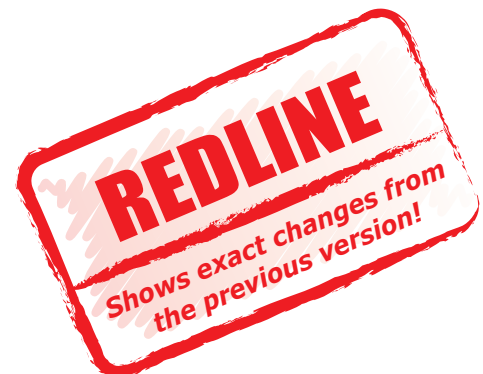




IEEE Guide for the Design and Installation of Cable Systems in Substations

IEEE Power Engineering Society

Sponsored by the
Substations Committee



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IEEE Guide for the Design and Installation of Cable Systems in Substations

Sponsor

Substations Committee
of the
IEEE Power Engineering Society

Approved 8 March 2007

IEEE-SA Standards Board

Abstract: The design, installation, and protection of wire and cable systems in substations are covered in this guide, with the objective of minimizing cable failures and their consequences.

Keywords: acceptance testing, cable, cable installation, cable selection, communication cable, electrical segregation, fiber-optic cable, handling, power cable, pulling tension, raceway, recommended maintenance, routing, separation of redundant cable, service conditions, substation, transient protection

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Introduction

This introduction is not part of IEEE Std 525-2007, IEEE Guide for the Design and Installation of Cable Systems in Substations.

This revision of the guide incorporates various changes in cable installation philosophies that have occurred since the 1992 version of the guide. Significant changes have been made in the following areas:

- a) Re-ordered much of the common information for all cables into the annexes, and rearranged the clauses to align with specific information for each differing type of cable
- b) Added a clause to cover communication cable
- c) Expanded and updated the clause for fiber-optic cable
- d) Arranged the annexes to better follow the flow of control cable systems selection and design
- e) Expanded and updated the annex for cable selection to include a table of common cable sizes and additional equations for calculating resistance effects, and added considerations for jacketing, attenuation and capacitance
- f) Added an annex as a design checklist for communication cables
- g) Expanded and updated the annex for transient protection (shielding)
- h) Added recommended maintenance
- i) Added a flowchart in Annex A that references each annex
- j) Added an example of cable system design in Annex O for a small substation
- k) Removed the fire systems clauses and recommended these be included in the updating of IEEE Std 979™-1994 [B63]^a
- l) Updated to latest version of the IEEE Standards Style Manual
- m) Corrected some of the axis labels for percent occupancy in Figure J.1 as required by IEEE Std 525-2007/Cor1:2008

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^a The numbers in brackets correspond to those of the bibliography in Annex P.

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1. Overview

The main clauses of the guide are organized by cable type and each of these clauses has been organized to match the general steps involved in the design process for a substation cable system (see Annex A for a flowchart diagram). Common information for each type of cable is placed in the annexes and is referenced from the body of the guide. The rationale for organizing the guide in this manner is to make it easier for the user to find the information needed as quickly and efficiently as possible, especially for those individuals unfamiliar with the design of cable systems in substations.

1.1 Scope

This document is a guide for the design, installation, and protection of insulated wire and cable systems in substations with the objective of minimizing cable failures and their consequences. This guide is not an industry standard or a compliance standard. ~~This guide is not intended for use in the design of wire and cable systems in generating stations, which is adequately covered in IEEE Std 422-1986¹ and IEEE Std 690-1984. Guidance for wire and cable design for gas-insulated substations (GIS) is available in IEEE Std C37.122-1983.~~

1.2 Purpose

The purpose of this guide is to provide guidance to the substation engineer in established practices for the application and installation of metallic and optical cables in electric power transmission and distribution substations with the objective of minimizing premature cable failures and their consequences. This guide emphasizes reliable electrical service and safety during the design life of the substation.

Regarding cable performance, no single cable characteristic should be emphasized to the serious detriment of others. In addition to good installation, design, and construction practices, a balance of cable characteristics is necessary to provide a reliable cable system.

Solutions presented in this guide may not represent the only acceptable practices for resolving problems.

This guide should not be referred to or used as an industry standard. It is being presented to aid in the development of wire and cable system installations and is not a compliance standard.

2. Normative references

The following referenced documents are indispensable for the application of this guide. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies. ~~This standard shall be used in conjunction with the following publications:~~

Accredited Standards Committee C2-2002, National Electrical Safety Code[®] (NESC[®]).^{1, 2}

IEEE Std 575, IEEE Guide for the Application of Sheath-Bonding Methods for Single-Conductor Cables and the Calculation of Induced Voltages and Currents in Cable Sheaths.^{3, 4}

IEEE Std 835, IEEE Standard Power Cable Ampacity Tables.

¹Information on references can be found in 1.3.

²The National Electrical Safety Code is available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

~~AEIC CS5-1987, Specifications for Thermoplastic and Cross-linked Polyethylene Insulated Shielded Power Cables
Rated 5 kV through 35 kV.³~~

~~AEIC CS6-1987, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables
Rated 5 kV
through 69 kV.~~

~~AEIC CS7-1987, Specifications for Cross-linked Polyethylene Insulated Shielded Power Cable Rated
69 kV
through 138 kV.~~

~~ANSI/NFPA 70-1990, National Electrical Code (NEC).⁴~~

~~ANSI/NFPA 72D-1990, Installation, Maintenance and Use of Proprietary Signaling~~

~~Systems. ASTM E119-1988, Standard Methods of Fire Tests of Building~~

~~Construction and Materials.⁵~~

~~IEC 183-1984, Guide to the Selection of High Voltage Cables.⁶~~

~~IEC 228-1978, Conductors of Insulated Cables.~~

~~IEC 331-1970, Fire Resisting Characteristics of Electric Cables.~~

~~IEC 332-1 (1979), Test on a Single Vertical Insulated Wire or Cable. IEC 332-3 (1982), Tests on Bunched Wires or Cables.~~

~~IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in AC Substation Grounding (ANSI).~~

~~IEEE Std 81-1983, IEEE Guide for Measuring of Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.~~

~~IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms.~~

~~IEEE Std 367-1987 IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault (ANSI).~~

~~IEEE Std 383-1974 (Reaff 1992), IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations (ANSI).~~

~~IEEE Std 400-1991, IEEE Guide for Making High-Direct Voltage Tests on Power Cable Systems in the Field (ANSI). IEEE Std 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations (ANSI).~~

~~IEEE Std 442-1981 (Reaff 1991), IEEE Guide for Soil Thermal Resistivity Measurements (ANSI).~~

³AEIC publications can be obtained from the Sales Department, Association of Edison Illuminating Companies, 600 North 18th Street, P.O. Box 2641, Birmingham, AL 35291-0992, USA.

⁴NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

⁵ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

⁶IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembe, CH 1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

~~IEEE Std 487-1992, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations.~~

~~IEEE Std 518-1982 (Reaff 1990), IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources (ANSI).~~

~~IEEE Std 634-1978, IEEE Standard Cable Penetration Fire Stop Qualification Test.⁷~~

~~IEEE Std 643-1980, IEEE Guide for Power-Line Carrier Applications (Reaff 1991) (ANSI).~~

~~IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations (ANSI).~~

~~IEEE Std 979-1984 (Reaff 1988), IEEE Guide for Substation Fire Protection (ANSI).~~

~~IEEE Std 1050-1989, IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations (ANSI).~~

~~IEEE Std C37.1-1987, IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control (ANSI).~~

~~IEEE Std C37.90.1-1989 (Reaff 1991), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (Supplement to IEEE C37.90-1989) (ANSI).⁸~~

~~IEEE Std C37.122-1983, IEEE Standard for Gas-Insulated Substations.~~

~~IEEE Std C57.13.3-1983 (Reaff 1991), IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases (ANSI).~~

~~IEEE S-135 (1962), IEEE/IPCEA Power Cable Ampacities.~~

~~NEMA TC 2-1990, Electrical Plastic Tubing (EPT) and Conduit (EPC-40 and EPC-80).⁹~~

~~NEMA TC 6-1990, PVC and ABS Plastic Utilities Duct for Underground~~

~~Installation. NEMA VE1-1991, Metallic Cable Tray Systems.~~

~~NEMA WC 3-1980 (R-1986), Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-19-81 6th ed.).~~

~~NEMA WC 5-1973 (R-1985), Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy. (ICEA S-61-402 3rd ed.).~~

~~NEMA WC 7-1988, Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-66-524).~~

⁷IEEE Std 634-1978 has been withdrawn; however, copies can be obtained from the IEEE Standards Department, IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA, (908) 562-3800.

⁸IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁹NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

~~NEMA WC 8-1988, Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-68-516).~~

~~NEMA WC 50-1976 (R-1988), Ampacities, Including Effect of Shield Losses for Single-Conductor Solid-Dielectric Power Cable 15 kV through 69 kV (ICEA P-53-426 2nd ed.).~~

~~NEMA WC 51-1986 (R-1991), Ampacities of Cables in Open-Top Cable Trays (ICEA P-54-440 3rd ed.).~~

~~NEMA WC 55-1986, Instrumentation Cables and Thermocouple Wire (ICEA S-82-22).~~

3. Special terms Definitions

The majority of definitions for terms or abbreviations used in this guide are included in the *The Authoritative Dictionary of IEEE Standards Terms* [B46].⁵ The following special terms include anomalous terms, acronyms, and abbreviations appearing in this guide.

The following definitions appear again in this standard in the clauses specific to the respective term.

3.1 ABS: Conduit fabricated from acrylonitrile-butadiene-styrene.

~~**1.4.2 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.~~

~~**1.4.3 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.~~

~~**1.4.4 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.~~

~~**1.4.5 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.~~

~~**1.4.6 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 electrostatic or electromagnetic induction.~~

~~**1.4.7 common-mode to normal-mode conversion:** In addition to the common-mode voltages which are developed in the single 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.~~

~~**1.4.8 crosstalk:** The noise or extraneous signal caused by ac or pulse type signals in adjacent circuits.~~

3.2 design life of the substation: The time during which satisfactory substation performance can be expected for a specific set of service conditions, [based upon component selection and applications](#).

3.3 EPC-40: Electrical plastic conduit for type DB applications, fabricated from PE; or for type DB and Schedule 40 applications, fabricated from PVC.

3.4 EPC-80: Electrical plastic conduit for Schedule 80 applications, fabricated from PVC.

3.5 EPT: Electrical plastic tubing for type EB applications, fabricated from PVC.

~~**1.4.10 EMT:** Electrical metallic tubing.~~

3.6 FRE: Conduit fabricated from fiberglass reinforced epoxy.

3.7 IMC: Intermediate metal conduit

¹ The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

² National Electrical Safety Code and NESC are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

³ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

⁴ The IEEE standards or products referred to in Clause 2 are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

⁵ The numbers in brackets correspond to those of the bibliography in Annex P.

3.8 IRIG-B: Inter-range instrumentation group—time code format B; a serial time code format to correlate data with time

3.9 OPGW: Optical power ground wire, or optical ground wire

3.10 RMC: Rigid metal conduit.

3.11 ROW: Right-of-way; a leased or purchased corridor for utility lines

3.12 Schedule 40: Duct designed for normal-duty applications above grade.

3.13 Schedule 80: Duct designed for heavy-duty applications above grade.

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

3.15 Type DB: Duct designed for underground installation without encasement in concrete.

3.16 Type EB: Duct designed to be encased in concrete. ~~when installed (also referred to as Type I duct), fabricated from PVC or ABS.~~

~~**1.4.14 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.~~

~~**1.4.15 fire-resistive barrier:** A wall, floor, or floor-ceiling assembly erected to prevent the spread of fire.~~

~~**1.4.16 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.~~

~~**1.4.19 normal-mode noise (transverse or differential):** The noise voltage which appears differentially between two signal wires and which acts on the signal-sensing circuit in the same manner as the desired signal.~~

~~**1.4.20 PE:** Conduit fabricated from polyethylene.~~

~~**1.4.21 PVC:** Conduit fabricated from polyvinyl chloride.~~

~~**1.4.24 shield (cable systems) (instrumentation cables):** A 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 which may be susceptible to or which may be generating unwanted (noise) electrostatic fields.~~

~~**1.4.27 Type I:** Duct designed to be encased in concrete.~~

~~**1.4.28 Type II:** Duct designed for underground installation without encasement in concrete.~~

~~**1.4.29 Type III:** Duct designed for normal duty applications above grade.~~

~~**1.4.30 Type IV:** Duct designed for heavy-duty applications above grade.~~

4. Control and instrumentation cable

4.1 General

Substation control cables are multiconductor cables used to transmit electrical signals with low voltage levels (less than 600 V) and relatively low current levels, between apparatus [e.g., power transformers, circuit breakers, disconnect switches, and voltage or current transformers (CTs), etc.], and protection, control and monitoring devices (e.g., relays and control switches, status lights, alarms, annunciators, etc.). Substation control signals may be digital or analog [e.g., voltage transformer (VT) and CT signals] and the control signal may be continuous or intermittent. Control signals may be “on” or “off,” with short or long time delays between a change of state.

The complete substation control cable assembly must provide reliable service when installed in equipment control cabinets, conduits, cable trenches, cable trays, or other raceway systems in the electric substation environment.

Instrumentation cables are multiconductor cables used to transmit low-energy (power-limited) electrical signals with low voltage levels (less than 130 V) and relatively low current levels between equipment (usually electronic, such as monitors and analyzers) and control equipment for apparatus. Signals in instrumentation cables could be continuous or intermittent depending on application.

As used in this guide, instrumentation cables consist of cables transmitting coded information (digital or analog) for Supervisory Controls and Data Acquisition (SCADA) systems, substation networks, event recorders, and thermocouple and resistance temperature detector cables.

In the United States, cables are usually designed and constructed in accordance with NEMA WC 57-2004/ICEA S-73-532 [B96].

As used in this guide, leads from CTs and VTs are considered control cables since in most cases they are used in relay protection circuits.

Cable performance

~~This clause provides guidance for establishing cable performance and should be considered in specifying cable for installation in substations. No single 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, is necessary to provide a reliable cable system.~~

4.2 Service conditions (see Annex B)

4.3 Cable selection (see Annex C)

4.3.1 Conductor sizing

The function and location of the control and instrumentation cable circuits affect the conductor size. A conductor that is used to connect the CT secondary leads may have different requirements than a cable that is used for the VT secondary leads. Outdoor control cables may require larger conductor size to compensate for voltage drop due to the relatively long distance between the equipment and the control vault, especially for high-voltage and extra-high-voltage (EHV) substations. Smaller size control cables can be used inside the control building due to the short runs between the panels.

Because of new designs using microprocessor relays and programmable logic devices, there has been a general trend to increase the number of wire terminals on individual panel segments and or racks. This trend is limited by the practicality of decreasing terminal block and test switch size in order to accommodate the additional terminals. Decreasing terminal size creates a practical limit of maximum wire size. However, violation of minimum wire size requirements could cause voltage drop that results in a failure to trip, or current overload that damages the cable.

4.3.1.1 CT circuits

A four-conductor control cable can be used for a CT secondary circuit, which contains all three phases and the neutral. The CT cable conductor should be sized such that the CT standard burden is not exceeded. The CT cable conductor should also be sized to carry the CT continuous thermal rating (e.g., 10 A, 15A) and up to 20 times its normal load current from 0.1 s to 0.5 s during a fault (IEEE Std C57.13.3™-1983 [B75]).

Excessive impedance in CT secondary circuits can result in CT saturation. The loop lead resistance of a CT secondary should not exceed the required maximums for relay, instrument, and revenue metering circuits.

4.3.1.2 VT circuits

VT secondary circuits connect the VT secondaries to the protective and metering devices. The load current for these devices is very small; however, the voltage drop should be considered. The conductor size should be selected such that the VT standard burden is not exceeded, and so that the voltage drop is very small in order to provide the protective and metering devices with the actual voltage at the location of the VTs.

4.3.1.3 Trip and close coil circuits

Ampacity and voltage drop requirements should be considered when determining the size of the control cables that connect to the trip and close coils of the circuit breakers. The conductor size should be capable of carrying the maximum trip coil current, and allow for adequate voltage drop based on the trip coil rating. To insure that actuation of a circuit protective device does not result in a failure to trip, the circuit protection should be selected with a trip rating that is significantly higher than the expected duty. The trip and close cable conductor should have an ampacity that equals, or exceeds, the trip rating of the fuse or circuit breaker protecting the circuit.

4.3.1.4 Circuit breaker motor backup power

Some high-voltage circuit breakers use an ac/dc spring-charging motor connected to the dc control circuit. These motors can run on dc, if the normal ac station service voltage supply to the circuit breaker is lost. The circuit breaker motor supply cable should be selected with a continuous duty ampacity that equals or exceeds the expected ac and dc motor current. The conductor should be sized such that the voltage drop, at the minimum expected ac and dc supply voltage, provides a voltage at the motor within the motor rating.

The load characteristic of a typical spring charging motor is shown in Figure 1. The typical current draw is much higher than the specified “run” current and should be considered in the design.

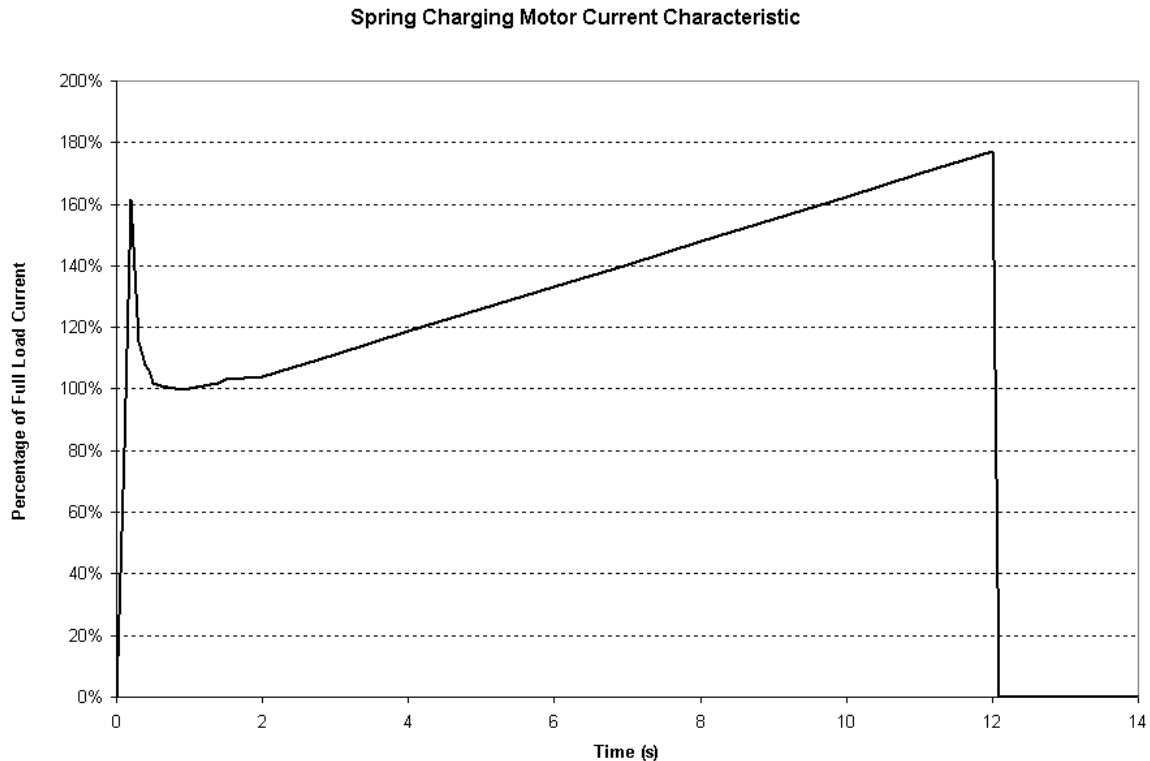


Figure 1—Spring charging motor load characteristic

4.3.1.5 Alarm and status circuits

Alarm and status circuits carry very small current, and voltage drop is not a concern. As a result, a smaller size conductor can be used for these circuits.

4.3.1.6 Battery circuits

The station battery will have an operating range with a minimum terminal voltage. DC utilization equipment, e.g., breaker trip coils, protective relays, will have a minimum voltage rating for operation. The battery cable conductors should be selected so that the voltage drop from the battery terminals to the utilization equipment, for the expected load current, does not result in a voltage below the minimum voltage rating of the utilization equipment. A designer should consider using end of discharge voltage for critical circuits. These would include circuit breaker trip and close coils that are required to operate at the end of a battery's discharge period.

4.3.2 Voltage rating

Low-voltage control cable rated 600 V and 1000 V are currently in use. For control cables applied at 600 V and below, 600 V rated insulation is most commonly used. Some engineers use 1000 V rated insulation because of past insulation failures caused by inductive voltage spikes from de-energizing electromechanical devices, e.g., relays, spring winding motors. The improved dielectric strength of today's insulation materials prompted some utilities to return to using 600 V rated insulation for this application.

4.3.3 Cable construction

The principal components of substation control cables include conductors, conductor insulation, shielding, tape and filler, and covering.

Conductors for substation control cables may be solid or stranded and may be uncoated copper, tin-coated copper, or lead/lead alloy coated wires. Stranded conductors usually consist of 7 or 19 wires for Class B stranding. Conductor size usually ranges from 9 to 14 AWG (American Wire Gauge), but conductor size as small as 22 AWG may be utilized. Caution should be exercised before using such small conductors because of the possibility of mechanical damage.

Insulation for each conductor in a control cable is made from an extruded dielectric material suitable for use in either wet or dry locations or dry-only locations, and at maximum conductor temperatures ranging from 60 °C to 125 °C, depending on the type of insulation material utilized. Common insulation materials include, but are not limited to polyethylene (PE), cross-linked PE (XLPE) Types 1 and 2, silicone rubber (SR), synthetic rubber (SBR), and ethylene propylene rubber (EPR) Types 1 and 2, and polyvinyl chloride (PVC). The thickness of insulation varies with the type of insulation material, conductor size, and voltage rating.

Tape consisting of dielectric material is utilized to bind and separate layers of construction, and fillers made from thermoplastic or other materials are utilized to form a cylindrical shape for most cable assemblies.

Methods for identification of control cable conductors by number with base and tracer colors on each conductor are discussed in Appendix E of NEMA WC 57-2004/ICEA S-73-532 [B96]. Inner jackets for multi-conductor cables may be color-coded as well (reference Table E-1, Table E-2, and Table E-3 of NEMA WC 57-2004/ICEA S-73-532 [B96] for guidance).

4.4 Cable raceway design (see Annex E)

4.5 Routing (see Annex F)

All control circuits in a substation should be installed in a radial configuration, i.e., route all conductors comprising a control circuit in the same cable; or if conduit is used, within the same conduit.

Radial arrangement of control circuitry reduces transient voltages. Circuits routed into the switchyard from the control house should not be looped from one piece of apparatus to another in the switchyard with the return conductor in another cable. All supply and return conductors should be in a common cable to avoid the large electromagnetic induction possible because of the very large flux-linking-loop arrangement otherwise encountered. Also, this arrangement helps avoid common impedances that cause differential and common-mode voltages. This recommendation is especially important for supply and ground circuits.

If the substation has a capacitor bank, all control cables not specifically associated with capacitor controls or protection should be removed from the immediate area around the capacitor bank to avoid induction of surges into relaying systems or possible control cable failure during capacitor bank switching. The routing of control cables from capacitor bank neutral CTs or VTs should be kept at right angles with respect to the common neutral for single point grounding and in parallel with the tie to the substation ground for peninsular grounding to minimize induction (“Shunt capacitor switching EMI voltages, their reduction in Bonneville Power Administration substations” [B26]). Control cables entering the capacitor bank area should be kept as close as possible to the ground grid conductors in the cable trench, or on top of the duct run, or in contact with the ground grid conductor if directly buried (see IEEE Std C37.99™-2000 [B74]).

All dc circuits are normally ‘radial,’ i.e., the positive and negative leads (‘go’ and ‘return’ circuits) are kept within the same cable. In alarm and relay circuits where there might be one positive and several negative returns, all leads should be in the same jacket.

In circuits where the positive and negative are in separate cables for specific reasons, such as the circuit between the charger and station battery, the positive and negative should be physically close together wherever practical.

Where dc motors are connected to the substation control battery, as for motor operated disconnect switches, the voltage may be provided by a “yard bus.” The yard bus is a single pair of large conductors that are sized to supply several, or all, of the connected motor loads simultaneously.

4.6 Transient protection (see Annex G)

High energy transients may cause failures in low-voltage substation equipment such as solid-state relays, transducers, measuring instruments, and remote terminal units (RTUs) connected at the ends of control or instrumentation cables. In a substation environment, the high energy sources typically include power-frequency fault currents, lightning, or switching transients. Sometimes these influences are also responsible for erroneous operations of relays causing partial or entire substation shutdown. The overvoltages may even damage transient surge suppressor devices such as metal oxide varistors or gas discharge tubes at the terminals. Shielded cables are typically applied in higher voltage substations (voltages at 230 kV and higher) or at lower voltages for specific applications.

4.7 Electrical segregation (see Annex H)

Segregation of control cables in the substation cable trench or cable tray system is generally not necessary.

Control cables should not be installed in ducts or trenches containing medium-voltage cables (greater than 1000 V).

4.8 Separation of redundant cable (see Annex I)

4.9 Cable pulling tension (see Annex J)

4.10 Handling (see Annex K)

4.11 Installation (see Annex L)

4.12 Acceptance testing (see Annex M)

Control cables should be insulation-resistance tested prior to connecting cables to equipment. They may be tested as part of the system checkout.

4.13 Recommended maintenance (see Annex N)

5. Communication cable

5.1 General

Substation communications requires multi-conductor cables to transfer signals at low voltage and current levels between intelligent electronic devices (IEDs) at the substation and communication equipment at the remote site. This data transfer involves multiple types of cables, including telephone, data and coaxial cables. Telephone cables transfer voice and data signals, unshielded twisted pair (UTP) cables transfer high-frequency data and coaxial cables transfer data for antenna and power-line carrier (PLC) tasks. A step-by-step checklist for the design of substation communications systems can be found in Annex D. Other means of communication exist within the substation, e.g., microwave. These other means are not covered in this guide, which focuses on substation cabling only. For additional information on substation communications, specifically fiber optics, see Clause 6 of this guide.

5.2 Service conditions (see Annex B)

5.2.1 Ground potential rise considerations

With any data connection to a substation or switchyard, ground potential rise (GPR) should be considered in order to protect sensitive equipment. This consideration requires close coordination with the engineering staff of outside entities (e.g., telephone company) to ensure appropriate isolation equipment is installed. As a result, offsite equipment is adequately protected from unacceptable voltage increases in the event of a fault.

5.3 Cable selection (see Annex C)

5.3.1 Telephone cable

Telephone cables have traditionally been essential for the transfer of voice and basic data signals. These communication conductors are twisted and shielded in pairs of 2 to 50. The conductors are typically individually insulated and range in size from 22 to 26 AWG copper. In selecting a cable, the larger sizes will help reduce the effects of resistance on signal transmission. These circuits can be either dial-up or dedicated.

5.3.1.1 Dial-up circuits

Dial-up circuits provide one communication path for multiple devices. Each device only uses the path for a relatively small amount of time; therefore, a dedicated circuit is not required. In some substations, telephone switch or circuit sharing equipment is used to reduce the number of telephone lines and the associated installation and rental fees. Within the confines of a substation, dial-up circuits have four main functions. First, operations and maintenance personnel use telephone voice circuits to receive switching instructions, report hardware status and provide emergency notifications. Second, dial-up service may be provided for feeder or transmission line revenue or operations/survey metering. In this case, revenue meters are polled for the latest measurements only at a specified time. Third, dial-up circuits are used for security and fire protection systems. If heat, smoke or intrusion detectors are activated, the dispatcher or local authorities are immediately notified via an auto dialer. Lastly, protection engineers can also access protective relays, or IEDs, via a dial-up connection to interrogate the hardware or modify settings.

The transfer rate of dial-up cables varies. Older cabling is limited to 24 kbps; however, with new coding techniques like high bit-rate digital subscriber lines, transmission of T1 services of 1.544 Mbps can be achieved. T1 is a time-domain modulation digital channel carrier that in combination with DS-1 (framing and transmitting specification) can provide up to twenty-four 64 kbps channels. T1 lines are generally used for bulk power substations with significant data transmission requirements.

Considering the cost of a cable installation from an off-site trunk line, a typical substation telephone cable connection generally has a 50% spare pair ratio.

5.3.1.2 Dedicated circuits

Some substation data is either highly critical to the functioning of the substation or needs to be constantly accessible. In these cases, telephone circuits that are either “always” active or are dedicated to a specific function are used. These applications may include protective relay communications for tripping signals and SCADA RTU “real time”—within the equipment polling parameters—operations data. RTUs on dedicated circuits provide switching equipment control, equipment (disconnect and circuit breaker) status, analog quantities (megawatts, Mvars, voltages) and alarm indications. These circuits are also expensive and, in addition to the installation costs, have significant monthly rental fees.

5.3.2 Data cables

UTP data cables for networking and data bus communication systems are relatively new in IED applications. Initially three commonly accepted “cable performance” levels were established for communications cable: 1) POTS (plain old telephone service); 2) low speed computer network applications; and 3) Ethernet “rings” with 16 MHz cable bandwidth frequencies. Later levels 4 and 5 were developed for a higher capacity of 100 Mbps. Later, the term “CAT” (category) was established by such standards as EIA/TIA 568 [B13], EIA/TIA 569 [B14], EIA/TIA 607 [B15], and the associated technical service bulletins (TSBs) 36, 40A, 53.

There are several designations for CAT cables. These designations are based on the frequency capability of the cable. Most CAT cables consist of four 24 AWG twisted pair solid copper conductors with the frequency performance dependant upon the number of twists and insulation type used. CAT 6 cables, for example, expand the frequency range to 155 MHz and CAT 7 may provide a frequency range from 200 MHz to as high as 600 MHz. Today’s applications generally employ CAT 5 cables. For most “small” local area networks (LANs), only two of the four pairs are used to provide full duplex, simultaneous bi-directional communications.

Data transfer requirements/limitations should also be considered when the cabling is selected.

Care should be taken in protecting CAT cables. They generally do not have control cable grade jackets and, if run in an exposed area, should be provided additional physical protection.

Figure 2 and Figure 3 demonstrate some typical examples of data cable utilization. In Figure 2, a human-machine interface (HMI) communicates through a CAT 5 cable to the operations meters, then the alarm I/O device and finally the protection relays. In Figure 3, CAT 5 cabling is used for data communications between a power plant DCIS and the RTU in the plant switchyard (IEEE Std 1050™-1996 [B65]).

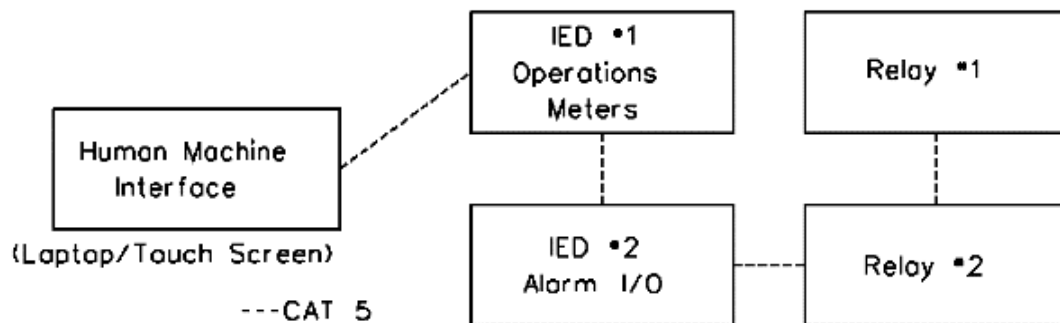


Figure 2—Data communication—HMI to meters

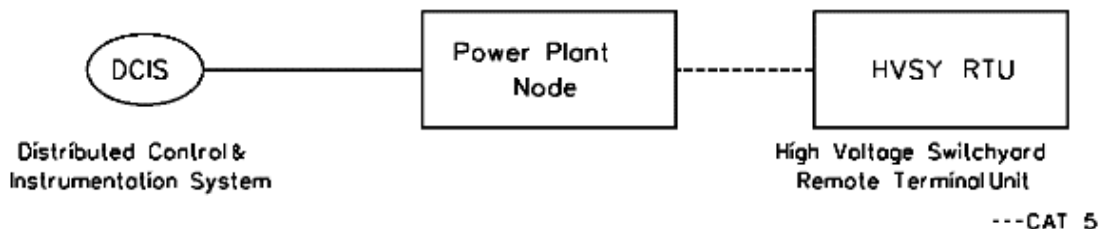


Figure 3—Data communication—Power plant to switchyard

5.3.3 Coaxial cable

A third type of hardwire data cabling used in substations is coaxial cable. This cable consists of an outer jacket, outer shield or conductor, a dielectric insulator (PE) and an inner solid or stranded conductor. The outer conductor or braid acts as both a shield and a return path conductor. Typical uses include antenna feeds for IRIG-B (time synchronization) and PLC applications. There are multiple types of coax depending on the application (e.g., RG-6 or 59). Advantages of coaxial cable include the following: high bandwidth, low signal distortion, low susceptibility to cross-talk and noise, and greater information security. However, coaxial cable is more difficult to install, heavier, and does not have the flexibility offered by twisted pair cables. Equipment manufacturers should be contacted to provide application-specific selection guidance.

Figure 4 shows two common applications of coaxial cables. The first is the connection between an IRIG-B port and an outdoor antenna in order to provide satellite time synchronization for protection equipment. The second example shows the connections involved in PLC communications.

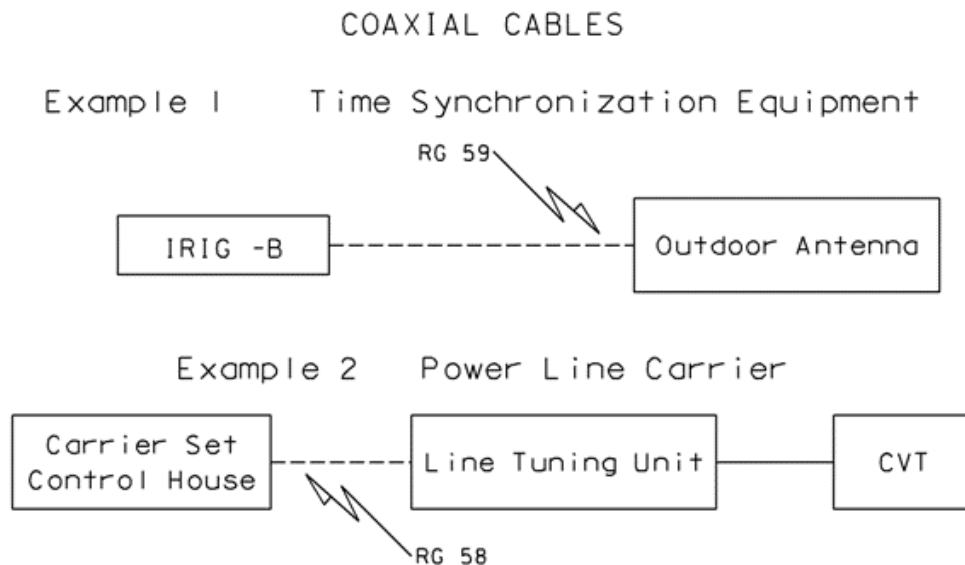


Figure 4—Example coaxial cable communications block diagram

5.4 Cable raceway design (see Annex E)

5.5 Routing (see Annex F)

5.5.1 Telephone cables

Figure 5 illustrates a typical telephone communications block diagram. The isolation device (high-voltage interface per IEEE Std 487™-2000 [B56]) separates the substation equipment (right-hand side of figure) from outside equipment such as the telephone company switch (left-hand side of figure). Signals from the remote source arrive first at the multiplexer. In this example, five circuits are then produced. The first is a standard telephone voice circuit. Second is an automatic dial-up fire/security line. The third circuit serves the revenue meters and digital fault recorder through a circuit-sharing device. Circuits 4 and 5 represent examples of dedicated circuits. Circuit 4 is dedicated to the RTU communications, and Circuit 5 is dedicated to protective relay communications.

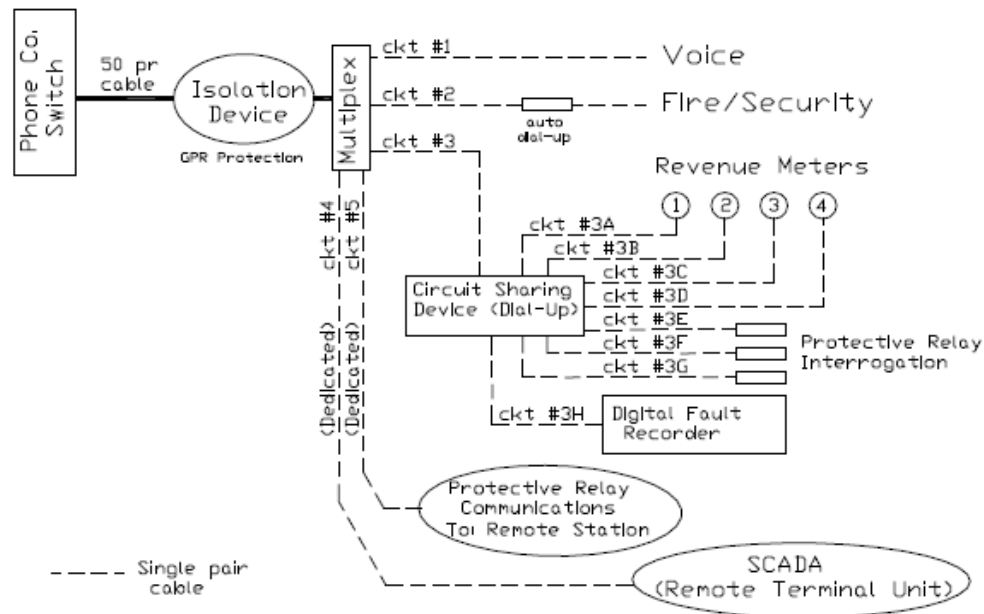


Figure 5—Example telephone communications block diagram

5.5.2 Data cables

These cables are generally installed within cabinets and cable trays to connect devices within a control house.

5.6 Transient protection (see Annex G)

5.6.1 High-speed data circuits

The following guidelines are provided for computer circuits and the circuits for high-speed data logging applications using low level analog signals:

- a) The circuits should be made up of twisted pair shielded cables. For noncomputer-type applications, such as annunciators, shielding may not be required.
- b) Twisting and shielding requirements for both digital input and digital output signals vary among different manufacturers of computerized measuring 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 proximity to each other, twisted pair multiple conductor cables with overall shield should be used 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.
- c) Cable shields should be electrically continuous except when 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.
- d) At the point of termination, the shield should not be stripped back any further than necessary from the terminal block.
- e) The shield should not be used as a signal conductor.
- f) Use of twisted pair shielded cable into balanced terminations greatly improves transient suppression.
- g) Use of a common line return both for a low-voltage signal and a power circuit should not be allowed (Garton and Stolt [B22]).
- h) Digital signal circuits should be grounded only at the power supply.
- i) 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.
- j) Multi-pair 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.
- k) 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.
- l) Each grounded RTD should be on a separate ungrounded power supply except that groups of RTDs embedded in the windings of transformers and rotating machines should be grounded at the frame of the respective equipment as a safety precaution. A separate ungrounded power supply should be furnished for the group of RTDs installed in each piece of equipment.
- m) When a signal circuit is grounded, the low or negative voltage lead and the shield should be grounded at the same point.

5.6.2 Telephone cables—Dial-up circuits

Cable shielding using metal braid or Mylar film is an important requirement for telephone cabling within a substation. Crosstalk, electromagnetic interference (EMI), and transient spikes can seriously affect the transmission of digital signals. The most effective method to provide a low signal to noise ratio is to shield the individual pairs. An overall shield limits exterior interferences but will not protect against internal coupling and cross-talk. In general, communications cable shields are grounded at one end to prevent ground loop potentials and the associated noise. In cases where equipment designs require grounds at both ends, capacitors can be used between the shield and ground to block dc voltages. Isolation amplifiers have also been employed.

5.6.3 Isolation of telecommunication cables

In general, the local telephone company provides one or more isolating devices in the substation and leases the protection interface including its maintenance to the power company. One or more of the following protection devices may be installed to protect against power-frequency GPR.

Typically, the following isolation equipment is used:

- a) Drainage unit (drainage reactor/mutual drainage reactor) is a center-tapped inductive device designed to relieve conductor-to-conductor and conductor-to-ground voltage stress by draining extraneous currents to ground.
- b) Isolating (insulating) transformers provide longitudinal (common mode) isolation for the facility. They can also be used in a combined isolating-drainage transformer configuration.
- c) Neutralizing transformers introduce a voltage into a circuit pair to oppose an unwanted voltage. They neutralize extraneous longitudinal voltages resulting from ground voltage rise or longitudinal induction, or both, while simultaneously allowing ac or dc metallic signals to pass.
- d) Optical couplers (isolators) provide isolation using a short-length optical path.

For additional information on these methods, see IEEE Std 487™-2000 [B56] and IEEE Std 1590™ [B71].

5.7 Electrical segregation (see Annex H)

5.8 Separation of redundant cable (see Annex I)

5.9 Cable pulling tension (see Annex J)

5.10 Handling (see Annex K)

5.11 Installation (see Annex L)

5.12 Acceptance testing (Annex M is not applicable)

Follow the cable manufacturer's recommendations.

5.13 Recommended maintenance (see Annex N)

6. Fiber-optic cable

6.1 General

Substation fiber-optic cable may be used to interconnect substation control and protection equipment, to connect the substation equipment to offsite circuits, and to connect instrumentation and communication devices [e.g., optical CTs and PTs (potential transformers)].

6.2 Service conditions (see Annex B)

6.3 Cable selection (see Annex C)

6.3.1 Fiber cable selection

Fiber-optic cables are typically specified with the following information for proper application:

- a) Number of fibers, e.g., 2, 4, 8 per cable
- b) Fiber type, e.g., single mode, multimode or hybrid
- c) Core/cladding diameter, e.g., 9/125, 50/125, 62.5/125 μm
- d) Wavelength of transmitted light, e.g., 1300 nm
- e) Distance to transmit signal
- f) Type of armor if required, including application as optical power ground wire (OPGW)

Single-mode fibers have small cores about 9 μm in diameter with a cladding about 125 μm in diameter. These fibers transmit infrared laser light with wavelengths of 1310 nm to 1550 nm. Single-mode cables are more efficient at signal transfer and are used for transmission distances nominally greater than 1 km.

Multi-mode fibers have larger cores typically about 62.5 μm in diameter with cladding about 125 μm diameter, and transmit infrared light with wavelengths of 850 nm to 1300 nm from light-emitting diodes. Multi-mode cables are less expensive to install, less efficient than single-mode cables, and are used for shorter runs within substations. The termination devices are less expensive than for single-mode.

Due to impurities in the glass fibers the light signal degrades within the fiber, depending upon the wavelength of the transmitted light and the distance over which it is to be transmitted. When the signal is transmitted over great distances, optical regenerators may be required to boost signal strength.

6.3.2 Cable construction

There is a wide variety of fiber-optic cable constructions. In addition to the choice of single mode or multi-mode, the number of fibers can range from two to hundreds. The available constructions include cable that meets standards requirements for designation as indoor, outdoor, or indoor/outdoor. Cable is available with surrounding loose (buffer) tube, an internal dielectric tension member, a duct that is integral with the cable, and armor. Cable diameter is a function of the construction and ranges from 4 mm to more than 20 mm. Additional information about available cable constructions is available at various websites,⁶ e.g., Bibliography, AFL Automotive,⁷ Corning,⁸ Prysmian,⁹ Superior Essex.¹⁰

⁶ [This information is given for the convenience of the users of this standard and does not constitute an endorsement by the IEEE of these products.](#)

⁷ http://www.alcoa.com/afl_auto

[To link substations together, fiber-optic cable may be installed on transmission or distribution lines using OPGW or all-dielectric self-supporting \(ADSS\) cable \(IEEE Std 1138™-1994 \[B66\]\). The OPGW or ADSS is usually terminated within the substation in an enclosure where the substation fiber-optic cable is connected to the OPGW or ADSS.](#)

[One of the types of conduit used for buried fiber-optic cable is the continuous-reeled type. Such continuous duct is popular because it is inexpensive and offers enough protection to allow the use of the less expensive cable constructions.](#)

6.4 Cable raceway design (see Annex E)

6.5 Routing (see Annex F)

6.6 Transient protection (Annex G is not applicable)

[Transient protection is not required due to the inherent properties of the fiber.](#)

6.7 Electrical segregation (see Annex H)

[The substation fiber-optic cable raceway may be cable tray, conduit, underground duct, or a trench system. However, conduit and duct offers protection from crushing, ground disruption, rodents, and other environmental abuse. In addition, the cable is easier to replace or upgrade in the future. Several methods and types of conduit systems are used. For example, one configuration includes pre-manufactured segregated ducts or large ducts with multiple plastic, high-density PE “inner ducts” installed inside. The inner ducts can be smooth walled or corrugated either longitudinally or horizontally.](#)

6.8 Separation of redundant cable (see Annex I)

6.9 Cable pulling tension (see Annex J)

[There may be special design considerations requiring maximum pulling tension or minimum bending radius that cannot be calculated using the guidelines in Annex J. For these situations follow the guidelines from the cable manufacturer.](#)

6.10 Handling (see Annex K)

[The glass fibers in the fiber-optic cable are reasonably robust. The glass fibers are usually well protected by buffer tubes, duct, armor, etc., which are part of the cable construction. Even though the glass in the fiber is actually stronger \(higher tensile strength per unit area\) than a metal conductor, there is very little cross-sectional area in a fiber available for strength and support. For this reason, most fiber-optic cables have other components to provide the strength for cable support during pulling, handling, etc.](#)

[Pulling lubricants with some unique features are required by the special nature of optical cable pulling, i.e., long pull lengths and lengthy pull duration.](#)

⁸ <http://www.corningcablesystems.com>

⁹ <http://www.us.prysmian.com>

¹⁰ <http://www.superioressex.com>

6.11 Installation (see Annex L)

Fiber-optic cable installation shall meet the requirements of the National Electrical Safety Code[®] (NESC[®]) (Accredited Standards Committee C2-2002¹¹). Although the National Electrical Code[®] (NEC[®]) (NFPA 70, 2007 Edition [B100]) is not applicable to substations under the exclusive control of electric utilities, it provides valuable guidance.

Fiber-optic cables in substations can be installed in the same manner as metallic conductor cables; however, this practice requires robust fiber-optic cables that can withstand normal construction handling and still protect the fibers inside. There are important differences to be considered in the handling and installation of fiber-optic cable, as compared to metallic conductor cable. In cable tray and trench, fiber-optic cable may be subjected to stress due to the weight of other cables which can induce microbending into the fiber-optic cable. Therefore, it is more-common practice to place the fiber-optic cable in a separate duct installed in the tray, trench or conduit (usually plastic), or use a cable construction with an integral duct. This not only protects the cable, but also allows easier identification from metallic cables.

Depending on the cable construction, the maximum allowable pulling tension on fiber-optic cable can vary from 200 N (45 lb) to more than 3000 N (680 lb). The maximum allowable tension for a particular fiber-optic cable should be obtained from the cable manufacturer. This maximum recommended pulling tension should be noted on any drawings, installation instruction, etc. The theory of pulling tension is the same for fiber-optic cable as it is for metallic conductor cable. Pulling tension can be calculated based on cable weight, conduit system design, and coefficient of friction.

Probably the most common installation mistake is making tight bends in the cable. Tight bends, kinks, knots, etc., in fiber cable can cause micro-cracking or growth of flaws in the fiber, with resulting loss of performance.

Minimum bending radius in fiber-optic cable is typically in the range of 20 times the cable diameter. This bending radius should be considered by the engineer when specifying conduit bends and pull box openings or sizing guide pulleys, sheaves, mid-assist capstans, etc.

Fiber-optic cables are often pulled for much longer distances than metallic conductor cables. These long pulls minimize the number of splices in fiber-optic cable which is desirable for fiber performance. The light weight of the cable, internal tension members, and tube or duct in the cable itself, makes these long pulls possible. Proper lubrication and good conduit installation are also necessities.

The special nature of fiber-optic cable pulling, i.e., long pull lengths and longer pull durations, require unique lubricants.

Lightweight fiber-optic cable rubs on all sides of the conduit through the natural undulation of long straight runs. Many common lubricants flow to the bottom of the raceway and lose effectiveness in this type of pulling.

As with metallic conductor cable, specific coefficients of friction depend on cable jacket type, conduit type, and the lubricant as well.

Short-length fiber-optic cable pulls may not require lubricant; however, for long or complex cable pulls, lubricant is critical to making an efficient, high quality installation. The requirements for fiber-optic cable

pulling lubricant are the same as those for metallic conductor cable:

- a) Compatibility with cable outer covering, tube, or duct
- b) Complete and even coating on the cable for friction reduction at all friction points
- c) Consistent low coefficient of friction (over time)

¹¹ For information on references, see Clause 2.

6.12 Acceptance testing (see Annex M)

Fiber-optic cable is tested for signal continuity and db signal strength after installation. This ensures that all connections have been performed properly, and the fiber has not been damaged during installation.

6.13 Recommended maintenance (see Annex N)

7. Power cable (ac and dc < 1 kV)

Low-voltage power cables are designed to supply power to utilization devices of the substation auxiliary systems rated 1000 V or less.

7.1 Service conditions (see Annex B)

Station service cable is likely to be exposed to open air at the transformer connections to the tray or weatherhead.

7.2 Cable selection (see Annex C)

7.2.1 Conductor sizing

See IEEE Std 835 for sizes based on ampacity and other factors.

7.2.2 Voltage rating

For power cables applied at 600 V and below, some use 1000 V rated insulation because of past insulation failures caused by inductive voltage spikes from de-energizing electromechanical devices, e.g., relays, spring winding motors. The improved dielectric strength of today's insulation materials prompted some utilities to return to using 600 V rated insulation for this application. Low-voltage power cable rated 600 V and 1000 V is currently in use.

7.3 Cable raceway design (see Annex E)

7.4 Routing (see Annex F)

7.5 Transient protection (see Annex G)

7.6 Electrical segregation (see Annex H)

Consideration should be given to insulation deformation when cable diameters differ greatly. When cable classifications are mixed, the power cable ampacity is calculated as if all the cables were power cables.

Segregating low-voltage power cables in the substation cable trench or cable tray system is generally not necessary.

7.7 Separation of redundant cable (see Annex I)

7.8 Cable pulling tension (see Annex J)

7.9 Handling (see Annex K)

7.10 Installation (see Annex L)

When single conductors are used in trays for two-wire or three-wire power circuits, cables should be trained and securely bound in circuit groups to prevent excessive movements caused by fault-current magnetic forces, and to minimize inductive heating effects in tray sidewalls and bottom.

Consideration of circuit voltage drop may lead to cables larger than the available space in typical service panels and connectors. This may lead to multiple conductors per phase, conductor reducing terminal connectors, or interior panel space and bending radius constraints.

7.11 Acceptance testing (see Annex M)

7.12 Recommended maintenance (see Annex N)

Low-voltage power cables may be insulation-resistance tested prior to connecting cables to equipment. These cables may be tested as part of the system checkout.

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 grounded in the same cable.

8. Power cable (1 kV to 35 kV)

Medium-voltage power cables are designed to supply power to substation utilization devices, other substations, or customer systems rated higher than 1000 V.

NOTE—Oil-filled and gas-insulated cables are excluded from this definition and are not covered in this guide.¹²

The proper design of medium voltage power cable systems is dependent on many factors, including system nominal voltage, system fault level, voltage drop, conductor material, insulation and shielding material, type of ductwork (whether direct buried or in duct), phase spacing (and conductor spacing), phase arrangement, number of conductors installed, method of shield grounding, earth thermal resistivity, ambient temperature, current loading, load cycling, and load factor. These factors make it prudent to consult industry codes.

¹² Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

8.1 Service conditions (see Annex B)

8.2 Cable selection (see Annex C)

8.2.1 Conductor sizing

Phase transposition and/or proximity heating should be considered for long runs of medium-voltage power cables. See IEEE Std 835.

8.2.2 Voltage rating

For medium-voltage cables, it is usual practice to select an insulation system that has a voltage rating equal to or greater than the expected continuous phase-to-phase conductor voltage. For solidly grounded systems, the 100% insulation level is typically selected, but the 133% insulation level may be selected where additional insulation thickness is desired. The 133% insulation level is also applied on systems without automatic ground fault protection.

8.2.3 Cable construction

A shield screen material is applied directly to the insulation and in contact with the metallic shield. It can be semiconducting material or, in the case of at least one manufacturer, a stress control material. At the high voltages associated with shielded cable applications, a voltage gradient would exist across any air gap between the insulation and shield. The voltage gradient may be sufficient to ionize the air, causing small electric arcs or partial discharge. These small electric arcs burn the insulation and eventually cause the cable to fail. The semiconducting screen allows application of a conducting material over the insulation to eliminate air gaps between insulation and ground plane.

Various shield screen material systems include the following:

- a) Extruded semiconducting thermoplastic or thermosetting polymer
- b) Extruded high-dielectric-constant thermoplastic or thermosetting polymer, referred to as a stress control layer

8.3 Cable raceway design (see Annex E)

8.4 Routing (see Annex F)

8.5 Transient protection (see Annex G)

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 electric field within the cable; to minimize deterioration of cable insulation or jackets caused by surface discharges; and to minimize radio interference. 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. The shielding recommendations contained in IEEE Std 575 should be followed.

8.6 Electrical segregation (see Annex H)

Medium-voltage power cables should be segregated from all other cables and installed so that their voltage cannot be impressed on any lower voltage system. Methods for achieving this segregation include the following:

- a) Installation of medium-voltage cables in raceways that are separated from low-voltage power and control cables and from instrumentation cables. Installation of different voltage classes of medium-voltage power cables in separate raceways is also recommended. Cables installed in stacked cable trays should be arranged by descending voltage levels, with the higher voltages at the top.
- b) Utilization of armored shielded cables (separate raceways are still recommended).

8.7 Separation of redundant cable (see Annex I)

8.8 Cable pulling tension (see Annex J)

For additional information on pulling of dielectric power cables, see AEIC CG5-2005 [B1].

8.9 Handling (see Annex K)

8.10 Installation (see Annex L)

The ends of medium-voltage power cables should be properly sealed during and after installation.

8.11 Acceptance testing (see Annex M)

Shielded and unshielded medium-voltage cables should not be subjected to high-voltage dc tests; insulation resistance tests are recommended (IEEE Std 400™-2001 [B53]).

8.12 Recommended maintenance (see Annex N)

3. Conductor sizing and voltage rating of power cables

This clause provides guidance for conductor sizing and determining 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, conductor temperature, earth thermal resistivity, load factor, current loading, system fault level, voltage drop, system nominal voltage and grounding, method of installation, and number of conductors being installed.

3.2 Cable construction

Cable insulation and shielding materials, dimensions, and configurations have been arranged in NEMA and AEIC standard rating structures with ratings for standard insulation and shielding configurations. The cable insulation system is determined by selection of a standard voltage rating.

The cable conductor is selected to meet ampacity and voltage drop criteria.

The cable jacket, or outer covering (if any), is selected to meet mechanical protection, fire resistance, and environmental criteria, or to provide a moisture barrier for the insulation system.

3.2.1 Voltage rating

The selection of the cable voltage rating is based on the service conditions of 2.1, the electrical circuit frequency, phasing, and grounding configuration, and the steady-state and transient conductor voltages with respect to ground and other energized conductors.

A voltage rating has been assigned to each standard configuration of shield and insulation material and thickness in NEMA WC 3-1980, NEMA WC 5-1973, NEMA WC 7-1988, NEMA WC 8-1988, and in AEIC CS5-1987, AEIC CS6-1987, and AEIC CS7-1987. The selected voltage rating must result in a cable insulation system that maintains the energized conductor voltage, without installation breakdown under normal operating conditions.

For high voltage cables, it is usual practice to select an insulation system that has a voltage rating equal to or greater than the expected continuous phase-to-phase conductor voltage. The NEMA standards provide for a cable voltage rating that is only 95% of the actual continuous voltage. For solidly grounded systems, it is usual to select the 100 Percent Insulation Level, but the 133 Percent Insulation Level is often selected where additional insulation thickness is desired. The 133 Percent Insulation Level is also applied on systems without automatic ground fault protection.

Distribution substations often utilize cable for the distribution circuits from the substation secondary switch yard (substation getaways). The insulation system selected for this distribution cable may have a voltage rating that is a class above the minimum NEMA rating for the actual circuit voltage and ground fault protection, because it is believed that the additional insulation will result in a lower probability of insulation failure.

Research conducted by the Electric Power Research Institute has led to cable construction recommendations published in EPRI EL-6271 [B10].¹¹ The EPRI recommendations for cable insulation systems have insulation thickness that are the same as those of the NEMA and AEIC standards.

For power and control cables applied at 600 V and below, some engineers use 1000 V-rated insulation because of past

~~insulation failures caused by inductive voltage spikes from de-energizing electromechanical devices, e.g., relays, spring winding motors. The improved dielectric strength of today's insulation materials prompted some utilities to return to using 600 V-rated insulation for this application. Low voltage power and control cable rated 600 V and 1000 V is currently in use.~~

~~The selection of the power cable insulation system also includes consideration of cost and performance under normal and abnormal conditions. Dielectric losses, resistance to flame propagation, and gas generation when burned are the most common performance considerations.~~

~~The IEEE S-135 (1962) method for determination of ampacity of cable installed in tray was found to be unsatisfactory. The industry accepted method for randomly installed cable in tray is given in NEMA WC-51-1986.~~

~~Besides ampacity, selection of power cable conductors may include consideration of the cost of losses.~~

3.2.3 Voltage drop

~~Voltage regulation requirements should be in the selection of conductor size. Motor feeder voltage drop under should be limited to allow the motor to operate within its design specifications.~~

4. Electrical segregation of cable systems

~~This clause provides guidance for electrical segregation of cable systems voltage levels, signal levels, and vulnerability to electrical noise pickup.~~

4 Cable classifications

~~High voltage power cables are designed to supply power to substation utilization devices, other substations, or customer systems rated higher than 1000 V.~~

~~NOTE — Oil filled and gas insulated cables are excluded from this definition and are not covered in this guide.~~

~~Low voltage power cables are designed to supply power to utilization devices of the substation auxiliary systems rated 1000 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 substation auxiliary system.~~

~~NOTE — As used in this document, leads from current and voltage transformers are considered control cables since in most cases they are used in relay protection circuits. However, when current transformer leads are in a primary voltage area exceeding 600 volts they should be protected required by the NESC, Rule 150.~~

~~As used in this document, instrumentation cables consist of cables for Supervisory Controls and Data Acquisition (SCADA) systems or event recorders, and thermocouple and resistance temperature detector cables.~~

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

4.2 Segregation

~~Segregating low voltage power cables, control cables, and instrumentation cables in the substation cable trench or cable tray system is generally not necessary. High voltage power cables should be segregated from all other cables.~~

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

4.2 High-voltage power cables

These cables should be installed so that the high voltage cannot be impressed on any lower voltage system. Methods for achieving this segregation are

- a) Installation of high-voltage cables in raceways that are separated from low-voltage power and control cables and from instrumentation cables. Installation of different voltage classes of high-voltage power cables in separate raceways is also suggested.
- b) Utilization of armored shielded cables (separate raceways are still suggested).

4.2.2 Low-voltage power and control cables

These cable classifications may be mixed. Consideration should be given to insulation deformation when cable diameters differ greatly. When cable classifications are mixed, the power cable ampacity is calculated as if all the cables were 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

- a) Installations that provide physical separation between the instrumentation cables and any electrical noise source [B15], [B38].
- b) Installation in separate enclosed magnetic raceways.
- c) Cable construction configurations, such as twisted conductors and shielding.
- d) Installation of analog signal cables separate from all power and control cables, and from unshielded cables carrying digital or pulse type signals. Shielded voice communications cable (without power supply conductors) may be included in raceways with analog signal cables.
- e) Segregation of telephone and other communication type cables from all other substation cables.

Additional information on instrumentation cable may be found in NEMA WC 55-1989.

4.2.4 Optical cable

From the outside, an optical cable looks like any electrical multiconductor cable; however, it is lightweight and flexible compared to metal conductor cable. Typical optical cable diameter ranges from less than 1/8 in (3.175 mm) to 3/4 in (19.4 mm), depending on fiber numbers and cable construction. The most common optical cable jacket materials are polyethylene (all types), PVC, and polyurethane.

The placement of optical cable in conduit is quite common. Conduit offers protection from crushing, ground disruption, rodents, and other environmental abuse. In addition, the cable is easier to replace or upgrade in the future. Several methods and types of conduit systems are used. For example, one configuration includes pre-manufactured segregated ducts or large ducts with multiple plastic, high density polyethylene "inner ducts" installed inside. The inner ducts can be smooth walled or corrugated either longitudinally or horizontally.

One method of installation involves a composite optical overhead ground wire (OPGW) on a transmission line to link substations together. The OPGW is usually terminated in a standard splice case at a substation structure. At this splice case, it is interfaced with the substation optical cable.

The substation optical cable should be installed in conduit from the splice case into the substation cable duct or trench system. The optical cable should be installed in conduit from the substation cable duct or trench system to the control house where it is terminated on a fiber termination panel. There are important differences to be considered in the handling and installation of fiber optic cable, as compared to metallic cable. In ladder-type cable tray, optical cable may be subjected to stress due to the weight of other cables which can induce microbending into the optical cable. Therefore, it may be a better practice to place the optical cable in a separate duct installed in the tray.

Optical cables in substations should be installed in the same manner as metallic conductor cables. This practice requires robust optical cables that can withstand normal construction handling and still protect the fibers inside.

6. Shielding and shield grounding

This clause provides information on the origin of transients in substations and guidance for shielding and shield grounding of high-voltage power, instrumentation, control, coaxial, and triaxial cable systems.

6.1 Origin of transients in substations

- a) *High voltage switching.* Opening or closing a switching device to de-energize or energize a section of substation bus is generally accompanied by arcing and will initiate a high-frequency transient. The frequency will be determined by the self-inductance and shunt capacitance of the high-voltage conductors involved. The resulting overvoltages can exceed two per unit. Both electric and magnetic coupling between high-voltage and low-voltage conductors can result in high-level transients in the low-voltage system.
- b) *Capacitor switching.* Switching a capacitor bank causes a current transient which is a function of the bank size and the circuit constants back to the source. If other capacitors are already connected nearby to the same line or bus, they lower the impedance seen by the switched capacitor, increasing the magnitude and frequency of the transient. Energy stored in the nearby bank may contribute further to the severity. The circuit between banks is likely to ring at a high frequency because of the low inductance in the short line connecting the banks and the reduced effective capacitance considering the banks in series [B39]. This phenomenon further enhances the tendency of the transient to interfere with nearby circuits.
- c) *Transmission line switching.* This phenomenon is similar to capacitor bank switching, with the difference being the distributed nature of the inductance and capacitance of the line. The magnitude of the line charging current tends to be substantially less than that for capacitor bank switching. The frequency of the transient current or voltage is inversely proportional to the line length [B38].
- d) *Coupling capacitor voltage transformers (CCVT).* The capacitors in these devices, in conjunction with inductances of the power system conductors, constitute a resonant circuit whose frequency can be in the megahertz range. Unless the base of the CCVT has a low surge impedance to the substation ground grid, a high voltage can appear between the CCVT secondary terminals and the grid. The high voltage will be generated primarily during air-break switching operations.
- e) *Ground voltage rise (GVR).* GVR is the voltage rise proportional to the magnitude of the ground current and to the ground resistance. Under normal conditions, the grounded electrical equipment operates at essentially zero ground voltage within the substation yard. During a fault, the portion of fault current which is conducted by a ground electrode in the earth causes a rise of the electrode voltage with respect to remote earth (see IEEE Std 80-1986 and [B26]).
- f) *Ground voltage rise differences.* Both electromagnetic coupling and conduction can contribute to substantial ground voltage rise differences, particularly at the higher frequencies typical of many transients occurring on a high-voltage power system. Even well-designed grounding grids that extend over the large areas needed for high-voltage switchyards have sufficient inductance to cause high-voltage differences. Electromagnetic coupling to the ground grid is directly proportional to the rate of change of flux and the length and orientation of the current-carrying conductor and inversely proportional to the height of the conductor above the ground grid. Conduction of power system transients to the ground grid is typically provided through metallic grounding of transformer neutrals and capacitive paths, such as bushings, coupling capacitors, and CCVTs. These are low-impedance high-energy paths that can induce common-mode voltages on control circuits (see

IEEE Std 367-1987).

- g) ~~Other transient sources.~~ Other phenomena that generate transients occur in power systems. Some examples are undesirable time spans between the closing of the poles of a circuit breaker, fault occurrence, fault clearing, load tap changing, line reactor de-energizing, series capacitor gap flashing, arcing ground faults, failing equipment, lightning, GIS surges, and capacitor reinsertion. Normally, the magnitudes of such transients are less than those of other phenomena described herein.

6.2 High-voltage power cable

~~The use of shielding and shield grounding of high-voltage power cables is a common practice to reduce the hazard of shock to personnel, to confine the electric field within the cable, to minimize deterioration of cable insulation or jackets caused by surface discharges, and to minimize radio interference. 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.~~

6.2.1 Definition

~~The following definition is used in this clause.~~

6.2.1.1 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.~~

6.2.2 Shielding practices

~~Single conductor cables rated above 2 kV and multiconductor cables with a common overall discharge-resisting jacket rated above 5 kV should be shielded, except for special applications or cable designs. Multiconductor cable applications in the operating range of 2 kV to 5 kV require careful judgment, and each installation should be evaluated based on the existing and anticipated conditions. Shielding can be used to monitor or test cable installation for additional assurance of insulation integrity. The following shielding recommendations contained in the NEMA standards publications for the type of insulation being utilized should be followed: NEMA WC 3-1980, NEMA WC 5-1973, NEMA WC 7-1988, and NEMA WC 8-1976.~~

~~A shield screen material is applied directly to the insulation and in contact with the metallic shield. It can be semiconducting material or, in the case of at least one manufacturer, a stress control material. At the high voltages associated with shielded cable applications, a voltage gradient would exist across any air gap between the insulation and shield. The voltage gradient may be sufficient to ionize the air, causing small electric arcs or partial discharge. These small electric arcs burn the insulation and eventually cause the cable to fail. The semiconducting screen allows application of a conducting material over the insulation to eliminate air gaps between insulation and ground plane.~~

~~Various shield screen material systems include:~~

- ~~a) Extruded semiconducting thermoplastic or thermosetting polymer~~
- ~~b) Semiconducting woven fabric tape~~
- ~~c) Semiconducting coating (paint) used with semiconducting woven fabric tape~~
- ~~d) Extruded high-dielectric constant thermoplastic or thermosetting polymer, referred to as a stress control layer~~

~~NEMA and AEIC standards require shielded power cable to be partial discharge or corona tested. This test evaluates the effectiveness of the conductor and shield insulation screen materials and application, and verifies the absence of voids within the insulation. A cyclic aging test is required by AEIC as a qualification of the cable design to ensure gaps~~

do not develop between tape layers as a result of expansion and contraction cycles.

Multiconductor cable shielding should be considered in the 2 kV to 5 kV range where any of the following conditions exist:

- a) Transition from conducting to nonconducting environment
- b) Transition from moist to dry environment
- c) Dry soil, such as in a desert
- d) Damp conduits
- e) Connections to overhead lines
- f) Locations where the cable surface collects conducting materials, such as soot or salt deposits
- g) Electrostatic discharges are sufficient in magnitude to interfere with control and instrumentation circuit functions
- h) Safety to personnel is involved
- i) Long underground cables
- j) Direct earth burial

6.2.3 Shield termination practices

The insulation shield system must be removed carefully and completely, and proper stress control materials or devices used. The manufacturer's instructions and recommendations as to the 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.

6.2.4 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 voltage at all times. For additional information see IEEE Std 575-1988. Accidental removal of the shield ground can cause a cable failure and a hazard to personnel. 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 derating of ampacity due to multiple-point short-circuited shields has a negligible effect in the following cases for three-phase circuits:

- a) Three-conductor cables encased by a common shield or metallic sheath
- b) Single-conductor shielded cables containing 500 kcmil copper or smaller installed together in a common duct
- c) Triplexed or three-conductor individually shielded cables containing 500 kcmil copper or smaller
- d) Single-conductor lead-sheathed cables containing 250 kcmil copper 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 must be taken in the termination of cable shield wires 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.

6.2.5 Induced shield voltages

Shields of single-conductor cable carrying alternating current will have a voltage buildup if they are grounded at only one point. Table can be used to calculate the induced shield voltage. A maximum voltage of 25 V, under normal operating conditions, is a commonly accepted limit.

To facilitate calculating the mutual reactance and shield resistance, the following formulas which neglect proximity loss, may be used for practical purposes:

where

X_M is the mutual inductance of shield and conductor (—/ft)
 a, b is the mutual inductance correction factors (—/ft)
 ρ is the micro-ohm⁶
 R_s is the resistance of shield (—/ft)
 t is the thickness of metal tapes used for shielding (inches)
 f is the frequency (Hertz)
 S is the spacing between center of cables (inches)
 r_m is the mean radius of shield (inches)
 ρ_a is the apparent resistivity of shield in —emil/ft at operating temperature (assumed 50°C). This includes allowance for the spiraling of the tapes or wires

Table 1—Formulas for calculating induced shield voltages and shield losses for single-conductor cables

Typical values of ρ :

Overlapped helical copper tape	30 emil/ft
Lead sheath	150 emil/ft
Aluminum sheath	20 emil/ft
Bare copper wires	10.6 emil/ft
Overlapped brass tape	70 emil/ft
Overlapped monent tape	2500 emil/ft
Overlapped ambrac tape	350 emil/ft
Aluminum interlocked armor	28 emil/ft
Galvanized steel armor wire	102 emil/ft
50–52 aluminum alloy	30 emil/ft
Galvanized steel	70 emil/ft
Interlocked armor	

For 60 Hz:

It is assumed that the cables are carrying balanced currents.

For cables installed three per conduit, use arrangement II in table . The spacing, S , in this case will be equal to the outside diameter of the cable 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 reduction of cable ampacity due to conduit heating should be considered. Also, no magnetic metal, such as clamps or reinforcing bar, should form a closed ring around the conduit.

Table 2 gives the maximum lengths of single conductor cable with shields grounded at one point to stay within the 25 V maximum for the conditions stated. Other conditions will permit different lengths. For example, cables operated at

less than rated ampacity will allow longer lengths. Direct-buried cables operating at their rated ampacity, with all other conditions being the same, will require shorter lengths to stay below the 25-V maximum.

Table 2—Maximum lengths for single-conductor cables operating at rated ampacity with single-point shield grounding

Conductor size	One cable per duct (1)				Three cables per duct (2)			
	Copper		Aluminum		Copper		Aluminum	
	A	ft (m)	A	ft (m)	A	ft (m)	A	ft (m)
1/0	249	1465 (446.5)	194	1875 (571.5)	214	4965 (1513)	167	6355 (1937)
4/0	371	1055 (321.5)	290	1350 (411.5)	278	3530 (1076)	248	4480 (1365)
350	496	820 (249.9)	387	1050 (320)	418	2610 (795.5)	329	3310 (1009)
500	608	695 (211.8)	472	890 (271.3)	504	2200 (670.6)	400	2770 (844.3)
750	762	595 (181.4)	601	750 (228.6)	626	1800 (548.6)	497	2260 (688.8)
1000	890	565 (172.2)	707	710 (216.4)				
2000	1237	420 (128)	1022	508 (158.6)				
NOTES: 1—15-kV cables in ducts on 7.5 in (19.1 cm) centers operating at 75% load factor. 2—Three single-conductor 15-kV cables in one duct operating at 75% load factor. The length listed is the duct length. 3—"A" is the ampacity of the cable.								

6.3 Instrumentation cable

This clause provides guidance for the shielding and grounding of instrumentation cables used in substations.

The general rules set forth should be tempered by specific manufacturer's recommendations. For further details on shielding and grounding of instrumentation and control circuits, see IEEE Std 1050-1989. For information on application of instrumentation and control cables for SCADA, see IEEE Std C37.1-1987.

6.3.1 Definitions

6.3.1.1 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:

- Electrostatic induction.* With equal capacitance between the signal wires and the surroundings, the noise voltage developed will be the same on both signal wires.
- Electromagnetic induction.* With the magnetic field linking the signal wires equally, the noise voltage developed will be the same on both signal wires.

6.3.1.2 common-mode-to-normal-mode conversion: In addition to the common-mode voltages which are developed in the single 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.

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

6.3.1.4 normal-mode noise (transverse 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:

- a) Electrostatic induction and differences in distributed capacitance between the signal wires and the surroundings.
- b) Electromagnetic induction and magnetic fields linking unequally with the signal wires.
- c) Junction or thermal voltages due to the use of dissimilar metals in the connection system.
- d) Common mode to normal mode noise conversion.

6.3.1.5 shield (cable systems) (instrumentation cables): A 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 shielded conductors 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 for reducing low frequency electromagnetic induction, as described herein, are preferred.

6.3.2 Methods for noise reduction

6.3.2.1 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, SCADA remote terminal unit (RTU), etc., either directly or through an intervening amplifier.

If the recorder, SCADA RTU, etc., is fed directly from a grounded voltage generating transducer such as a thermocouple, the terminal circuits must be capable of high common mode rejection, or they should be isolated from ground. Isolating the 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 terminal. Therefore, the situation is not changed, so the same procedure should be followed with the terminal 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.