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IEEE Std 3004.7™-2021

Recommended Practice for Conductor Protection in Industrial and Commercial Power Systems

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IEEE Recommended Practice for Conductor Protection in Industrial and Commercial Power Systems

Developed by the

Industrial and Commercial Power Systems Standards Development Committee
of the
IEEE Industry Applications Society

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IEEE SA Standards Board

Abstract: The protection of power cables used in industrial and commercial power systems is covered in this recommended practice. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Keywords: conductors, IEEE 3004.7™, overcurrent protection, power distribution protection, power system protection, wire

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Introduction

This introduction is not part of IEEE Std 3004.7™-2021, IEEE Recommended Practice for Conductor Protection in Industrial and Commercial Power Systems.

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This recommended practice was developed by the Industrial and Commercial Power Systems Standards Development Committee of the Industry Applications Society, as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material included in the 13 "color books" will be included in a series of new standards. Approximately 60 additional "dot" standards, organized into the following categories, will provide in-depth treatment of many of the topics formerly covered in the color books:

— Power Systems Design (3001 series)
— Power Systems Analysis (3002 series)
— Power Systems Grounding (3003 series)
— Protection and Coordination (3004 series)
— Emergency, Standby Power, and Energy Management Systems (3005 series)
— Power Systems Reliability (3006 series)
— Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

IEEE Std 3004.7™

This publication provides a recommended practice for the electrical design of commercial and industrial facilities. This recommended practice covers the protection of conductors used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited commercial or industrial plant experience. It can also be an aid to all engineers responsible for the electrical design of commercial and industrial facilities. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and general reference on electrical design for commercial and industrial facilities.

Tables, charts, and other information that have been extracted from codes, standards, and other technical literature are included in this publication. Their inclusion is for illustrative purposes; where technical accuracy is important, the latest version of the referenced document should be consulted to assure use of complete, up-to-date, and accurate information.

This publication is based on North American installation codes and product standards, primarily those in the United States and Canada, and thus will be most useful in those jurisdictions and in jurisdictions that follow North American codes and standards. Elsewhere similar codes and standards may apply, such as those published by the International Electrotechnical Commission (IEC).

The material in this recommended practice was originally published in Chapter 9 of IEEE Std 242™-2001 (*IEEE Buff Book*™) [B16] and has been updated as required based on US codes and standards.

Contents

IEEE Recommended Practice for Conductor Protection in Industrial and Commercial Power Systems

1. Overview

1.1 Scope

This recommended practice covers the protection of conductors used in main and branch power circuits in industrial and commercial power systems against damage from short circuits and overloads as well as against physical damage from mechanical hazards, adverse environmental conditions, and improper handling.

1.2 Purpose

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals is *required to*).[1,2]

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals is *recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals is *permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals is *able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

[1]The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.
[2]The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

CSA C22.1-2018, Canadian Electrical Code (CE Code-2018).[3]

ANSI/ICEA P-32-382-2007 (R2013), Short-Circuit Characteristics of Insulated Cables.[4]

ANSI/ICEA P-45-482-2017, Short-Circuit Performance of Metallic Shields and Sheaths on Insulated Cable.

ANSI/NEMA WC 51/ICEA P-54-440-2009 (R2014) Ampacities of Insulated Cables Installed in Open-Top Cable Trays, Ampacities of Cables in Open-Top Cable Trays.

NFPA 70-2020, National Electrical Code® (NEC® 2020).[5,6]

The United States Department of Agriculture (USDA) Rural Utilities Service, Design Guide for Rural Substations, RUS Bulletin 1724E-300, June 2001.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

3.1.1 General

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[7]

Arriving at definitions for the terms used in this document has been challenging as there seems to be as many different definitions for the terms as there are sources for such definitions. While the following are descriptive, it should be recognized that they are not perfect and that other reputable sources may vary slightly.

cable: A factory assembly of one or more wires with or without an additional outer jacket, sheath, or armor, or a single wire with an additional outer jacket or armor.

conductor: A conductive material, such as wire or bus bar, that is constructed for the purpose of carrying electric current from one piece of electrical equipment to another or to ground.

jacket: A non-metallic covering on a cable which provides mechanical and environmental protection for the cable.

raceway: An exposed channel designed expressly for holding wire, cables, or bus bars. Cable tray and conduit are not considered raceways (per the National Electric Code, NEC 2020).

shield: A conducting envelope enclosing an insulated conductor or conductors, sometimes also referred to as a *sheath*.

wire: A single bare, covered or insulated conductor composed of one or more strands of metal.

3.1.2 Cable current (I)

I is current flowing in cable

[3]CSA publications are available from the Canadian Standards Association (https://www.csa.ca/).
[4]ANSI publications are available from the American National Standards Institute (https://www.ansi.org/).
[5]NFPA publications are published by the National Fire Protection Association (https://www.nfpa.org/).
[6]The NEC is published by the National Fire Protection Association (https://www.nfpa.org/). Copies are also available from The Institute of Electrical and Electronics Engineers (https://standards.ieee.org/).
[7]*IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

I_O	is initial current prior to a current change
I_F	is final current after a current change
I_N	is normal loading current on base ambient temperature
I_{N1}	is normal loading current on non-base ambient temperature
I_E	is emergency loading current on base ambient temperature
I_X	is current at values other than normal or emergency loading
I_{SC}	is three-phase short-circuit current

3.1.3 Cable temperature (°C)

T	is temperature, in general
T_O	is initial temperature prior to a current change
T_f	is final temperature after a current change
T_N	is normal loading temperature
T_E	is emergency loading temperature
T_X	is temperature at any loading current
T_t	is temperature at time t after a current change
T_a	is base ambient temperature
T_{a1}	is non-base ambient temperature

3.1.4 Miscellaneous

t	is time (units as noted)
CM	is conductor size (circular mils)
EPR	is ethylene propylene rubber
F_{ac}	is skin effect ratio or ac/dc ratio. This ratio may be calculated from the conductor properties in Table 8 and Table 9 of the 2020 National Electrical Code® (NEC®)
K	is time constant or geometric factor of cable heat flow
K_t	is correction factor for initial and final short-circuit temperature
PILC	is paper insulated lead covered
TCC	is time-current characteristic curve (There is no clear definition for this acronym. In prior standards it is sometimes referred to as *time-current characteristic* and in other instances *time-current curve*.)
XLPE	is cross-linked polyethylene

3.1.5 Reactances (%)

X_T	is transformer reactance
$X_{d''}$	is subtransient reactance of a rotating machine
$X_{d'}$	is transient reactance of a synchronous machine

4. General discussion

4.1 Introduction

This recommended practice deals with insulated power cable protection. The primary considerations are presented along with some methods of application. It is based on North American codes, standards, and practices (NEC, CE Code, UL, CSA, ANSI, NEMA, ICEA, etc.), not IEC standards and practices. Offshore, shipboard, submarine, and mining cables are not completely covered in this recommended practice. There are additional issues to be managed with electrical heat tracing cables; refer to IEEE Std 515™ [B25], IEEE Std 60079-30-1 [B40], and IEEE Std 60079-30-2 [B41]. For overhead distribution lines with bare conductors, protection should be based on IEEE Std C37.230™ [B43]. Some industrial applications may require some adaptations from this standard, which is based on power distribution utility practices.

The proper selection and rating or derating of power cables is as much a part of cable protection as the application of the short-circuit and overcurrent protection devices. The whole scheme of protection is based on a cable rating that is based on the environment and the operating conditions. Methods of assigning these ratings are discussed.

Power cables require short-circuit current, overload current, and physical protection in order to meet the requirements of the applicable installation codes.[8] A brief description of the phenomena of short-circuit current, overload current, and their temperature rises is presented, followed by a discussion of the time-current characteristics of both cables and protective devices. In addition, a number of illustrations of cable systems and examples of cable selection considering the protective device settings are included.

The general intent of this recommended practice is to provide a basis for design, to point out the problems involved, and to provide guidance in the application of power cable protection. Each specific case and type of cable requires attention. In most cases, the attention is routine, but the out-of-the-ordinary cable schemes require careful consideration. The application of cables, both single and multi-cable configurations, in factory assembled products, such a low-voltage and medium-voltage motor control centers for example, may utilize different cable application principles based on the requirements of the standards associated with those products. Different utilization characteristics may be applied in these products, based on the specific design standards and may be validated through temperature and environmental type testing.

Electrical installation codes are location specific; consult the version authorized by the relevant authority having jurisdiction (AHJ).

4.2 Code requirements for cable protection

Codes and regulations are established to control the installation and operation of electric cable systems. Although many different codes and regulations may be applied, depending on governmental, geographical, or company requirements, the NEC is most often quoted; and portions of it are mandatory by the Occupational Safety and Health Administration's (OSHA) 29 CFR Part 1910.302–1910.309. The engineer is responsible for determining which codes are applicable to each project. The discussion in this clause is limited to the national installation codes (NEC and Canadian Electrical Code [CE Code]), which is principally concerned with overtemperature (or overcurrent), short-circuit, and mechanical protection in regard to cable applications.

Overcurrent protection is covered in NEC 2020 Article 240 and CE Code-2018 Rule 14–100, both of which require all conductors to be protected in accordance with their current-carrying capacities (or ampacity), as discussed in 7.2.2 below. In general, the current-carrying capacity of cables is determined from the tables contained in NEC 2020 Article 310, which concerns the installation of conductors, or from the CE Code Section 4 and associated tables.

[8]Local authorities do not necessarily enforce the most current revision of national codes. Check with local authorities to determine the revision that is being enforced for a specific location.

Overcurrent protection of feeders or conductors rated 1000 V or less should be in accordance with their current-carrying capacities as given in code tables or an alternate method in accordance with the NEC 2020 and CE Code-2018. When the ampacity of a conductor requires a protective device rated 800 A or less, and the ampacity does not correspond to a standard rating size, the next higher standard protective device rating may be used to protect the conductor. However, protective devices rated over 800 A may not be used to protect conductor ampacities lower than the device's rating. Other exceptions may be allowed by the installation codes based on the specific types of loads to be supplied, such as capacitors or welders or transformer secondary conductors.

The NEC 2020 permits protection device ratings or settings for transformers to be set higher than the maximum current rating of a transformer. See NEC 2020 Articles 240 and 450 for requirements pertaining to the maximum ratings and settings of protection devices and minimum conductor ampacities for transformer primary and secondary conductors.

The minimum motor branch-circuit conductor ampacity depends on many factors. The codes may permit protection device ratings or settings for motors to be higher than the full-load current rating of the motor. However, the minimum ampacities of motor branch-circuit conductors are based on the NEC 2020 full-load current values found in NEC 2020 Article 430 tables for motors up to 600 V, nominal. For minimum motor branch-circuit ampacities for motors greater than 1000 V, see NEC 2020 Article 430 Part XI, in addition to other applicable articles.

For minimum conductor ampacity of feeders where there is more than a single motor served, see NEC 2020 Articles 215, 220, 240, 310, 311, and 430.

Cables are also required by the installation codes to have short-circuit protection, which may be provided by a fuse or circuit breaker with the ratings complying with the specific requirements of the codes. For some circuits over 1000 V, such as those for motor branch-circuits, engineering supervision is required by the NEC 2020 when determining protection settings to include at a minimum appropriate short-circuit analysis and time-current coordination analysis of protective device characteristics and cable damage curves.

Feeders rated more than 1000 V are required by the NEC 2020 to have short-circuit protection, which may be provided by a fuse rated at no more than 300% of the conductor ampacity or by a circuit breaker set to trip at no more than 600% of the conductor ampacity. The NEC 2020 also requires that overcurrent protection for circuits over 1000 V be developed under engineering supervision, to include at a minimum appropriate short-circuit analysis and time current coordination analysis of protective device characteristics and cable damage curves. Although not required by the NEC 2020, improved protection of these circuits is possible when overload protection is also provided in accordance with the conductor ampacity.

The minimum required ampacity of motor feeder and branch circuit conductors for motors 600 V, nominal, or less, are based on the motor full-load current table values in NEC 2020, Article 430, Parts II and XIV. For motors 600 V, nominal, or less, nameplate full-load current ratings must not be used when calculating motor feeder and branch circuit conductors, unless specifically allowed by the NEC 2020. For motors greater than 600 V, nominal, the protection device settings for the motor and conductors must be determined under engineering supervision.

NOTE—Although the discussion in this recommended practice concerns only cables, motor overload and overcurrent protective devices may also provide the required overcurrent protection. In addition, maximum permitted ratings or settings of the short-circuit and ground-fault protection devices for motor feeder conductors are addressed in Articles 220, 240, and 430, Part V. Maximum ratings or settings for the motor branch-circuit short-circuit and ground-fault protective devices are addressed in NEC 2020, Part IV.

NEC 2020 Article 310 ensures that cables are adequate for their service applications by specifying currents that may be carried by particular conductors with specific insulation classifications and under specific governing conditions. It also requires the selection of cable materials that are suitable for application conditions, including moisture, chemicals, and nonstandard temperatures. This article permits the use of multiple cables if means are provided to ensure the equal division of current, and if essentially identical conditions and materials are used for each of the parallel paths.

NEC 2020 Chapter 3 specifies wiring methods and protection required for cables subject to physical damage.

These articles pertain specifically to cable protection, but are not the only provisions of the NEC that deal with the subject. Any specific cable or cable system comes under the provisions of one or more sections of the NEC, and responsible parties should ensure that the protective methods they have selected comply with both the relevant provisions and any special requirements that they may impose.

5. Cable protection

Cables are the essential connecting links between equipment in an electric system. If the cable system is inadequate or inadequately protected, unsatisfactory operation inevitably results. Cables are not unlimited in power capability and, therefore, must be applied within their listing and provided protection to prevent possible operation beyond their capabilities. Improper application and protection of cables can result in premature cable failure and unsafe operation, posing a danger to personnel and therefore must be addressed.

Cables are generally classified as either power or control. Power cables are divided into two voltage classes based on the cable manufacturing standards: 2000 V and below, and above 2000 V. Control cables include cables used in the control of equipment and for voice communication, metering, and data transmission.

Excessive conductor temperature due to overload currents, nonlinear loads, or mechanical damage, is a frequent cause of decreased cable life and failure. Power cables, internally heated primarily as a result of their resistance to the current being carried, can undergo insulation failure if the temperature buildup becomes excessive. Proper selection of a cable for an application is necessary to assure a long and safe life. Suitable protection is provided to address concerns about abnormal operating conditions and faults. Traditionally, time-current sensitive protection functions are used among other protection functions to provide cable protection. In addition to insulation breakdown, protection is also required against unexpected overload and short-circuit current. Overcurrent can occur due to an increase in the number of connected loads, or due to overloading of existing equipment, or due to nonlinear loads causing excessive neutral conductor current.

While the extraordinary temperature of a short-circuit arc produces extensive destruction of materials at a fault location, cables carrying energy to (and from) a fault may also incur thermal damage over their entire length if the fault current is not interrupted quickly enough. Depending on conductor size, insulation type, and available fault current, the clearing time of the protection system should be short enough (i.e., coordinated) to stop the current flow before damaging temperatures are reached.

Physical conditions can also cause cable damage and failure. Failure due to excessive heat may be caused by high ambient temperature conditions or by fire. Mechanical damage may result in short circuits or reduced cable life and may be caused by persons, equipment, animals, insects, fungi, or strand breakage due to frequent flexing.

Cable protection is required to protect personnel and equipment and to ensure continuous service. From the standpoint of equipment and process, the type of protection selected is generally determined by economics and the engineering requirements. Personnel protection also receives careful engineering attention and special consideration to ensure compliance with the various codes that may be applicable to a particular installation.

Protection against overload is generally achieved by a device sensitive to current magnitude and duration. Short-circuit–protective devices are sensitive to much greater currents and shorter times. Protection against environmental conditions takes on many forms.

Cables may also be damaged by sustained overvoltages that exist during a ground fault on one phase conductor. While low-voltage (LV) cable insulation thickness is governed by mechanical constraints, which result in a greater thickness than the utilization voltage would indicate (i.e., insulation volts/mil capability), medium-voltage (MV) cable insulation is different. MV cable insulation systems in North America are rated based on a system voltage; the voltage capability of one MV conductor is only the system (or rated) voltage/√3. Hence, while a 600 V conductor is designed to continuously withstand 600 V applied between the conductor and an adjacent grounded metal object, a MV conductor rated 5 kV 100% insulation level (IL) should only be expected to perform satisfactorily when placed against a grounded metal plate if subjected to a voltage of 5000/√3 = 2887 V. While this is adequate for solidly grounded systems, cables will be damaged by overvoltages in ungrounded or resistance grounded systems. Modern medium-voltage cables now bear a rating called *percent insulation level* (or % IL). This rating is described as follows (refer to NEMA WC74/ICEA S-93–639–2012 Table 4–4 for additional details regarding cable construction for these insulation levels):

a) 100% IL—Cables that shall not be required to operate longer than 1 min in case of a ground fault.

b) 133% IL—Cables that shall not be required to operate longer than 1 h in case of a ground fault.

c) 173% IL—Cables that may be required to operate longer than 1 h continuously with one phase conductor grounded (manufacturers should be consulted for suitability).

NOTE—This rating is not available in CSA certification standards. A higher base voltage rating must be chosen to achieve the equivalent IL of 173%, where required.

Cable insulation may also be damaged by transient overvoltages, such as from lightning strikes or switching transients. For a general treatment of this subject, refer to Chapter 6 of IEEE Std 141™ [B13]. For discussion regarding the analysis of switching transients, refer to Chapter 11 of IEEE Std 399™ [B18].

Subclause 7.1.3 of IEEE Std 1242™ [B30] notes that the various cable standards sometimes have slightly different requirements for insulation thickness for these ILs, and that common industry practice is to defer to the recommendations of cable manufacturers for insulation thickness in such cases. The timing of the permissible protective system should be in accordance with the IL rating of the cables involved.

In general, this recommended practice covers methods of rating cables and the conditions and problems listed in this clause. It also provides a starting point from which further refinements may be made and other features added for improved power cable protection.

6. Short-circuit current protection of conductors

6.1 General

A conductor should be protected from overheating due to excessive short-circuit current flow. The fault point may be on a section of the protected conductor or on any other load side part of the electric system. If the fault point is on the cable, the faulted cable section is, of course, to be replaced after the fault has been cleared.

During a fault between live conductors, the I^2R heating in the live conductors elevate first the temperature of the conductor, followed by the insulation materials, protective jacket, raceway, and surroundings. During a ground fault in a solidly grounded system, the I^2R heating in both the live conductor and any metallic raceway elevate the temperature in a similar manner to faults between live conductors.

For cables with metallic shielding, the shielding of the cable on the line side of the fault also carries part of the short-circuit return current, which may return along the shields of other conductors or equipment grounding paths, from common grounding points. Refer to 6.3.2 for additional discussion.

When the short-circuit current is interrupted either instantaneously or in a short time by the protective device, the amount of heat transferred from the metallic conductors outward to the insulation and other materials is small. Because the heat from I^2R losses is contained almost entirely in the conductors, it can be assumed that 100% of the I^2R losses result in elevating the conductor temperature. This is called *adiabatic heating*. During the period that the short-circuit current is flowing, the conductor temperature should not be permitted to rise to the point where it may damage the insulating materials. The task of providing cable protection during a short-circuit condition involves determining the following:

— Maximum available short-circuit currents

— Maximum conductor temperature that will not damage the insulation

— Cable conductor size, which affects the I^2R value and the capability of the cable to withstand the heat

— Longest time that the fault current can flow without insulation degradation

Molded-case circuit breakers (MCCBs) listed to UL 489 [B61] are required to be tested with rated wire if they are provided with wire connectors. (Note that UL 489 is a harmonized standard with CSA C22.2 No. Five in Canada and NMX-J-266 in Mexico.) Damage to the wire insulation during the interrupting tests is not permitted for all tested circuit breakers in order to pass such tests. (Exception: UL 489 allows 15 A or less 277 V, 347 V, 480 V, and 600 V rated circuit breakers to be tested with 12 AWG wire.) Because of this UL 489 requirement, it is not necessary to perform wire protection calculations for wires rated and tested with the subject breakers. Wire protection calculations should be conducted in instances where the protective device has not been tested with wire. It may be noted that that cable damage subjected to such tests is ascertained visually, and such criteria are not identical to those used by ICEA for short-circuit cable damage determination.

Cable protection calculations may be made by the following method:

$$I_p = I_a \times A \times B \times C \times D \times E \times G$$

where

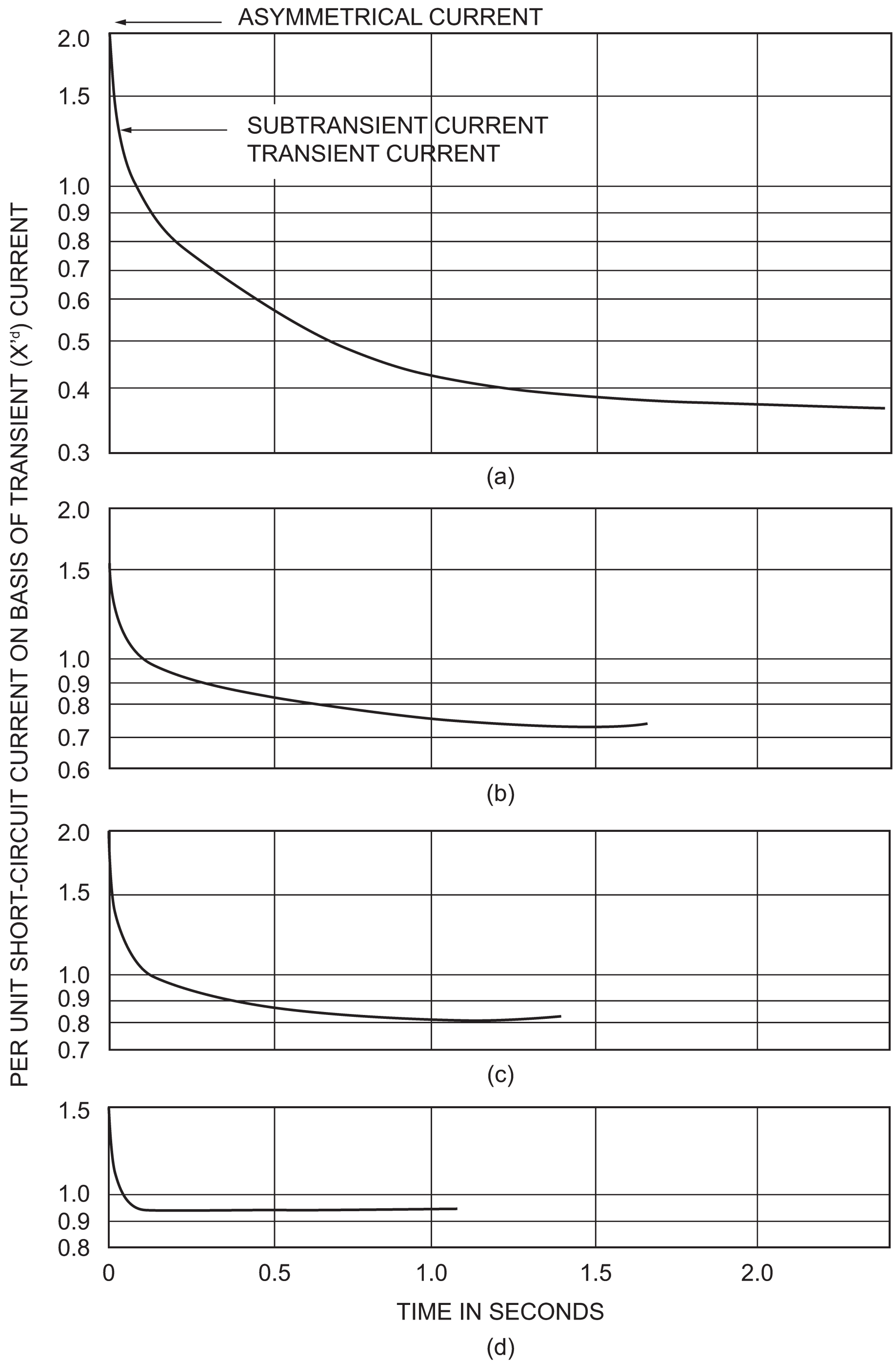
I_p is the circuit breaker rating
I_a is the full-load rms current the circuit must be capable of carrying
A is the wire size factor
B is the ambient temperature factor
C is the frequency factor
D is the altitude rating factor
E is the load class rating factor
G is the safety factor normally 1.0 for intermittent loads and 1.25 for continuous loads

The above listed factors are discussed in the following subclauses of this recommended practice.

6.2 Short-circuit current

6.2.1 Phase-fault current and rates of decay

The fundamentals of short-circuit current behavior and the calculation of short-circuit currents are described in Chapter 4 of IEEE Std 141 [B13], Chapter 7 of IEEE Std 399 [B18], IEEE Std 551™ [B27], and IEEE Std 3002.3™-2018 [B36]. The magnitude of short-circuit current should be properly determined. As illustrated in Figure 1, the initial peak current is called *asymmetrical current* (or *current for momentary duty*). This current then decays in sequence to the subtransient current, transient current, and symmetrical current or sustained short-circuit current. The short-circuit current contains a decaying exponential component superimposed on the symmetrical short-circuit current in the subtransient and transient periods. Figure 1 shows the approximate rate of decay of the total current. Four typical systems are illustrated in this figure to give a general picture of the fault-current behavior. The decay rate in each system depends on the X/R ratio of the system; higher X/R ratios are found on medium-voltage systems with local generation.



a) Plant generator system, medium voltage
b) Utility-power supplied system, medium voltage, with large synchronous motors
c) Utility-power supplied system, medium voltage, no synchronous motor
d) Utility or plant generation, low-voltage 240 V or 480 V load centers

Figure 1—Typical rate of short-circuit decay

6.2.2 Maximum short-circuit currents

Generally, the subtransient current of a system is used to designate the maximum available short-circuit current in the cables protected by the instantaneous overcurrent relays that trip medium-voltage switchgear circuit breakers. For cables protected by noncurrent-limiting fuses or noncurrent-limiting low-voltage instantaneous trip circuit breakers, the asymmetrical current value is used. The effective current for cables protected by current-limiting devices [e.g., fuses, molded-case circuit breakers (MCCBs), cable limiters] in the current-limiting range is the root-mean-square (rms) value of the let-through current as determined from the manufacturers' let-through curves (see Example 1 in 6.5.1.2). For delayed tripping of 0.2 s or longer, the rms value of the decayed current over the flow period of fault current should be used.

6.2.3 Ground-fault currents and rates of decay

The fundamentals of ground short-circuit current behavior are similar to the characteristics of fault currents between current-carrying conductors, but the calculations are different, as described in IEEE Std 3003.2 [B36] and Chapter 8 of IEEE Std 242™ [B16]. For a solidly grounded system, the ground-fault current is of the same order of magnitude as the three-phase fault current. For a high-resistance-grounded system or low-resistance-grounded system, the magnitude of the ground-fault current is limited to a value determined by the resistor's current rating. See IEEE Std 3003.1™ [B35]. The decay of the dc component occurs so rapidly that the asymmetry effect in the current wave shape can be ignored.

NOTE—This subclause provides a glimpse of the information for system grounding and ground-fault protection, only highlighting the impacts on conductor insulation levels and ratings. See Dunki-Jacobs, Shields, with St. Pierre [B5], Shipp and Angelini [B57], IEEE Std 141 [B13], IEEE Std 142™ [B14], and IEEE Std 241™ [B15], as applicable, for more details on the selection and characteristics of different power system grounding techniques. Refer to IEEE Std 242 [B16] Chapter 8 for additional information on ground-fault protection and device clearing time. Discussed in Clause 5, cable insulation level should be compatible with the clearing time of protective devices for ground-fault conditions. Consult the applicable codes (such as the NEC or CE Code).

6.3 Conductor temperature rise caused by short circuits

6.3.1 Temperature rise of phase, neutral, or insulated grounding conductors

On the basis that all heat is absorbed by the conductor metal and no heat is transmitted from the conductor to the insulation material, the temperature rise is a function of the size of the metallic conductor (CM), the magnitude of the fault current (I), and the time of the current flow (t). These variables are related by the following empirical equations (see ANSI/ICEA P-32–382–2007):

for copper,

$$\left(\frac{I}{CM}\right)^2 (tF_{ac}) = 0.0297 \log_{10}\frac{T_f + 234}{T_O + 234} \tag{1}$$

for aluminum,

$$\left(\frac{I}{CM}\right)^2 (tF_{ac}) = 0.0125 \log_{10}\frac{T_f + 228}{T_O + 228} \tag{2}$$

The initial temperature T_O is typically the maximum continuous temperature rating of the conductor as listed in Table 2. T_O may include the effects of derating due to the maximum temperature rating of the conductor terminations. In special cases, if the actual continuous operating temperature of the conductor has been calculated, this temperature may be used as the initial temperature. The final temperature T_F is based on the insulation material as shown in Table 2.

The ac/dc ratio (or skin effect ratio) F_{ac} is approximately 1 for conductors 500 kcmil and smaller, so F_{ac} may be neglected (set equal to 1) and the results will be slightly conservative. For larger conductor sizes with more pronounced skin effects, setting F_{AC} equal to 1 becomes increasingly conservative, so it may be desirable to include actual values of F_{AC} in the calculation. F_{AC} may be obtained from the conductor manufacturer or calculated based on Table 8 and Table 9 in the 2020 NEC.

If the initial temperature T_O and final temperature T_f are predetermined as described above, the current I versus time t relation of current flow can be plotted for each conductor size (CM) of a particular conductor type.

6.3.2 Temperature rise of shield and sheath

On the same basis as for phase currents, the temperature rise of the shield or sheath due to fault currents can be related to the magnitude of the fault current I in amperes flowing in the shield or sheath, the effective cross-sectional area of the shield and sheath A in circular mils, the time t in seconds the fault current is flowing, and the initial and final temperature of the shield or sheath. Some commonly used values are shown in Table 1. Note that the final temperature is governed by the allowable temperature of the material adjacent to the shield or sheath; the maximum allowable temperature recommended by ICEA for thermoplastic materials (commonly used for inner jackets in industrial cables) is 200 °C. For additional guidance and other operating conditions, refer to ANSI/ICEA P-45–482–2017.

NOTE—Typically, only conductors rated over 2000 V (NEC) or 5000 V (CE Code) have a ground plane shield or sheath. Conductors rated lower than this are not usually shielded/sheathed.

Table 1—Temperature rise of shield and sheath due to ground-fault current

Temperature rise of shield and sheath due to ground-fault current shield or sheath material	Initial shield operating temperature/maximum allowable shield temperatures			
	65 °C/150 °C	65 °C/200 °C	90 °C/200 °C	90 °C/250 °C
Copper	$I = 0.0568\frac{CM}{\sqrt{t}}$	$I = 0.0694\frac{CM}{\sqrt{t}}$	$I = 0.062\frac{CM}{\sqrt{t}}$	$I = 0.0779\frac{CM}{\sqrt{t}}$
Aluminum	$I = 0.0371\frac{CM}{\sqrt{t}}$	$I = 0.0453\frac{CM}{\sqrt{t}}$	$I = 0.041\frac{CM}{\sqrt{t}}$	$I = 0.0509\frac{CM}{\sqrt{t}}$
Lead	$I = 0.0103\frac{CM}{\sqrt{t}}$	$I = 0.0124\frac{CM}{\sqrt{t}}$	$I = 0.012\frac{CM}{\sqrt{t}}$	$I = 0.0141\frac{CM}{\sqrt{t}}$
Steel	$I = 0.0205\frac{CM}{\sqrt{t}}$	$I = 0.0249\frac{CM}{\sqrt{t}}$	$I = 0.023\frac{CM}{\sqrt{t}}$	$I = 0.0281\frac{CM}{\sqrt{t}}$

where
CM is effective cross-sectional area of the shield or sheath in circular mils
I is fault current flowing in the shield or sheath in amperes
t is time the fault current is flowing in seconds

NOTE—The temperatures in Table 1 are temperatures of the shield or sheath, and are normally different from those of the conductor.

A comprehensive study has been conducted of the flow of ground-fault currents through shields, conduits, and ground wires during ground faults in connected equipment (see Hamer and Wood [B6]). Contrary to intuition, most of the ground-fault return current does not return through the shields of the cables connected to the phase that includes the equipment ground fault. (In a fault between a conductor and its own metallic shield, the faulted shield would carry most of the ground return current, but external ground faults in connected equipment are the major concern of this subclause.) Tests show that little difference exists in the magnitudes of the ground-fault return currents through the shields of individual cables connected to equipment that contains a ground fault. The impedances of cable shields routinely used in industry are relatively high compared with other ground return paths, such as ground wires within conduits or the conduit itself. Accordingly, the ground-fault return current divides among several paths with most of the current diverted away from the shields. While the scope of this recommended practice does not include covering the actual division of these currents, guidelines for protecting shields can be provided. For ground faults of under 1000 A and conventional operating times of ground protection relays, Hamer and Wood have concluded that metallic shields are not being damaged during ground faults. For ground faults exceeding 1000 A, a ground wire should be included within the conduits to provide a reliable low-impedance ground return path. This setup is especially applicable for systems using rigid-steel conduit as the return path. Without ground wires within the conduit, sparking at the couplings (see Kaufmann [B44]) may occur during faults with the resulting risks for conduits routed through hazardous (or classified) locations (see the NEC and CE Code). The use of a ground wire also eliminates concern over corroded or loose couplings and bushings. Installation codes and IEEE Std 3003.2 [B36] contain information regarding the sizing of grounding (earthing) conductors.

6.3.3 Maximum short-circuit temperature ratings

ANSI/ICEA P-32–382–2007 established a guideline for short-circuit temperatures for various types of insulation as shown in Table 2. The short-circuit temperature ratings are considered the maximum temperatures and, to protect the cable insulation from damage, should not be exceeded. General agreement does not exist that the temperatures from ANSI/ICEA P-32–382–2007 accurately depict conductor temperatures because they are calculated rather than measured. However, agreement does exist that the temperatures shown in Table 2 are higher than actual and, therefore, conservative for the purposes of this recommended practice.

Table 2—Examples of conductor insulation types and their maximum short-circuit temperature[a]

Type of insulation, NEC designation, trade name	Type letter	Continuous temperature rating T_O (°C): dry	Continuous temperature rating T_O (°C): wet	Short-circuit current temperature rating T_f (°C)
Thermoset (2001 V to 46 kV shielded)[b] and (2001 V to 5000 V nonshielded)[c]				
Cross-linked polyethylene (XLPE or TR-XLPE)	MV-90	90 dry	90 wet	250
	MV-105	105 dry	105 wet	
Ethylene propylene rubber (EPR)	MV-90	90 dry	90 wet	250
	MV-105	105 dry	105 wet	
Low-voltage thermoset (up to 1000 V)[d]				
Cross-linked polyethylene (XLPE)[e]	RHH, XHH	90 dry	90 damp	250
	XHWW	90 dry	90 damp/75 wet	
	RHW, RW75, RWU75	75 dry	75 wet	
	RHW-2, XHHW-2 RW90, RWU90	90 dry	90 wet	
Cross-linked polyvinyl chloride (XL-PVC)	XHHW	90 dry	90 damp	250
Chlorinated polyethylene (CPE)	RHH	90 dry	90 damp	250
	RHW-2, RW90, RWU90	90 dry	90 wet	

Table continues

Table 2—Examples of conductor insulation types and their maximum short-circuit temperature[a] *(continued)*

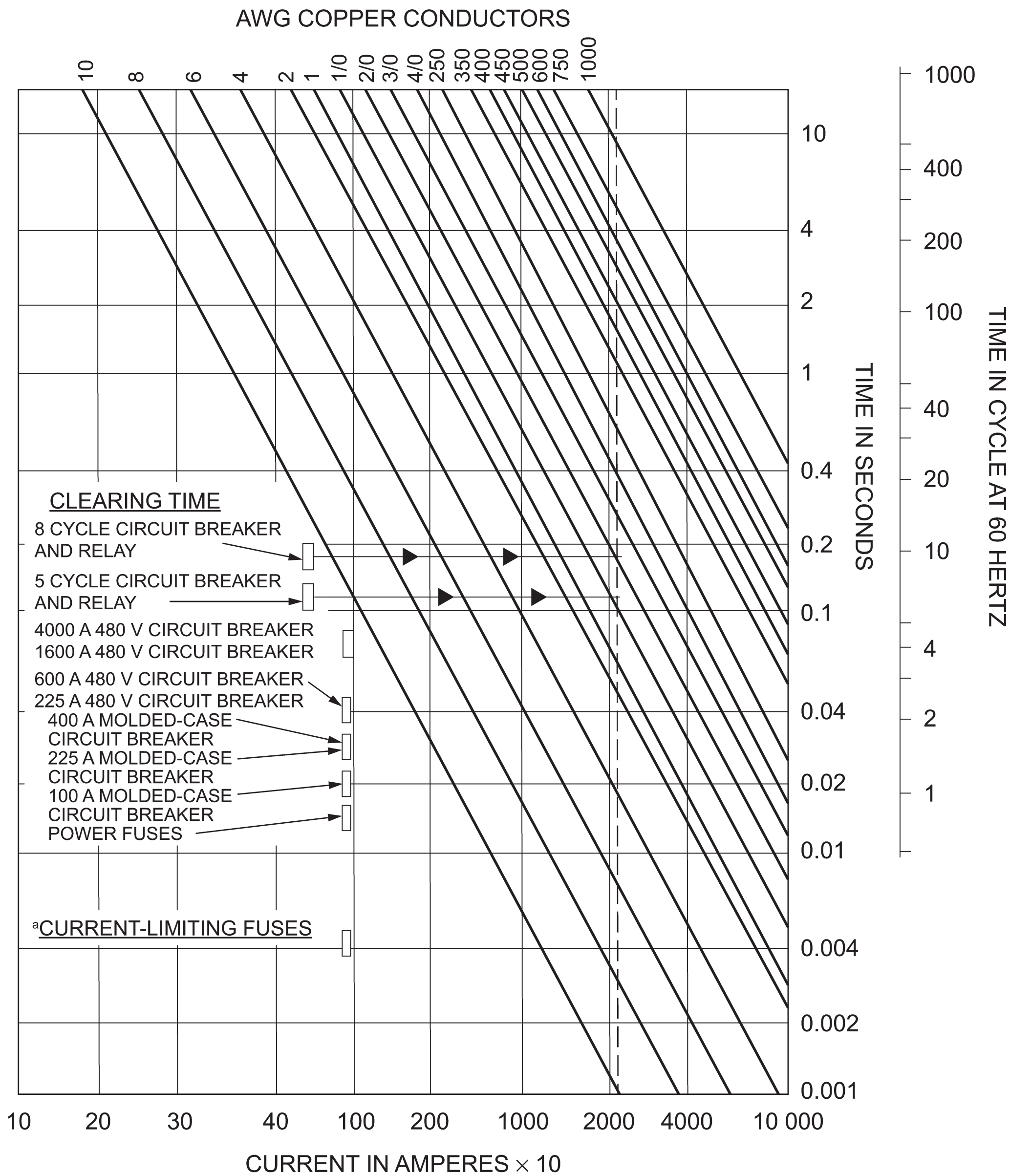
Type of insulation, NEC designation, trade name	Type letter	Continuous temperature rating T_O (°C): dry	Continuous temperature rating T_O (°C): wet	Short-circuit current temperature rating T_f (°C)
Ethylene propylene rubber (EPR)[e]	RHH, XHH	90 dry	90 damp	250
	RHW-2, XHHW-2	90 dry	90 wet	
	RW90, RWU90	90 dry	90 wet	
Styrene butadiene rubber (SBR)	RHW, RW75, RWU75	75 dry	75 wet	200
Butyl rubber (BR)	RHH	90 dry	90 damp	200
	RHW	75 dry	75 wet	
	RHW-2	90 dry	90 wet	
Silicone	SA	90 dry	90 damp	250
	SA (special)	200 dry	200 damp	
	SIS	90 dry		
Low-voltage thermoplastic (600 V)[f]				
Polyvinyl chloride (PVC)	THHN	90 dry	90 damp	150
	T90	90 dry	90 damp	
	THW, TW75, TWU75	75 dry	75 wet	
	THHW, THWN, TWN75	90 dry	75 wet	
	THW-2, THWN-2	90 dry	90 wet	

[a]Consult the conductor manufacturer for specific conductor properties. Temperature ratings may also vary with the year of manufacture.
[b]Refer to NEMA WC74/ICEA S-93–639 [B53], ICEA S-97–682 [B11], CSA C685.10–20 [B4], and UL 1072 [B67] for information on shielded MV conductors.
[c]Nonshielded 5 kV conductors may have been used in NEC jurisdictions in older installations or new industrial installations with metal-clad (MC) type cable; however, newer NEC installations typically use shielded conductors over 2 kV. Nonshielded 5 kV conductors have been acceptable in the CE Code for some time. Refer to NEMA WC 71/ICEA S-96–659 [B52], UL 44/CSA C22.2 No. 38/NMX-M-451-ANCE [B59], and UL 1072 [B67] for information on nonshielded MV conductors. Not all conductor designations are available at all voltage ratings; refer to the standards for details.
[d]NEC jurisdictions typically use 600 V conductors and conductors are permitted to be rated for 1000 V if listed and marked. CE Code jurisdictions typically use 1000 V conductors. Refer to NEMA WC-70/ICEA S-95–658 [B51] and UL 44/CSA C22.2 No. 38/NMX-J-451-ANCE [B59] for information on thermoset insulated conductors.
[e]RHH, RHW, and RHW-2 solid dielectric conductors may be rated up to 2000 V. R90, RW75, and RW90 may be rated up to 5000 V (Canada only).
[f]Refer to UL 83/CSA C22.2 No. 75/NMX-J-010-ANCE [B60] for information on thermoplastic insulated conductors.

The conductor damage curve is plotted on the coordination plot. The damage curve should be above and to the right of the motor overload and short-circuit–protective device curves with clear space between the curves.

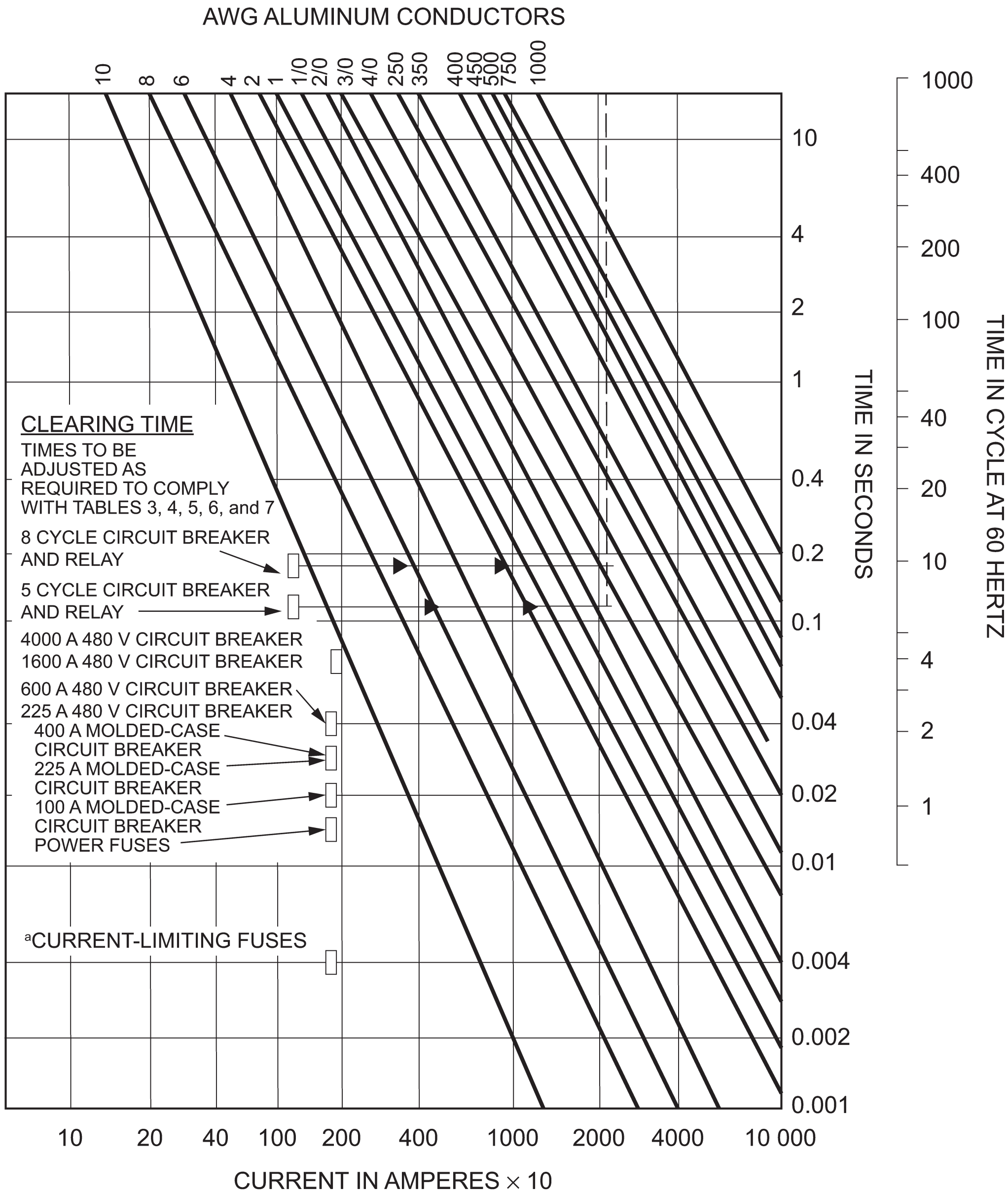
6.3.4 Temperature-current-time curves

For convenience in determining the cable size, the curves depicting the relationship of temperature-current-time are prepared from the temperature rise formula and are based on the temperature rise from the continuous to short-circuit temperature limits. Figure 2 and Figure 3 show the curves for copper and aluminum conductors from 75 °C to 200 °C. They also incorporate the total fault-clearing times of various types of switching equipment. For competent design, a cable should be selected on the basis of the expected load current, total short-circuit clearing time, and available short-circuit current as required. For example, AWG # 2/0 copper cable may be selected for connection to a circuit capable of producing 21 000 A with a clearing time of 8 cycles (0.13 s), and #3/0 aluminum cable may be selected for connection to the same circuit.



[a] Clearing time of current-limiting fuses and current-limiting MCCBs in current-limiting range is approximately 0.25 cycles (0.004 s). See Table 3 through Table 7.

Figure 2—Maximum short-circuit current for insulated copper conductors (initial temperature 75 °C; final temperature 200 °C; for other temperatures use correction factors of Figure 4)



[a] Clearing time of current-limiting fuses and current-limiting MCCBs in current-limiting range is approximately 0.25 cycles (0.004 s). See Table 3 through Table 7.

Figure 3—Maximum short-circuit current for insulated aluminum conductors (initial temperature 75 °C; final temperature 200 °C; for other temperatures use correction factors of Figure 4)

6.3.5 Initial and final temperatures

For cables rated at initial (or operating) and final (or maximum short-circuit) temperatures vary from 75 °C and 200 °C, respectively, correction factors for use with Figure 2 and Figure 3 may be determined by use of Figure 4. With this chart, a correction factor is obtained by which the actual available fault current is converted to a virtual available fault current that is then used with Figure 2 and Figure 3. The actual available fault current is multiplied by the correction factor K_t to obtain the virtual available fault current.

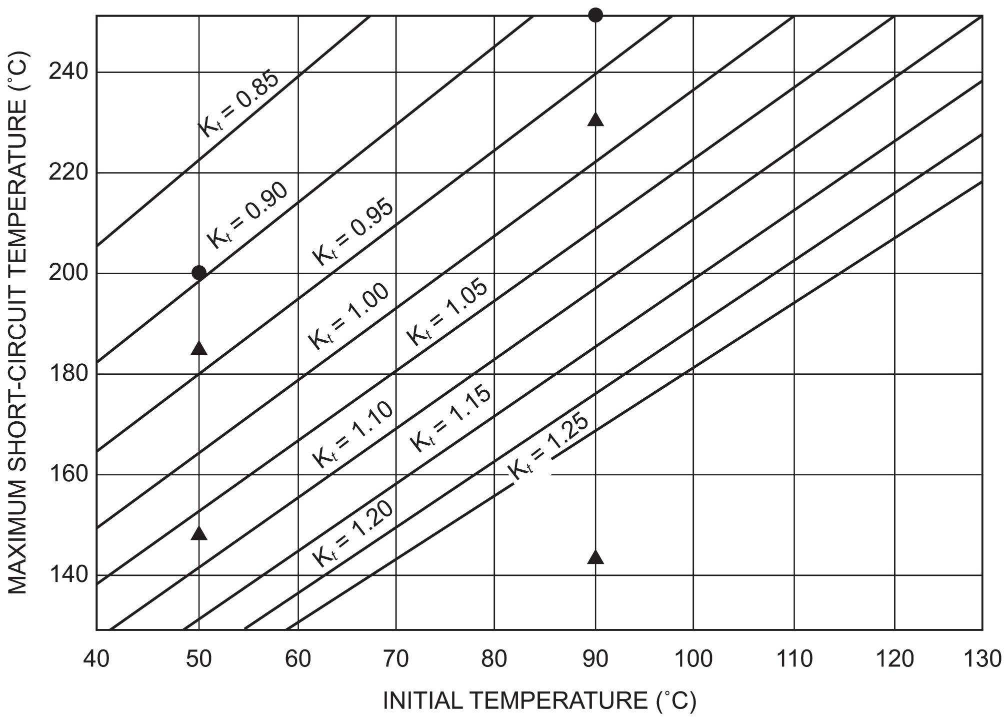


Figure 4—Correction factors K_t for initial and maximum short-circuit temperatures

Using Figure 4, the following examples were calculated:

a) Initial temperature = 50 °C

Maximum fault temperature = 200 °C

K_t = 0.899

Actual available fault current = 20 000 A

Virtual available fault current = 0.899 × 20 000 = 17 980 A on Figure 2 and Figure 3

b) Initial temperature = 90 °C

Maximum fault temperature = 250 °C

K_t = 0.925

Actual available fault current = 20 000 A

Virtual available fault current = 0.925 × 20 000 = 18 500 A on Figure 2 and Figure 3

In both cases, a smaller conductor might be safely used.

6.4 Protective devices

6.4.1 Total fault-clearing time

Devices to protect cables against short-circuit damage should have high reliability and fast fault-clearing time. In the protective scheme, primary protection is the first line of defense, and backup protection, the second line of defense. Primary protection normally provides prompt, but not necessarily instantaneous, fault-clearing time, while backup protection is timed for more delayed fault-clearing time. Whether these two levels of protection are to be provided for all cables is a decision to be made in initial design stages. Total clearing times are defined as follows:

a) *Relayed circuit breaker*. Total fault-clearing time equals overcurrent relay time plus auxiliary relay time (if used) plus circuit breaker interrupting time.

b) *Direct tripping circuit breaker*. Total fault-clearing time equals circuit breaker clearing time.

NOTE—A direct tripping circuit breaker is one having an integral trip unit.

c) *Fuses*. Total fault-clearing time equals melting time plus arcing time.

6.4.2 Protective devices and clearing time

The total clearing time of various types of protective devices depends on the type of relay and circuit breakers or fuses used and the amount of current flowing through them. Table 3 through Table 7 estimate the total clearing times of various types of protective devices, the time-current characteristic curves should always be consulted for accurate clearing times.

Table 3—Estimated clearing times of protective devices: relayed circuit breakers, 2.4 kV to 38 kV

	Type of relay			
	Electromechanical plunger, instantaneous	**Electromechanical induction, instantaneous**	**Static digital instantaneous**	**Induction, inverse time**
Relay times (cycles)	0.25 to 1	0.5 to 2	0.5 to 1.5	6 to 6000
Circuit breaker interrupting time (cycles)	3 to 8	3 to 8	3 to 8	3 to 8
Total time (cycles)	3.25 to 9	3.5 to 10	3.5 to 9.5	9 to 6000

Table 4—Estimated clearing times of protective devices: power circuit breakers, 600 V and below

	Frame size	
	225 A to 800 A	**1600 A to 4000 A**
Instantaneous (cycles)	2 to 5	3 to 5
Short time (cycles)	5 to 30	5 to 30
Long time (s)	over 100	over 100
Ground fault (cycles)	5 to 30	5 to 30

Table 5—Estimated clearing times of protective devices: molded-case breakers, 600 V and below

	Frame size		
	100 A	**225 A to 1200 A**	**100 A to 1200 A (current limiting)**
Instantaneous (cycles)	0.5 to 1	1 to 1.5	Less than 0.5[a]
Long time (s)	over 100	over 100	over 100

[a]Current-limiting breakers operating in their current-limiting range introduce impedance fast enough to interrupt the current in 1/4 to 1/2 cycle.

Table 6—Estimated clearing times of protective devices: medium- and high-voltage fuses

High current	0.25 cycles (for current-limiting fuses operating in their current-limiting range) 1.0 cycles (for power fuses at maximum current)
Low current	600 s (for E-rated fuses operating at 2 times nominal rating; other ratings are available with different times at 2 times nominal rating)

Table 7—Estimated clearing times of protective devices: low-voltage fuses

High current	0.25 cycles (in current-limiting range)
Low current	1000 s (at 1.35 to 1.5 times nominal rating)

For convenience, the total clearing times of current-limiting fuses and current-limiting MCCBs are shown in the lower left-hand corner of Figure 2 and Figure 3. These data can be used together with maximum short-circuit current for proper selection of cable sizes.

6.4.3 TCCs of protective devices

A protective device provides adequate protection if the total clearing time of the device is below the temperature-current-time curve of the cable short-circuit current. For protective devices whose TCCs are plotted as bands with a minimum sensitivity and maximum clearing time plotted as the lower and upper bounds of the time band, respectively, coordination between the protective device and protected cable requires clear space between the plotted protective device TCC and the cable temperature-current-time curve. When a circuit breaker and overcurrent relay are used to protect the cable, a minimum coordinating time interval (CTI) of 0.20 s should be maintained between the relay TCC and the cable temperature-current-time curve. For more information on development of the coordinating time interval, see IEEE Std 242-2001 section 15.5.

Thus, the selection of fuses, overcurrent relays, or circuit breakers is vitally important to the protection of cables. Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11 illustrate the characteristics of relays and devices commonly used in feeder circuits. Shown also are the maximum available short-circuit currents of the system and the maximum short-circuit current curve of the cable.

6.4.4 Backup protection

In some instances, the setting or rating of a given device, rather than just protecting the immediate load side element, may be selected to protect the second load side elements (e.g., cable). This setup would be activated if a protective device failed; in other words, the next device on the line side would operate in adequate time to prevent damage to elements, such as cable on the load side of the failed device. This feature is known as *backup protection*. When a protective device fails to operate, the next protective device on the line side must provide backup protection for the zone (conductors) whose protection has failed. Good backup protection should be sufficiently sensitive and fast to provide protection for the smaller conductors, however properly coordinated with the primary protection.

6.5 Application of short-circuit current protective devices

6.5.1 Protection and coordination

6.5.1.1 Introduction

The protective device should be selected and coordinated to give the cable sufficient short-circuit protection. This process can be done easily by plotting the temperature-current-time curves of the protected cable and the time-current curves (TCC) of the protective device on the same log-log plot. The TCC of the protective device should always be below and to the left of the maximum short-circuit TCC of the protected cable. For protective devices whose TCCs are plotted as bands with a minimum sensitivity and maximum clearing time plotted as the lower and upper bounds of the time band, respectively, coordination between the protective device and protected cable requires clear space between the plotted protective device TCC and the cable temperature-current-time curve. When a circuit breaker and overcurrent relay are used to protect the cable, a minimum coordinating time interval (CTI) of 0.20 s should be maintained between the relay TCC and the cable temperature-current-time curve. For more information on developing the coordinating time interval, see IEEE Std 242-2001 15.5. Examples are shown in Figure 2 and Figure 3. Figure 5 through Figure 11 illustrate that a #4/0 copper insulated cable may be protected by various protective devices as follows:

— A 5 kV #4/0 feeder is protected by a current-limiting fuse (see Figure 5) or a Device 50/51 or Device 49/50 relay (see Figure 6).

— A 600 V #4/0 feeder is protected by instantaneous tripping (see Figure 7) and by short-time tripping (see Figure 8), or by a instantaneous MCCB (see Figure 9).

— A 600 V #4/0 motor circuit is protected by a 400 A current-limiting fuse (see Figure 10).

— Short-circuit and overload protection is provided using overload relays and fuses (see Figure 11).

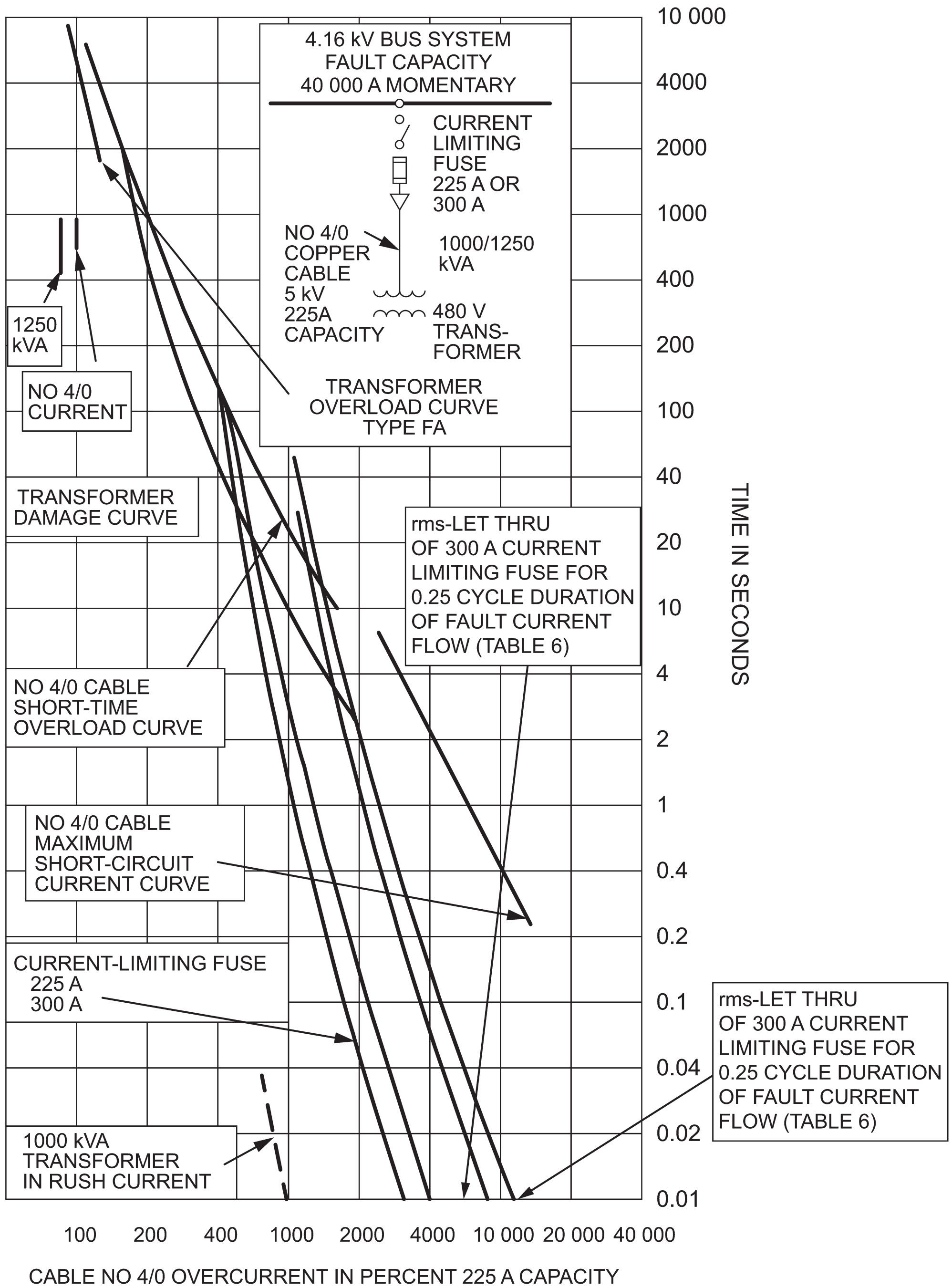


Figure 5—Short-circuit and overload protection of a 5 kV cable with fuses

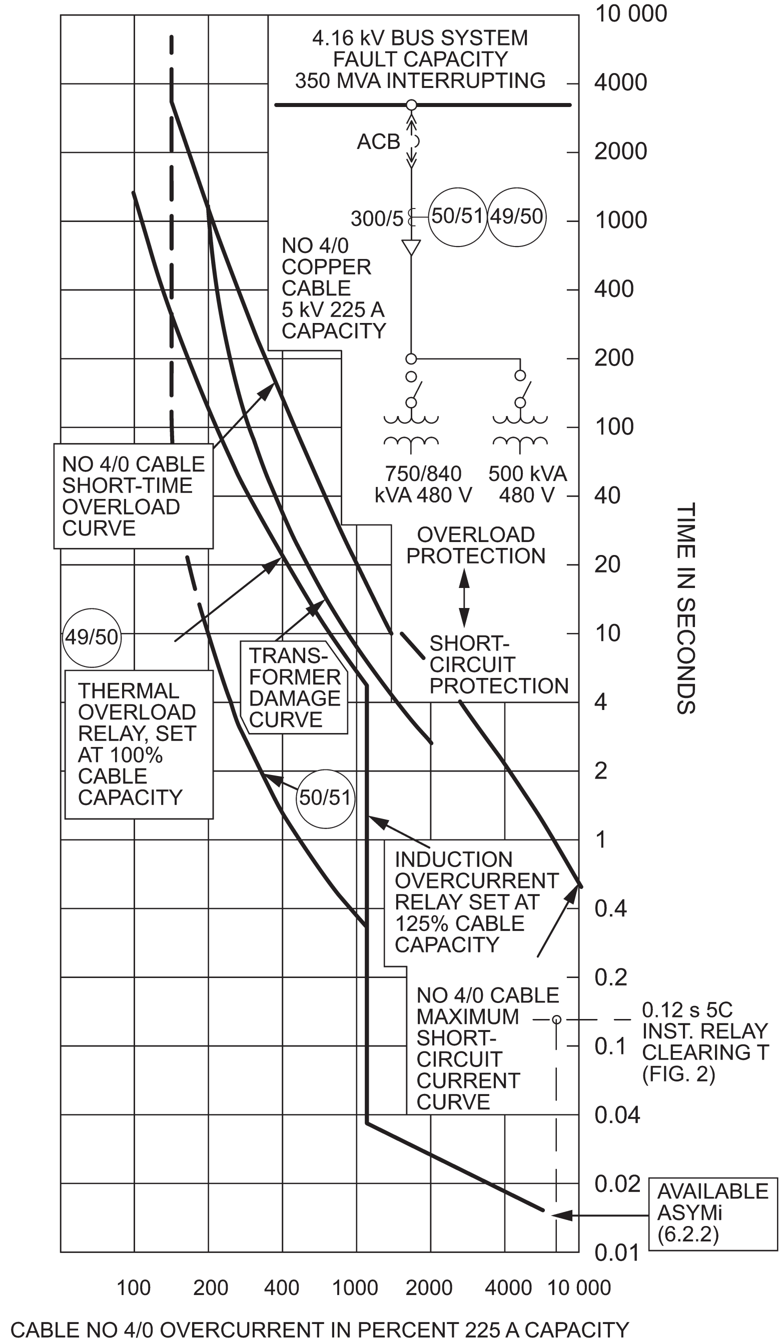


Figure 6—Short-circuit and overload protection of a 5 kV cable with protective relays

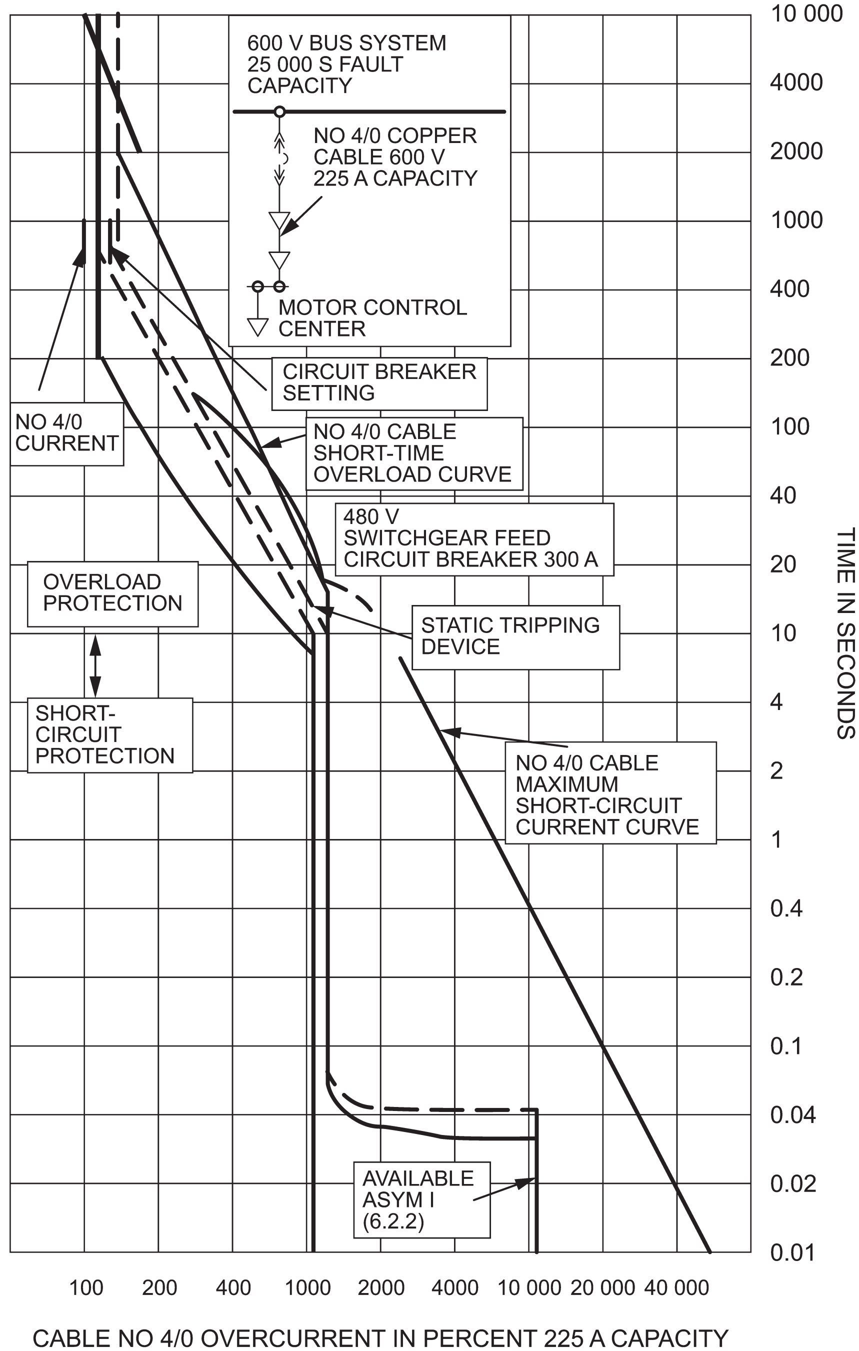


Figure 7—Short-circuit and overload protection of a 600 V cable with long-time and instantaneous equipped circuit breakers

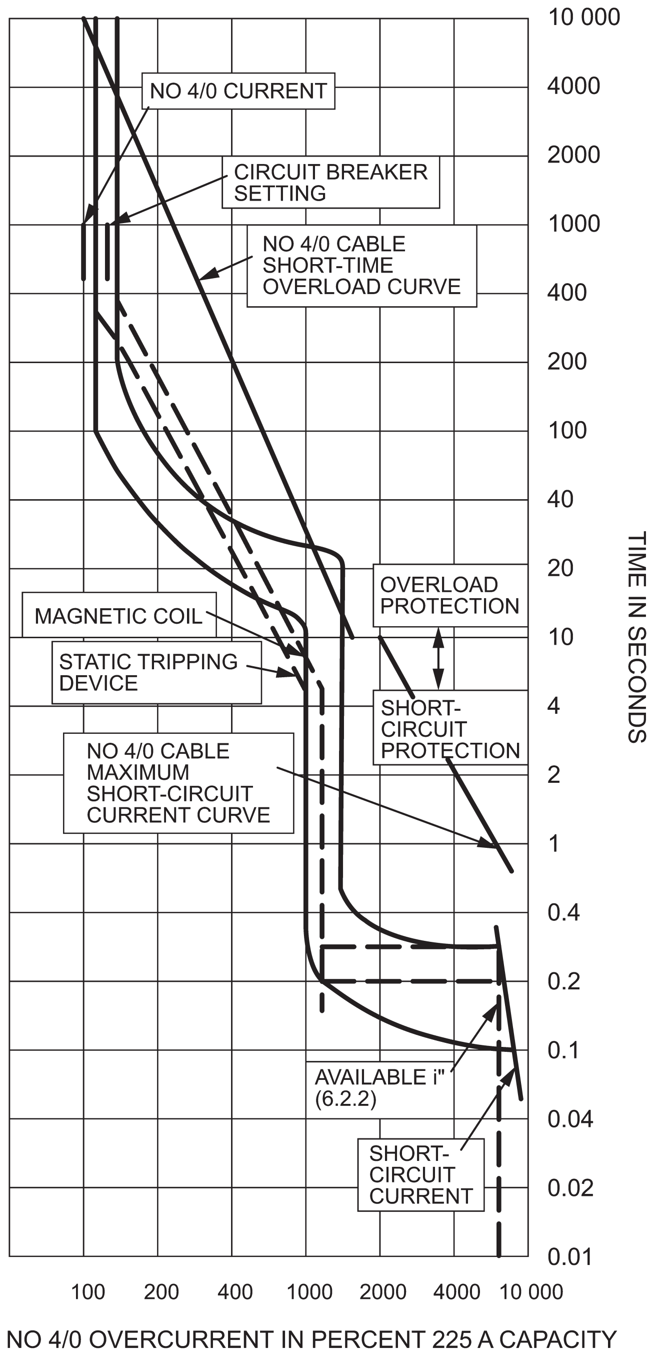


Figure 8—Short-circuit and overload protection of a 600 V cable with long-time and short-time equipped circuit breakers

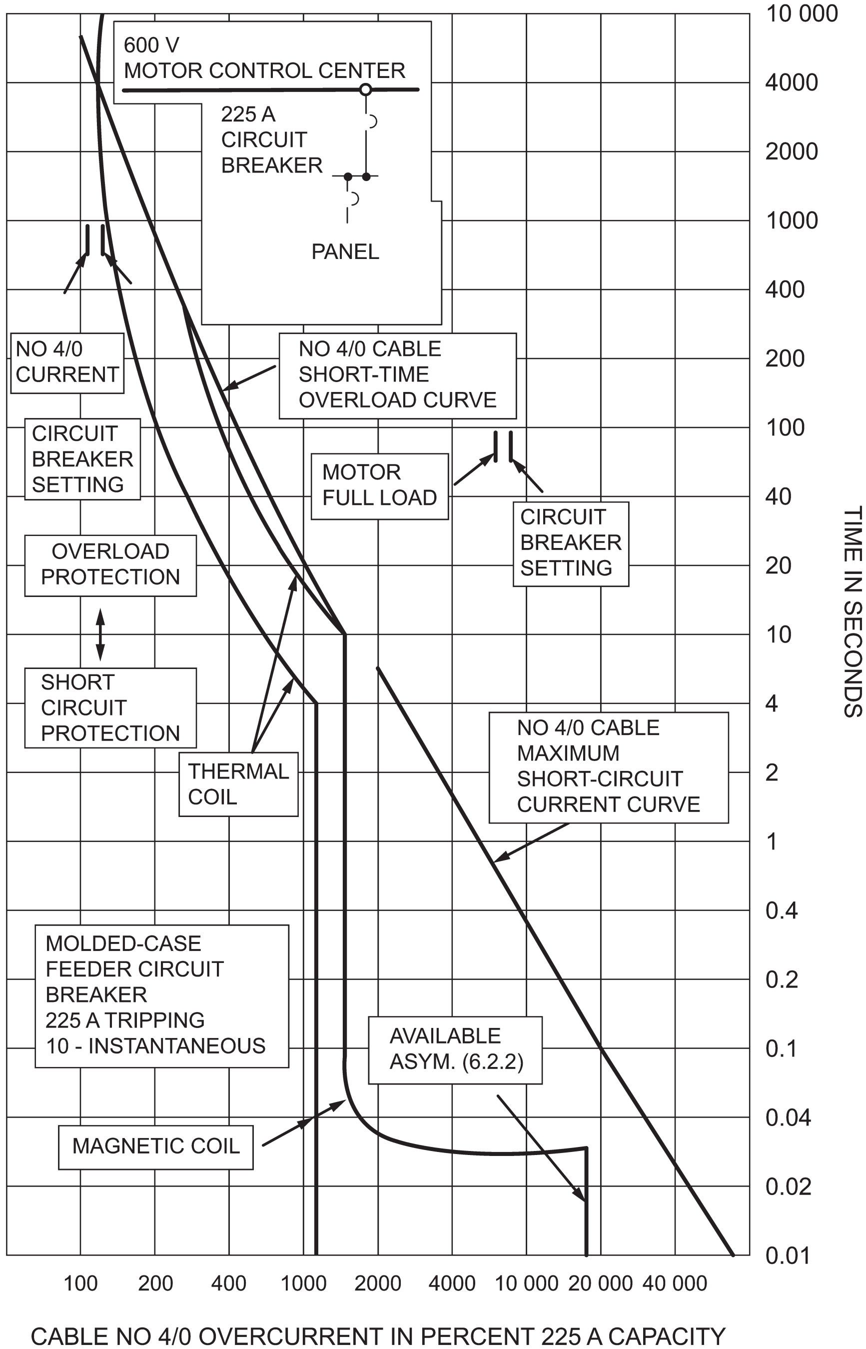


Figure 9—Short-circuit and overload protection of a 600 V cable using a thermal-magnetic circuit breaker

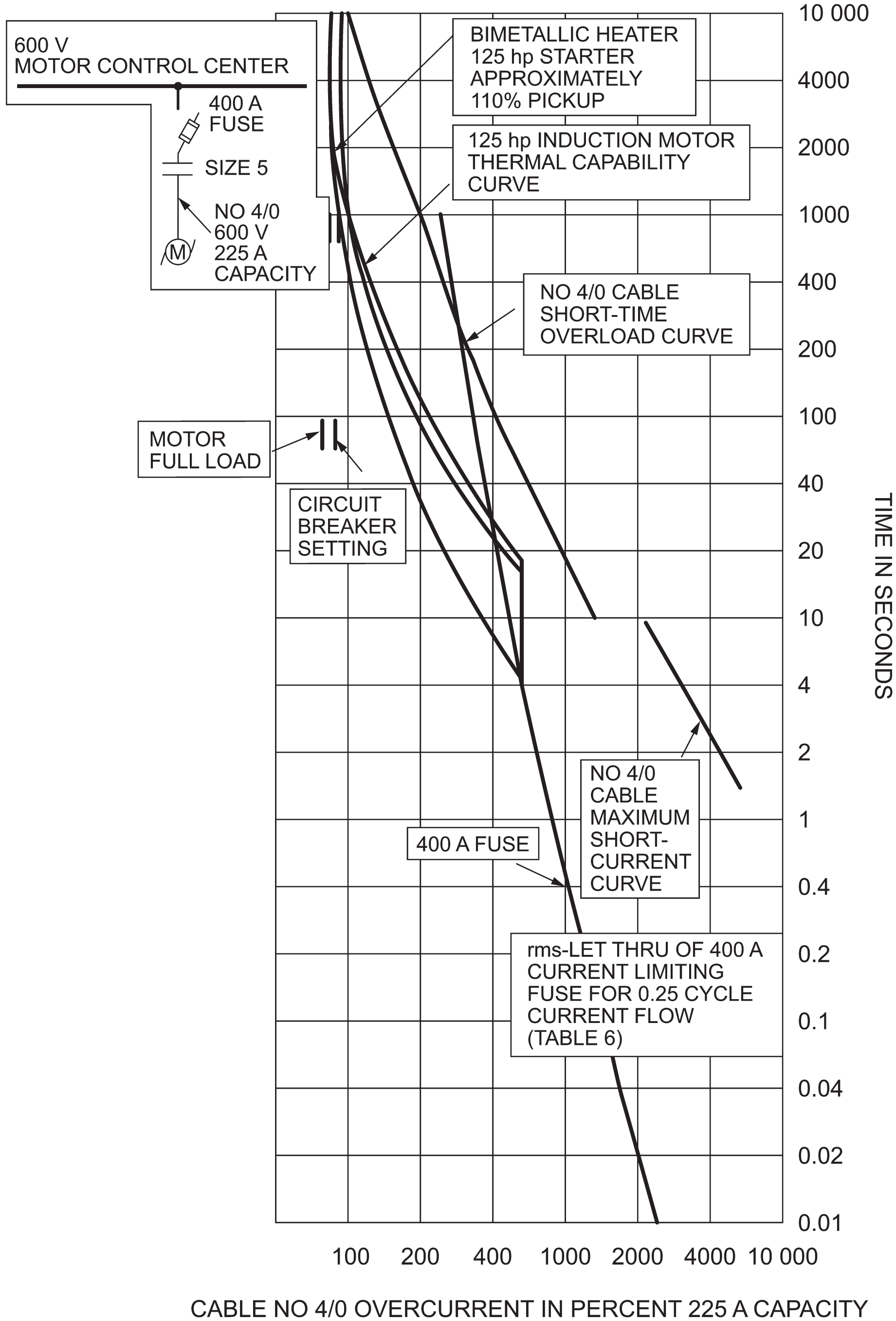


Figure 10—Short-circuit and overload protection of a 600 V cable using fuses

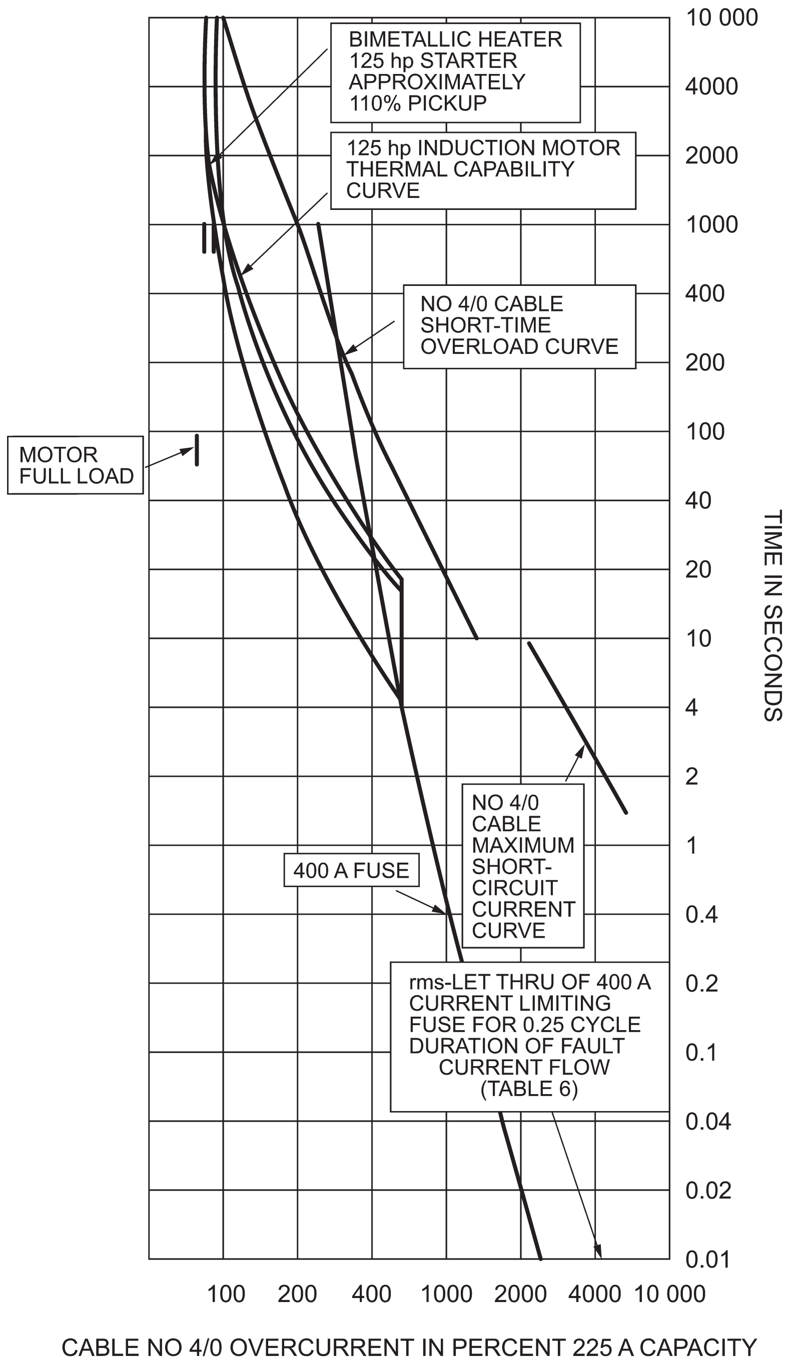


Figure 11—Short-circuit and overload protection of a 600 V cable using overload relay fuses

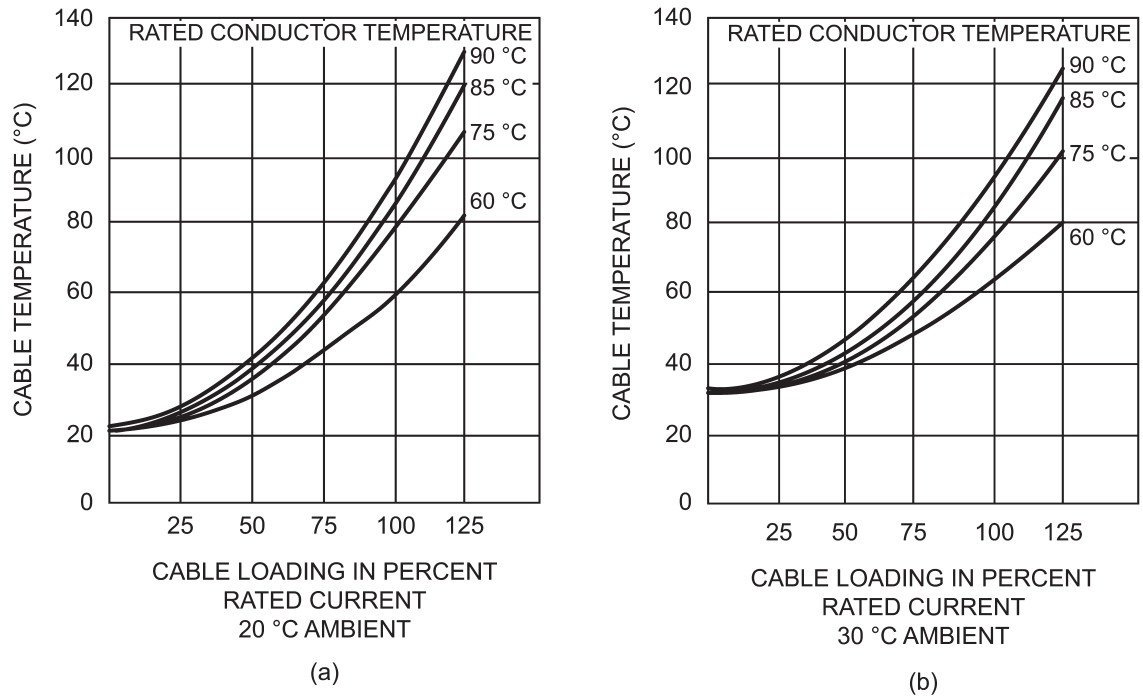


Figure 12—Cable loading and temperature rise

Special consideration is required whenever equipment-grounding conductors are sized smaller than the phase conductors because the phase over current devices may not provide protection of those conductors. Two additional factors to consider are the reduction in the fault current during a ground fault and any phase-to-ground protection that is provided. The smaller conductors will add impedance to the fault, reducing the magnitude of a phase-to-ground fault compared to a phase-to-phase fault. Ground-fault protection of equipment can provide lower pickup points and faster clearing times where practical to aid in equipment grounding conductor protection. Where the anticipated ground-fault current is lower than the phase-to-phase fault current, phase-to-ground-fault settings and delays can be much lower than the phase protection. The reduction in fault current and the reduced settings of the phase-to-ground protection will not subject the equipment grounding conductors to the same stress as the phase conductors. Examples of short-circuit protection are given in 6.5.1.2 and 6.5.1.3.

6.5.1.2 Example 1

Figure 13 presents a one-line diagram for Example 1.

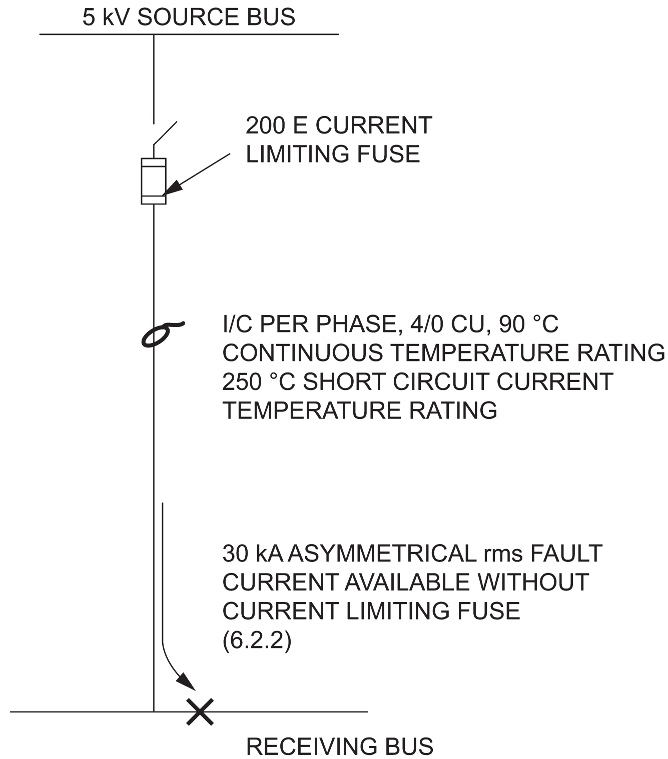


Figure 13—One-line diagram for Example 1

a) Find rms let-through current of the current-limiting fuse.

Entering the let-through curve of the current-limiting fuse at 30 kA, and using the up, over, and down method, the rms let-through current is found to be 12 kA (see Figure 14). Some manufacturers use symmetrical available short-circuit current. The manufacturer's instructions should be followed for use of let-through curves.

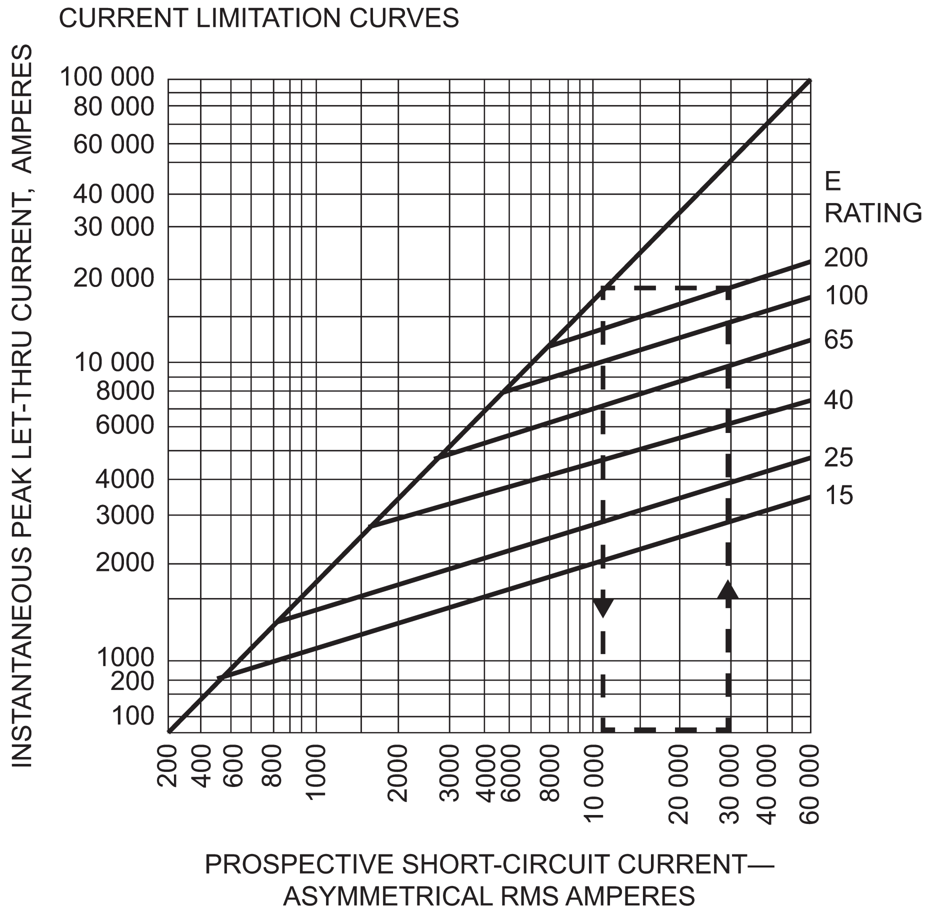


Figure 14—Current-limiting fuse let-through for use with Example 1

b) Current-limiting fuse let-through for use with Example 1.

c) Find the short-circuit capability of the #4/0 copper conductor.

d) In this example, assume that the initial operating temperature is the 90 °C continuous rating of the cable. The reason for this conservative assumption is that the initial operating temperature is a function of not only the loading, but also the ambient temperature. In this example, predicting the actual cable operating temperature at the time a fault occurs is not practical.

e) Entering Figure 4 with an initial temperature of 90 °C and a maximum short-circuit temperature of 250 °C, K_t is found to be 0.925. (See 6.3.5 for additional information on the use of Figure 4.)

f) The virtual available fault current should be found for use with Figure 2. Virtual available fault current is defined in 6.3.5 as the product of the actual available fault current and K_t. In this example, the actual available fault current is reduced to 12 kA because of the current-limiting effect of the 200E current-limiting fuse. Therefore,

virtual available fault current = $K_t \times 12$ kA

= 0.925 × 12 kA

= 11.1 kA

g) Entering Figure 2 with the virtual fault current of 11.1 kA, the #4/0 cable is found to safely carry 11.1 kA for approximately 100 cycles. Referring to Table 3 through Table 7, a medium-voltage current-limiting fuse operating in the current-limiting range is found to clear a fault in 0.25 cycles. Therefore, the cable is well protected from short-circuit damage.

h) Plot cable short-circuit thermal limit curve on a coordination plot.

i) The short-circuit thermal limit curve for this example is constructed by shifting the #4/0 copper damage curve of Figure 2 by a correction factor of 1/K_t and plotting points from the shifted curve of Figure 2 on to the protection plot in Figure 15. An example of curve shifting is given in Figure 16.

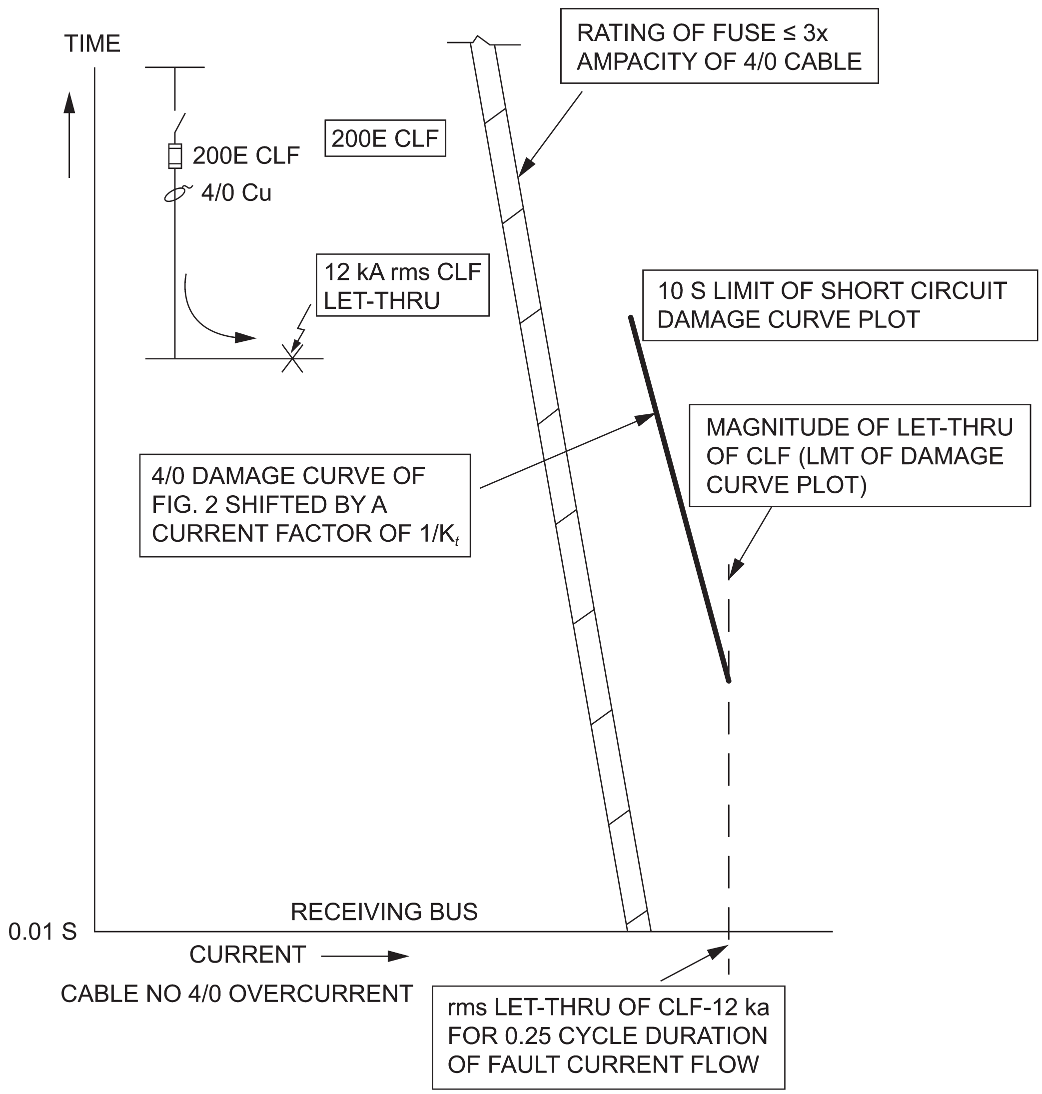


Figure 15—Short-circuit protection plot for Example 1

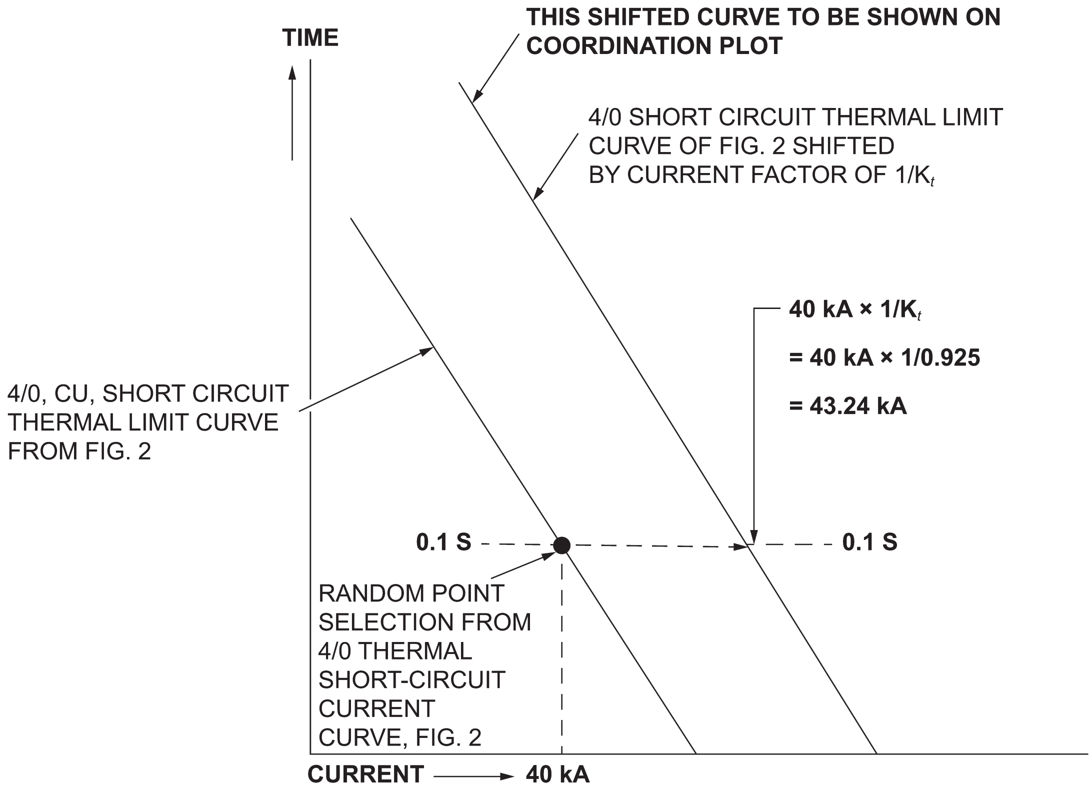


Figure 16—Shifting of thermal limit curve for use with coordination plot of Example 1

6.5.1.3 Example 2

Figure 17 presents a one-line diagram for Example 2.

a) Find the equivalent rms value of the fault current flowing over the time required to clear fault.

b) From 6.2.2, the subtransient current is assumed to flow over the time required for a medium-voltage circuit breaker and instantaneous relay to clear the fault. From Figure 3 and Table 3 through Table 7, the total clearing time of a 5 cycle circuit breaker and instantaneous relay is taken as 0.12 s. Therefore, 40 kA subtransient short-circuit current is assumed to flow for 0.12 s.

c) Find the short-circuit capability of the 500 kcmil aluminum conductors.

d) The initial and final temperatures in Example 2 are the same as in Example 1. Therefore, $K_t = 0.925$. (See Example 1 for determination of K_t and the virtual available fault current.) In order to find the short-circuit capability of the 500 kcmil aluminum cable; Figure 3 should be entered with the virtual available fault current. Therefore,

   virtual available fault current $= K_t \times 40$ kA

   $= 0.925 \times 40$ kA

   $= 37$ kA

Entering Figure 3 with 37 kA, a single conductor 500 kcmil aluminum cable is found to carry 37 kA for about 0.6 s. The fault is cleared in 0.12 s; therefore, the cable is well protected from short-circuit damage.

NOTE—In this example, under short-circuit conditions, all fault current is assumed to flow through a single conductor when multi-conductor feeders are utilized.

The short-circuit protection plot is shown in Figure 18. See Example 1 for the method of plotting the thermal limit curve on the short-circuit protection plot. The shifted short-circuit thermal limit curve should be plotted on the coordination plot between the current limits shown in Figure 18.

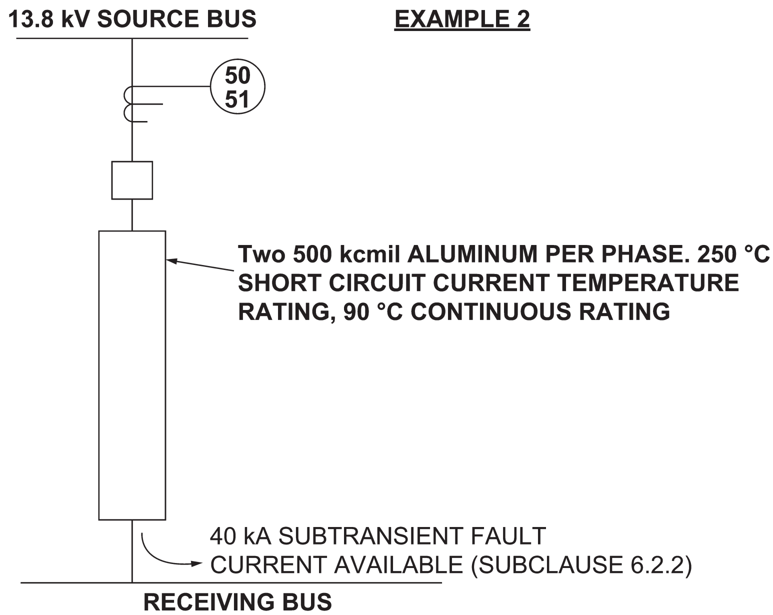
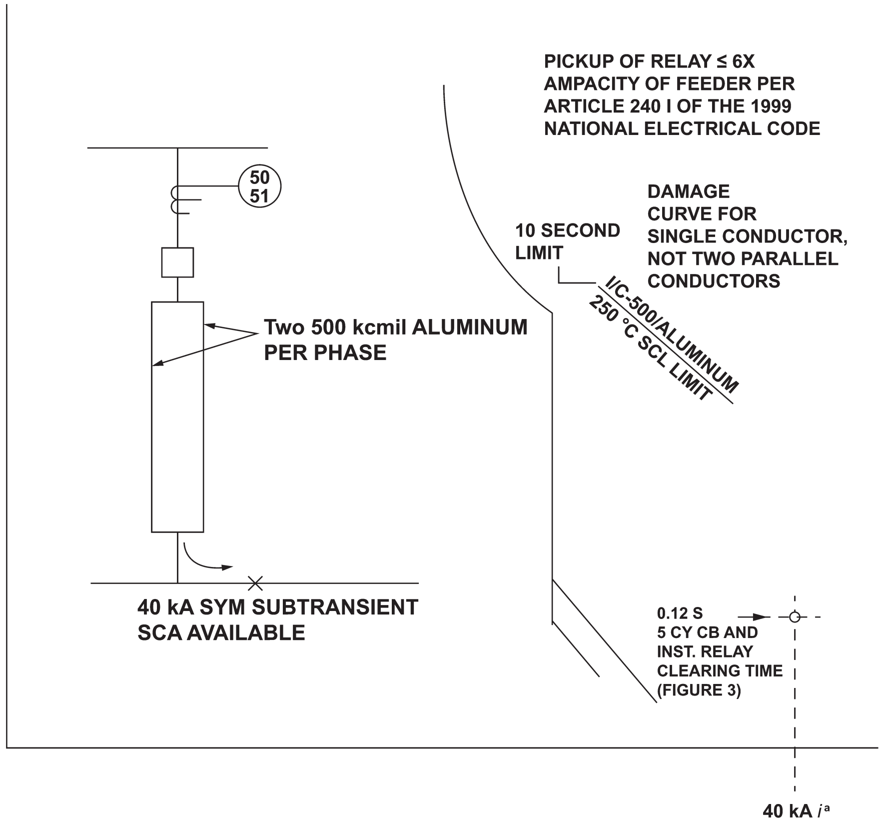


Figure 17—One-line diagram for Example 2



[a] *i* is the equivalent value of the rms fault current over the duration of flow of the fault current (see 6.2.2).

Figure 18—Short-circuit protection plot for Example 2

7. Overload protection of conductors

7.1 Introduction

Overload protection cannot be applied until the current-time capability of a conductor is determined. Protective devices can then be selected to coordinate conductor rating and load characteristics.

7.2 Normal current-carrying capacity

7.2.1 Heat flow and thermal resistance

Heat is generated in conductors by I^2R losses. It must flow outward through the cable components including insulation, armor, and sheath (if any), as well as the surrounding medium including the air surrounding the cable, the raceway structure, and/or the surrounding earth in accordance with the following thermal principle (see AIEE Committee Report [B2], Neher and McGrath [B46], Shanklin and Buller [B56], Wiseman [B72]):

$$\text{heat flow} = \frac{\text{difference between conductor and ambient temperature}}{\text{thermal resistance from materials}} \tag{3}$$

The conductor temperature resulting from heat generated in the conductor varies with the load. The thermal resistance of the cable insulation may be estimated with a reasonable degree of accuracy, but the thermal resistance of the raceway structure and surrounding earth depends on the size of the raceway, the number of ducts, the number of power cables, the raceway structure material, the coverage of the underground duct, the type of soil, and the amount of moisture in the soil. These considerations are important in the selection of cables.

7.2.2 Ampacity

The ampacity of each cable is calculated on the basis of fundamental thermal laws incorporating specific conditions, including type of conductor, ac/dc resistance of the conductor, thermal resistance and dielectric losses of the insulation, thermal resistance and inductive ac losses of sheath and jacket, geometry of the cable, thermal resistance of the surrounding air or earth and duct or conduits, ambient temperature, and load factor. The ampacities of the cable under the jurisdiction of the NEC are tabulated in its current issue or amendments. The current-carrying capacity of cables under general operating conditions that may not come under the jurisdiction of the NEC are published by other standard-developing organizations. The ampacities of specific types of cables are calculated and tabulated by manufacturers. Their methods of calculation generally conform to IEEE Std 835™ or NEC 2017, for a wide range of underground applications, and for some free-air applications. The comparable data for cables in random filled cable trays is published in ANSI/NEMA WC 51/ICEA P-54–440–2009 (R2014) (NEMA WC 51), which is based on IEEE Std 835 free-air data. The Insulated Cable Engineers Association (ICEA) publishes ICEA P-117–734 to supplement IEEE Std 835. For fire-protected cables, refer also to IEEE Std 848™. For high-temperature circuit integrity cables, refer to IEEE Std 1810™. For mine cables, refer to NEMA WC 58/ICEA W-75–381 [B50].

The United States Department of Agriculture (USDA) Rural Utilities Service [B71] presents in section 10.6 “Underground Raceways,” various ampacity calculations:

— 10.6.1 “Direct-Buried Cables”
— 10.6.2 “Direct-Buried Conduit”
— 10.6.3 “Concrete-Encased Conduit (Duct Bank)”
— 10.6.4 “Cable Trenches”
— 10.6.5 “Manholes”
— 10.6.6 “Handholes”

7.2.3 Temperature derating factor (TDF)

The ampacity of a cable is based on a set of physical and electrical conditions and a base ambient temperature defined as the no-load temperature of a cable, duct, or conduit. The base temperature generally used for most ampacity tables in the relevant codes and standards is 20 °C for underground installations, 30 °C for low-voltage above ground conduits or trays, and 40 °C for medium-voltage above ground conduits or trays. In all cases, the ampacity needs to be adjusted when the ambient temperature of an application exceeds the base ambient temperature in the reference table. It is common to assume an ambient temperature of 30 °C for indoor (non-process building) applications and 40 °C for outdoor applications, when better data is not available. Ideally the temperature should be based on the site ambient conditions if they are known.

TDFs for ambient temperatures other than base temperatures are based on the maximum operating temperature of the cable and are proportional to the square root of the ratio of temperature rise, that is,

$$\text{TDF} = \frac{I_N}{I_M} = \frac{\text{current capacity at base ambient temperature}}{\text{current capacity at other ambient temperature}}$$

$$= \sqrt{\frac{T_N - T_a}{T_N - T_{a1}}} = \sqrt{\frac{\text{temperature rise above base ambient temperature}}{\text{temperature rise above other ambient temperature}}}$$

7.2.4 Grouping derating factor

The no-load temperature of a cable in a group of loaded cables is higher than the base ambient temperature. To maintain the same maximum operating temperature, the current-carrying capacity of the cable should be derated by a factor of less than 1. Grouping derating factors are different for each installation and environment. Generally, they can be classified as follows:

— For cable in free air with maintained space
— For cable in free air without maintained space
— For cable in exposed conduits
— For cable in underground ducts

NEC 2020 Table 392.22(A) and Table 392.22(B) (1) list fill limits for cables rated up to 2000 V in cable trays. NEC 2020 Section 392.80 and the CE Code 2018 Section 4 covers the ampacity of cables rated 2000 V or less in cable trays.

7.2.5 Frequency and harmonic derating factors

Chapter 9 of IEEE Std 141-1993 [B13] and 9 of IEEE Std 3001.5–2013 [B33] contain information pertaining to the derating of cables as the result of harmonics and frequency considerations. (Six-pulse harmonic current distribution is covered in IEEE Std 141-1993 [B13] 9.8.2.3, and IEEE Std 3001.5™ [B33] Figure 32 treats 400 Hz and 800 Hz systems.)

7.2.6 Ambient temperature adjustments in rooftop applications

When raceway or cables are installed on rooftops where exposed to sunlight, the ambient temperature used for determining the current-carrying capability of the conductor increases with the proximity to the rooftop surface. In addition to the actual ambient air temperature, an adder must be used to account for the radiated heat from the roof surface. Per NEC 2020, Section 310.15(B) (2), when a raceway containing insulated conductors is exposed to direct sunlight, and is less than 7/8 in, measured from the top of the roof to the bottom of the raceway, a temperature adder of 33 °C (60 °F) must be added to the maximum outdoor ambient temperature for the application of the correction factors in NEC 2020, Table 310.15(B) (1) or Table 310.15(B) (2), unless otherwise permitted. (Note that the Canadian Electrical Code does not provide any specific guidance for rooftop applications, but does address ambient temperature.)

7.3 Overload capacity

7.3.1 Normal loading temperature

Cable manufacturers specify for their products the normal loading temperature, which results in the most economical and useful life of the cables. Based on the normal rate of deterioration, the insulation can be expected to have a useful life of at least 30 years. Normal loading temperature of a cable determines the cable's current-carrying capacity under given conditions. In regular service, rated loads or normal loading temperatures are reached only occasionally because cable sizes are generally selected conservatively in order to cover the uncertainties of load variations. In many industrial facilities, many conductors are oversized to achieve an acceptable voltage drop on the cable. Table 8 shows the maximum operating temperatures of various types of insulated cables.

Table 8—Typical normal and emergency loading of insulated cables

Insulation	Insulation type	Normal voltage	Normal loading (°C)	Emergency loading (°C)
Thermoplastic	T, TW[a]	600 V	60	85
	THW	600 V	75	90
	THH	600 V	90	105
	Polyethylene	0 kV to15 kV	75	95
		> 15 kV	75	90
Thermoset	R, RW, RU	600 V	60	85
	XHHW	600 V	75	90
	RHW, RH-RW	0 kV to 2 kV	75	95
	Cross-linked polyethylene (XLPE)	5 kV to 15 kV	90	140
	Ethylene-propylene rubber (EPR)	5 kV to 15 kV	90	140
Varnished polyester		15 kV	85	105
Varnished cambric[b]		0 kV to 5 kV 15 kV	85 77	102 85
Paper lead	PILC	15 kV	80	95
Silicone rubber		15 kV	125	150

[a]For type letter designation and operation temperature, please refer to NEC 310.104A.
[b]This insulation is no longer readily available, but is included for reference.

7.3.2 Cable current and temperature

The temperature of a cable rises as the square of its current. The cable temperature for a given steady load may be expressed as a function of percent full load by the following formula:

$$T_X = T_a + (T_N - T_a)(I_X / I_N)^2 \quad (4)$$

Figure 19 shows this relation for cables rated at normal loading temperatures (T_N) of 60 °C, 75 °C, 85 °C, and 90 °C.

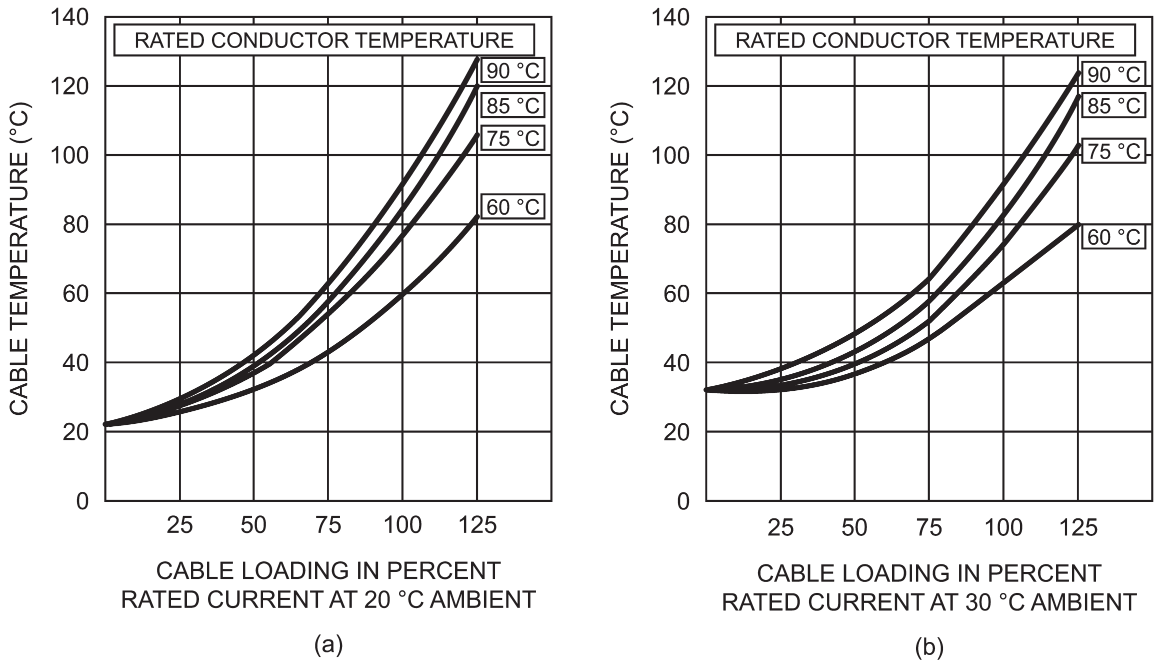
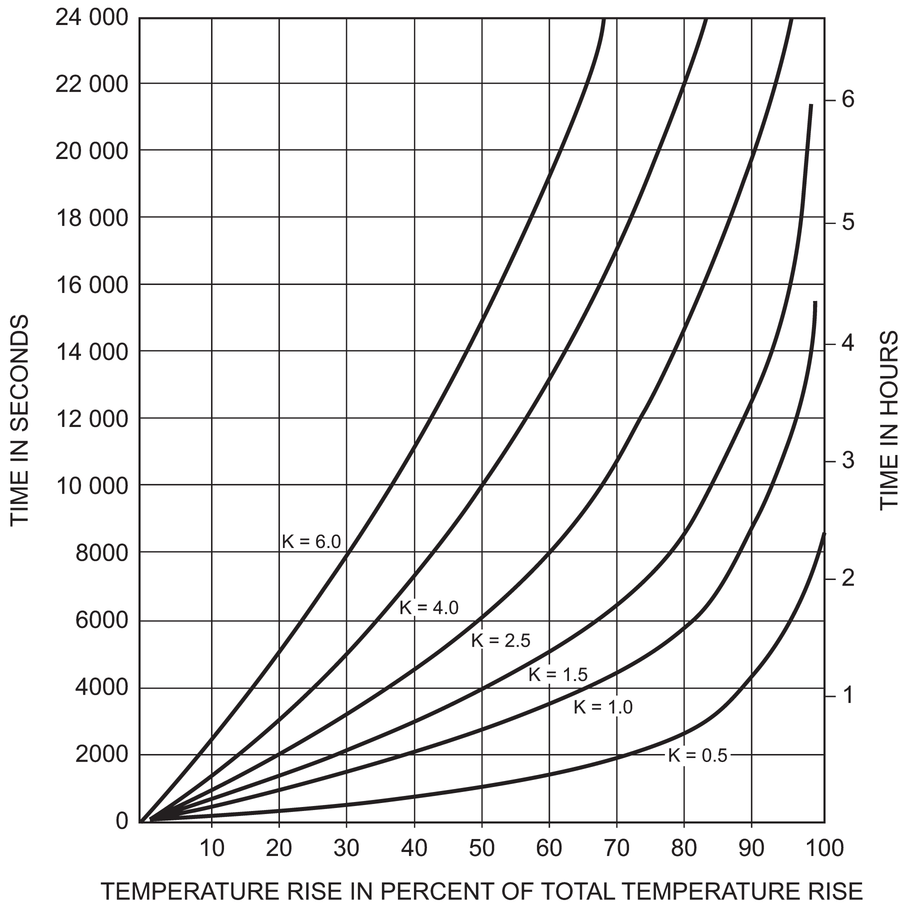


Figure 19—Cable loading and temperature rise, cable no 4/0 overcurrent in percent 225 A capacity

7.3.3 Intermediate and long-time zones

Taking into account the intermediate and long-time ranges from 10 s out to infinity, the definition of temperature versus current versus time is related to the heat dissipation capability of the installation relative to its heat generation plus the thermal inertias of all parts. The tolerable temperatures are related to the thermal degradation characteristics of the insulation. The thermal degradation severity is, however, related inversely to time. Therefore, a temperature safely reached during a fault could cause severe life reduction if it were maintained for even a few minutes. Lower temperatures, above the rated continuous operating temperature, can be tolerated for intermediate times.

The ability of a cable to dissipate heat is a factor of its surface area, while its ability to generate heat is a function of the conductor cross-section, for a given current. Thus, the reduction of ampacity per unit cross-section area as the wire sizes increase tends to increase the permissive short-time current for these sizes relative to their ampacities. It may be seen in Figure 20 that the extension of the intermediate characteristic, on a constant I^2t basis, protects the smallest wire sizes and overprotects the largest sizes. Constant I^2t protection is readily available and is actually the most common; therefore, a simplification of protection systems is possible.



Temperature rise	Percent total temperature rise
Temperature at any time	Initial temperature and temperature rise
Final temperature	Initial temperature and total temperature rise

K = 0.5	Small cable in air
K = 1.0	Medium cable in air Small cable underground
K = 1.5	Large cable in air Small cable direct burial
K = 2.5	Medium cable underground Medium cable direct burial
K = 4.0	Large cable underground
K = 6.0	Large cable direct burial

NOTE—See Table 9 for more information on K factors, including the size ranges for small, medium, and large conductors.

Figure 20—Rate of temperature rise due to current increase

The continuous current, or ampacity, ratings of cable have been long established and pose no problems for protection. The greatest unknown in the cable thermal characteristic occurs in the intermediate time zone, or the transition from short time to long time or continuous state.

7.3.4 Development of intermediate characteristics

Cable, with the thermal inertia of its own and of its surroundings, takes from 1 h to 6 h to change from initial to final temperature as the result of a current change. Consequently, overloads substantially greater than its continuous rating may be placed on a cable for this range of times.

Additionally, all cables except polyethylene (not cross-linked) withstand, for moderate periods, temperatures substantially greater than their rated operating temperatures. This is a change recently developed from work done within ICEA and published by that organization (see Clause 2). For example, EPR and XLPE cables have emergency ratings of 130 °C based on a) maximum time per overload of 36 hours, b) a maximum of three such overload periods per year, and c) an average of one such overload period per year over the life of the cable. Thermoplastic cables degrade in this marginal range by progressive evaporation of the plasticizer and can operate for several hours at the next higher-grade operating temperature (90 °C for 75 °C rating, and so forth) with negligible loss of life. Therefore, emergency operating overloads may reasonably be applied to cables within the time and temperature ratings. This capability should be the basis of application of protection of the cables. It must not be inferred from this that XLPE can be regularly operated at temperatures higher than stated by the manufacturer. This is because, as IEEE Std 1242-2016 states on page 47, "XLPE type insulations have a poly-crystalline structure. However, this structure is temperature sensitive, and changes at the upper limit of rated operating temperature (approximately 90 °C) to semi-amorphous. When operated at this temperature, the physical and electrical characteristics of this insulation type, which are generally desirable for conductor insulation, are substantially worse. If operation at the emergency temperature rating is contemplated, the user must consider the risks that are associated with this elevated temperature operation . . ."

The complete relationship for determining intermediate overload rating is as follows:

$$\frac{I_E}{I_N}\% = \sqrt{\frac{\dfrac{T_E - T_O}{T_N - T_O} - \left(\dfrac{I_O}{I_N}\right)^2 e^{\frac{-\theta}{K}}}{1 - e^{\frac{-\theta}{K}}}\left(\frac{230 + T_N}{230 + T_E}\right)} \times 100 \qquad (5)$$

where

I_E is emergency operating current rating
I_N is normal current rating
I_O is operating current prior to emergency
T_E is conductor emergency operating temperature
T_N is conductor normal operating temperature
T_O is ambient temperature
K is a constant, dependent on cable size and installation type (see Table 9)
230 is zero-resistance temperature value (Average value. For copper use 234, for aluminum use 228.)
e is base for natural logarithms
θ is time (s)

Table 9—K factors for equations in 7.3.4

Cable size	Air		Underground duct	Direct buried
	No conduit	In conduit		
Small < #2	0.33	0.67	1.00	1.25
Medium #2 to #4/0	1.00	1.50	2.50	3.00
Large ≥ 250 kcmil	1.50	2.50	4.00	6.00

If the cable has been operated at its rated current prior to the excursion, then $I_O/I_N = 1$ so the relation is simplified to:

$$\frac{I_E}{I_N}\% = \sqrt{\frac{\dfrac{T_E - T_O}{T_N - T_O} - e^{\frac{-\theta}{K}}}{1 - e^{\frac{-\theta}{K}}}\left(\frac{230 + T_N}{230 + T_E}\right)} \times 100 \qquad (6)$$

This equation is the basic formula used in this recommended practice as representing the maximum safe capability of the cable.

While many medium-voltage cables are operated at less than full rated capacity, most low-voltage cables are operated near their rated ampacity. Even for medium-voltage cable, full loading is occasionally impressed. Regardless of preloading, protection should be coordinated with cable characteristics, not loading. Therefore, data presented in this subclause are based on 100% preloading, by the preceding equation. Factors are developed for approximating the characteristic for lower preloadings. For such preloadings, the data presented in this subclause are even more conservative.

Intermediate zone characteristics of medium-voltage cables and 75 °C and 90 °C thermoplastic cables are tabulated in Table 12 with the characteristics of medium-voltage cable illustrated graphically in Figure 21. These factors all apply to preloading at rated ampacity at 40 °C ambient temperature. For lower ambient temperatures and when cable ampacities have been increased to take this into account, the intermediate overload current percent should be reduced by the factors shown in Table 10 for each degree decrease in ambient temperature below 40 °C.

Table 10—Intermediate overload multipliers when cable ampacities are increased due to lower ambient temperature

Cable	Factor
EPR or XLPE	0.004
THH	0.002
THW	0.0037

For preloading less than 100% of rating, emergency overload percentages can be increased by the factors given in Table 11.

Table 11—Emergency overload multipliers based on preloading less than 100% of rating

	Preloading		
	75%	**80%**	**90%**
All insulation types	1.33	1.25	1.11
NOTE—This may safely be done only for permanent preloadings of these percentages.			

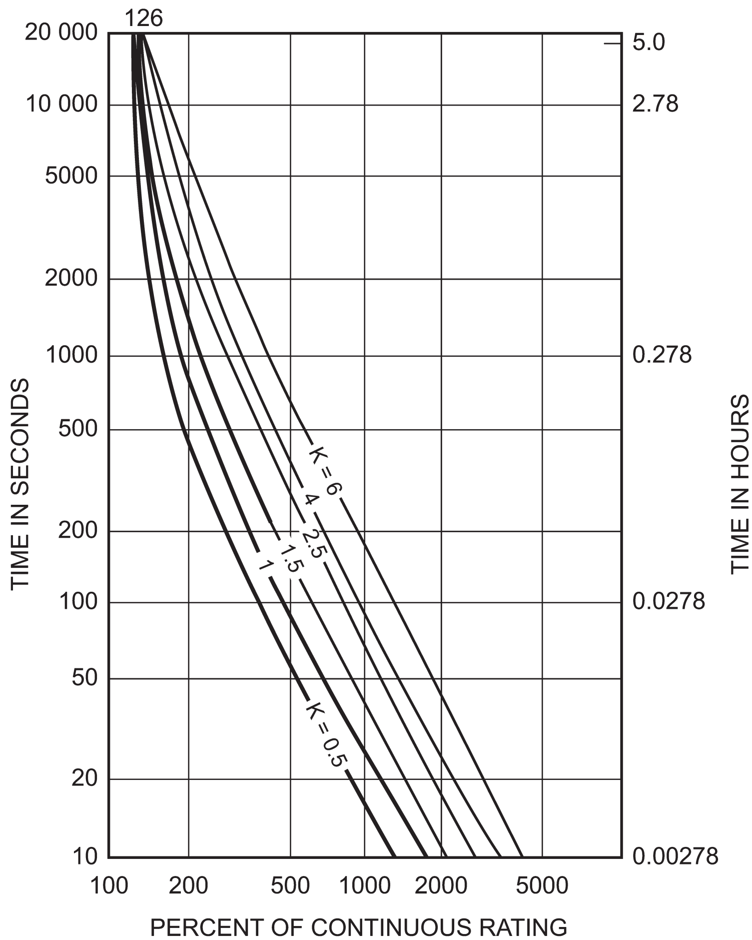


Figure 21—Emergency overload current protection of continuous rating, EPR-XLPE insulated cable, 40 °C ambient temperature

Intermediate time-current overload curves such as in Figure 22 can also be determined by use of Table 12 and Table 14. An example of the use of the tables follows.

Example

Determine the intermediate time-current emergency overload curve for three, single-conductor, #2 AWG copper, 5 kV EPR cables in conduit in air in an ambient temperature of 40 °C.

Table 12—Emergency overload current I_E, percent of continuous rating at 40 °C ambient temperature

Time		Values of K					
Seconds	**Hours**	**0.5**	**1**	**1.5**	**2.5**	**4**	**6**
		EPR or XLPE	T_N = 90 °C		T_E = 130 °C		
10	0.00278	1136	1602	1963	2533	3200	3916
100	0.0278	374	518	629	807	1018	1244
1000	0.278	160	195	226	277	339	407
10 000	2.78	126	128	132	140	152	168
18 000	5.0	126	127	128	131	137	147
		THH	T_N = 90 °C		T_E = 105 °C		
10	0.00278	725	1020	1248	1610	2033	2487
100	0.0278	250	338	407	518	651	794
1000	0.278	127	146	163	192	229	270
10 000	2.78	111	112	114	118	124	131
18 000	5.0	111	111	112	113	116	121
		THW	T_N = 75 °C		T_E = 95 °C		
10	0.00278	987	1390	1703	2197	2775	3396
100	0.0278	329	452	548	702	884	1080
1000	0.278	148	177	202	245	298	357
10 000	2.78	121	123	125	132	142	154
18 000	5.0	121	121	122	125	130	137

For #2 AWG EPR insulated cables in conduit in air, the K factor is 1.5 (see Table 9). NEC 2020 Table 311.60(C)(73) lists an ampacity of 130 A for #2 AWG, 5 kV copper cables in conduit in air. Incorporation of these data into Table 12 is tabulated in Table 13.

Table 13—Allowable emergency overload

From Table 12		
Percent of continuous-current capability for EPR or XLPE at K = 1.5	**Time (s)**	**Allowable emergency overload amperes based on 130 A continuous-current rating (40 °C ambient temperature)**
1963	10	2552
629	100	818
226	1000	294
132	10 000	172
128	18 000	166

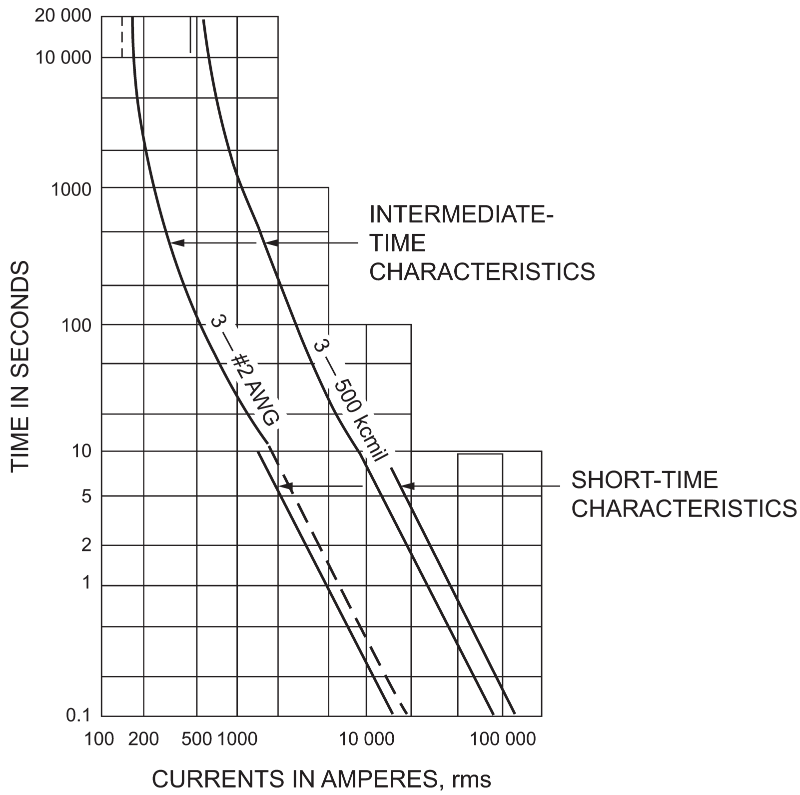


Figure 22—Ratings of small and large cable in conduit in air, intermediate and short time, EPR and XLPE

Table 14—Emergency overload current I_K, percent of continuous rating at 20 °C ambient temperature, direct buried, T_N = 65 °C, T_E = 80 °C

Time		Values of K		
Seconds	Hours	1.5	3	6
10	0.00278	1313	1853	2616
100	0.0278	427	594	834
1000	0.278	168	213	282
10 000	2.78	115	121	134
18 000	5.0	113	116	123

7.3.5 Direct buried cables

With direct buried cables, the conductor operating temperature needs to be kept at no more than 65 °C to keep the outside surface temperature below 60 °C, unless the supply of moisture in the soil is ample. For higher surface temperature, moisture in the normal soil migrates away from the cable, raising the soil thermal resistivity and resulting in overtemperature of the cables. Therefore, for intermediate emergency overload, a maximum conductor temperature of 80 °C has been selected as suitable to preserve this thermal resistivity condition for the times involved. Consequently, the tables and curves shown for air and duct use are not applicable. Table 14 lists values applicable for direct buried installations. The short-time ratings for 250 °C are still applicable for this service because the times involved do not cause moisture migration.

7.3.6 Additional observations

The absolute values of the short-time temperature and the emergency operating loading temperature are not precise. They are values selected and proven to apply to the respective cable types without undue deterioration. For example, tests by Georgia Power Company of fault conditions imposed on medium-voltage cable showed no appreciable degradation even where the nominal short-time temperature was exceeded by about 50 °C. Likewise, the 130 °C emergency operating temperature has an applicable time value of 36 h for no undue deterioration. Deducing that this insulation can tolerate a somewhat higher temperature (e.g., 150 °C to 175 °C) for a time shorter than 36 h is only logical. This condition is undoubtedly true, but its inclusion in calculations would make them unreasonably complicated.

A compensating factor exists in the intermediate range. An overcurrent in the 10 s to 100 s range, for example, would not have sufficient time to cause heat to be dissipated by earth that was in contact with the cable. Times over 100 s, and certainly 1000 s, would see this region of the heat dissipation chain contributing to the action. Therefore, attributing the surrounding medium's heat dissipation characteristics in the shorter portion of the intermediate zone is illogical. Yet, a rigorous mathematical consideration would again substantially complicate the analysis.

Therefore, a trade-off exists: the ability of insulation to withstand higher than nominal operating temperatures for shorter periods is considered adequate compensation for the lack of contribution of the surrounding media in absorbing heat during the shorter portion of the intermediate zone. Without this convention, establishing both varying allowable temperatures and K factors over the whole range of the intermediate zone would be necessary, and such calculations would be an undue burden when the present method yields satisfactory results.

Even the 36-h nominal limit for 130 °C operation for medium-voltage cable does not mean that lower operating temperatures cannot be tolerated for longer periods. For example, to illustrate the nature of the situation, 120 °C might be tolerated for 75 h, 110 °C for 150 h, and 100 °C for 500 h. Setting a continuous protective device to trip at precisely the 80 °C ampacity is almost certain to result in nuisance tripping on power surges. Therefore, the device may typically be set near 110% of rated cable ampacity, or an operating temperature of 100 °C. Visual or similar monitoring would be used to keep the continuous loading of a cable from exceeding its rated ampacity for long periods of time.

7.4 Overload protective devices

7.4.1 Time-current curves

The time-current overload characteristics (see Figure 21 and Figure 22) of the cables differ from the short-circuit current characteristic (see Figure 2 and Figure 3). The overloads can be sustained for a much longer time than the short-circuit current, but the principle of protection is the same. A protective device provides maximum protection if its TCC closely matches the temperature-current-time curve of the cable overload characteristic. Overcurrent protective devices are available today with a wide selection of protection characteristics. Some of the characteristics are well suited for thermal protection of cable insulation. Other characteristics may be suitable for the protection of other distribution equipment, end use equipment, and addressing other failure conditions, such as arcing. Protective device characteristics may also be intended primarily to provide selective coordination rather than optimized strictly for cable insulation thermal protection. The power system design must balance these multiple requirements while maintaining the protection of the cables and other equipment.

7.4.2 Overcurrent relays

Overcurrent relays have inverse time characteristics of varying slopes. In the order of increasing slope, these characteristics with standardized slopes are referred to as *inverse, very inverse,* and *extremely inverse*. Inverse time relays are not necessarily intended to provide cable insulation temperature protection. Very inverse or extremely inverse relays provide better protection than inverse relays. However, all overcurrent relays can be set to afford the cables sufficient protection. Figure 6 shows the cable protection given by overcurrent relays (Device 51). This protection can be provided by overcurrent relays of the induction disk, static, or digital electronic relay types. Modern protective relays also commonly provide user-defined curves which may optimize protection or provide adequate protection where the standard curves do not.

7.4.3 Thermal overload relays

Thermal overload relays are typically applied for motor protection and consequently may partially protect the conductors feeding the motor. Thermal overload relays may be applied in conjunction with molded-case circuit breakers, motor circuit protectors, or fuses to protect low-voltage motors or with fused contactors or circuit breakers to protect medium-voltage motors. Thermal overload relays may be bimetallic, electromechanical, static analog, or microprocessor devices.

Thermal overload relay ratings or characteristics are generally selected to protect the motor after taking into account the conflicting goals of adequately protecting the motor from overload while providing maximum flexibility to the driven equipment operation. Consequently, if a particular thermal overload relay characteristic does not adequately protect a cable as outlined in 6.4.3, it is usually not practical to decrease the time delay of the relay since this would afford the motor operation less flexibility. Instead, the conductor size is typically increased so the cable has sufficient thermal withstand capability to be adequately protected by the initial overload relay characteristic.

IEEE Std 3004.8™ [B39] has extensive information on overload relays, including the cold and warm overload relay curves.

7.4.4 Fuses

Where selected to match the ampacity of the cable, fuses provide protection against overcurrents, which include high-magnitude short-circuit currents and overloads. Fuses are available with varying time-current curves. Fuse curves will vary depending on whether they are fast acting or if they incorporate a time delay. Figure 5 and Figure 11 illustrate these applications. Figure 11 illustrates a combination of fast-acting 400 A fuse and motor overload relays. Had a 225 A dual-element fuse (selected for the ampacity) been used, the fuse alone would have provided overload protection.

Detailed treatment of fuses is given in IEEE Std 3004.3™-2020 [B37], in Chapter 5 of IEEE Std 141-1993 [B13], and in Chapter 5 of IEEE Std 241-2007 [B15].

7.4.5 Low-voltage power circuit breakers in switchgear

Contemporary low-voltage power circuit breakers are typically equipped with digital electronic trip units. A common long-time protection function is an I^2t = constant tripping curve. This tripping curve provides protection of the cable in the long-time region since the I^2t characteristic closely matches the characteristic of the cable heating. Other curves, such as I^4t, may also be available; these curves can offer cable protection in addition to coordination with other overcurrent protective devices, such as fuses on the transformer primary. Also, commonly available are short time and instantaneous trip functions with wide ranging settings that can be adjusted to provide excellent protection against high-magnitude faults.

Legacy low-voltage power circuit breakers with magnetic trip devices have a wide range of tripping tolerances. Their long-time characteristics match the cable overload curves for almost three quarters of an hour (see Figure 7). Static trip devices provide better protection than magnetic direct-acting trip devices. However, for safe cable protection, the long-time pickup should be set below the heating curves of the cable by sizing the cable with normal loading current slightly greater than the trip device pickup current.

7.4.6 Thermal magnetic trip devices on MCCBs

Thermal magnetic trip MCCBs provide good thermal protection for all long-term overloads, as shown in Figure 9. The instantaneous magnetic trip also provides good protection for higher magnitude faults. MCCBs properly selected for the ampacity of the cable can be expected to provide this full range of cable protection. Furthermore, for applications with extremely high available fault currents, current-limiting circuit breakers can be used. Current-limiting circuit breakers provide excellent protection against these extremely high-magnitude short circuits.

7.5 Application of overload protective devices

7.5.1 Feeder circuits to panels

A single- or multiple-cable feeder leading to a panel with or without an intermediate pull box should be protected from excessive overload by a thermal overcurrent device. If there are splice joints and a different type of installation, such as from an exposed conduit to an underground duct, the cable segment with the lowest current-carrying capacity should be used as the basis for protection.

A single-cable feeder with taps to individual panels cannot be protected from excessive overload by a single protective device at the sending end unless the cable is oversized. Therefore, overload protection of the tap cable should be provided at the receiving end. The protection should be based on the current-carrying capacity of the cable supplying power to the panel. A multiple-cable feeder with only a common protective device does not have overload protection for each cable feeder. In this case, overload protection should be provided at the receiving end. The application of taps and multiple cable feeders is restricted by the NEC; see NEC 2020 Sections 240.21(B) and 310.10(G) or the CE Code-2018 Section 4.

7.5.2 Feeder circuit to transformers

A feeder circuit to one or more transformers should be protected in a similar manner as for feeder circuits to the panels. However, a protective device selected and sized for transformer protection also provides protection for the primary cable because the cables sized for a full transformer load have higher overload capability than the transformer. (See Figure 5 for a comparison of the TCCs between cable and transformer.) Transformer protection must also consider the required inrush to energize the transformer.

7.5.3 Cable circuit to motors

A cable circuit to one or more motors should be protected in a similar manner as for cable circuits to panels. Again, a protective device selected and sized for motor overload protection also provides cable protection because the cable has a higher overload capability than the motor (see Figure 11). For more information, see 5.12, Motor and conductor protection, in IEEE Std 3004.8 [B39].

7.5.4 Protection and coordination

Protective devices should be selected and cables sized for coordinated protection from short-time overload. The method of coordination is the same as for the short-circuit protection, that is, the TCC of the protective device should be below and to the left of the cable overload curve (see Figure 21 and Figure 22). Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11 illustrate the protective characteristics of relays and devices commonly used in cable circuits for overload protection.

8. Physical protection of cables

8.1 General

Cables require protection against physical damage, as well as from electrical overload and short-circuit conditions. The physical conditions that should be considered are divided into three categories: mechanical hazards, adverse ambient conditions (excluding high temperatures), and attack by foreign elements. Cables can also be (and frequently are) damaged by improper handling during installation. Guidance for selection of cables for many industrial applications can be found in IEEE Std 1242, IEEE Std 576™, and AEIC GC5. IEEE Std 525™, although written for utility substation design, has some useful guidance for the design and installation of cable systems for industrial and commercial facilities. Refer to NEMA "Storm Reconstruction" [B48] for consideration when specifying new/replacement conductor systems.

8.2 Mechanical hazards

Electric cables can be damaged mechanically by vehicles, falling objects, misdirected excavation, or failure of adjacent circuits. Mechanical protection should serve the dual function of protecting cables and limiting the spread of damage in the event of an electrical failure. NEC 2020 Section 300.4 and CE Code Section 12 discuss protection against physical damage.

Isolation is one of the most effective forms of mechanical protection. Conduit, tray, and duct systems are more effective if they are physically out of the way of probable accidents. A highly-elevated cable is adequately protected against vehicles and falling objects. Where conduits or other enclosures must be run adjacent to roadways, large steel or concrete barriers provide adequate protection.

8.3 Exposed raceways

The most popular form of mechanical cable protection is the use of conduits or raceways. In addition to the electrical benefits of the grounded enclosure, the metallic conduit or raceway protects the cable against most types of mechanical damage. Cable trays are also common because they are economical and convenient for power and control cable systems. Cables may have increased protection from mechanical damage through the use of solid metal tray covers and metal barriers in the trays between different circuits. Covers incur derating, however. Refer to NEMA WC 51 for guidance on derating for tray covers.

8.4 Underground systems

The NEC 2020, Section 300.5 and Section 300.50, or the CE Code-2018 Clause 12–012, provide requirements for protecting underground installations from damage. Underground ducts or embedded conduits provide similar mechanical protection. Ducts should be encased in concrete for best results. Where they are subject to heavy traffic or poor soil conditions, including susceptibility to movement from frost heaving, reinforcement of the concrete envelope is desirable. Because excavation near underground cable runs is always a problem, coloring the concrete around electrical ducts is advisable. The addition of approximately 1.5 kg of iron oxide per 25 kg sack of cement provides a readily identifiable red color, which is meant as a warning to anyone digging into the run. The color is effective even in mud or similarly colored soil because it is conspicuous as soon as the concrete is chipped.

8.5 Direct buried cables

The NEC 2020, Sections 300.5 300.50 and the CE Code Section 12, provides requirements for protecting underground installations from damage. The direct buried cables should be carefully routed to minimize damage from traffic and digging and to avoid areas where plant expansion is predicted. Cables should be covered with some type of special material, such as detectable aluminum foil underground warning tape that has black text ELECTRIC LINE on a red background and is 100 mm (4 in) to 150 mm (6 in) below the surface, and a wooden or concrete plank. Warning signs should also be placed above ground at frequent intervals along the cable route. Retention and regular update of underground drawings is essential.

8.6 Aerial cable systems

Insulated cables on a messenger require special care. These systems are especially susceptible to installation damage. They should be located away from possible interference from portable cranes and support systems and protected from vehicle damage. Space or solid barriers provide reasonable protection for supports, whereas warning signs and nonelectric cables strung between electric cables and roadways offer protection against cranes and high vehicles. Where road crossings are necessary, some users have installed permanent inverted U-shaped metal pipes as additional protection against damage from portable cranes or high vehicles.

8.7 Portable cables

Exposed portable cables require extra consideration from a mechanical standpoint. Because they must remain portable, enclosures are not practical. The proper selection of a portable cable type provides one of the best methods of protection. It should be selected to match operating conditions. Moisture resistance, resistance to cutting or abrasion, and type of armor are all considerations that influence cable life. However, even the best cables require mechanical consideration in service. They should not be subjected to vehicular or steel-tired hand-pushed traffic. Means should be arranged to allow traffic to pass over or under cables without contacting the cable. Care should also be taken in moving portable cables to avoid snags or cuts. They should be located where they are clear of welding and where falling objects are not a serious hazard. A conspicuous color on the jacket is beneficial in warning personnel of the location of a portable cable. Some users have found cables specially designed for oil well drilling applications (commonly described as type P cable) or for mine use (mine trailing cables) as described in ICEA S-75–381/NEMA WC 58) to be useful in some of these severe duty applications.

8.8 Adverse ambient conditions

Protection from overtemperature caused by short-circuit current or overload conditions has been discussed in Clause 6 and Clause 7. Other ambient conditions, however, cannot be protected by overcurrent devices or by compensation for elevated ambient temperatures.

In any type of cable enclosure, water or dampness should be considered, although underground installations are the most susceptible. Repeated cycles of high and low temperature, combined with humid air, can fill conduits or enclosures with water produced by "breathing" and condensation. Stopping the breathing is almost impossible, but suitable drains at low points will remove water as it collects. Preventing immersion is always desirable, and duct systems and other raceways should be designed to slope so that the water can be removed.

Many of the available cable insulations are highly resistant to moisture; but where moisture is expected, extra care should be taken in selecting the insulation appropriate for that application.

In industrial plants, the moisture problem may be amplified by the presence of various chemicals, and the possibility of chemical contamination should be considered for cables run through any process facility. Chemical seepage into ground water, or direct contact due to process misoperation, may result in chemicals coming into contact with a cable system. The enclosure, insulation, and conductor should all be tested to determine the effect of possible chemical contaminants and selected to be most resistant to such chemicals. Where chemical contamination is severe, rerouting of the system should be considered. Acids and organic solvents are especially harmful. Where cables may be subject to combustible vapors, hazardous location (HL) rated cables are tested against migration of vapors due to no more than atmospheric pressure when used at more than a nominal minimum length.

Fires, which may result directly from cable failure or from unrelated external conditions, can cripple almost any cable system. Critical circuits should be separated from other circuits, to lessen the extent of fire damage. The use of multiple circuits following different routes can assure continuous service.

Pull boxes, pits, and manholes used as pulling points or sorting areas are the greatest fire hazards with respect to fault conditions; and elimination of the common enclosure for several circuits, where possible, offers valuable protection.

Where it is not possible to adequately separate critical cables from combustibles, there are two basic ways to protect a cable from an impinging fire. A variety of fire-resistant wraps or coatings can be applied to the cables (such as in IEEE Std 848), or cables designed and tested to resist specific fire conditions can be installed. Cables which are inherently fire resistive are called *circuit integrity cables*. There are presently two general types of circuit integrity cables—cables designed to withstand building fires, and cables designed to withstand hydrocarbon pool fires. The hydrocarbon pool fire cable test (IEEE Std 1717™) rises to its target temperature extremely rapidly compared with the building fire test (UL 2196). However, it is common for UL 2196 cables to be required to be serviceable for a fire exposure of up to three hours, especially when used in life safety systems for high-rise buildings. IEEE 1717 cables, on the other hand, are often only required to withstand their fire exposure for approximately 15 min, due to the nature of their typical installations.

When subject to building fire exposure, cables for use in critical applications (electrical fire pumps, ventilation/smoke exhaust and pressurization fans, emergency lighting and alarm and speaker systems, access doors, elevators used by emergency personnel/fire responders, etc.) are recommended to be listed to UL 2196 (2nd edition)/CAN/ULC-S139 (3rd edition) [B70]. It is necessary that splices and joints also be certified to the UL Product Category Code FHIT Electrical Circuit Integrity Systems. Stainless steel cable ties and identification systems should be considered for these applications.

When subject to hydrocarbon pool fires (for example, in some parts of a petroleum refinery), cables for use in critical applications (typically safety shut down equipment) should be tested to IEEE Std 1717 and installed in accordance with IEEE Std 1810.

In all cases the selection of proper cable routings, enclosures, coverings, and specialty cable types can minimize fire damage. The method chosen should be based on the potential risks involved. Underground installation, redundant cables with diverse routings, heavier or fire-protected enclosures, higher cable racks, fire protective over-insulation, and special fire-resistive cables, are all considerations for protection from various types of fire damage. When cables are exposed to sunlight, they should be marked as sunlight resistant, as required by both the NEC and the CE Code.

8.9 Attack by foreign elements

In some environments, cable systems may be subject to attack by animals, insects, plants, and fungi, all of which may possibly cause cable failure. Rodents such as gophers, rats, squirrels, as well as termites may attack aerial and underground cables. Consult the cable manufacturers for products having appropriate metallic armor and jackets for the application.

In certain applications, such as food processing plants and tropical environments, fungus, mold, and bacteria may grow on cable and wire systems. The creation of a dry atmosphere is an effective deterrent, although fungus-resistant coatings and insulations are the protection methods most often employed.

9. Busway

9.1 Introduction

This section is intended to cover busway products manufactured by various major manufacturers of electrical equipment for use in LV distribution within commercial and industrial facilities. These are often referred to as *sandwich bus*. It does not cover isolated-phase bus (IPB), also known as *phase-isolated bus (PIB)* in some countries, a method of distributing power for circuits carrying very large currents, typically between a generator and its step-up transformer in a steam or large hydro-electric power plant. Nor does it cover segregated and non-segregated bus in large housings used, typically, for short runs in industrial facilities. For additional information on busway see:

- The busway section in IEEE Std 3001.5 [B33]
- UL 857/CSA C22.2 No. 27/ANCE NMX-J-148 [B66], the predominant standard for listed and certified LV busway
- IEEE Std C37.23™ [B42] includes non-segregated-phase bus, cable bus, segregated-phase bus, and isolated-phase bus
- CSA C22.2 No. 201
- CSA/ANSI C22.2 No. 273

Installation requirements are also described in the NEC 2020 Article 368.

9.2 Busway-related definitions

busway: Defined by the National Electrical Manufacturers Association (NEMA) as a pre-fabricated electrical distribution system consisting of bus bars in a protective enclosure, including straight lengths, fittings, devices, and accessories. Busway may also be referred to as *bus duct*. It is an alternative means of conducting electricity to power cables or cable bus. Within the NEC it is defined as a raceway consisting of a metal enclosure containing factory-mounted, bare or insulated conductors, which are usually copper or aluminum bars, rods, or tubes. *Syn:* **bus duct**.

feeder busway: Used for conducting electricity from a source to a load. Loads may be tapped via power-takeoff devices bolted on to connections within the busway length or at the ends.

plug-in busway: Used for conducting electricity from a source to multiple loads. Load are connected to devices that plug into the busway along its length. Plugs may be available on one or two sides of the busway along all or parts of its length.

9.3 Busway protection

Busway predominantly used in modern commercial and industrial facilities is built as sandwich bus which consists of copper or aluminum bus bars encased in some type of insulating material and placed close together. Other types of busway may depend on space as the insulating material between busbars, and in some cases may have grounded isolating planes between phases. This later type, referred to as *isolated-phase bus,* has limited application, usually in generating facilities, and is not the subject of this text. Busway may be used indoors or outdoors if the housing is rated for outdoor installation.

Ground-fault protection should be selected similarly as for any other conductor. Attention should be paid to the impedance of the ground path. Generally, the lower the impedance the more reliable ground-fault protection may be. Busway manufacturers may offer alternative construction styles that may offer alternative ways to carry ground current.

The NEC 2020 Section 368.17 includes overcurrent protection requirements for busway, which may be summarized as follows:

- A busway must be protected against overcurrent conditions based on the allowable current rating of the busway, which includes the temperature at which the busway is applied. Applicable provisions of NEC 2020 Section 240.4 (or other installation codes as applicable) shall apply.

- Reduction in ampacity size of busway along a run are allowed under specific circumstances only, otherwise overcurrent protection shall be required where busways are reduced in ampacity.
- In industrial facilities busway reduced to no less than 1/3 of the capacity and for no longer than 15 m (50 ft) of the overcurrent protection may be installed.
- Feeder or branch circuits from busway may be implemented via plug-in connections for tapping off feeder or power takeoffs that contain the overcurrent devices required for the protection of the feeder or branch circuits.
- The disconnect device shall be an externally operable circuit breaker or an externally operable fusible switch that may be operated from floor level even if that requires ropes, chains, or other mechanism to access the operating handle.

The NEC provides minimum installation guidelines. Certain other exceptions apply. For a full reading of the text, refer to the NEC edition applicable within the relevant jurisdiction.

9.4 Types of faults

9.4.1 Introduction

As with other conductors, faults associated with busways are either bolted or arcing. The faults may occur on the bus or be through-faults located in load side equipment or conductors. Common causes for faults are incorrectly installed joints or connections or where water intrusion is allowed from incorrectly installed outdoor busway. Penetrations through walls where part of the bus is outdoors and part is indoors may be subject to water intrusion if the penetration is not well sealed. It is important that busway be tested for dielectric integrity prior to energization after initial installation, maintenance, or any modification.

9.4.2 Bolted faults

Bolted faults, in this context, refers to the inadvertent fastening together of bus bars in a solid fashion resulting in an unintended connection between phases. Due to the prefabricated nature of busways, bolted faults may be rare, but could occur in an incorrectly installed joint or where connected to equipment. Bolted faults can occur during the initial installation or because of modifications made to the system after installation. The actual offending connection might be found in a bus duct connection piece, but it is more often found in pieces of equipment connected to the busway, such as a switchboard connection or a load served from a bus plug. Because a bolted connection implies a very-low-resistance connection, a high level of fault current may flow as identified by the short-circuit study; therefore, circuit-protective elements should be selected to protect the busway from this high fault level. Bolted faults result in a distribution of energy through the entire length of the busway circuit. This energy flow results in an intense magnetic field around each conductor that opposes or attracts fields around adjacent conductors. The mechanical forces thus created are high and capable of bending bus bars, tearing busway casings apart, or damaging insulation. For this reason, the busway should have a short-circuit withstand rating that is greater than the maximum available fault current and the time that the protection will take to operate at that current. Such ratings are published by the various busway manufacturers and are based on the ability of the busway to withstand the fault current, typically, for three cycles. Often the manufacturers will specify current-limiting fuses that should be used if the possible fault current in the circuit exceeds the intrinsic short-circuit withstand of the busway, so the busway can be applied in higher fault current circuits. Specific manufacturers and products may have higher ratings than those listed in the Table 15. Table 15 provides some minimum short-circuit and withstand ratings available for one manufacturer. However, manufacturers may offer different ratings that may vary with busway conductor material. Table 16 shows increased short-circuit ratings for the same busway when protected by Class L fuses.

Table 15—Busway minimum short-circuit and withstand ratings in kA for one manufacturer

Current rating	Aluminum			Copper		
	3 and 6 cycles	1 s	3 s	3 and 6 cycles	1 s	3 s
225	50	24	14	50	40	21
400	85	24	14	50	40	21
600	85	24	14	85	40	21
800	100	42	24	85	40	21
100	100	50	29	100	51	21
1200	125	62	36	100	65	29
1350	150	84	49	100	76	37
1600	150	95	55	125	95	44
2000	150	121	70	150	129	55
2500	200	132	76	150	150	75
3000	200	169	97	200	191	107
3200	200	169	97	200	191	110
4000	200	200	140	200	200	110
5000				200	200	149
6000				200	200	200

Table 16—Fuse protected short-circuit ratings for the same manufacturer as Table 15

Current rating		Maximum class L fuse	
Aluminum	Copper	100 kA	200 kA
225	225	1200	800
400		1200	800
		1200	800
600	800	2000	1200
	1000		2000
800	1200		2500
1000	1350		2500
1200	1600		3000
1350	2000		4000
1600			4000
2000	2500		4000

9.4.3 Arcing faults

In contrast to the bolted fault, arcing faults can occur at any time in the life of a system. Although many individual factors may initiate an arcing fault, they generally involve one or more of the following: loose connections, foreign objects, insulation failure, voltage spikes, and water entrance. Because of the resistance of the arc and the impedance of the return path, current values may be substantially reduced from the bolted fault level. Lack of maintenance or improper installation can lead to lose connections over time and improper maintenance practices can lead to other issues.

Although the magnitude of current present in an arcing fault is usually less than in a bolted fault, the thermal effect is concentrated at the arc location and can result in significant damage where the arc settles. Furthermore, the arcing fault may be an arc flash hazard to nearby personnel.

9.5 Types of protection

9.5.1 Introduction

Like any other circuit, busways may be subject to overloads, bolted faults, arcing phase faults, and arcing ground faults. Each of these is characterized by different levels of undesirable current and in the case of a ground fault, a characteristic return path, therefore the busway requires a range of protective responses. Busway should be rated based on a temperature rise basis to help provide reliable service.

Conductor size (cross-sectional area) should not be used as the sole criterion for specifying busway. Busway may have seemingly adequate cross-sectional area yet have a dangerously high temperature rise. The UL requirement for temperature rise (55 °C) (see UL 857/CSA C22.2 No. 27/NMX-J-148-ANCE [B66]) should be used to specify the maximum temperature rise permitted. Larger cross-sectional areas can be used to provide lower voltage drop and temperature rise.

Although the temperature rise will not vary significantly with changes in ambient temperature, it may be a significant factor in the life of the busway. The limiting factor in most busway designs is the insulation life, and there is a wide range of types of insulating materials used by various manufacturers. If the ambient temperature exceeds 40 °C or a total temperature in excess of 95 °C is expected, then the manufacturer should be consulted.

9.5.2 Overload protection

Overloads are the temporary conditions that cause a busway to carry currents greater than its continuous-current rating. Short-duration overloads, such as motor-starting currents or transformer inrush, generally are not harmful to the busway because each motor or transformer served is usually small in comparison to the capacity of the busway. However, if the busway is dedicated to a single large load that has temporary inrush, or overload conditions, the busway should be sized and protected appropriately for the expected steady state and transient load conditions. Overloads are more likely to occur because, over time, loads are added to an existing busway circuit until its capacity is exceeded. Because busways tend to use large conductors, they exhibit considerable thermal inertia. For this reason, overloads of a temporary nature may require a substantial time before their effect is noticed. UL 857/CSA C22.2 No. 27/NMX-J-148-ANCE [B66] defines required thermal performance for busway. Busway may be provided with 105 °C or 130 °C insulation systems. Busway may be rated to operate within a 40 °C or 50 °C ambient environment. Manufacturers will provide guidance on clearances that must be maintained between busway and walls to maintain thermal performance and on other parameters that may affect thermal performance, such as harmonic content of the current.

For voltage drop analysis, consult the busway manufacturer and NEMA BU 1.2 [B47] and IEEE Std 3004.5 [B38]. Special considerations may be required for loads rich in harmonics. Consult with the manufacturer to determine if de-rating of the busway is required. Also, the thermal capability of the busway may be impacted by the orientation of the installation, horizontal versus vertical, flat side of bars down or edge down, or if several runs are installed in close proximity. Consult with the manufacturer to get exact guidance.

9.5.3 Arcing fault protection

Arcing fault currents in low-voltage, solidly grounded systems may be a fraction of the prospective bolted-fault current calculated for the same circuit, particularly for single phase ground faults. Such faults, because of their destructive and dangerous nature, should be removed as quickly as possible even if they are low magnitude. If attention is not paid to how quickly the protection operates, at the possible low values of arcing fault current protection, speed may not be sufficient to prevent significant equipment damage or reduce hazard to the levels that may be more acceptable or more easily manageable.

Busway may use as a ground path its case, made from steel or aluminum, an internal dedicated ground bar or a ground bar built into the case structure. How the ground path is achieved by the various designs is less important than the expected ground path impedance. Busway manufacturers may offer multiple optional designs. Generally, it is best to select the design that yields the lowest ground impedance path which may vary by manufacturer or bus rating. The important point is that the lower the ground path resistance, the higher the ground-fault current, and hence the easier it may be to detect and cause the ground-fault protection to operate quickly.

The best protection against an arcing fault is to prevent the fault with well-insulated bus, and the second best is fault protection able to detect the expected low magnitude ground fault combined with a low impedance ground path.

9.5.4 Bolted-fault (short-circuit) protection

Bolted-fault currents can approach the maximum theoretical calculated available fault levels; therefore, protective elements should be able to interrupt these maximum values and the busway must be able to withstand the high fault current for however long the protective device may take to clear the fault. Circuit breakers are suitable in most cases, but current-limiting fuses may be needed when the available fault current exceeds the capability of the busway. The exact protection requirements will vary by manufacturer and busway current rating.

Under certain conditions, busways may be applied on circuits capable of delivering fault currents substantially above the short-circuit withstand rating of the busway. Although electromagnetic forces increase as the square of the current, the energy limitation provided by fast current-limiting fuses permits busways to be applied on circuits having available fault currents higher than the busway stated short-circuit rating. The busway short-circuit rating is based on the busway being able to withstand the fault current for three cycles, while current-limiting fuses clear the short circuit such that the fault current never reaches the prospective fault current peak and the bus never develops the corresponding damaging mechanical forces. Current-limiting fuses limit the magnitude of the peak-let-through fault current to let-through values typically shown in graphs provided by the fuse manufacturers.

In general, a busway may be protected by a Class J, Class R, Class T, or Class L fuse against the mechanical or thermal effects of the maximum energy the fuse allows to flow, providing the fuse continuous-current rating is equal to the bus duct continuous-current rating. Most manufacturers have conducted tests and certify that their designs are satisfactory for use with fuses at least one rating larger than the busway. These higher fuse ratings are often needed for coordination with a circuit breaker in series with the fuse. UL lists busways for maximum short-circuit currents when protected with specific circuit breakers or umbrella fuses. (Umbrella fuses are specifically manufactured to pass the maximum allowable I_p and I^2t permitted by a fuse standard. They are used only for the testing of equipment and devices in order to achieve withstand or series connected ratings.)

9.5.5 Mechanical protection

Busway requires an installation cognizant of mechanical hazards, such as:

- Seismic events and movement within a structure
- Seismic events and movement within multiple structures
- Thermal expansion and contraction of the busway or the structure to which the busway is anchored
- Water intrusion from leaks or rain
- Moving equipment and accidental contact
- Fire

Busway manufacturers will provide mounting hardware and mounting instructions that include spring hangers and methods to allow busway to accommodate its own movement due to thermal expansion and contraction or the movement of the structure within it is installed. Generally, when busway spans a gap between two structures, particularly in seismically-active zones, the installation must account for potential movement of one building with respect to the other so that the busway does not attempt to hold two buildings together. Long runs of busway may be subject to significant thermal expansion or contraction with different ambient temperatures and load levels. Special expansion joints or fittings may be needed, and other aspects of the installation should be designed to accommodate some expected movement. The longer the busway, the more special provisions to accommodate movement may be needed.

Busways installed in a coastal area or zone [as defined by Federal Emergency Management Agency (FEMA) or a state agency] should be specified with non-corrosive (stainless steel or aluminum) housings and fittings (brass, stainless steel, or aluminum).

Water intrusion may be a risk in high-rise buildings if there is a leak in sprinkler systems, water accumulation on a floor, or for other reasons. Penetration openings in floors must have some sort of lip or raised edge, at least 4 in tall per the NEC 2020, to minimize the possibility of the bus duct penetration becoming the preferred channel for leaked water to flow downward.

Penetrations through walls often need fire-proofing to meeting building codes. Some busway may be available with specific materials to provide suitable fire barriers. Bus should always be located so that accidental contact by moving machinery or workers is not probable.

The manufacturer's literature should be reviewed for the specific methods and parts required to provide the various methods of mechanical protection required.

Annex A

(informative)

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