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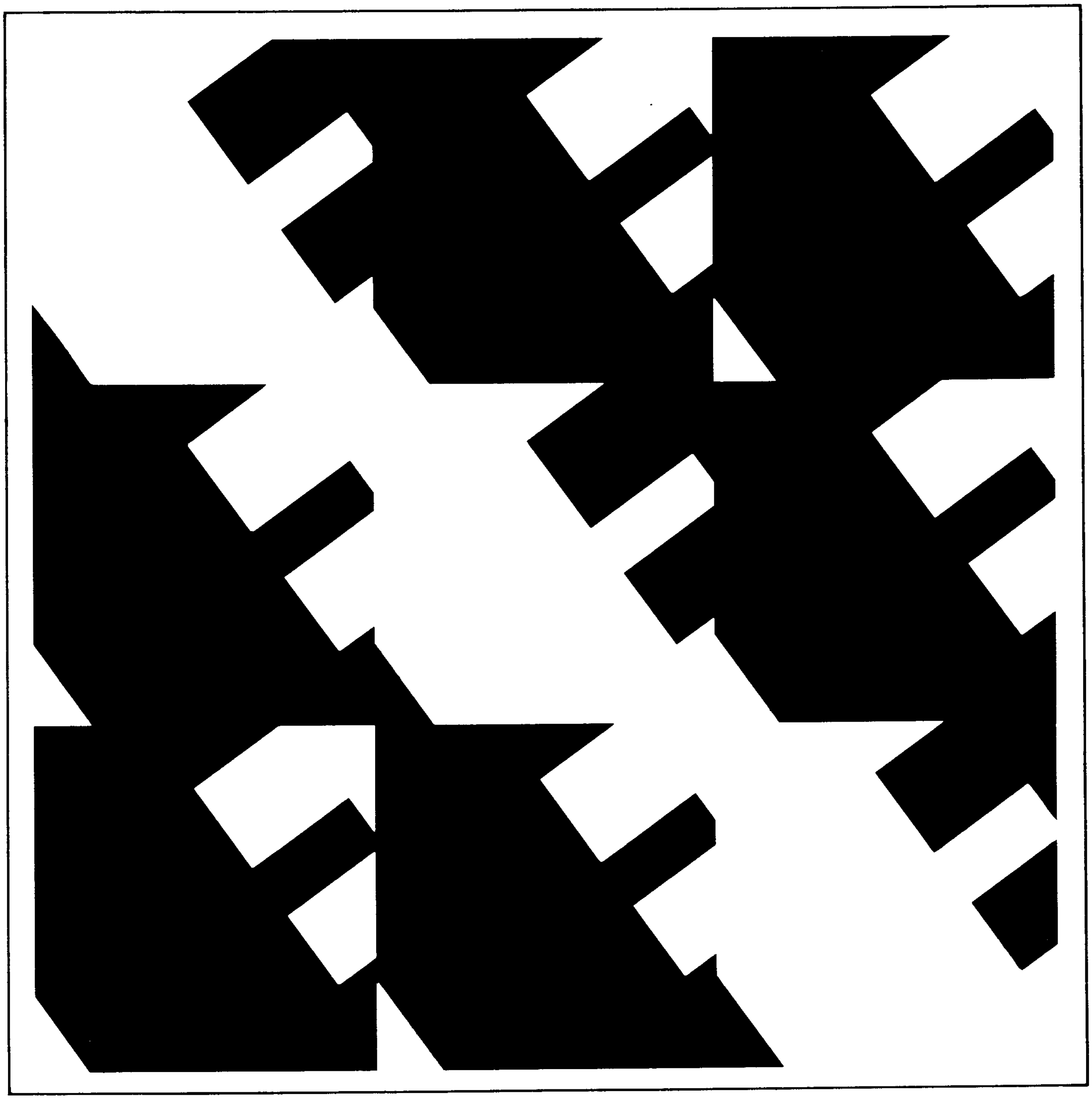
AMERICAN NATIONAL STANDARD

ANSI/IEEE Std 422-1986
(Revision of IEEE Std 422-1977)

IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations



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Std 422-1986
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An American National Standard

IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations

Sponsor

Power Generation Committee of the IEEE Power Engineering Society

Approved March 21, 1985

IEEE Standards Board

Approved July 26, 1985

American National Standards Institute

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Foreword

(This Foreword is not part of ANSI/IEEE Std 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations.)

All sections of this guide have been revised to incorporate the changes in installation philosophies that have occurred since its last issue. Also, Section 12 (Flame Tests) has been dropped since the general industry philosophy has been to reference the section on flame tests given in ANSI/IEEE Std 383-1974 for all installation applications rather than the section on that topic in this document.

This guide was prepared by the Wire and Cable Systems Working Group of the Station Design Subcommittee, Power Generation Committee. The membership of the working group during the preparation of this draft was:

At the time this standard was approved, the members of the Station Design Subcommittee were:

At the time this standard was approved, the members of Power Generation Committee of the IEEE Power Engineering Society were:

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An American National Standard

IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations

1. General

1.1 Scope and Purpose. This document has been developed as a guide for the design and installation of wire and cable systems in generating stations with the objective of minimizing failures and their consequences. It is not intended for use in the design of wire and cable systems in switchyards or substations, which is covered in IEEE Std 525-1978 [17].

This guide applies to both nuclear and nonnuclear electric power generating stations except for the special requirements of wire and cable installations in Class 1E systems of nuclear stations for which the user should refer to ANSI/IEEE Std 690-1984 [5].[1]

1.2 References

[1] AEIC CS5-82, Specification for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 Through 46 kV.[2]

[2] AEIC CS6-82, Specification for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 Through 69 kV.

[3] ANSI/IEEE Std 383-1974, IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generation Stations.[3]

[4] ANSI/IEEE Std 400-1980, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field.

[5] ANSI/IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations.

[6] ANSI/NFPA 70-1984, National Electrical Code (NEC).[4]

[7] ANSI/NFPA 72D-1979, Installation, Maintenance and Use of Proprietary Protective Signaling Systems.

[8] ANSI/NFPA 72E-1984, Automatic Fire Detectors.

[9] ASTM E119-83, Standard Methods of Fire Tests of Building Construction and Materials.[5]

[10] ICEA P-32-382, Short Circuit Characteristics of Insulated Cable.[6]

[11] ICEA P-54-440/NEMA WC51, Ampacities in Open Top Cable Trays.[7]

[1] The numbers in brackets correspond to those of the references listed in 1.2.

[2] AEIC publications are available from Association of Edison Illuminating Companies, 51 East 42nd Street, New York, NY 10017.

[3] IEEE publications are available from the Sales Department, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

[4] NFPA publications are available from Publications Sales, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

[5] ASTM publications are available from the Sales Department of the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

[6] ICEA publications are available from Insulated Cable Engineers Association, PO Box 411, South Yarmouth, MA 02664.

[7] ICEA/NEMA publications are available from Insulated Cable Engineers Association, PO Box 411, South Yarmouth, MA 02664 and NEMA, 2101 L Street, NW, Washington, DC 20037.

[12] ICEA S-19-81/NEMA WC3, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[13] ICEA S-61-402/NEMA WC5, Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[14] ICEA S-66-524/NEMA WC7, Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[15] ICEA S-68-516/NEMA WC8, Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[16] IEEE S-135/ICEA P-46-426, Power Cable Ampacities for Copper and Aluminum Conductors (SH07096).

[17] IEEE Std 525-1978, IEEE Guide for Selection and Installation of Control and Low-Voltage Cable Systems in Substations.

[18] NEMA VE 1-1984, Metallic Cable Tray Systems.[8]

2. Cable Performance

This section provides guidance for cable performance and should be considered in specifying cable for installation in generating stations. No one cable characteristic should be emphasized to the serious detriment of others. A balance of cable characteristics as well as good installation, design, and construction practices are necessary to provide a sound cable system.

2.1 Definitions

design life of a power generating station. The time during which satisfactory station performance can be expected for a specific set of operating conditions.

service life of cable. The time during which satisfactory cable performance can be expected for a specific set of service conditions.

2.2 Service Conditions

(1) Cables may be directly buried, installed in duct banks and trenches below grade, or installed in cable trays, conduits, and wireways above ground. Cable should be suitable for operation in wet and dry locations.

(2) Cable operating temperatures in generating stations are normally based on 40 °C ambient air or 20 °C ambient earth. Special consideration should be given to cable installed in areas where ambient temperatures exceed these values.

(3) Cables should be suitable for all environmental conditions that occur in the areas where they are installed.

2.3 Cable Performance

2.3.1 Service Life. The service life of the cable should be at least equal to the design life of the power generating station.

2.3.2 Thermal Stability. The cable should maintain such insulating properties as required by operating conditions when subjected to maximum ambient temperature and its own generated heat during the design life.

2.3.3 Moisture Resistance. The cable should maintain its required insulating properties for its service life when installed in wet locations, especially underground.

2.3.4 Chemical Resistance. The cable should maintain its required insulating properties when exposed to chemical environments.

2.3.5 Flame Propagation Resistance. Cables installed in open or enclosed cable trays, wireways, or in other raceway systems where flame propagation is of concern should pass the applicable flame test requirement of ANSI/IEEE Std 383-1974 [3].

2.3.6 Radiation Resistance. Cables installed in nuclear power generating stations should maintain their required insulating properties when exposed to the expected cumulative radiation dosage postulated by plant design criteria.

3. Conductor Sizing and Voltage Rating of Power Cables

This section provides guidance for the determination of conductor sizing and voltage ratings of power cables for various types of installations.

3.1 Design Considerations. The proper design of power cable systems requires the consideration of many factors. These factors include ambient temperature, normal and emergency loading, system fault levels, voltage drops, and system nominal voltage and grounding.

[8] NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037.

3.1.1 Ambient Temperature. This factor is an important design parameter because it helps determine the continuous current-carrying capability (ampacity) of a cable of a given size in a particular type of installation. In areas where temperatures exceed stated ambient, cables may require ampacity derating and special types of insulation and jacket material.

3.1.2 Current Loading. Power cables should be capable of carrying normal and emergency load currents. IEEE S-135 [16] provides cable ampacity tables for various cable constructions and methods of installation. These tables are based on 40 °C ambient air and 20 °C ambient earth and include data for various conductor temperatures. Appropriate factors for cable and conduit grouping are also given, as well as an adjustment formula for change in parameters. Note that the ampacities for cables in underground duct banks are based on all power cable ducts being peripherally located and single-conductor, nontriplexed, medium-voltage cable shields grounded at one point. (For ampacity derating due to shield currents of medium-voltage cables with shields grounded at more than one point, refer to 6.1.5.)

Ampacities for nonspaced cables in open top trays should be determined from ICEA P-54-440/NEMA WC51 [11] rather than from IEEE S-135 [16].

Where cables are routed through several types of installation conditions (buried, sun exposure, exposed conduit, covered cable trays, wireways, near hot steam lines, etc), conductor size should be selected for the most severe thermal condition. The application of fire-retardant coverings, penetration fire stops, etc, may affect cable ampacities and should be considered.

NOTE: Guidance for cable ampacity derating is suggested in the following publications:
(1) ENGMANN, GARY. Ampacity of Cable in Covered Tray, *IEEE Transactions on Power Apparatus and Systems,* vol PAS-103, no 2, Feb 1984, pp 345–352.
(2) ENGMANN, GARY. Cable Ampacity in Tray with Raised Covers, accepted for presentation at the 1985 IEEE Power Engineering Society Winter Meeting.
(3) ESTEVES, OSCAR M. Derating Cables in Trays Traversing Firestops or Wrapped in Fireproofing, *IEEE Transactions on Power Apparatus and Systems,* vol PAS-102, no 6, June 1983, pp 1478–1481.
(4) HESTER, V. J., BARRY, R. E., and BEGAN, T. A. Ampacity Test of a Silicone Foam Firestop in a Cable Tray, *IEEE Transaction on Power Apparatus and Systems,* vol PAS-100, no 11, Nov 1981, pp 4680–4684.
(5) NAMGNE, ROY and ASHBAUGH, LOU. Fire Protection of Cables in Central Generating Stations, *IEEE Transactions on Power Apparatus and Systems,* vol PAS-97, no 2, Mar 1978, p 326.
(6) NEMETH, C. W., ROCKLIFFE, G. B., and LEGRO, J. R. Ampacities for Cables in Trays with Firestops, *IEEE Transactions on Power Apparatus and Systems,* vol PAS-100, no 7, July 1981, pp 3573–3579.

3.1.3 System Fault Level. Fault current capabilities of insulated conductors are given in ICEA P-32-382 [10].

3.1.4 Voltage Drop. Voltage regulation requirements should be considered when selecting conductor size. Motor feeder voltage drop under starting and running conditions should be limited to allow the motor to operate within its design specifications.

3.1.5 System Nominal Voltage and Grounding. These factors determine the cable voltage rating and insulation level. ICEA and AEIC standards (see references [1], [2], [10], [11], [12], [13], [14], [15], and [16]) provide guidelines for the proper selection of cable rating and insulation level as well as the overvoltage capabilities associated with cable voltage ratings.

4. Electrical Segregation of Cable Systems

This section provides guidance for the electrical segregation of cable systems according to voltage levels, signal levels, and vulnerability to electrical noise pickup.

4.1 Cable Classifications. Medium-voltage power cables are designed to supply power to utilization devices of the plant auxiliary systems rated 601–15 000 V.

Low-voltage power cables are designed to supply power to utilization devices of the plant auxiliary systems rated 600 V or less.

Control cables are applied at relatively low current levels or used for intermittent operation to change the operating status of a utilization device of the plant auxiliary system.

Instrumentation cables are used for transmitting variable current or voltage signals (analog) or those used for transmitting coded information (digital).

4.2 Segregation. Cables installed in stacked cable trays generally should be arranged by descending voltage levels with the higher voltages at the top.

4.2.1 Medium-voltage Power Cables. These cables should be installed so that the medium-voltage cannot be impressed on any lower voltage system. Methods for achieving this segregation are

(1) Installation of medium-voltage cables in raceways that are separated from low-voltage power and control cables and from instrumentation cables. Installation of different classes of medium-voltage power cables in separate raceways is also suggested.

(2) Utilization of armored shielded cables (separate raceways are not required).

4.2.2 Low-voltage Power and Control Cables. These cable classifications may be mixed if their respective diameters do not differ greatly and they have compatible operating temperatures and voltage ratings. When this is done, the power cable ampacity is calculated as if all the cables are power cables.

4.2.3 Instrumentation Cables. These cables should be installed to minimize noise pickup from adjacent circuits and equipment. Methods for achieving segregation are

(1) Installations that provide physical separation between the instrumentation cables and any electrical noise source;

(2) Installation in separate enclosed magnetic raceways;

(3) Cable construction configurations such as twisted conductors and shielding;

(4) Installation of analog signal cables separate from all power and control cables and from unshielded cables carrying digital or pulse-type signals. Shielded voice communication cable (without power supply conductors) may be included in raceways with analog signal cables.

5. Separation of Redundant Cable Systems

This section provides guidance for the separation of redundant cable systems.

5.1 Redundant Cable Systems. These are two or more systems serving the same objective. They may be systems where personnel or public safety is involved, such as fire pumps, or systems provided with redundancy because of the severity of economic consequences of equipment damage.

NOTE: Turbine-generator ac- and dc-bearing oil pumps are examples of redundant equipment under this definition.

5.2 Design Considerations. Redundant cable systems should be separated to assure that no single credible event will prevent the operation of a particular required plant function. Separation should also be applied to partial capacity systems, such as three 50% systems, to improve service reliability. The degree of separation required varies with the potential hazards to the cable systems in particular areas of the power generating station.

NOTE: Where transient fire loads are possible and need to be accounted for, administrative controls such as procedures, security measures, or fire watch patrols should constitute acceptable measures of protection.

These areas may be classified as follows:

(1) Mechanical damage area
(2) Fire hazard area
(3) Cable spreading room
(4) Cable penetrations

5.2.1 Potential Hazard Areas. Areas requiring special consideration are:

(1) Mechanical Damage Area. Physical arrangement or protective barriers, or both, should be such that no credible missile can cause the destruction of the redundant cable systems. Possible sources of missiles include

(a) Large rotating equipment
(b) High-pressure piping and pressure vessels
(c) Transformers and switchgear
(d) Overhead cranes

NOTE: Crane loads handled only during plant shutdown need not be considered.

(2) Fire Hazard Areas. Redundant cable systems should be arranged to assure that postulated credible fires cannot

(a) Damage more than one system. Routing of redundant cable systems through an area where there is potential for accumulation of large quantities of oil or other combustible material (including coal dust) should be avoided.

(b) Propagate from one system to another. Cables of redundant systems should have sufficient horizontal and vertical separation to prevent ignition of the cables in one system by a fire in the other. If this separation is not attainable, a fire-resistant barrier should be installed.

5.2.2 Cable Spreading Area. The cable spreading area is normally adjacent to the control room where cables leaving the panels are dispersed into various cable trays for routing to all parts of the plant.

(1) Where cables of redundant systems are located such that there is no adequate assurance that a postulated credible fire in one system will not ignite the cable in the redundant system, barriers should be installed between the redundant cable systems. Enclosing both systems in metallic raceways or enclosing one system by cocoon are examples of acceptable barriers.

(2) The cable spreading area should not contain high energy equipment such as switchgear, transformers, rotating equipment, or potential sources of missiles or pipe whip, and should not be used for storing flammable materials. Circuits in the cable spreading area should be limited to control and instrument functions and those power supply circuits and facilities serving the control room and instrument systems. Power supply feeders to instrument and control room distribution panels should be installed in enclosed metallic raceways.

Other power circuits that are required to traverse this area should be assigned to a minimum number of routes consistent with their separation requirements and allocated solely for these power circuits. Such power circuits should be separated from other circuits in this area in accordance with Section 4.2.

NOTE: An acceptable alternative routing for such traversing power circuits would be to route them in embedded conduit or in a separate enclosure (for example, a concrete duct bank or other suitable enclosure), which in effect removes them from the cable spreading area.

6. Shielding and Shield Grounding

This section provides guidance for shielding and shield grounding of medium-voltage power and instrumentation cable systems.

6.1 Medium-voltage Power Cable. The use of shielding and shield grounding of medium-voltage power cables is a common practice to reduce the hazard of shock to personnel, to confine the dielectric field within the cable, and to minimize deterioration of cable insulation or jackets caused by surface discharges. The selection of the shield grounding locations and the effects of single and multiple grounds are points to be considered for the proper installation of shielded cable.

6.1.1 Definition

cable shielding. A nonmagnetic, metallic material applied over the insulation of the conductor or conductors to confine the electric field of the cable to the insulation of the conductor or conductors.

6.1.2 Shielding Practices. Cables rated above 5 kV should be shielded except for special applications or cable designs and where shielding will be used to monitor or test cable installation for additional assurance of insulation integrity. Cable applications in the operating range of 2–5 kV require careful judgment, and each case should be considered on its own merits. The shielding recommendations contained in the ICEA / NEMA standards publications for the type of insulation being utilized should be followed (see ICEA S-19-81 / NEMA WC3 [12], ICEA / NEMA S-61-402 / NEMA WC5 [13], or ICEA S-66-524 / NEMA WC7 [14]).

Cable shielding should be considered in the 2–5 kV range where any of the following conditions exist:

(1) Transition from conducting to nonconducting environment

(2) Transition from moist to dry earth

(3) Dry soil, such as in a desert

(4) Damp conduits

(5) Connections to overhead lines

(6) Locations where cable surface collects conducting materials, such as soot or salt deposits

(7) Electrostatic discharges are sufficient in magnitude to interfere with control and instrumentation circuit functions

(8) Safety to personnel is involved

(9) Long underground cables

(10) Single-conductor cables in trays

6.1.3 Shield Termination Practices. The insulation shield system must be removed carefully and completely, and proper stress control materials or devices used. Manufacturer's instructions and recommendations as to termination of shielded cables should be followed in detail. If all elements of the shield are not removed, excessive leakage current with tracking or flashover may result.

6.1.4 Grounding Practices. Cable shields and metallic sheath / armor should be solidly grounded at one or more points so that they operate at or near ground potential at all times. The length of cable run should be limited by the acceptable voltage rise of the shield if the shield is grounded at only one point. The correction is usually negligible in the following cases for three-phase circuits:

(1) Three-conductor cables encased by a common shield or metallic sheath

(2) Single-conductor shielded cables 500 kcmil conductor or smaller installed together in a common duct

(3) Triplexed or three-conductor individually shielded cables 500 kcmil conductor or smaller

(4) Single-conductor lead-sheathed cables 250 kcmil conductor or smaller installed together in a common duct

Because of the frequent use of window type or zero-sequence current transformers for ground overcurrent protection, care should be taken in the termination of cable shields at the source. If the shield wire is passed through the window-type current transformer, it should be brought back through this current transformer before connecting to ground in order to give correct relay operation.

6.1.5 Shield Losses That Affect Ampacity. Shields or sheaths that are grounded at more than one point carry induced circulating currents. Compensation for the heating effect of the induced circulating current should be considered when calculating the cable ampacity. The magnitude of circulating currents flowing in shields grounded at more than one point depends on the mutual inductance between the cable shielding and the cable conductors and the mutual inductance to the conductors in other cables, the current in these conductors, and the impedance of the shield. Circulating currents heat the shield and reduce the effective ampacity of the cable. Table 1 gives formulas for calculating the shield loss for single-conductor cables.

To facilitate calculating the mutual reactance and shield resistance, the following formulas may be used (these formulas neglect proximity loss, but are accurate enough for practical purposes):

$$X_M = 2\pi f\left(0.1404 \log_{10} \frac{S}{r_m}\right) \mu\Omega/\text{ft} \qquad \text{(Eq 1)}$$

$$\left(X_M = 52.92 \log_{10} \frac{S}{r_m} \mu\Omega/\text{ft at 60 Hz}\right)$$

$$a = 2\pi f(0.1404 \log_{10} 2)\ \mu\Omega/\text{ft} \qquad \text{(Eq 2)}$$

$$(a = 15.93\ \mu\Omega/\text{ft at 60 Hz})$$

$$b = 2\pi f(0.1404 \log_{10} 5)\ \mu\Omega/\text{ft} \qquad \text{(Eq 3)}$$

$$(b = 36.99\ \mu\Omega/\text{ft at 60 Hz})$$

$$R_s = \frac{\rho}{8 r_m t}\ \mu\Omega/\text{ft} \qquad \text{(Eq 4)}$$

where

X_M = mutual inductance of shield and conductor ($\mu\Omega$/ft)
a,b = mutual inductance correction factors for various cable arrangements ($\mu\Omega$/ft)
$\mu\Omega$ = micro-ohm = $\Omega \cdot 10^{-6}$
R_s = resistance of shield ($\mu\Omega$/ft)
t = thickness of metal tapes used for shielding (in)
f = frequency (Hz)
S = spacing between center of cables (in)
r_m = mean radius of shield (in)
I = conductor current (A)
ρ = apparent resistivity of shield in Ω(cmil)/ft at operating temperature (assumed 50 °C). This includes allowance for the spiraling of the tapes or wires.

Typical values of ρ:

overlapped copper tape	30 Ω(cmil)/ft
lead sheath	150 Ω(cmil)/ft
aluminum sheath	20 Ω(cmil)/ft

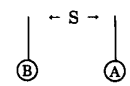
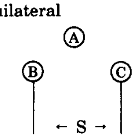
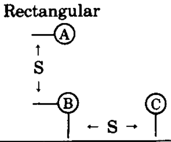
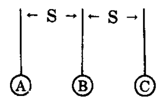
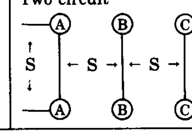
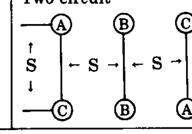
It is assumed that the cables are carrying balanced currents.

For cables installed three per conduit, use Arrangement II in Table 1. The spacing S in this case will be equal to the outside diameter of the able increased by 20% to allow for random spacing in the conduit.

All three phases of a circuit should be installed in the same conduit. When it is necessary to run only one phase per conduit, then nonmetallic or nonmagnetic metallic conduit should be used. If nonmagnetic metallic conduits are used, the effect of additional losses in cable ampacity due to increased reactance should be considered.

6.1.6 Induced Shield Voltages. Shields of single-conductor cable carrying alternating current grounded at only one point will have an increase in potential to ground along the cable length away from the ground point. Table 1 can be used to calculate the induced shield voltage. Table 2 gives the typical cable lengths for shields grounded at only one point to limit the maximum steady-state shield voltage to 25 V. If higher potentials are allowed, the extrapolation is linear. Induced shield voltages also depend on insulation thickness, cable geometry, and spacing. If greater precision than is given in Table 2 is required, separate calculations should be made. Under unbalanced fault conditions, not involving the cable, higher shield potentials may be experienced at the ungrounded end and

Table 1
Formulas for Calculating Shield Voltages—Currents and Losses for Single-Conductor Cables

Cable Arrangement Number and Diagram	I One phase 	II Equilateral 	III Rectangular 	IV Flat 	V Two circuit 	VI Two circuit 
Induced Shield Voltage—Shields Open Circuited			Microvolt to Neutral per ft (Multiply by 10^{-6} to Obtain V_P/ft)			
Cable—A Cable—C	IX_M	IX_M	$\frac{I}{2}\sqrt{3Y^2 + \left(X_M - \frac{a}{2}\right)^2}$	$\frac{I}{2}\sqrt{3Y^2 + (X_M - a)^2}$	$\frac{I}{2}\sqrt{3Y^2 + \left(X_M - \frac{b}{2}\right)^2}$	$\frac{I}{2}\sqrt{3Y^2 + \left(X_M - \frac{b}{2}\right)^2}$
Cable—B	IX_M	IX_M	IX_M	IX_M	$I\left(X_M + \frac{a}{2}\right)$	$I\left(X_M + \frac{a}{2}\right)$
Shield Loss—Shields Solidly Bonded			Microwatt per ft (Multiply by 10^{-6} to Obtain W/ft)			
Cable—A Cable—C	$I^2 R_S \frac{X_M^2}{R_S^2 + X_M^2}$	$I^2 R_S \frac{X_M^2}{R_S^2 + X_M^2}$	$I^2 R_S \frac{(P^2 + 3Q^2) + 2\sqrt{3}(P - Q) + 4}{4(P^2 + 1)(Q^2 + 1)}$			
Cable—B	$I^2 R_S \frac{X_M^2}{R_S^2 + X_M^2}$	$I^2 R_S \frac{X_M^2}{R_S^2 + X_M^2}$	$I^2 R_S \frac{1}{Q^2 + 1}$			
Total loss	$2I^2 R_S \frac{X_M^2}{R_S^2 + X_M^2}$	$3I^2 R_S \frac{X_M^2}{R_S^2 + X_M^2}$	$3I^2 R_S \frac{P^2 + Q^2 + 2}{2(P^2 + 1)(Q^2 + 1)}$			
		$P = \frac{R_S}{Y}$ $Y =$	$X_M + \frac{a}{2}$	$X_M + a$	$X_M + a + \frac{b}{2}$	$X_M + a + \frac{b}{2}$
		$Q = \frac{R_S}{Z}$ $Z =$	$X_M - \frac{a}{6}$	$X_M - \frac{a}{3}$	$X_M + \frac{a}{3} - \frac{b}{6}$	$X_M + \frac{a}{3} - \frac{b}{6}$

* This table has been derived from EEI Underground Systems Reference Book, Ch 10, Table 26. It is reprinted here with permission.

Table 2
Typical Lengths for Cables with Shields Grounded at One Point to Limit Shield Voltage to 25 V

Size Conductor	One Cable Per Duct (ft)	Three Cables Per Duct (ft)
1/0 AWG	1250	4500
2/0 AWG	1110	3970
4/0 AWG	865	3000
250 kcmil	815	2730
350 kcmil	710	2260
400 kcmil	655	2100
500 kcmil	580	1870
750 kcmil	510	1500
1000 kcmil	450	—
2000 kcmil	340	—

should be considered with regard to cable jacket dielectric failure.

These lengths are based on the highest loading condition of copper conductors likely to be encountered. They apply to cables operating at any 60 Hz voltage. The lengths given are from the grounded point to the shield insulating joint. If the midpoint of the section is grounded, the total length between insulating joints can be twice the length given.

6.2 Instrumentation Cable. This subsection provides guidance for shielding and grounding of signal cables used with instrumentation systems.

Specific requirements for and the application of coaxial and triaxial cables are not covered; however, their use wherever required or otherwise deemed applicable is not precluded by these guidelines.

The general rules set forth should be tempered by specific manufacturer's recommendations.

6.2.1 Definitions

normal-mode noise (transversal or differential). The noise voltage that appears differentially between two signal wires and acts on the signal sensing circuit in the same manner as the desired signal.

Normal-mode noise may be caused by one or more of the following:

(1) Electrostatic coupling and differences in distributed capacitance between the signal wires and the surroundings

(2) Electromagnetic induction caused by varying magnetic fields linking unequally with the signal wires

(3) Junction or thermal potentials due to the use of dissimilar metals in the connection system

(4) Common-mode to normal-mode noise conversion

common-mode noise (longitudinal). The noise voltage that appears equally and in phase from each signal conductor to ground. Common mode noise may be caused by one or more of the following:

(1) Electrostatic coupling. With equal capacitance between the signal wires and the surroundings, the noise voltage developed will be the same on both signal wires.

(2) Electromagnetic induction. With the magnetic field linking the signal wires equally, the noise voltage developed will be the same on both signal wires.

common-mode to normal-mode conversion. In addition to the common-mode voltages that are developed in the signal conductors by the general environmental sources of electrostatic and electromagnetic fields, differences in voltage exist between different ground points in a facility due to the flow of ground currents. These voltage differences are considered common-mode when connection is made to them either intentionally or accidentally, and the currents they produce are common-mode. These common-mode currents can develop normal-mode noise voltage across unequal circuit impedances.

crosstalk. The noise or extraneous signal caused by ac or pulse-type signals in adjacent circuits.

shield (cable systems) (instrumentation cables). Metallic sheath (usually copper or aluminum) applied over the insulation of a conductor or conductors for the purpose of providing means for reducing electrostatic coupling between the conductors so shielded and others that may be susceptible to or that may be generating unwanted (noise) electrostatic fields.

NOTE: When electromagnetic shielding is intended, the term *electromagnetic* is usually included to indicate the difference in shielding requirement as well as material. To be effective at power system frequencies, electromagnetic shields would have to be made of high-permeability steel. Such shielding material is expensive and is not normally applied. Other less expensive means or reducing low-frequency electromagnetic induction, as described herein, are preferred.

6.2.2 Methods for Noise Reduction

6.2.2.1 Ground Signal Circuit at One Point. The signal circuit may originate at a source such as a transducer and terminate at a load such as a recorder, either directly or through an intervening amplifier.

If the recorder is fed directly from a grounded voltage generating transducer such as thermocouple, the recorder circuits must be capable of high common mode rejection, or they should be isolated from ground. Isolating the recorder circuits from ground effectively opens the ground common mode voltage path through the signal circuit. If an intervening amplifier is a single-ended amplifier, the low side of the signal circuit is not broken and is grounded at the recorder. Therefore, the situation is not changed, so the same procedure should be followed with the recorder as indicated above.

A guarded isolated differential amplifier provides isolation of both input terminals from the chassis (or ground) and from the output. This amplifier is capable of high common-mode rejection and provides the input-output isolation so that the output ground will not affect the input circuit.

Typically, the common-mode rejection ratio of an isolated differential amplifier used in instrumentation systems is about 10^6:1 (120 dB) and is the ratio of common-mode voltage applied to the amount of normal-mode voltage developed in the process.

When an ungrounded transducer is used, it may be possible to obtain satisfactory results by leaving the transducer circuit ungrounded, connecting the cable shield to the amplifier guard shield, and grounding the shield at either the transducer end or the amplifier end. However, connecting cable shield to amplifier guard shield and grounding both transducer cable shield and circuit at the transduer will result in a less noisy, more stable system.

6.2.2.2 Electrostatically Coupled Noise. Shielding of signal cables will reduce electrostatically coupled noise voltage. A properly grounded shield will greatly reduce the capacitance between the signal conductors and external sources of electrostatic noise so that very little noise voltage can be coupled in the signal circuit.

6.2.2.3 Electromagnetically Induced Noise. The use of twisted-pair cables is the most effective method of electromagnetic noise reduction. By alternately presenting each conductor to the same electromagnetic field, equal (and in phase) voltages are induced in each conductor with respect to ground. The common-mode voltage so developed is converted to a small amount of normal-mode noise as determined by the common-mode rejection ratio of the signal amplifier (isolated differential or equivalent). The frequency of twisting (lay) affects noise reduction ability and, therefore, should be considered in specifying twisted-pair cable.

The materials normally used for shielding of instrument cable are nonferrous and cannot shield against power frequency electromagnetic fields. The steels normally used in conduit or tray are not of high enough permeability to provide very effective shielding at power frequencies. However, some benefit may accrue from the use of rigid steel conduit or steel trays with solid bottoms and tightly fitting solid steel covers.

6.2.2.4 Crosstalk. Using cables with twisted-pair conductors and individually insulated shields over each pair is the best method to minimize crosstalk.

6.2.2.5 Separation (Segregation). Physical separation of instrumentation cables can be utilized to reduce noise pickup. However, physical separation in itself, unless carefully analyzed, may not achieve the desired degree of immunity. Cables should be run in accordance with Section 4.

6.2.2.6 Shield Grounding. Connect shield to ground at only one point, for example, where the signal is grounded. If shield is grounded at some point other than where the signal is grounded, charging currents may flow in the shield due to differences in potential between signal and shield ground locations. If the shield is grounded at more than one point, differences in ground potential will drive current through the shield. In either case, shield current can induce common-mode noise current into the signal leads, and by conversion to normal mode-noise, voltage, proportional to signal circuit resistance unbalance, can reduce accuracy of signal sensing. In a system with grounded transducer and isolated-input differential amplifier, the cable shield should connect to amplifier guard shield, but grounding the shield at the amplifier will reduce the amplifier's common-mode rejection capability. Grounding the shield only at the transducer will maintain the shield at the same ground potential as the transducer, which will minimize shield-induced common-mode current while permitting the amplifier to operate at maximum common-mode rejection capability. Also see paragraph 6.2.2.1

for shield and signal circuit grounding of ungrounded transducers.

6.2.3 Shielding Practices.

(1) The cable for computer or high-speed data logging application, using low-level analog signals, should be made up of twisted, shielded pairs. For noncomputer-type applications, such as annunciators and event recorders, individual shielding may not be required.

(2) Twisting and shielding requirements for both digital input and digital output signals vary among different manufacturers of computerized instrumentation systems. Separation of digital input cables and digital output cables from each other and from power cables may be required. Where digital inputs originate in close proximity to each other, twisted-pair multiple-conductor cables with overall shield may be permitted, or multiple-conductor cable with common return may be permitted, and overall shielding may not be required. Digital output cables of similar constructions may also be permitted. Individual twisted and shielded pairs should be considered for pulse-type circuits.

(3) Cable shields should be electrically continuous except where specific reasons dictate otherwise. When two lengths of shielded cable are connected together at a terminal block, an insulated point on the terminal block should be used for connecting the shields.

(4) Shields should be isolated and insulated except at their selected grounding point to prevent stray and multiple grounds to the shield.

(5) At the point of termination, the field should not be stripped back any further than necessary from the terminal block.

(6) The shield should not be used as an electrical conductor.

6.2.4 Grounding Practices.

(1) All shields should be grounded in accordance with 6.2.2.6.

(2) Signal circuits, if grounded, should be grounded at only one point.

(3) Digital signal circuits should be grounded only at the power supply.

(4) The shields of all grounded junction thermocouple circuits and the shields of thermocouple circuits intentionally grounded at the thermocouple should be grounded at or near the thermocouple well.

(5) Multipair cables used with thermocouples should have twisted pairs with individually insulated shields so that each shield may be maintained at the particular thermocouple ground potential.

(6) Each resistance temperature detector (RTD) system consisting of one power supply and one or more ungrounded RTDs should be grounded only at the power supply.

(7) Each grounded RTD should be on a separate ungrounded power supply except as follows: Groups of RTDs embedded in winding of transformers and rotating machines should be grounded at the frame of the respective equipment for safety. A separate ungrounded power supply should be furnished for the group of RTDs installed in each piece of equipment.

(8) When a signal circuit is grounded, the low or negative potential lead and the shield should be grounded at the same point.

7. Cable Penetration Fire Stops, Fire Breaks, System Enclosures, and Coatings

This section provides guidance for the selection and application of cable penetration fire stops, cable fire breaks, cable system enclosures (cocoons), and coatings for cable systems. For guidance in ampacity derating where using these systems, refer to note in 3.1.2.

7.1 Definitions

fire-resistive barrier. A wall, floor, or floor-ceiling assembly erected to prevent the spread of fire. (To be effective, fire barriers must have sufficient fire resistance to withstand the effects of the most severe fire that may be expected to occur in the area adjacent to the fire barrier, and must provide a complete barrier to the spread of fire.)

fire-resistive barrier rating. This is expressed in time (hours and minutes) and indicates that the wall, floor, or floor-ceiling assembly can withstand, without failure, exposure to a standard fire for that period of time. The test fire procedure and acceptance criteria are defined in ASTM E119-83 [9].

cable penetration. An assembly or group of assemblies for electrical conductors to enter and continue through a fire-rated structural wall, floor, or floor-ceiling assembly.

cable penetration fire stop. Material, devices, or an assembly of parts providing cable penetrations through fire-rated walls, floors, and floor-ceiling assemblies and maintaining their required fire rating.

cable fire break. Material, devices, or an assembly of parts installed in a cable system, other than at a cable penetration of a fire-resistive barrier, to prevent the spread of fire along the cable system.

cable system enclosure (cocoon). An assembly installed around a cable system to maintain circuit integrity, for a specified time, of all circuits within the enclosure when it is exposed to the most severe fire that may be expected to occur in the area.

fire-protective coatings. A material applied to a completed cable or assembly of cables to prevent the propagation of flame. Fire-protective coatings include liquids, mastics, and tapes.

7.2 Cable Penetration Fire Stops. The fire stop should prevent fire propagation along a cable system through a fire-rated wall, floor, or floor-ceiling barrier while maintaining the integrity of the fire barrier through which the cable system penetrates.

7.2.1 Design Considerations. In selecting materials for use as fire stops, the following factors should be considered:

(1) Physical and chemical compatability between penetration fire stop and cable covering and raceway materials

(2) Heat dissipation resulting in power cable ampacity derating

(3) Thermal expansion, which might crush insulation or jacket during installation and operation

(4) Toxic or corrosive gases developed during installation or during a fire

(5) Ability to withstand pressure differentials

(6) Aging

(7) Temperature rise during curing of material

(8) Ease of installation

(9) Provision for the installation of additional cables

(10) Ability to withstand a hose-stream test that is acceptable for use on an electrical fire

The cable penetration fire stop should have a fire rating equal to or greater than the required fire rating of the wall, floor, or ceiling. Modifications or additions of cables through the fire stop should not compromise the integrity of the fire stop.

7.2.2 Sleeve and Tray Penetrations. Where pressure integrity or liquid seals are required, conduit sleeves may be used with a fire-resistive sealant or a compound packed into the area between the cable and sleeve walls. A special example of this method is using a solid section of tray which is then filled with sealant. The sealant or compound should be compatible with the cable outer surface material.

Where penetrations are made into areas classified as NEC Class I Hazardous (Classified) Locations (ANSI/NFPA 70-1984 [6], Article 500), explosionproof fittings should be used. The void around the cable should be filled with a fire-resistive seal.

Cable penetration fire stops should be used where sleeve or tray penetrations are used beneath control boards or other panels.

7.3 Cable Fire Breaks. When cable does not meet the flame propagation characteristics of 2.3.5, cable fire breaks should be installed in the tray at intervals not exceeding 20 ft.

7.4 Cable System Enclosure. Consideration should be given to utilizing cable system enclosures when redundant or critical cables are routed through fire hazard areas.

7.5 Cable Coatings. Consideration should be given to applying flame-retardant coatings on all cables in open raceway that do not meet the flame propagation characteristics of 2.3.5.

8. Fire Detection Systems

This section provides guidance or information for the selection of fire detection systems for cable systems.

Automatic fire detection systems may be installed in areas of high cable concentration. One method of determining an area of high cable concentration is as follows: An area of high cable concentration (actual or potential) exists for horizontal cable trays when more than $7\frac{1}{2}$ ft of total cable tray width exists in the zone of influence. The zone of influence is determined by extending lines from the bottom of the side rails of the lowest cable tray at a 30° angle from vertical (see Fig 1).

Fire detection systems may also be considered in cable spreading rooms and in areas of lesser cable concentration that provide vital service,

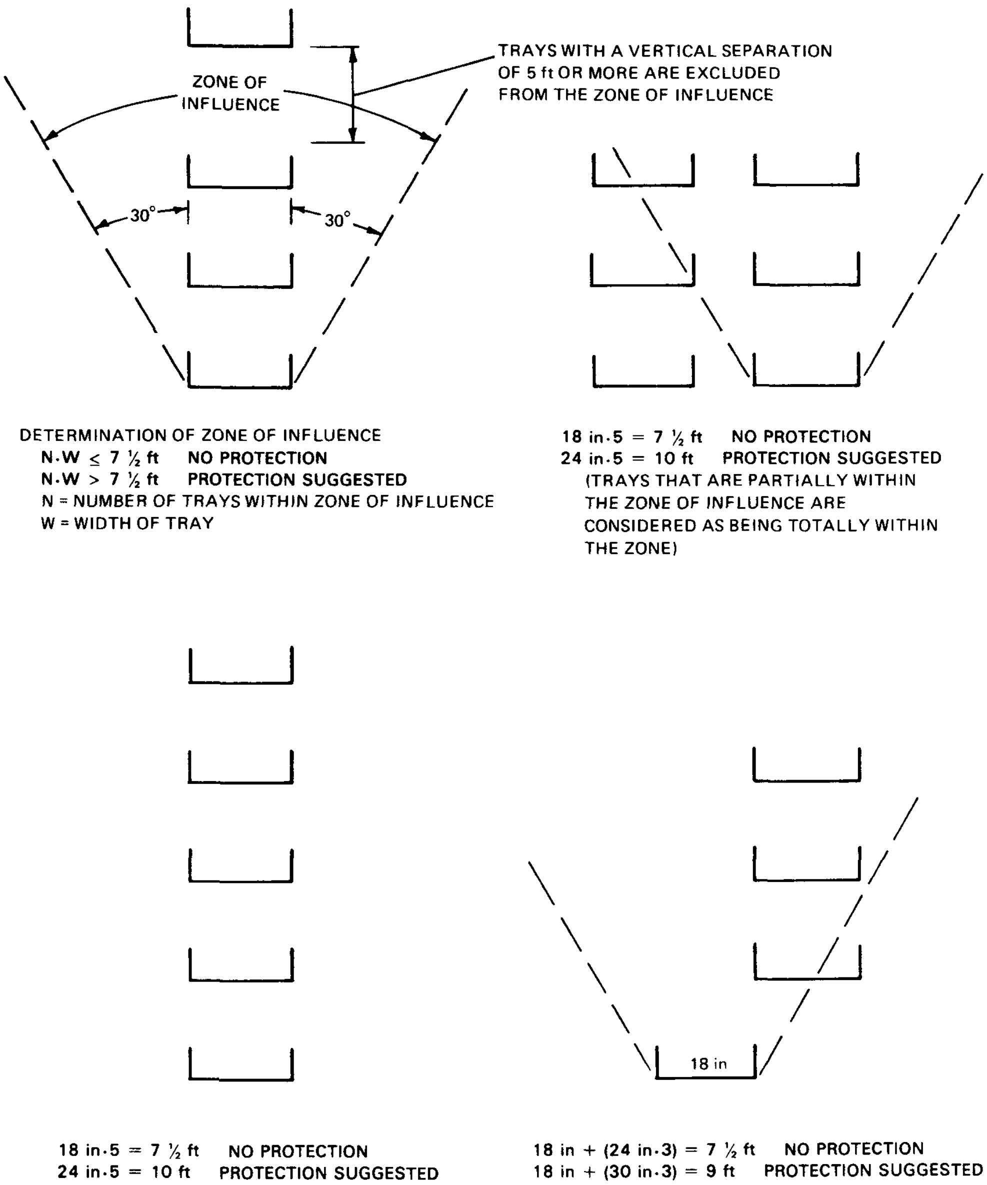


Fig 1
Determination of Potential High Cable Concentration

or areas where, due to their location, cable fires may go unnoticed for a relatively long period of time.

8.1 Heat Detectors. Heat detectors may be used in areas where trace products of combustion may result in false alarms (diesel generator rooms, etc), or where the primary hazard is from other than cable concentrations (that is, oil hazards). The heat detectors should be located directly over and within 18 in of each cable tray.

Heat detectors may be the fixed-temperature, rate-compensated, rate-of-rise, or combination fixed-temperature and rate-of-rise type, with thermally sensitive elements of the spot-pattern or line-pattern design.

8.1.1 Fixed-Temperature Detectors. Fixed-temperature detectors are set to operate when the detector is exposed to temperatures at or above the set point of the detector. The detectors are available in various temperature ranges to allow choosing a detector that will detect fire promptly, yet not false alarm due to normal and expected ambient room temperature swings.

The various types of fixed-temperature detectors are

(1) Bimetallic strip thermostat
(2) Snap-action disc thermostat
(3) Thermostatic cable
(4) Thermostatic line sensors
(5) Fusible metal
(6) Quartzoid bulb

Neither bimetallic thermostats nor snap-action thermostats are destroyed or permanently damaged by actuation. The fusible metal, quartzoid bulb, and some types of thermostatic cable and thermostatic line sensors should be replaced following actuation.

8.1.2 Combination-Fixed-Temperature and Rate-of-Rise Temperature Detectors. Rate-of-rise detectors operate when the detector is exposed to a temperature rise in excess of the design ΔT per unit time of the detector. There are several advantages of rate-of-rise devices over fixed-temperature devices. They sense a rapidly developing fire before temperatures increase sufficiently to operate a fixed-temperature detector. They can be set to operate more rapidly, are effective across a wide range of ambient temperatures, usually recycle more rapidly, and tolerate slow increases in ambient temperatures without giving an alarm. Combination fixed-temperature and rate-of-rise thermal detectors will respond directly to a rapid rise in ambient temperature caused by fire, tolerate slow increases in ambient temperature without registering an alarm, and recycle automatically on drop in ambient temperature. Their disadvantages are that the detector will not respond to a fire that propagates slowly until the fixed temperature is attained, and false alarms may be registered on rapid increase in ambient temperature resulting from conditions other than hostile combustion.

The various types of combination fixed-temperature and rate-of-rise detectors include

(1) Thermopneumatic detector (spot-pattern)
(2) Thermoelectric detector (spot-pattern)
(3) Thermopneumatic tube detector (line-pattern)

8.2 Smoke Detectors. Smoke detectors are employed where the type of fire anticipated will generate invisible and visible products of combustion before temperature changes are sufficient to actuate heat detectors.

8.2.1 Photoelectric Detectors. Photoelectric detectors are of the spot type or beam type. The spot type operates by one of two methods: the obsuration or the scattering of a photoelectric beam by visible products of combustion between a receiving element and a light source. The beam type operates by the obsuration of a photoelectric beam, typically over distances of a few feet or more. This type of detector should be installed in areas exposed to a constant radiation level in excess of 7.5 R and in areas where traces of combustion products may be present under normal conditions.

8.2.2 Combustion Products Detectors. Ionization detectors and condensation nuclei detectors alarm at the presence of visible and invisible combustion products. Combustion products entering the outer chamber of an ionization detector disrupt a small current across the field between ionization chambers and causes alarm actuation. The air in the chamber is ionized by a small amount of radioactive material housed within the detector. Condensation nuclei detectors operate on the cloud chamber principle, which allows invisible particles to be detected by optical techniques.

Ionization detectors should not be installed in areas exposed to a constant radiation level in excess of 20 R/h, nor in areas where traces of combustion products may be present under normal conditions such as in diesel generator rooms.

8.3 Flame Detectors. Flame detectors alarm at the presence of light from flames, usually in the ultraviolet or infrared range. Detectors are set to detect the typical flicker of a flame. Detectors may be provided with a time delay to eliminate false alarms from transient flickering light sources.

8.4 Design Considerations. Current national laboratory testing methods and manufacturer's detector spacing requirements are maximums based on smooth-ceiling and static airflow conditions. In the environs of a power generating station, detector spacing should be established to account for high, irregular ceilings, drafts, and mechanical ventilation that may exist.

For additional guidance or information on electrically supervising the fire detection system, refer to ANSI/NFPA 70-1984 [6] (Article 760), ANSI/NFPA 72D-1979 [7], and ANSI/NFPA 72E-1984 [8].

9. Fire Extinguishing Systems

This section provides guidance for the selection and application of fire extinguishing systems protecting cable systems.

9.1 Extinguishing Systems.

9.1.1 Water in Fixed Extinguishing Installations. When water is considered for use as an extinguishing agent on energized wire and cable systems, a fixed system of sprays or sprinklers or hoses with fine fog nozzles approved for electrical fires should be used.

Sprinklers proide effective control and extinguishment without increasing damage to the electrical and electronic equipment beyond the damage traceable to heat, flame, and smoke. Proper drainage of the floor surfaces should be provided to further minimize damage to equipment and associated cabling as a result of flooding.

9.1.2 Carbon Dioxide in Fixed Extinguishing Installations. Carbon dioxide does not conduct electricity and can be used on energized electrical equipment. Electrical equipment rooms that are not excessively large and that have relatively few openings, can be protected by carbon dioxide (CO_2). Carbon dioxide has the advantage of being able to penetrate small areas such as the spaces between cables.

Cable spreading areas and cable tunnels are usually not readily accessible in the case of a cable fire because of the heavy concentration of smoke. Carbon dioxide may be applied in these areas, but caution should be taken not to allow carbon dioxide to spread through cable openings or ventilation ducts into areas normally occupied by plant personnel.

9.1.3 Dry Chemicals and Carbon Dioxide in Portable Extinguishers. Dry chemicals should not be used where delicate electrical equipment is located. The insulating properties of dry chemicals might render the contacts inoperative. Portable extinguishers for use where energized electrical equipment may be encountered should utilize dry chemicals or carbon dioxide as an extinguishing agent, or both.

9.1.4 Halogen Extinguishing Systems. Caution is recommended when the use of halogenated compounds are proposed in areas where electrical equipment is located due to the corrosive breakdown products of the compounds.

9.1.5 Foam Extinguishing Systems. All foams are electrically conductive and should not be used on fires where the foam can come in contact with uninsulated electrical equipment.

9.2 Fixed Fire Extinguishing System Application and Design. A study should be conducted to determine if fixed automatic fire extinguishing systems are needed for areas of high cable concentration and for spaces below raised floors or above false ceilings containing exposed cables.

If the activation of fixed automatic water spray discharge could cause undesirable consequences, sensitive equipment should be protected from the spray and sealed against potential water damage due to water traveling along the cable system. If the equipment cannot be protected, an extinguishing system utilizing another extinguishing agent should be provided.

The design of fixed fire extinguishing systems, whether manual or automatic, should alert control room operators of any abnormal condition detected in the plant fire extinguishing system. The operation of each system should be annunciated. System design should also provide for operational testing.

An automatic timer delayed release, together with local predischarge alarm (audible and visible, as applicable), should be provided for all carbon dioxide and halogenated agent total flooding systems to permit personnel evacuation after initiation of the actuating sequence.

In confined areas where forced ventilation would circulate smoke or gaseous extinguishing agents, or both, to other areas, mechanical ventilation systems should be shut down upon system actuation, and gravity fire dampers should be closed by mechanical or electrical releases prior to fire extinguishing system discharge.

For additional guidance or information on electrically supervising the fire detection system, refer to ANSI/NFPA 70-1984 [6] (Article 760) and ANSI/NFPA 72D-1979 [7].

10. Installation and Handling

This section provides guidance for the construction methods, materials, and precautions in handling and installing cable systems.

10.1 Storage. Reels should be stored upright on their flanges and handled in such a manner as to prevent deterioration of or physical damage to the reel or to the cable. During storage, the ends of the cables should be sealed against moisture or contamination.

10.2 Installation.

(1) The cable manufacturer's recommendations on minimum ambient temperature limits during installation should be reviewed. Handling or pulling cables in extreme low temperatures can cause damage to the cable's sheathing, jacketing, or insulation. To prevent temperature damage of this nature, store cables in a heated building at least 24 h prior to installation.

Table 3 provides recommended cable manufacturers' low temperature limits for handling and pulling cables with various types of jackets and insulations.

Table 3
Low Temperature Limits for Cable Handling

Cable Insulation and Jacket Material	Low Temperature Limits	
	Celsius	Fahrenheit
EPR (Ethylene Propylene Rubber)	−40	−40
CPE (Chlorinated Polyethylene)	−35	−31
PVC (Polyvinyl Chloride)	−10	+14
CSPE (Chlorosulfonated Polyethylene)	−20	−4
Neoprene (Polychloroprene)	−20	−4
XLP (XHHW) (Cross-linked Polyethylene)	−45	−49

(2) Cable pulling lubricants should be compatible with cable outer surface and should not set up or harden during the installation period.

(3) Pulling winches and other necessary equipment should be of adequate capacity to ensure a steady continuous pull on the cable.

(4) Cable reels should be supported such that the cable may be unreeled and fed into the raceway without subjecting the cable to a reverse bend as it is pulled from the reel.

(5) A tension measuring device should be used on runs when pulling force calculations indicate allowable stresses may be approached.

(6) Pulling tension will be increased when the cable is pulled off of the reel. Turning the reel and feeding slack cable to the duct entrance may change a difficult pull to an easy one.

(7) The direction of pulling has a large influence on the pull if bends are included. Whenever a choice is possible, pull so that the bend or bends are closest to the reel. The worst condition possible is to pull out of a bend at or near the end of the run.

(8) Sufficient cable slack should be left in each manhole and temporarily supported so that the cable can be trained to its final location on racks, hangers, or trays along the sides of the manhole. Cable splices should not be placed directly on racks or hangers.

(9) The use of single-roller or multi-roller cable sheeves of the proper radius should be used when installing cable around corners or obstructions.

(10) Guidance on conduit fill can be found in ANSI/NFPA 70-1984 [6].

(11) Cables should be identified by a permanent marker at each end in accordance with the design documents.

10.2.1 Protection of Cable.

(1) Special care should be exercised during welding, soldering, and splicing operations to prevent damage to cables. If necessary, cables should be protected by fire-resistant material.

(2) After cable installation has started, trays and trenches should be periodically cleaned as necessary to prevent the accumulation of debris.

(3) A suitable feeder device should be used to protect and guide the cable from the cable reel into the raceway. The radius of the feeder device should not be less than the minimum bending radius of the cable. If a feeder device is not used, the cable should be hand-guided into the raceway.

(4) Bare wire rope should not be used to pull cables in conduits.

(5) The ends of medium-voltage power cables should be properly sealed during and after installation. The ends of all other cables should be properly sealed during and after installation in wet locations. Cables such as aluminum, mineral-insulated, paper, and varnished cambric should be resealed after pulling regardless of location.

If water has entered the cable, a vacuum should be pulled on the cable or the cable should be purged with nitrogen to extract the water.

(6) A swivel should be attached between the pulling eye and the pulling cable. Projections and sharp edges on pulling hardware should be taped or otherwise covered for protection against snagging at conduit joints and to prevent damage to conduit.

(7) Cables should only be pulled into clean raceways. A mandrel should be pulled through all underground ducts prior to cable pulling. Any abrasions or sharp edges that might damage the cable should be removed.

(8) Cables should be installed in raceway systems that have adequately sized bends, boxes, and fittings so that cable manufacturer's minimum allowable bending radii and sidewall pressures for cable installations are not violated. Guidance for the number of bends between pull points can be found in ANSI / NFPA 70-1984 [6].

(9) Pulling instructions for all cable should follow the cable manufacturer's recommendations.

(10) Cables should not be pulled around sharp corners or obstructions.

(11) The cable end within a pulling device should be removed from the cable prior to termination.

(12) After the cable pull is complete, cable manufacturer's recommendations for minimum training radius should be followed.

(13) Where single conductors are used in trays for two-wire or three-wire power circuits, these conductors should be securely bound in circuit groups to prevent excessive movements due to fault-current magnetic forces and to minimize inductive heating effects in tray sidewalls and bottom.

10.2.2 Supporting Cables in Vertical Runs. The weight of a vertical cable should not be supported by the terminals to which it is connected.

Vertically run cables should be supported by holding devices in tray or in the ends of the conduit, or in boxes inserted at intervals in the conduit system.

Cable installed in vertical conduit should be supported in accordance with the following:

Maximum Distances Between Cable Supports

Conductor Sizes (AWG in kcmils)	Maximum Distance (ft)
14 to 0	100
00 to 0000	80
220 to 350	60
Over 350 to 500	50
Over 500 to 750	40
Over 750	35

Support recommendations for special cables such as armor, shielded, coaxial, etc, should be obtained from the cable manufacturer.

10.2.3 Dressing Cables in Vertical Runs. Cable installed in vertical cable trays should be secured to the cable tray at least every 5 ft.

10.3 Cable Pulling Lengths in Conduit and Duct Systems. Caution should be observed to prevent the pulling tensions on cables from exceeding allowable limits.

10.3.1 Maximum Distance for Cable Pulled in Conduits. The maximum distance a cable may be pulled in conduits without subjecting it to damage depends on the following factors:

(1) Maximum allowable sidewall pressure of the cable construction

(2) Tensile strength of conductor or jacket

(3) Coefficient of friction between cable jacket and conduit surface

(4) Weight of cable

(5) Number, location, angle, and radius of bends

(6) Slope

(7) Lubrication

(8) Method of pulling cable (pulling eyes, basket weave grip, etc)

(9) Limits of cable pulling and reel handling equipment

10.3.2 Maximum Cable Pulling Length. Conduit and duct system design should consider the maximum pulling lengths of cables to be installed. The maximum pulling length of a cable or cables is determined by the maximum allowable pulling tension and sidewall pressure.

The pulling length will be limited by one of these factors.

10.3.3 Maximum Allowable Pulling Tension. The maximum allowable pulling tension should be determined from the following formula, unless otherwise indicated by the cable manufacturer.

(1) Based on pull by conductor

$$T_{max} = K \cdot N \cdot \text{cmil} \qquad \text{(Eq 5)}$$

where

T_{max} = maximum allowable pulling tensions (lbs)
cmil = circular mil area of each conductor
K = 0.008 lb/cmil for annealed copper and hard aluminum
= 0.006 lb/cmil for 3/4 hard aluminum
N = number of conductors

(2) Based on pull by basket grip applied over

nonshielded jacket cables	T_{max} = 2 000 lb
shielded jacketed cables	T_{max} = 1 000 lb

Do not exceed tension limit of 10.3.3 (1).

(3) When using a basket-weave-type pulling grip applied over a lead-sheathed cable, the force should not exceed 1500 pounds as determined by the following formula:

$$T_{max} = K_m \pi t\,(D - t) \qquad \text{(Eq 6)}$$

where

T_{max} = maximum force (lbs)
t = lead sheath thickness (in)
D = outside diameter of lead sheath (in)
K_m = maximum allowable pulling stress (lbs/in^2) (1500–2000, depending on lead alloy)

NOTE: For lead-sheathed cables with neoprene jackets, T_{max} equals 1000.

(4) Pulling instructions for coaxial, triaxial, and other special cables should follow the manufacturer's recommendations.

10.3.4 Maximum Allowable Sidewall Pressure. Sidewall pressure is the radial force exerted on the insulation and sheath of a cable at a bend point when the cable is under tension. The maximum allowable sidewall pressure is 500 lb/ft of radius for power and control cables subject to modification by the cable manufacturer. For instrumentation cable, use cable manufacturer's recommendations.

10.3.5 Expected Pulling Tension. The expected pulling tension of one cable in a straight section of duct may be calculated from the following formula, which does not consider slope:

$$T = LWK_o \qquad \text{(Eq 7)}$$

where

T = total pulling line tension (lbs)
L = length of conduit runs (ft)
W = weight of cable (lbs/ft)
K_o = basic coefficient of friction

The expected pulling tension of a cable in an inclined section of duct may be calculated from the following formulas:

upward $$T = WL\,(K_o \cos\alpha + \sin\alpha) + \text{(prior tension)} \qquad \text{(Eq 8)}$$

downward $$T = WL\,(K_o \cos\alpha - \sin\alpha) + \text{(prior tension)} \qquad \text{(Eq 9)}$$

where

α = angle from horizontal

For conduit runs containing horizontal bends, the expected pulling tension around a bend should be determined as follows:

Refer to Fig 2 and assume pulling from A to D.

Then,

$$T_C = T_B(e)^{K_o \alpha} \text{ (belt friction formula)} \qquad \text{(Eq 10)}$$

where

T_C = tension after the bend (lbs)
T_B = tension into the bend (lbs)
e = Napierian logarithm base (2.72)
K_o = basic coefficient of friction
α = angle of the bend (rads) (1 degree = 0.01745 rads)

T_B is determined for the pull by the straight-length method given in Eq 10.

For conduit runs containing vertical bends, the expected pulling tension around a bend should be determined as follows:

Refer to Fig 2, parts (b), (c), (d), and (e).

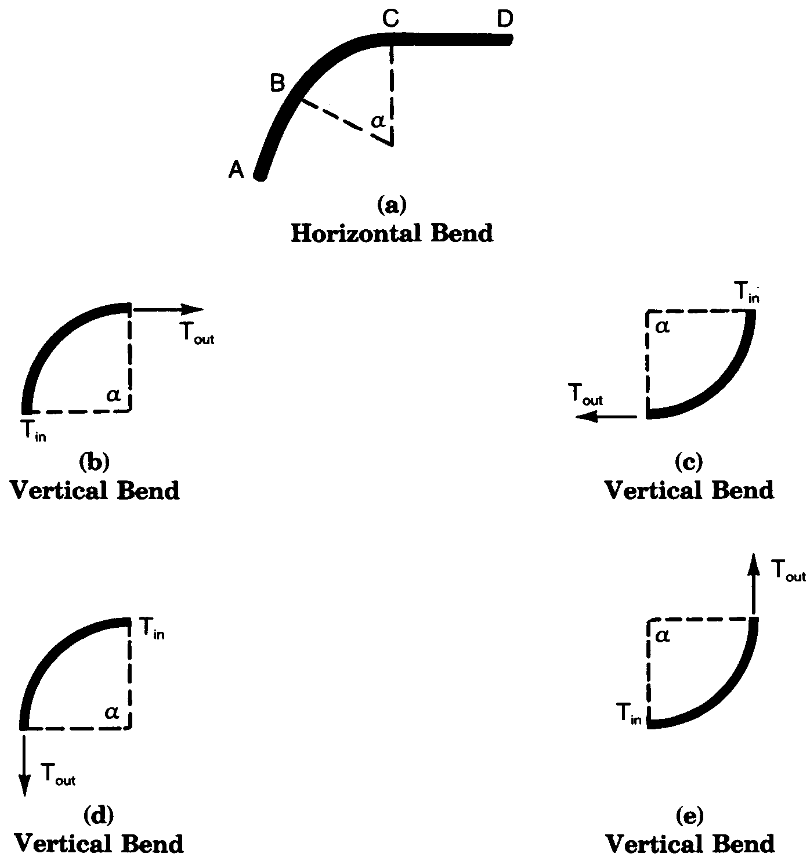


Fig 2
Expected Pulling Tension Around a Horizontal or a Vertical Bend for Conduit or Duct Runs

$$T_{out} = T_{in}(e)^{K_o\alpha} \pm \frac{WR}{1+K_o^2}\,[2K_o(e)^{K_o\alpha}\sin\alpha + (1 - K_o^2\,W_c^2)(1 - (e)^{K_o\alpha}\cos\alpha)] \quad \text{(Eq 11)}$$

("+" for Fig 2(b))
("−" for Fig 2(c))

$$T_{out} = T_{in}(e)^{K_o\alpha} \pm \frac{WR}{1+K_o^2}\,[2K_o\sin\alpha - (1 - K_o^2\,W_c^2)((e)^{K_o\alpha} - \cos\alpha)] \quad \text{(Eq 12)}$$

("+" for Fig 2(d))
("−" for Fig 2(e))

where

T_{out} = tension after bend (lbs)
T_{in} = tension into bend (lbs)
e = Napierian logarithm base (2.72)
K_o = basic coefficient of friction
α = angle of bend (rads) (1 degree = 0.01745 rads)
W = weight of cable (lbs/ft)
R = radius of bend (ft)
W_c = weight correction factor (from Fig 3)

The basic coefficient of friction typically ranges from 0.3 or well-lubricated cables pulled into smooth, clean conduits to 0.5 for lubricated cables pulled into rough or dirty conduits. The use of a different coefficient of friction may be substantiated by comparison of the actual versus calculated pulling tension, and these coefficients may vary from those given depending on cable and duct arrangement.

When three cables are pulled into a duct, the pulling tension is not simply three times that of a single cable pull. Because of the wedging action between cables and duct, even in a straight pull, the effect is to produce a side pressure that is treated as an increase in the basic coefficient of friction (K_o), and is called the weight correction factor (W_c). The effective coefficient of friction (K) is

$$K = W_c K_o \quad \text{(Eq 13)}$$

The pulling tension for three cables then becomes

$$T = 3KLW \text{ for straight pulls} \quad \text{(Eq 14)}$$

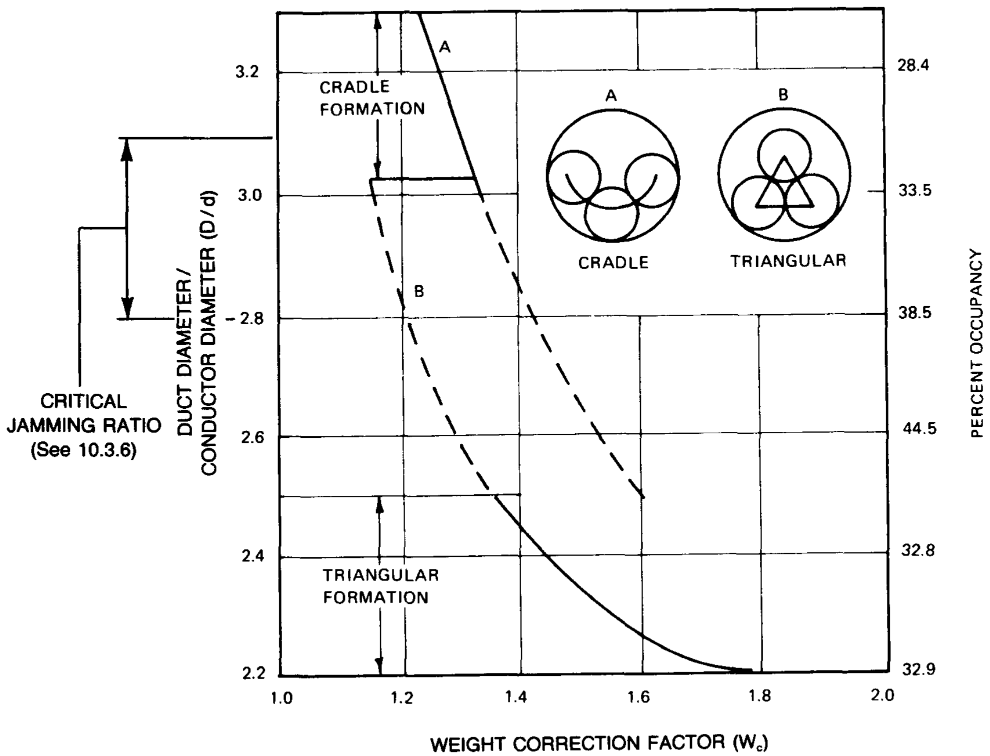
The additional tension imposed by a bend is calculated the same way as for a one-cable pull, except that K_o is replaced by K.

Figure 3 can be used to determine W_c when the ratio of the duct inside diameter and cable outside diameter (D/d) is known.

Pull points or manholes should be installed wherever calculations show that expected pulling tensions exceed either maximum allowable pulling tension or sidewall pressure.

10.3.6 Critical Jamming Ratio. When three cables are pulled into a conduit, it is possible for the center cable to be forced between the two outer cables, while being pulled around a bend, if the D/d ratio approaches a value to 3.0. Up to a ratio of 2.5, the cables are constrained into a triangular configuration. However, as the value approaches 3.0, jamming of the cables could occur, and the cables would *freeze* in the duct causing serious cable damage. To allow for tolerances in cable and conduit sizes and for ovality in the conduit at a bend, the D/d ratios

Fig 3
Weight Correction Factor (W_c)



between 2.8 and 3.1 should be avoided (see Fig 3).

10.3.7 Expected Sidewall Pressure. The sidewall pressure acting upon a cable at any bend may be estimated from the following equations:

(Eq 15)

$$P = \frac{T}{R}$$ for one cable

$$P = \tfrac{1}{3}(3W_c - 2)\frac{T}{R}$$ for three cables in cradle formation where the center cable presses hardest against the duct

$$P = \frac{W_c T}{2R}$$ for cables in triangular formation where the pressure is divided equally between the two bottom cables

where

P = sidewall pressure on the critical cable(s) (lbs/ft)
T = total pulling tension leaving the bend (lbs)
R = radius of bend (ft)
W_c = weight correction factor (see Fig 3)

The cable manufacturer's recommendations should be followed for all cable configurations not covered by the formula given above.

11. Acceptance Testing of Installed Cables

This section provides guidance for the testing of cables after installation but before their connection to equipment, and includes cable terminations, connectors, and splices.

11.1 Purpose. The purpose of the tests is to verify that major cable insulation damage did not occur during storage and installation. It should be noted, however, that these tests may not detect damage that may eventually lead to cable failure in service—for example, damage to cable jacket or insulation shield on medium voltage cable or to low-voltage cable insulation.

11.2 Tests. Safety precautions should be observed during all phases of testing. Cable ends should be properly cleaned of all conducting material. Cable test results, environmental conditions, and data should be recorded and filed for plant maintenance reference. The following tests should be performed, as applicable, in conjunction with the cable manufacturer's recommendations:

(1) Low-voltage power, control, and instrumentation cables should be either insulation resistance tested prior to connecting cables to equipment or functionally tested (at equipment operating voltage) as part of the checkout of the equipment system.

(2) The low-voltage power cable insulation resistance tests should measure the insulation resistance between any possible combination of conductors in the same cable and between each conductor and station ground, with all other conductors in the same cable grounded.

The test voltage should be a minimum of 500 V dc. The minimum acceptable insulation resistance is

$$R \text{ in } M\Omega = (\text{rated voltage in kV} + 1) \cdot 1000/\text{length in ft} \quad \text{(Eq 16)}$$

(3) Testing of control cable and prefabricated cable assemblies in a similar manner is suggested. Cable manufacturer's recommendations should always be considered.

(4) Shielded medium-voltage power cables should be dc high-potential tested in accordance with ANSI/IEEE Std 400-1980 [4], AEIC standards [1], [2], or ICEA standards [12], [13], [14], [15], prior to equipment connection. Unshielded medium-voltage cables should not be subjected to high-voltage dc tests; insulation resistance tests are suggested.

(5) Low-level instrumentation cables should be subjected to insulation resistance measurements if circuit performance is dependent upon insulation resistance. Cable manufacturers' testing recommendations should always be considered.

12. Raceways

This section provides guidance for both a means of supporting cable runs between electrical equipment and physical protection to the cables. Raceway systems consist primarily of cable tray and conduit.

12.1 Definitions

ABS. Conduit fabricated from Acrylonitrile-Butadiene-Styrene.

EMT. Electrical metallic tubing.

FRE. Conduit fabricated from fiberglass reinforced epoxy.

IMC. Intermediate Metal Conduit.

PVC. Conduit fabricated from polyvinyl chloride.

RS. Rigid steel conduit.

Type EB (formerly Type I). Conduit designed to be encased in concrete when installed.

TYPE DB (formerly Type II). Conduit deigned for underground installation without encasement in concrete.

12.2 Conduit

12.2.1 Conduit Application. (1) RS or IMC zinc-coated conduit may be used exposed in wet and dry locations, embedded in concrete, and directly buried in soil. When used in cinder fills, it should be protected by noncinder concrete at least 2 in thick. When used where excessive alkaline conditions exist, it should be protected by a coat of bituminous paint or similar material. PVC-coated steel conduit may be used in corrosive environments. Plugs should be used to seal spare conduits in wet locations.

(2) ABS or PVC conduit may be used exposed, directly buried (Type DB), or embedded in concrete (Type EB).

Since ABS and PVC conduit may have different properties, a review should be made of their brittleness and impact-strength characteristics. Coefficient of expansion should also be considered for outdoor applications with exposure to direct sunlight. Flammability of such conduits is of particular concern in indoor exposed locations. Burning or excessive heating of PVC may result in the formation of hydrochloric acid in the presence of moisture which can, in turn, attack reinforcing steel, deposit chlorides on stainless steel surfaces, or attack electrical contact surfaces. The use of exposed PVC conduit indoors should generally be avoided, but may be considered for limited use in corrosive environments.

(3) EMT may be used in dry accessible locations to perform the same functions as RS conduit except in hazardous areas (as defined by ANSI/NFPA 70-1984 [6], Article 500) or where mechanical damage could occur. Compression couplings should be used where possible. EMT should not be relied upon to provide a ground fault return path.

(4) Aluminum conduit (Alloy 6063), plastic-coated steel conduit, Type DB PVC, and Type FRE may be used in fresh water cooling tower areas because of the corrosive environment and for other applications where uncoated steel conduit would not be suitable. Aluminum conduit may be used exposed in wet and dry locations. Aluminum conduit should not be embedded in concrete or directly buried in soil. Aluminum may be used, exposed, or concealed where a strong magnetic field exists. Aluminum conduit should not be used in areas subjected to chemical sprays that may result in the release of hydrogen, which can accumulate to explosive concentrations.

12.2.2 Conduit System Design

12.2.2.1 Exposed Conduit. (1) Flexible conduit should be used between conduit and equipment connection boxes where vibration is anticipated. Liquid-tight flexible conduit is commonly used for this application. Flexible conduit length should be as short as practicable, but consistent with its own minimum bending radius, the minimum bending radius of the cable to be installed, and the relative motion expected between connection points.

(2) Where it is possible for water or other liquids to enter conduits, sloping of conduit runs and drainage of low points should be provided.

(3) Electrical equipment enclosures should have conduit installed to prevent the entrance of water and condensation. Drain fittings in the equipment enclosure should also be considered.

(4) The entire metallic conduit system, whether rigid or flexible, should be electrically continuous and grounded.

(5) When installed in magnetic conduit, all phases of three-phase ac circuits and both legs of single-phase ac circuits should be installed in the same conduit or sleeve.

(6) All conduit systems should have suitable pull points (pull boxes, manholes, etc) to avoid over-tensioning the cable during installation.

12.2.2.2 Embedded Conduits and Manholes. (1) Spacing of embedded conduits should permit fittings to be installed. This spacing may vary in accordance with the class of concrete being used around the conduits.

(2) Conduit in duct runs containing one phase

of a three-phase power circuit or one leg of a single-phase power circuit should not be supported by reinforcing steel forming closed magnetic paths around individual conduits. Reinforcing steel in the manhole walls should not form closed loops around individual nonmetallic conduit entering the manhole. Nonmetallic spacers should be used.

(3) Concrete curbs or other means of protection should be provided where other than RS conduits turn upward out of floor slabs.

(4) The lower surface of concrete-encased conduit duct banks should be located below the frost line. Where this is not practicable, lean concrete or porous fill can be used between the frost line and the duct bank.

(5) Concrete-encased duct banks should be adequately reinforced under roads and in areas where heavy equipment may be moved over the duct bank.

(6) Directly buried nonmetallic conduits should not be installed under roadways or in areas where heavy equipment may be moved over them unless protected structurally or where conduits are made from resilient compounds suitable for this service.

(7) Conduits in duct banks should be sloped downward toward manholes or drain points.

(8) Duct lengths should not exceed those that will develop pulling tensions or sidewall pressures in excess of those allowed by the cable manufacturers.

(9) Manholes should be oriented to minimize bends in duct banks.

(10) Manholes should have a sump to facilitate the use of a pump if necessary.

(11) Manholes should be provided with means for attachment of cable pulling devices to facilitate pulling cables out of conduits in a straight line.

(12) Provisions should be made to facilitate racking of cables along the walls of the manhole.

(13) Exposed metal in manholes, such as conduits, racks, and ladders, should be grounded.

(14) End bells should be provided where conduits enter manholes or building walls.

(15) Manholes and manhole openings should be sized so that the cable manufacturers minimum allowable cable bending radii are not violated.

(16) When installed in magnetic conduit, all phases of three-phase ac circuits and both legs of single-phase ac circuits should be installed in the same conduit or sleeve.

12.2.3 Conduit Installation. (1) Supports of exposed conduits should follow NEC recommendations (ANSI / NFPA 70-1984 [6], Article 500) or industry standards.

(2) When embedded in concrete, installed indoors in wet areas, and in all outdoor locations, threaded conduit joints and connections should be made watertight and rustproof by means of the application of a thread compound that will not insulate the joint. Each threaded joint should be cleaned to remove all of the cutting oil before the compound is applied. The compound should be applied only to the male conduit threads to prevent obstruction.

(3) Running threads should not be utilized, and welding of conduits should not be done.

(4) Field bends should not be of lesser radius than suggested by ANSI / NFPA 70-1984 [6] and should show no appreciable flattening of the conduit.

(5) Large radius bends should be used to reduce the cable sidewall pressure during cable installation and in conduit runs when the permissible minimum bending radius of the cable to be contained in the conduit exceeds the radius of standard bends.

(6) Conduit installed in concrete should have ends plugged or capped before the concrete is poured.

(7) All conduit interiors should be free of burrs and be cleaned after installation.

(8) Exposed raceways should be marked in a distinct permanent manner at each end and at points of entry to, and exit from, enclosed areas.

(9) Flexible conduit connections should be used for all motor terminal boxes and other equipment that is subject to vibration, but the connections should be of minimum lengths and should employ at least the minimum bending radii established by the cable manufacturer.

(10) Conduit should not be installed in close proximity to hot pipe or other heat sources.

(11) Proper fittings should be used at conduit ends to prevent cable damage.

12.3 Cable Tray

12.3.1 Tray Design. (1) Cable tray design should be based upon the required loading and the maximum spacing between supports. Loading should include the static weight of cables and a concentrated load of 200 lbs at midspan. The tray load factor (safety factor) should be at least 1.5 based on collapse of the tray when supported as a simple beam.

(2) When ladder-type tray is specified, rung spacing should be a nominal 9 in. For horizontal elbows, rung spacing should be maintained at the center line.

(3) Design should minimize the possibility of the accumulation of fluids and debris on covers or in trays.

12.3.2 Tray System Design. (1) In general, vertical spacing for cable trays should be 12 in, measured from the bottom of the upper tray to the top of the lower tray. A minimum of 9 in clearance should be maintained between the top of a tray and beams, piping, etc, to facilitate installation of cables in the tray.

(2) Cables installed in stacked cable trays should be arranged by descending voltage levels with the higher voltage at the top.

(3) When stacking trays, the structural integrity of components and the pullout values of support anchors and attachments should be verified.

(4) Provisions for horizontal and vertical separation of redundant system circuits are described in Section 5.

12.3.3 Tray Application. The usual materials from which tray is fabricated are aluminum, galvanized steel, and fiberglass. In selecting material for trays, the following should be considered:

(1) Aluminum, when subjected to certain chemical sprays, can combine with the spray to release hydrogen, which may accumulate to explosive concentrations.

(2) Galvanized tray will corrode in locations such as outdoors near the ocean or immediately adjacent to a cooling tower where the tray is continuously wetted by chemically treated water. If aluminum tray is used for such applications, a corrosive-resistant type should be specified. Special coatings for steel tray may also serve as satisfactory protection against corrosion. The use of nonmetallic tray should also be considered for such applications.

(3) For cable tray and tray support systems located outdoors, the effect of the elements on both the structure and the trays should be considered. Ice, snow, and wind loadings must be added to loads described in 12.3.4. Aluminum Alloys 6061-T6, 6063-T6, and 5052-M34 are acceptable with careful recognition of the differences in strength. Mill-galvanized steel should normally be used for indoor application. Hot-dipped, galvanized-after-fabrication steel should be used for outdoor and damp locations.

(4) When the galvanized surface on the steel tray is broken, the area should be coated to protect against corrosion.

(5) Consideration should be given to the relative structural integrity of aluminum versus steel tray during a fire.

12.3.4 Tray Load Capacity. (1) The quantity of cables in any tray may be limited by the structural capacity of the tray and its supports. Tray load capacity is defined as the allowable weight of wires, cables, and fire protection materials carried by the tray. This value is independent of the dead load of the tray system. In addition to, and concurrent with, the tray load capacity and the dead load of the tray system, no tray should either fail or be permanently distorted by a concentrated load of 200 lbs at midspan at the center line of the tray or on either side rail.

(2) A percentage fill limit is needed for random filled trays because cables are not layed in neat rows and secured in place. This results in cable crossing and void areas that take up much of the tray cross-sectional area. Generally, a 30–40% fill for power and control cable and 40–50% fill for instrumentation cables will result in a tray loading such that no cable will be installed above the top of the side rails of the cable tray except as necessary at intersections and where cables enter or exit the cable tray systems.

(3) The quantity of cables in any tray may be limited by the capacity of the cables at the bottom of the tray to withstand the bearing load imposed by cables located adjacent and above. This restraint is generally applicable to instrumentation cabling but may also apply to power and control cables.

12.4 Cable Tray Installation

12.4.1 Dropouts. (1) Drop-out fittings should be provided where required to maintain the minimum cable training radius.

(2) Where the conduit is attached to the tray to carry exiting cable, the conduit should be rigidly clamped to the side rail. When the conduit is rigidly clamped, consideration should be given to the forces at the connection during dynamic (seismic) loading of the tray and conduit system. Conduit connections through the tray bottom or side rail should be avoided.

12.4.2 Covers. (1) Horizontal trays exposed to falling objects or to the accumulation of debris should have covers.

(2) Covers should be provided on exposed vertical tray risers at floor levels and other locations where possible physical damage could occur.

(3) Where covers are used on trays containing power cables, consideration should be given to ventilation requirements and cable ampacity derating. For guidance in ampacity derating, refer to note in 3.1.2.

12.4.3 Grounding. Cable tray systems should be electrically continuous and solidly grounded. When cable trays are used as raceways for solidly grounded or low-impedance grounded power systems, consideration should be given to the tray system ampacity as a conductor. Inadequate ampacity or discontinuities in the tray system may require that a ground conductor be attached to and run parallel with the tray. The ground conductor may be either bare or insulated depending upon metallic compatibility.

12.4.4 Identification. Cable tray sections should be permanently identified with the tray section number as required by the drawings or construction specifications.

12.4.5 Supports. The type and spacing of cable tray supports will depend on the loads. Tray sections should be supported near section ends and at fittings such as tees, crosses, and elbows (NEMA VE 1-1984 [18]).

12.4.6 Location. The tray should not be installed in close proximity to hot pipes or other heat sources.

12.5 Wireways. Wireways are generally sheet metal troughs with hinged or removable covers for housing and protecting wires and cables. Wireways are for exposed installations only and should not be used in hazardous areas. Consideration should be given to the wireway material where corrosive vapors exist. In outdoor locations, wireways should be of raintight construction. The sum of the cross-sectional areas of all conductors should not exceed 40% of the interior cross-sectional area of the wireway. Taps from wireways should be made with rigid intermediate metal, flexible metal conduit, or armored cable.