.242}) =$$

$$= \frac{1}{2}\left[1,125(\cos 0,242 + j\sin 0,242) - 0,89(\cos 0,242 + j\sin 0,242)\right] =$$

$$= 0,114 + j0,242$$

Ikkinchl giperbolik funksiya ifodasi:

$$ch\gamma l = (0,118 + j0,242) = 0,98 + j0,028$$

Aniqlangan kompleks qiymatni kuchlanish tenglamasiga qo'yamiz:

$$\dot{U}_1 = \dot{U}_2\left[(0,98 + j0,028) + \frac{475e^{-j26^0}}{800e^{37^0}}(0,114 + j0,242)\right] =$$

$$= \dot{U}_2\left[0,98 + j0,028 + 0,6e^{-j63} \cdot (0,114 + j0,242)\right] = \dot{U}_2(1,14 + j0,035)$$

Liniya boshidagi: $\dot{U}_1 \approx 1,14\dot{U}_2 = 114\ kV$

Liniya boshidagi va oxiridagi kuchlanish orasidagi fazadagi farq kompleks mavhum ifodadagi haqiqiy songa nisbati bilan aniqlanadi:

$$tg\varphi_U = \frac{0,035}{1,14} = 0,0306$$

Tangens burchak juda ham kichik bo'lsa, uning argumenti o'ziga teng bo'ladi

yoki: $\varphi_U \approx 0,0306 = 1,75^0$

Masala 11.6. Isrofsiz liniya parametri $L = 2,25\frac{mGn}{km}$, $C = 4,6\frac{mkF}{km}$ bo'lib, uzunligi *l= 200 km* ga teng. Liniya oxirida chastota: *f= 50 Gs* va *U₂= 100 kV* kuchlanishga ulangan. Iste'molchi qarshlligi liniya xarakteristik tenglamasiga teng $\underline{Z}_2 = \underline{Z}_C$.

Liniya boshidagi tok I_l va kuchlanish $\dot{U}_1$ qiymati va fazadagi farq aniqlansin.

Yechish.

Isrofsiz lihiya tavsifiy qarshiligi sof aktiv qarshiligi bo‘lib:

$$Z = R = \sqrt{\frac{L}{C}} = \sqrt{\frac{2{,}25\cdot 10^{-3}}{4{,}6\cdot 10^{-9}}} = 1000\cdot 0{,}7 = 700\ Om$$

Liniya oxiridagi tok: $I_2 = \frac{U_2}{Z_H} = \frac{U_2}{Z} = \frac{100000}{700} = 143A$

Liniya boshi va oxiridagi kuchlanish $\dot{U}_1$ va $\dot{U}_2$ muvozanati:

$$\dot{U}_1 = \dot{U}_2\, e^{\gamma l} = \dot{U}_2\, e^{j\alpha l}$$

Bunda isrofsiz liniya bo‘lganligi uchun faza koeffitsienti $\beta = 0$:

Xuddi shunga o‘xshash tok tenglamasi: $\dot{I}_1 = \dot{I}_2\, e^{j\alpha l}$

Faza koeffitsientini aniqlaymiz:

$$\alpha = \omega\sqrt{LC} = 314\sqrt{2{,}25\cdot 4{,}6\cdot 10^{-3}\cdot 10^{-9}} = 1{,}02\cdot 10^{-3}\ \frac{1}{km}$$

To‘lqin uzunligi:

$$\lambda = vT = \frac{1}{\sqrt{LC}\cdot f} = \frac{2\pi}{\omega\sqrt{LC}} = \frac{2\pi}{\alpha} = \frac{2\pi\cdot 10^{-3}}{1{,}02} = 6160\ (km)$$

yoki: $\alpha e = 2\pi\frac{e}{\lambda} = 2\pi\frac{200}{6160} = 0{,}204$

$\dot{U}_2$ kuchlanish haqiqiy son ekanligini hisobga olganda liniya boshidagi kuchlanish: $\dot{U}_1 = 100e^{j11{,}7^0}\ (\kappa B)$

Tok esa: $\dot{I}_1 = 143e^{j11{,}7}\ (A)$

Masala 11.7. Signal shakli o‘zgarmas bir jinsli liniyaning parametri: $L = 1\frac{MGn}{km}$, $C = 11{,}2\cdot 10^{-3}\frac{mkF}{km}$ va *R=8 Om/km* bo‘lib, liniya oxiriga R_H = *100 Om* aktiv qarshilik ulangan. Liniya uzunligi *l=40 km*, chastotasi *f=10*^{4} *Gs*, liniya oxiridagi kuchlanish U_2 *=1000* bo‘lganda, liniya boshidagi kuchlanish aniqlansin.

Yechish.

Liniya birlamchi parametrini bog‘lovchi tenglamadan o‘tkazuvchanlik aniqlanadi:

$$\frac{R}{L}=\frac{g}{C};\quad g=\frac{RC}{L}=\frac{8\cdot 11{,}2\cdot 10^{-9}}{10^{-3}}=89{,}6\cdot 10^{-6}\frac{1}{Om\cdot km}$$

Faza koeffitsienti: $\beta=\sqrt{Rg}=\sqrt{89{,}6\cdot 8\cdot 10^{-6}}=26{,}8\cdot 10^{-3}\ \frac{1}{km}$

So'nish koeffitsienti:

$$\alpha=\omega\sqrt{LC}=6{,}28\cdot 10^{-3}\sqrt{1\cdot 11{,}2\cdot 10^{-3}\cdot 10^{-9}}=0{,}21\ \frac{1}{km}$$

To'lqin uzunligi: $\lambda=\frac{2\pi}{\alpha}=\frac{6{,}28}{0{,}21}=30\ km$

To'lqin tavsifiy qarshlligi: $Z=\sqrt{\frac{L}{C}}=\sqrt{\frac{10^{-3}}{11{,}2\cdot 10^{-9}}}=300\ Om$

Liniya oxiridagi tok kompleks ifodasi: $\dot{I}_2=\frac{\dot{U}_2}{R_H}=\frac{1000}{100}=10\ A$

(11.10) tenglamani kuchlanish $\dot{U}_2$ va tok $\dot{I}_2$ qavsdan tashqariga chiqariladi:

$$\left.\begin{aligned}\dot{U}_1&=\dot{U}_2(ch\gamma X+\frac{\underline{Z}}{\underline{Z}_H}sh\gamma X)\\ \dot{I}_1&=\dot{I}_2(ch\gamma X-\frac{\underline{Z}_H}{\underline{Z}}sh\gamma X)\end{aligned}\right\}\qquad (*)$$

X=l = 40 km.

Bunda: $\beta l=26{,}8\cdot 10^{-3}\cdot 40=1{,}07\qquad \alpha l=0{,}21\cdot 40=8{,}4$

yoki:

$$ch(\beta e+j\alpha e)=ch(1{,}07+j8{,}4)=ch1{,}07\cdot\cos 8{,}4+jsh1{,}07\cdot\sin 8{,}4=$$
$$=1{,}63(-0{,}5)+j1{,}29\cdot 0{,}866=-0{,}815+j1{,}12$$
$$sh(\beta e-j\beta e)=sh1{,}07\cdot\cos 120^\circ+jch1{,}07\cdot\sin 120^\circ=-0{,}645+j1{,}41$$

Liniyadagi qarshilik nisbati: $\frac{\underline{Z}}{\underline{Z}_H}=\frac{300}{100}=3$

Aniqlangan qiymat (*) tenglamadagi tok va kuchlanish ifodasiga qo'yiladi:

$$U_1=U_2\left[-0{,}815+j1{,}12+3(0{,}645+j1{,}41)\right]=$$
$$=U_2(-2{,}85+j5{,}35)=1000\cdot 6\cdot 07e^{j118^\circ}=6070e^{j118^\circ}$$

Kuchlanish haqiqiy qiymati: $U_1=6070\ V$

$$\dot{I}_1 = \dot{I}_2\left[-0{,}815 + j1{,}12 + \frac{1}{3}(0{,}645 + j1{,}41)\right] = \dot{I}_2(-1{,}03 + j1{,}6) = 10\cdot 1{,}9e^{j123^\circ} = 19e^{j123^\circ}$$

tok haqiqiy qiymati: $I_1 = 19\,A$.

11.3. Mustaqil yechish uchun masalalar

Masala 11.1. Ikki simli uzatish liniyasi birlamchi parametri: $R_0 = 6\dfrac{Om}{km}$, $L_0 = 1{,}6\cdot 10^{-3}\dfrac{Gn}{km}$, $g_0 = 10^{-6}\dfrac{1}{Om\cdot km}$, $C_0 = 6{,}4\cdot 10^{9}\dfrac{F}{km}$ Liniya chastotasi f_1=100 Gs va f_2=100 Gs bo‘lgan hollarda to‘lqin tarqalish koeffitsienti, to‘lqin uzunligi, to‘lqin qarshiligi aniqlansin.

Javob: $\underline{\gamma}_1 = 5{,}3\cdot 10^{-3}e^{j44^\circ}\dfrac{1}{km}$, $\underline{Z}_{C1} = 1150\cdot e^{-j34^\circ 30'}Om$,

$\alpha_1 = 3{,}82\cdot 10^{-3}\dfrac{1}{km}$, $\beta_1 = 3{,}65\cdot 10^{-3}\dfrac{1}{km}$,

$v_1 = 173\cdot 10^3 km/sek$, $\lambda_1 = 173km$. $\underline{\gamma}_2 = 22{,}9\cdot 10^{-3}e^{j74^\circ}\dfrac{1}{km}$,

$\underline{Z}_{C2} = 510\cdot e^{-j15^\circ}Om$, $\alpha_2 = 6{,}4\cdot 10^{-3}\dfrac{1}{km}$, $\beta_2 = 22\cdot 10^{-3}\dfrac{1}{km}$,

$v_2 = 288\cdot 10^3 km/sek$, $\lambda_2 = 288km$

Masala 11.2. Koaksial kabel parametri: R=7Om/km, $L = 0{,}3\cdot 10^{-3}\dfrac{Gn}{km}$, $C = 0{,}2\dfrac{mkF}{km}$, $g = 0{,}5\cdot 10^{-6}\dfrac{1}{Om\cdot km}$ bo‘lib, chastotasi f= 800 Gs.

Kabel to‘lqin qarshiligi $\underline{Z}_C$, α, β koeffitsienti, to‘lqin tarqalish tezligi v va to‘lqin uzunligi λ aniqlansin.

Javob: $\underline{Z}_C = 843e^{-j39^\circ}Om$, $\beta = 5{,}36\cdot 10^{-2}\dfrac{1}{km}$, $\alpha = 6{,}62\cdot 10^{-2}\dfrac{1}{km}$,

$v = 0{,}75\cdot 10^5 km/sek$, $\lambda = 95km$.

Masala 11.3. Isrofsiz liniya to‘lqin qarshiligi $\underline{Z}_C = 865\ Om$, uzunligi l=200 km bo‘lib, f=1000 Gs chastotali o‘zgaruvchan kuchlanish U_1= 50 V ga ulangan. Liniya oxirida salt va qisqa tutashuv tajribalariga asosan liniya boshidagi kompleks qarshilik Z_{10} va $\underline{Z}_{1K}$ qiymati aniqlansin.

Javob: $\underline{Z}_{10} = -j500$ Om, $\underline{Z}_{1K} = j1500\ Om$

Masala 11.4. Shakli o'zgarmas liniya koeffitsienti $\beta = 26{,}8 \cdot 10^{-3} \dfrac{1}{km}$, $\alpha = 3{,}34 \cdot 10^{-6} \dfrac{1}{km}$ va to'lqin qarshiligi $\underline{Z}_C = 300\ Om$ ga teng. Liniya uzunligi $l = 100\ km$, $f = 400\ Gs$ bo'lganda salt ishlash va qisqa tutashuv holatidagi qarshilik Z_{10} va Z_{1K} aniqlansin.

Javob: $Z_{10} = 300\ Om;\ Z_{1K} = 300\ Om.$

Masala 11.5. Uzunligi $l=100\ km$, chastotasi $f=1600\ Gs$ bo'lgan telefon liniyasida o'tkazilgan qisqa tutashuv va uzilgan holat uchun $\underline{Z}_{10} = 900e^{-j40^\circ}Om$, $\underline{Z}_{1K} = 100e^{-j40^\circ}Om$ qarshilik qiymati aniqlangan.

Liniya to'lqin qarshiligi Z_C tarqalish koeffitsienti γ, induktivlik va sig'im parametrlari aniqlansin.

Javob: $\underline{Z} = 300Om$, $L = 10^{-8}\dfrac{Gn}{km}$, $C = 11{,}2 \cdot 10^{-3}\dfrac{mkF}{km}$

$$\gamma = \beta + j\alpha = \left(2{,}5 \cdot 10^{-3} + j3/35 \cdot 10^{-2}\right)\frac{1}{km}$$

Masala 11.6. Elektr energiya uzatish liniya uzunligi $l=1000\ km$ ga teng bo'lib, birlamchi parametri: $R_0 = 0{,}035\dfrac{Om}{km}$, $\omega L_0 = 0{,}392\dfrac{Om}{km}$, $g_0 = 4{,}17 \cdot 10^{-8}\dfrac{sim}{km}$, $\omega C = 2{,}92 \cdot 10^{-6}\dfrac{Om}{km}$, liniya oxiriga ulangan iste'-molchi quvvati $P_2 = 300MVt$, kuchlanishi $U_2 = 220{,}3kV$ va $\cos\varphi = 1$ ga teng. Liniyaning ikkilamchi parametri va kirish qismidagi $\dot{I}_1$ tok va $\dot{U}_2$ kuchlanish qiymati aniqlansin.

Javob: $\underline{Z}_i = 367e^{-j2^\circ 15'}Om$; $g = 1{,}07 \cdot 10^{-3}e^{j87^\circ}\dfrac{1}{Om}$;

$\dot{U}_2 = 201e^{j57^\circ}kV$; $\dot{I}_1 = 570e^{j65^\circ 30'}A$

11.4. Nazorat savollari

1. Tarqoq parametrli elektr zanjiri nima? Misol keltiring.
2. Tarqoq uzunlikdagi liniyaning qaysi parametri birinchl yoki ikkinchi hisoblanadi?
3. Bir jinsli liniya to‘lqin yoki tavsifiy qarshiligi va liniya tarqallsh koeffitsienti ifodalarini yozing.
4. Elektromagnit to‘lqin tarqalish va to‘lqin uzunligi tenglamasini yeching.
5. Bir jinsli tarqoq parametrli zanjirdagi tok ekvivalent sxemasini chizib, tenglamasini yozing.
6. Isrofsiz liniyaning salt holatdagi tok va kuchlanish tenglamasini yozing.
7. Bir jinsli uzun liniya to‘rt qutbli T va П sxemaga ekvivalent shaklda almashtirish mumkinmi?
8. Isrofsiz liniya nima ekanligini tushuntirib bering.
9. Qanday sharoitda elektromagnit jarayon liniyada turg‘un to‘lqin hosil qiladi?
10. Isrofsiz liniyada kuchlanish «bo‘rtiq» lari va «tugun» lari qanday hosil bo‘ladi?
11. To‘lqin uzunligi bilan tarqalish fazasi qanday bog‘langan? Ifodasini yozing.
12. Isrofsiz uzatish liniyasida elektromagnit to‘lqin tarqalish tezligi qanchaga teng?
13. To‘lqin tarqallsh koeffitsient ifodasida so‘nish koeffitsienti va faza koeffitsienti fizik ma’nosini tushuntirib, birligini yozing.
14. Iste’molchi qarshiligi liniya bilan muvofiqlashtirilganda qanday xususiyatga ega bo‘ladi?
15. Elektromagnit jarayon turg‘un to‘lqin holatda bo‘lganda energiya liniya bo‘ylab tarqaladimi?

ILOVALAR

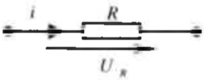
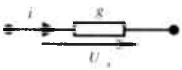
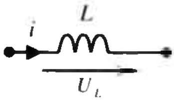
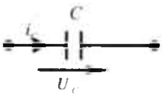
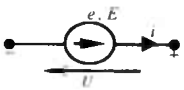
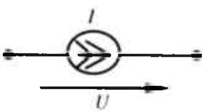
1-ilova

Elektr va magnit kattaliklarning birliklari

Elektromagnit kattaliklar nomi	**Kattalik belgisi**	**Birligi**	**Birlik nomi**	**Birlik belgisi**
1	**2**	**3**	**4**	**5**
1-umumiy elektr magnit kattaliklari				
Elektr miqdori (hajmi) zaryadi	Q,q	Amper-sekund	Kulon	K
Elektr maydon kuchlanganligi, potensial gradienti	E, gradφ	Voltmetr	–	V/m
Elektr zaryad siljishi	D	Kulon taqsim metr KV.	–	Kl/m^2
Elektr doimiyligi	ε_0	Farada taqsim metr		F/m
Elektr sig'im	C	Kulon taqsim metr	Farada	f
Elektr yurituvchi kuch, kuchlanish potensiali	e, U, φ	Volt	Volt	V
Elektr tok, elektr tokning zichligi	I, i δ	Amper Amper taqsim metr kvadrat	Amper -	A A/m^2
Elektr qarshilik	R, r	Volt amper	Om	Om
Elektr o'tkazuvchanlik	G, g	Amper volt	Simens	Sm
Elektr energiya (elektr bajargan ish)	W, A	Amper (vatt-sekund)	Joul	J
Elektr quvvat	R	Volt-amper	Vatt	Vt
Magnit oqimi	ϕ	amper Volt-sekund	Veber	Vb
Ilashgan magnit oqimi	$\psi = w\Phi$	Volt-sekund	Veber	Vb
Magnit induksiya	B	Veber taqsim metr kvadrat	Tesla	T*l*
Magnit maydon kuchlanganligi	H	Amper taqsim metr	–	A/m
Magnit doimiyligi	μ_0	Genri taqsim metr		G/m

Induktivlik	L	Veber taqsim amper	Genri	G
O'zaro induktivlik	M	Veber taqsim amper	Genri	G
Magnit yurituvchi kuch (magnitlovchi kuch)	F=Hl	Amper	Amper	A
P. O'zgaruvchan (sinusoidal) tokga oid kattaliklar				
Elektr tok: oniy	i	Amper	Amper	A
Amplitudaviy	I_m	Amper	Amper	A
Effektiv (amaliy)	$I = I_m / \sqrt{2}$	Amper	Amper	A
O'rta	$I_{o'r}$	Amper	Amper	A
Tok davri	T	sekund	sekund	*sek*
Tok chastotasi	$f = 1/T$	Bir taqsim sekund	Gers	Gs
Burchak chastota	$\omega = 2\pi f$	Radian - sekund		Rad/s
Tokning (EYK ning, kuchlanishning) boshlang'ich fazasi	ψ_e, ψ_i, ψ_u	Radian (gradus)	–	–
Tok va kuchlanish o'rtasidagi fazaviy siljish	$\varphi = \psi_u - \psi_i$	Radian (gradus)	–	–
Quvvat: aktiv	$P = UI \cdot \cos\varphi$	Volt-amper	Vatt	Vt
Reaktiv	$Q = UI \sin\varphi$	Volt-amper	Volt-amper reaktiv	Var
To'la	$S = UI$	Volt-amper	Volt-amper	VA
Quvvat koeffitsienti	$\cos\varphi$	–	–	–
Rezonans chastota	$\omega = \frac{1}{\sqrt{LC}}$	Radian -sekund		rad/sek
To'lqin qarshiligi	$\rho = \sqrt{LC}$	Volt amper	Om	Om

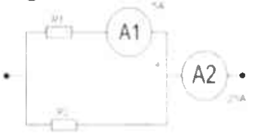
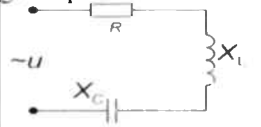
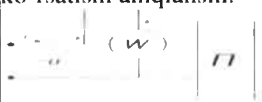
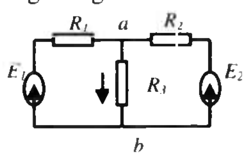
Elektr zanjir elementlarining asosiy tavsifi.

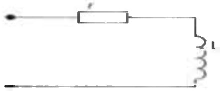
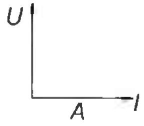
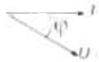
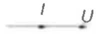
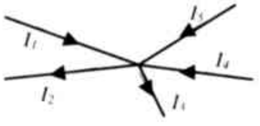
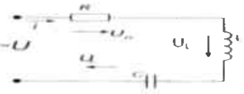
Elementlar	Shartli belgilar	Elektr kuchlanish (V)	Tok (A)	Quvvat yoki energiya (Vt, KVt) (Dj)
Aktiv qarshilik (rezistor)		$U_R = iR$	$i = \frac{U_R}{R}$	$P = Ri^2$
O'tkazuvchanlik		$U_g = \frac{i}{g}$	$i = U_g g$	$P = gu_g^2 = \frac{I_g^2}{g}$
Induktivlik		$U_L = L\frac{di_L}{dt}$	$i_L = \frac{1}{L}\int U_L dt$	$W_L = \frac{Li_L^2}{2}$
Sig'im		$U_C = \frac{1}{C}\int i_C dt$	$i_C = C\frac{du_C}{dt}$	$W_C = \frac{CU_C^2}{2}$
Elektr yurituvchi kuch		$e = -u$	i–istalgan qiymat	$P_e = ei$
Tok manbai		u–istalgan qiymat	$i = I$	$P_i = ui$

Test savollari

№	SAVOLLAR	Javob variantlari			
		A	B	C	D
1	Kuchlanish $u=30\sin(157t+30^0)$ Ifoda uchun ω va f topilsm.	*157 rad/s; 25 Gs;	157 rad/s; 50 Gs;	157 rad/s; 157 Gs	25 rad/s; 157 Gs.
2	$u=141\sin(314t+80^0)$ $i=14{,}1\sin(314t+20^0)$ Zanjirning aktiv quvvati aniqlansin.	* 500 Vt	616 Vt	1000 Vt	308 Vt,
3	Kuchlamish va tok bo'yicha iste'molchining kompleks qarshiligi yozilsin. $u=147\sin(\omega t+102°40')$ $i=42\sin(\omega t+155°50')A$	* $(2{,}1-j2{,}8)$	$(2{,}8-j2{,}1)$	35	$(2{,}8+j2{,}1)$
4	Tenglamalardan qaysi biri o'zgaruvchan tok zanjirining to'la qarshiligini ifodalaydi.	* $Z=\sqrt{R^2+X^2}$	$Y=\sqrt{g^2+b^2}$	$b=\frac{1}{\omega L}-\omega C$	$X=\omega L-\frac{1}{\omega C}$
5	Formulalardan qaysi biri kommutatsiyaning birinchi qonunini ifodalaydi?	* $i_L(0_-)=i_L(0_+)$	$L\frac{di(0_-)}{dt}=L\frac{di(0_+)}{dt}$	$u_c(0_-)=u_c(0_+)$	$\frac{dq(0_-)}{dt}=\frac{dq(0_+)}{dt}$
6	Quvvatni ifodalovchi formulalarning qaysi biri xato yozilgan?	* $P=UI\sin\varphi$	$S=UI$	$S=\sqrt{P^2+Q^2}$	$Q=UI\sin\varphi$
7	Formulalarning qaysi biri o'zgaruvchan tok zanjirining reaktiv qarshiligini ifodalaydi?	* $X=\omega L-\frac{1}{\omega C}$	$Y=\sqrt{g^2+b^2}$	$b=\frac{1}{\omega L}-\omega C$	$Z=\sqrt{r^2+x^2}$
8	Keltirilgan kompleks miqdorlarning qaysi biri trigonometrik tarzda ifodalangan?	* $\dot{A}=(\cos\alpha+j\sin\alpha)$	$\dot{A}=a_1+ja_2$	$\dot{A}=Ae^{j\alpha}$	$\dot{A}=\dot{B}+\dot{C}$

9	Transformatorning ishlash prinsipi:	*Elektromagnit induksiyasi qonuniga asoslangan	Amper qonuniga asoslangan	Lens prinsipiga asoslangan	Hech qanday qonunga asoslanmagan
10	Yulduzcha shaklida ulangan uch fazali tok zanjirida tok va kuchlanish munosabatlari qanday ifodalanadi?	* $I_л = I_\varphi$ $U_л = \sqrt{3} U_\varphi$	$U_л = U_\varphi$ $I_л = \sqrt{3} I_\varphi$	$I_л = I_\varphi$ $\sum I_0 = 0$	$U_{00} = U_\varphi$ $I_л = I_\varphi$
11	Elektr zanjirning kuchlanishi U=220, toki I=10A, aktiv quvvati P=1,1kVt ga teng bo‘lganda, cosφ nimaga teng?	*Cosφ=0,5	Cosφ=1	Cosφ=0	Cosφ=0,75
12	Neytral simli uch fazali tok zanjiri qanday sxemada ulanadi?	*Yulduzcha	Uchburchak	Ketma-ket	Parallel
13	4 qutbli zanjir simmetrik bo‘lganda:	*A=D A^2-BC=1	B=C	B=D	AD-BC=0
14	Nosinusoidal tok R, L, C zanjiri k-yuqori garmonikadan iborat bo‘lsa, to‘la qarshlligi qanday ifodalanadi?	$Z_k = \sqrt{R^2 + (k\omega L - \frac{1}{k\omega C})^2}$	$y = \sqrt{g^2 + (b_l - b_c)^2}$	$X = kX_L - kX_c$	*$Z_K = \sqrt{R^{2+} \cdot (X_l - X_c)}$
15	Rezonans holatda elektromagnit maydon energiyasi qanday munosabatda bo‘ladi?	*$W_Э = W_M$	$W_M \neq W_Э$	$W_Э \rangle W_M$	$W_Э \langle W_M$
16	Agar faza kuchlanishlari $U_A=U_B=U_C=220$ V bo‘lsa va yulduzcha shaklida ulangan aktiv va reaktiv iste’molchilarning qarshiliklari R=10 *Om* X_L=10 X_C=10 *Om* bo‘lsa, uch fazali zanjirning reaktiv quvvati qancha bo‘ladi?	4840 var	14520 var	9680 var	*0

17	Agar sxemada R_2=3 *Om* va ampermetrlar ko'rsatishi I_1=5*A*, I_2=25*A* bo'lsa, R_2 qarshilik miqdori qanchaga teng? 	*12 *Om*	20 *Om*	15 *Om*	25 *Om*
18	Agar R=4 *Om*, X_L=4 *Om*, X_C=4 *Om* bo'lsa, zanjirning to'la qarshiligi aniqlansin. 	*Z=4 *Om*	Z=12 *Om*	$Z = 4\sqrt{2}$ *Om*	$Z = 4/\sqrt{2}$ *Om*
19	Passiv ikki qutbli zanjir qismlaridagi kuchlanish va tokning kompleks amplituda qiymatlari $U_m=100e^{130}$ *V* va $I_m=10e^{130}$ *A* Vattmetrk ko'rsatishi aniqlansin. 	*1000 *Vt*	500 *Vt*	250 *Vt*	200 *Vt*
20	Rasmda ko'rsatilgan zanjirda E_1=12*V*, E_2=24*V*, R_1=R_2=2 *Om*, R_3=1 *Om* bo'lsa, *A* va *B* tugunlari orasidagi kuchlanish U_{ab} necha voltga teng? 	*9 *V*	12 *V*	18 *V*	24 *V*

21	Keltirilgan vektor diagrammalarning qaysi biri sxemaga mos keladi? 				
22	Ushbu tugun uchun Kirxgof 1-qonuni asosida yozilgan qaysi tenglama to‘g‘ri keladi? 	*$I_1-I_2-I_3+I_4+I_5=0$	$I_1+I_2+I_3-I_4-I_5=0$	$-I_1+I_2-I_3+I_4-I_5=0$	$I_1+I_2-I_3-I_4+I_5=0$
23	Ko‘rsatilgan sxemada $U=25$ B, $U_L=60$B va $U_C=40$ B bo‘lsa, rezistordagi kuchlanish qancha? 	*15V	115 V	75V	35V

Test savollarini yechish namunalari

1. **2-test savol yechimi:** Aktiv quvvat ifodasidan $P = UI\cos\varphi$, kuchlanish effektiv qiymati $U = \frac{U_m}{V_2} = \frac{141}{1,41} = 100B$. Tok effektiv qiymati esa $I = \frac{I_m}{\sqrt{2}} = \frac{14,1}{1,41} = 10A$ bo'lib, b tok va kuchlanish orasidagi faza farqi: $\varphi = \varphi_u - \varphi_i = 80^0 - 20^0 = 60^0$, yoki $\cos\varphi = 60^0 = \frac{1}{2}$.

Demak aktiv quvvat ifodasidan

$$P = UI\cos\varphi = 100\cdot 10\cdot 0,5 = 500Vt$$

2. **17-test savol yechimi:** Masalanimg shartiga ko'ra uch fazali zanjir simmetrik bo'lib, to'la qarshilik ifodasidan:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{10^2 + (10-10)^2} = \sqrt{10^2 + 0}.$$

Demak, reaktiv qarshilik x= 0 bo'lganligi uchun reaktiv quvvat ham Q=Q_L–Q_C=0.

3. **21-test savol yechimi:** Parallel sxemada ulangan zanjir, ikkita tugun potensiallar usuliga asosan:

$$U_{ab} = \varphi_a - \varphi_b = \frac{E_1Y_1 + E_2Y_2}{Y_1 + Y_2 + Y_3} = \frac{12\cdot\frac{1}{2} + 24\cdot\frac{1}{2}}{\frac{1}{2} + \frac{1}{2} + \frac{1}{10}} = \frac{6+12}{1+1} = 9$$

4. **24-test savol yechimi:** Zanjir ketma-ket ulangan bo'lib, vektor ifodasidan umumiy kuchlanish:

$$\bar{U} = \bar{U}_R + \bar{U}_L + \bar{U}_C = \sqrt{U_R^2 + (U_L - U_C)^2}$$

Bundan rezistordagi kuchlanish:

$$U_R = \sqrt{U^2 - (U_L - U_C)^2} = \sqrt{625 - 400} = \sqrt{225} = 15B$$

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MUNDARIJA

O'quv nashri

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Nashriyot litsenziyasi AI № 158.14.08.09.
Bosishga 2015-yil 9-fevralda ruxsat etildi.
Bichimi 60x84 $^{1}/_{16}$. Ofset qog'ozi.
«Times New Roman» garniturasida ofset usulida bosildi.
Shartli bosma tabo g'i 19,06.
Nashr tabog'i 17,19. Adadi 300 nusxa.
Buyurtma № 15-87.

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