

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

IEEE Power and Energy Society

Developed by the
Substations Committee

IEEE Std 525™-2025
(Revision of IEEE Std 525-2016)



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

Developed by the

Substations Committee
of the
IEEE Power and Energy Society

Approved 12 February 2025

IEEE SA Standards Board

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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, IEEE 525™, power cable, pulling tension, raceway, recommended maintenance, routing, separation of redundant cable, service conditions, substation, transient protection

The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 979-8-8557-1849-2 STD27694
Print: ISBN 979-8-8557-1850-8 STDPD27694

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Introduction

This introduction is not part of IEEE Std 525-2025™, IEEE Guide for the Design and Installation of Cable Systems in Substations.

This revision of the guide makes the following changes:

- Additions were made to [Annex C](#) on design attributes and selection criteria for cable systems.
- Various paragraphs in [Clause 6](#) were revised for clarity and updated to reflect current guidance on standards, materials, and design requirements. Specific details and references to these changes were also reflected in changes to [Annex Q](#).
- Additions were made to [Annex L](#) on low temperature installations.
- [Annex R](#) was added to provide information on cable derating in trenches.

Miscellaneous updates were made throughout the document for clarity.

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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 helping to minimize cable failures and their consequences. Cable systems with voltages greater than 35 kV are not covered in this guide.

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 helping to minimize 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 exclusion of others. In addition to good installation, design, and construction practices, an evaluation 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 or compliance standard. This document is presented as a guide to aid in the design of insulated wire and cable system installations in substations.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

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

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IEEE Std 575™, IEEE Guide for ~~the Application of Sheath~~ Bonding Shields and Sheaths of Methods ~~for~~ Single-Conductor Power Cables Rated 5 kV through 500 kV.^{10,11} ~~and the Calculation of Induced Voltages and Currents in Cable Sheaths.~~^{3,4}

IEEE Std 835™, IEEE Standard Power Cable Ampacity Tables.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.^{12 5}

authority having jurisdiction (AHJ): The organization, office, or individual that has the responsibility and authority for approving equipment, installations, or procedures.

design life of the substation: The time during which satisfactory substation performance can be expected for a specific set of service conditions, based on component selection and applications.

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EPC-40: Electrical plastic conduit for Type DB applications, fabricated from polyethylene (PE); or for Type DB and normal-duty applications, fabricated from polyvinyl chloride (PVC).

EPC-80: Electrical plastic conduit for heavy-duty applications, fabricated from polyvinyl chloride (PVC).

EPT: Electrical plastic tubing for Type EB applications, fabricated from polyvinyl chloride (PVC).

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

Type DB: Direct burial duct designed for underground installation without encasement in concrete.

Type EB: Encased burial duct designed to be encased in concrete.

utility: As used in this document, refers to the end user/owner/operator of the installation

3.2 Acronyms and abbreviations

ABS acrylonitrile-butadiene-styrene (fabricated conduit)

ADSS all-dielectric self-supporting

AHJ authority having jurisdiction

AWG American wire gauge

BIMMF bend-insensitive multimode fiber

BISMF bend-insensitive single-mode fiber

BNC bayonet Neill-Concelman

CAT category

CATV cable television

CPE chlorinated polyethylene

CSPE chlorosulfonated polyethylene

CT current transformer

CTS clear to send

CVT	capacitive voltage transformer
DCE	data communications equipment
DMD	differential mode dispersion
DTE	data terminal equipment
EHV	extra-high-voltage
ELTCTL	equal level transverse conversion transfer loss
EMI	electromagnetic interference
EMT	electrical metallic tubing
ENT	electrical nonmetallic tubing
EOD	end of discharge
EPC	electrical plastic conduit
EPT	electrical plastic tubing
EPR	ethylene propylene rubber
ESD	electrostatic discharge
FRE	fiber- ~~fiberglass~~ reinforced epoxy (fabricated conduit)
GIS	gas-insulated substations
GPR	ground potential rise
HCS	hard-clad silica
HMI	human-machine interface
HPS	high-pressure sodium
IACS	International Annealed Copper Standard
IED	intelligent electronic device
IMC	intermediate metal conduit
IP	ingress protection

<u>IRIG</u>	<u>inter-range instrumentation group</u>
<u>ISDN</u>	<u>integrated service digital network</u>
<u>LSZH</u>	<u>low-smoke zero-halogen</u>
<u>MICE</u>	<u>mechanical, ingress, climatic, or electromagnetic</u>
<u>N</u>	<u>Neill (connector)</u>
<u>OFNG</u>	<u>optical fiber nonconductive general-purpose</u>
<u>OFNP</u>	<u>optical fiber nonconductive plenum</u>
<u>OFNR</u>	<u>optical fiber nonconductive riser</u>
OPGW	optical ground wire
<u>OSP</u>	<u>outside plant</u>
<u>PCP</u>	<u>polychloroprene</u>
PE	polyethylene
<u>PF</u>	<u>power factor</u>
PLC	power line carrier
<u>PMMA</u>	<u>polymethyl methacrylate</u>
<u>POF</u>	<u>polymer/plastic optical fiber</u>
<u>POTS</u>	<u>plain old telephone service</u>
<u>PSTN</u>	<u>public switched telephone network</u>
PVC	polyvinyl chloride
RJ	registered jack
RMC	rigid metal conduit
ROW	-right-of-way (a leased or purchased corridor for utility lines)
RTD	resistance temperature detector
<u>RTS</u>	<u>request to send</u>

RTU	remote terminal unit
RX	receive data
SBR	synthetic rubber
SCADA	Supervisory Control and Data Acquisition
SFP	small form-factor pluggable
SR	silicone rubber
STP	shielded twisted pair
SWBP	sidewall bearing pressure
TCL	transverse conversion loss
TGPR	transient grid potential rise
TNC	threaded Neill-Concelman
TX	transmit data
UTP	unshielded twisted pair
UV	ultraviolet
VT	voltage transformers
XLPE	cross-linked PE
XLPO	cross-linked polyolefin

4. Control and instrumentation cable

4.1 General

Substation control cables are multiconductor cables used to transmit electrical signals with low voltage levels ([typically](#) 600 V or less) and relatively low current levels, between apparatus (~~e.g.,~~ power transformers, circuit breakers, disconnect switches, ~~and~~ voltage transformers [VTs] 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., 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 should 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 (typically 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 Control and Data Acquisition (SCADA) systems, substation networks, event recorders, and thermocouple and resistance temperature detector (RTD) cables.

In the United States, control and instrumentation cables are usually designed and constructed in accordance with NEMA WC 57/ICEA S-73-532 [[B185](#) ~~B157~~]^{[13](#)} ⁶. Other standards may apply outside the United States.

As used in this guide, [secondary connections](#) ~~leads~~ from CTs and VTs are considered control cables [because](#) ~~since~~ in most cases they are used in relay protection circuits.

[For an example of how to apply the principles of this clause to a practical substation, see Annex P.](#)

¹³ ⁶The numbers in brackets correspond to those of the bibliography in Annex [S](#) ~~R~~.

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 building, 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 when metallic cables are used. 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. Consideration should also be given for minimum sizing for mechanical strength.

4.3.1.1 CT circuits

CT secondary circuits connect the CT secondaries to protective and metering devices. A multiconductor control cable is typically used for a CT secondary circuit, which contains all three phases (or one phase only for a single-phase CT circuit) 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™ [[B156](#) [B129](#)]).

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. Long cable runs, such as those found in large transmission stations, can lead to increased impedance values. Methods to reduce [the](#) impedance of the CT secondary circuit include increasing the conductor size and, though not preferred, running parallel conductors. The physical parameters of the termination points should be considered when utilizing large and/or multiple conductors.

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 terminal voltage is within the device's operational requirements.

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 control devices 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. The circuit protection should be selected with a trip rating that is significantly higher than the expected duty to help ensure that actuation of a circuit protective device does not result in a failure to trip. The trip and close cable conductor should have an ampacity that 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 to operate the breaker mechanism. 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.

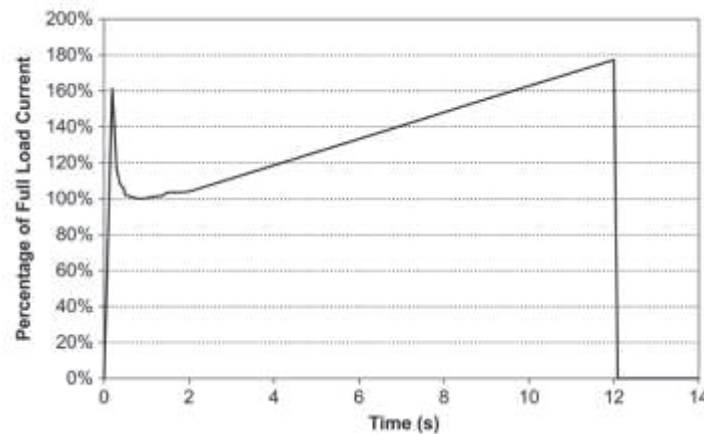


Figure 1—Spring-charging motor load characteristic

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 DC ~~Battery~~ circuits

The station battery will have a nominal ~~an~~ operating range with a minimum terminal voltage as defined by the user. 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. DC utilization equipment, such as breaker trip coils and protective relays, will have a minimum voltage rating for operation. A designer should use 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, [for example 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 constructio

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

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 [wires](#) or 19 wires for Class B stranding. Conductor sizes typically range from 6 [AWG](#) to 14 AWG (American wire gauge), but other conductor sizes may also be utilized. Refer to Table C.3 for parameters of common AWG and circular mil (cmil) sizes. Caution should be exercised before using small conductors ([e.g., smaller than AWG 10](#)) 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), 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.

Shielding is used in some control and instrumentation cables to reduce or eliminate electromagnetic interference ([EMI](#)) from outside sources on cable conductors, groups of conductors, or to reduce or eliminate [EMI](#) ~~electromagnetic interference~~ between cable conductors or groups of cable conductors within a cable. Cable shields typically consist of metal braid, helical wrapped tape, longitudinally corrugated tape, or foil tape that encloses the insulated conductor or group of conductors. The shield type can affect the physical characteristics of the cable (flexibility, weight, etc.) and should be considered in relation to the installation requirements. A drain wire is frequently found on shielded cables using metal foil tape to aid in the ease of shield termination. Shields and drain wires are usually constructed of copper, copper alloy, or aluminum.

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.

Control and instrumentation cables are provided with an outer jacket that can provide mechanical protection, fire resistance, or moisture protection. Care should be taken to utilize a jacket material that is suitable for the environment in which it is installed. Factors to consider include moisture, chemicals, fire, temperature, [ultraviolet \(UV\)](#) exposure, personnel occupancy, etc. [See NEMA WC 70/ICEA S-95-658 \[B186\] for more information on various jacket materials and their properties.](#)

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/ICEA S-73-532 [[B185](#) ~~B157~~]. Inner jackets for multiconductor cables may be color-coded as well (reference Table E-1, Table E-2, and Table E-3 of NEMA WC 57/ICEA S-73-532 [[B185](#) ~~B157~~] 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, [that is i.e.](#), route all conductors comprising a control circuit in the same cable; and if conduit is used, within the same conduit.

Radial arrangement of control circuitry reduces transient voltages. Circuits routed into the switchyard from the control building 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 help avoid induction of surges into relaying systems and reduce the risk of 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 “peninsula” grounding to [help](#) minimize induction (Gillies and Rogers, [1974](#), [B52 B44]). 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™ [B152 B125]).

All dc circuits are normally “radial,” [that is 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 jacketed cable.

In circuits where the positive and negative are in separate cables for specific reasons, the positive and negative should be physically close together wherever practical. Measures should be taken to avoid shorting the positive and negative, such as barriers, insulation, separate conduits, or by landing on non-adjacent terminals, etc. The positive and negative could be in separate cables due to the required size of the conductors or the physical location of the connected positive and negative terminals, such as the circuit between the station battery and the battery charger or dc panel board.

Where dc motors are connected to the substation control battery, as for motor-operated disconnect switches or circuit breakers, 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 [control](#) cables are typically applied in higher-voltage substations ([bus](#) voltages at 230 kV and higher) or at lower voltages for specific applications including shunt capacitor banks, [CVTs](#) ~~capacitive voltage transformers~~, and gas-insulated substations.

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 [calculations](#) (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 tested [for](#) insulation-resistance ([e.g., see ICEA T-27-581 \[B4\]](#)) and [continuity](#) prior to connecting cables to equipment. They may be tested as part of the system checkout.

4.13 Recommended maintenance [and inspection](#) (see Annex N)

5. Metallic communication cables

5.1 Introduction

This clause covers the following for metallic communication cables within and to substations:

- General
- Service conditions
- Metallic cable selection
- Cable system design
- Transient protection
- Cable-pulling tension
- Handling
- Installation
- Acceptance testing
- Recommended maintenance

[For an example of how to apply the principles of this clause to a practical substation, see Annex P.](#)

5.2 General

5.2.1 Introduction

Substation communications may require multiconductor metallic communication cables to transfer communication signals at low voltage and current levels, to the substation and/or within the substation, using a protocol. Those cables that enter the substation, either overhead or underground, are addressed by other IEEE standards such as:

- IEEE Std 487™ [B114 B91]. This standard presents engineering design practices for special high-voltage protection systems intended to protect wire-line telecommunication facilities serving electric supply locations. IEEE Std 487 has been broken down into a family of related documents (i.e., dot-series) segregated on the basis of technology. IEEE Std 487 contains the general considerations common to the entire dot-series. The documents in the entire series are the following:
 - IEEE Std 487 [B114 B91] for general considerations.
 - IEEE Std 487.1™ [B115 B92] for applications using on-grid isolation equipment.
 - IEEE Std 487.2™ [B116 B93] for applications consisting entirely of optical-fiber cables.
 - IEEE Std 487.3™ [B117 B94] for applications of hybrid facilities where part of the circuit is on metallic wire-line and the remainder of the circuit is on optical-fiber cable.
 - IEEE Std 487.4™ [B118 B95] for applications using neutralizing transformers.
 - IEEE Std 487.5™ [B119 B96] for applications using isolation transformers.
- IEEE Std 789™ [B125 B102]. This standard covers the appropriate design requirements, electrical and mechanical parameters, ~~the~~ testing requirements, and ~~the~~ handling procedures for wires and cables, used principally for power system communications and control purposes, that are to be installed and operated in high-voltage environments where they may be subjected to high voltages either by conduction, or induction coupling, or both. Coaxial and fiber-optic cables, except for those used in Ethernet applications, are specifically excluded.

This guide addresses the design and installation of the following metallic cable types wholly contained within a substation:

- a) Telephone cables and other multiconductor communications cables that are not serial, Ethernet, or coaxial cables
- b) Serial cables, such as RS232 (the official standard is EIA/TIA-232-F [B34 B28]), RS485 (the official standard is ANSI/TIA/EIA-485 [B16 B14]), and USB
- c) Ethernet cables

d) Coaxial cables

This clause also addresses the different terminations used for these types of cables. Metallic communication cables are typically unshielded twisted pairs (UTP), such as many types of Ethernet and serial, telephone, and Ethernet cables. Shielded twisted pairs (STP) are also common. ISO/IEC 11801 [B158 B131] describes characteristics and/or requirements for different combinations of cable screening (unscreened, foil screened, braid screened, braid and foil screened), ~~and~~ pair shielding (unscreened or foil screened), and number of twisted conductors (twisted pair and twisted quad), but provides no formal definition of the terms.

5.2.2 Telephone cable and multiconductor communication cables

These types of cables have been essential for providing voice and data circuits to substations for decades. Phone cable types can be dictated by whether the connection is dial-up or leased line. In many cases, two copper wires (tip and ring) for each dial-up telephone line are run from a substation to a local telephone company's point of presence (POP), usually addressing the ground potential rise (GPR) design issues in IEEE Std 487 [B114 B91]. Tip and ring refers to the two wires or sides of an ordinary telephone line, where tip is the ground side (positive) and ring is the battery side (negative).

Phone circuits are typically identified with the plain old telephone service (POTS) or voice grade communications, which are limited in bandwidth to between 300 Hz and 3400 Hz, so modems provide digital service over the analog phone lines. POTS lines are part of the public switched telephone network (PSTN). Today, the PSTN has migrated from the original days of copper telephone lines to include fiber-optic cables, microwave transmission links, cellular networks, communications satellites, and undersea cables. The PSTN connects these together in switching centers, allowing any telephone in the world to communicate with any other. The PSTN is now almost entirely digital in its core and includes mobile as well as fixed telephones.

Multiconductor communication cables may also be used for pilot wire protection using pilot wires, which may use any combination of private wires and telco wires. Pilot wire connects together two or more protective relays using dc or ac signals. AC pilot-wire protection is mostly akin to modern line-differential protection. A relay at each end of the protected circuit converts the current flow at one-line terminal to a composite single-phase quantity. Because the two relays are connected by pilot wires, the quantity at one terminal can be electrically compared with the quantity at the other terminal. If the correct match between terminals does NOT occur, a trip of the circuit breakers at each terminal will be initiated. More information on pilot wire systems exists in IEEE Std 487 [B114 B91] and IEEE Std C37.236™ [B154 B127]. Once inside a substation, pilot wire cables will be run from some terminal point to the end device.

In addition to POTS lines and pilot wires, multiconductor communications cables are used for dedicated four-wire leased line phone circuits, typically providing low-speed serial SCADA communications and teleprotection applications as described in IEEE Std C37.236 [B154 B127]. Unlike dial-up connections, a leased line is always active, is not connected to a telephone exchange (no phone number), does not provide dc power, dial tone, busy tone, or ring signal. ~~Because~~ ~~Since~~ the connection is dedicated, the carrier can assure a given level of quality, typically considered Class A, B, or C service. As defined in IEEE Std C37.93™ [B151 B124] and IEEE Std 487 [B114 B91] as follows.

Class A is non-interruptible service performance (shall function before, during, and after the power fault condition). ; Class B is self-restoring interruptible service performance (shall function before and after power fault condition), and Class C is interruptible service performance (can tolerate a station visit to restore service). Due to the telephone network's transition to a digital system with associated signal latency (delays), the telephone network may not provide acceptable performance.

Not all leased lines are four-wire circuits. Leased lines can transmit full duplex (transmit and receive at the same time) or half duplex (transmit or receive one at a time). Leased lines can be synchronous, where the data is transmitted at a fixed rate with the transmitter and receiver synchronized. Leased lines are not just limited to low-speed serial communications.

Phone cable conductors, regardless of dial-up or leased line, are individually insulated. The conductors range in size from 22 AWG to 26 AWG copper. The conductors are twisted and may be shielded in pairs (other groups of pairs are possible). ANSI/NEMA WC 57-2014 [B5] (equivalent to ICEA ~~S-73-532-2014~~^{me S-73-532-2014}) includes various color coding methods that may or may not be provided because the twisted pairs also have a de-facto standard color code for up to 25 pairs. Typically, cables over 25 pairs have the first 25 pairs isolated with ribbons using the colors of the color code starting with the first color code, the second 25 pairs with a ribbon with the second color code, and so on until all cables are identified into a “super” binder. Those super binders can then be combined using the same color code scheme, too, forming even larger cables. Because of this, designers should understand the color-coding designation used in the provided cable to ensure the design includes the proper wiring connections to allow communications.

5.2.3 Serial cables

5.2.3.1 Introduction

Serial cables have traditionally been essential for the transfer of basic digital data signals to and within a substation. Typically, serial cables do not enter a substation, but can be abundant within a substation. The conductors are twisted and can be STP or UTP, with or without overall shielding. The RS232 and RS485 standards do not define specific cable construction requirements, only cable characteristics such as capacitance. Both RS232 and RS485 cables are typically unshielded, but there may be an overall cable shield and/or braid. The cables may have twisted pairs (more typical of RS485) or not (more typical of RS232).

Serial cables may need to support baud rates between 1200 kbps to 115 kbps for RS232 and can extend to over 1 Mbps for RS485. Baud rates are typically limited by several factors, including cable length and capacitance. See IEEE Std C37.1TM [B149 B122].

5.2.3.2 Serial RS232 cables

RS232 cables typically have between two and nine conductors, depending upon what signals are required by the devices being connected together. The standard actually specifies 20 different signal connections; typically, substation intelligent electronic devices (IEDs) today use only transmit data (TX), receive data (RX), and signal ground; others that may be included are request to send (RTS) and clear to send (CTS) and are commonly referred to as “hardware handshaking” signals. When RTS and CTS are not present, software flow control or handshaking is used. Connections with modems will typically have even more signals and conductors. Cables should be properly selected in tandem with the connectors used as discussed in 5.2.3.9.2.

RS232 devices are classified as either data communications equipment (DCE) or data terminal equipment (DTE). DCE devices are digital devices that connect to a communications line for the purpose of data transfer, without regard to its content (e.g., a modem). DTE devices are digital devices that transmit or receive data and require communications equipment for the data transfer. DTE devices terminate a communication line and require DCE equipment for the data transfer. DCE devices are connected directly to the communication circuit used between two DTE devices. DTE devices usually use a male plug connector and DCE devices a female connector. As a general rule, nine-pin DTE devices transmit on pin 3 and receive on pin 2 and nine-pin DCE devices transmit on pin 2 and receive on pin 3. Avoiding the use of DCE equipment is very common between two devices. This is accomplished [using ~~through the use of~~](#) a null modem cable that acts as a DCE between the devices by swapping the corresponding signals (such as TX-RX, and RTS-CTS). [The current standard is EIA/TIA 232F which states that the maximum signal distance is 15m or \(50 ft\) with a typical cable at this length corresponding to a maximum resistive load of 7 kΩ and a capacitive load of 2500 pF. Using a cable with less resistance and less capacitance will enable the signal to travel further.](#)

5.2.3.3 Serial RS485 cables

True RS485 cables have three conductors, two for the communication bus and one for signal ground. There does exist “4 wire” RS485, but these do not strictly adhere to the TIA/EIA-485-A standard. RS485 has three signal wires, typically denoted as:

- “A”, “-”, and “TxD-/RxD-”
- “B”, “+”, and “TxD+/RxD+”
- “SC”, “G”

This does not mean that all vendors denote them the same way, which means care is required in wiring together devices that are from different vendors. Re-wiring an RS485 circuit is not uncommon because of this labeling problem and good documentation is recommended, especially when vendors’ implementations do not agree, and the A line should be connected to the B line for the circuit to work. Care should be used to not use the shield as the third conductor (“SC” or “G”), as this may introduce noise into the communications circuit and cause the communications to fail when noise becomes an issue. Optical isolation provided in many devices may remove the need for the signal ground, and circuits may combine devices that use optical isolation and those that do not.

Serial cable conductors are typically individually insulated and range in size from 22 AWG to 26 AWG copper. The cables may be assembled with terminations, may be twisted, may have shielded pairs, may have an overall shield/foil/braid, and may have armor—in any combination. The shield protects the signal conductors from interference. A bare drain conductor may be present to provide a grounding connection for the shield. [The current standard states that the maximum signal distance over twisted pair cable is generally accepted as data rates up to 10 Mbit/s with distances up to 1200 m \(4000 ft\). As a rule of thumb, the speed in bit/s multiplied by the length in meters should not exceed 108. Thus, a 50-m cable should not signal faster than 2 Mbit/s.](#)

5.2.3.4 USB cables

USB was designed to standardize the connection of typical computer peripherals such as keyboards, pointing devices, and printers; but also digital cameras, portable media players, disk drives, and network adapters. USB is used to communicate and to supply low-voltage dc power. It has become commonplace on other devices, such as smart phones and video game consoles. USB has effectively replaced a variety of earlier communication interfaces, such as serial and parallel ports, as well as separate power sources for portable devices because of the power supply allowed in the specification. USB, USB 2.0, USB 3.0, and USB wireless specifications are maintained by the USB Implementers Forum and are available for download.

USB 2.0 is most common today, where the specification specifies a cable with four conductors: two power conductors, and two signal conductors; plus different connector styles. The cable impedance should match the impedance of the signal drivers. The specification allows for a variable cable length, where the maximum cable length is dictated by signal pair attenuation and propagation delay as well as the voltage drop across the ground conductor. The minimum wire gauge is calculated from the current consumption. There are differences between high-speed/full-speed cables and low-speed cables, most notably the required shield in the former and an optional shield in the latter; also the required drain wire in the latter. The specification requires a shield be terminated to the connector plug for completed assemblies. The shield and chassis are bonded together. The user-selected grounding scheme for USB 2.0 devices and cables is to be consistent with accepted industry practices and regulatory agency standards for safety and electromagnetic interference/electrostatic discharge/radio frequency interference (EMI/ESD/RFI).

USB cable may be used for applications of RS232 and/or RS485 communication provided there is a proper converter from USB to RS232/RS485. These converters are commonplace today. Other applications, which may be critical, are for peripheral connections from computers to keyboards, pointing devices, and touch screens. Care should be used in selecting USB cables and converters that meet the environmental requirements of the application. Rugged USB cables and connectors are available, but the connectors may be vendor-specific and may not be supported by devices. Cable lengths should be carefully considered given the performance-based length specification. It is possible to convert USB to Ethernet or extend USB's range by converting to Ethernet cable, given the proper converter.

5.2.3.5 Ethernet cables

There are several designations for communication cables, which originally started out as "levels" and eventually became known as categories and then abbreviated to "CAT" (for category) designations that today primarily apply to Ethernet cables. Some are still official categories maintained by the TIA/EIA. The TIA/EIA cable category characteristics and use are listed below in Table 1.

Cat 7 cable, with four individually-shielded pairs inside an overall shield, has been proposed but is not in common use today. Cat 7 is designed for transmission frequencies up to 600 MHz, which should enable it to carry 10-Gigabit Ethernet (10GBaseT), but requires a redesigned RJ-45 connector (called a GG45) to achieve this speed. 10GBaseT networks are not yet widely available, and may not be able to compete with fiber-optic networks.

Table 1—Cable characteristics or “CAT” cables

Category	Use	Standard	Frequency	Bandwidth	Networks supported
1	Known as “voice grade” UTP copper circuits used for POTS.	No standard exists.	Less than 1 MHz	—	—
2	Low-speed UTP cabling for older computer networks, telephone networks, and is no longer commonly used.	No standard exists.	4 MHz	4 Mbps	—
3	Typically UTP cabling, although also available in screened twisted pair, commonly called “station wire” that was the first cabling category standardized by the TIA/EIA and commonly used on 10BaseT Ethernet networks in the 1990s.	TIA/EIA-568-C	16 MHz	10 Mbps	100 Ethernet 10Base-T
4	UTP cabling briefly used for 10BaseT networks that was quickly superseded by CAT 5/5e cable that is no longer recognized by TIA/EIA.	—	20 MHz	16 Mbps	—

(New)

Table 1—Cable characteristics or “CAT” cables (*continued*)

Category	Use	Standard	Frequency	Bandwidth	Networks supported
5	Cabling that is typically UTP but also could be STP, can also carry video, telephony, and serial signal, and is no longer recognized by the TIA/EIA.	Originally defined in TIA/EIA-568-A[B213].	100 MHz	10 Mbps, 100 Mbps, 1000 Mbps	100 Ethernet 10Base-T, 100Base-TX, 1000BaseT
5e	Enhanced CAT5 cabling that can be 24 AWG to 26 AWG UTP or STP, which improved upon CAT5 cable’s performance and resulted in CAT5 cable being no longer recognized by the TIA/EIA.	Originally defined in TIA/EIA-568-A-5[B213] in 1999.	100 MHz	10 Mbps, 100 Mbps, 1000 Mbps	100 Ethernet 10Base-T, 100Base-TX, 1000BaseT
6	Standard cabling for gigabit Ethernet networks is 22 AWG to 24 AWG UTP or STP.	TIA/EIA-568-C	250 MHz	10 Mbps, 100 Mbps, 1000 Mbps, 10GBaseT	100 Ethernet 10Base-T, 100Base-TX, 1000BaseT, 55 10GBaseT
6A	Augmented CAT6 cabling can be UTP or STP.	TIA/EIA-568-C	500 MHz		100 Ethernet 10Base-T, 100Base-TX, 1000BaseT, 10GBaseT

(New)

Category	Use	Standard	Frequency	Bandwidth	Networks supported
1	Known as "voice grade" UTP copper circuits used for POTS (plain old telephone service).	No standard exists. Originally called Anixter level 1.	Less than 1 MHz		
2	Low-speed UTP cabling for older computer networks, telephone networks, and is no longer commonly used.	No standard exists. Originally called level 2 by Anixter.	4 MHz	4 Mbps	
3	Typically UTP cabling, although also available in screened twisted pair, commonly called "station wire" that was the first cabling category standardized by the TIA/EIA and commonly used on 10Base-T Ethernet networks in the 1990s.	TIA/EIA-568-C	16 MHz	10 Mbps	100 Ethernet 10Base-T
4	UTP cabling briefly used for 10Base-T networks that was quickly superseded by CAT 5/5e cable that is no longer recognized by TIA/EIA.		20 MHz	16 Mbps	
5	Cabling that is typically UTP but also could be STP, can also carry video, telephony, and serial signal, and is no longer recognized by the TIA/EIA.	Originally defined in TIA/EIA-568-A	100 MHz	10 Mbps, 100 Mbps, 1000 Mbps	100 Ethernet 10Base-T, 100Base-TX, 1000Base-T
5e	Enhanced CAT5 cabling that can be 24 AWG to 26 AWG UTP or STP, which improved upon CAT5 cable's performance and resulted in CAT5 cable being no longer recognized by the TIA/EIA.	Originally defined in TIA/EIA-568-A-5 in 1999.	100 MHz	10 Mbps, 100 Mbps, 1000 Mbps	100 Ethernet 10Base-T, 100Base-TX, 1000Base-T
6	Standard cabling for gigabit Ethernet networks is 22 AWG to 24 AWG UTP or STP.	TIA/EIA-568-C	250 MHz	10 Mbps, 100 Mbps, 1000 Mbps, 10GBase-T	100 Ethernet 10Base-T, 100Base-TX, 1000Base-T, 55 10GBase-T
6A	Augmented CAT6 cabling can be UTP or STP.	TIA/EIA-568-C	500 MHz		100 Ethernet 10Base-T, 100Base-TX, 1000Base-T, 10GBase-T

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5.2.3.6 Coaxial cables

Coaxial cable consists of [the following](#):

- An outer jacket
- An outer shield consisting of one or more layers of braid and/or foil
- A dielectric insulator, such as PE

- d) An inner solid or stranded conductor

The outer shield of foil and/or braid acts as both a shield and a return path conductor. An ideal shield would be a perfect conductor without bumps, gaps, or holes and connected to a perfect ground. However, a smooth, solid, and highly conductive shield would be heavy, inflexible, and expensive. Thus, cables compromise between shield effectiveness₇ and flexibility, which may have a bearing on cost. Braided copper wire for the shield allows the cable to be flexible, but it also means there are gaps in the shield layer₄, thus reducing the shield's effectiveness. Foil improves the coverage when combined with the braid.

There are names for coaxial cables originating from military uses, in the form "RG-#" or "RG-#/U". The RG designation stands for Radio Guide; the U designation stands for Universal. These date from World War II and were listed in MIL-HDBK-216 published in 1962, which is now withdrawn. The RG unit indicator is no longer part of the military standard, now MIL-C-17. Some of the new numbers have similar characteristics as the old RG numbers. One example is Mil-C-17/2 and RG-6 cables. These cables are very similar, however Mil-C-17/2 has a higher working voltage at 3000 V (versus 2700 V for RG-6) and the operating temperature of Mil-C-17/2 is much higher at 185 °C (versus 80 °C for RG-6).

The RG designations are still common. Cable sold today under any RG label is unlikely to meet military MIL-C-17 specifications. Subsequently, there is no standard to guarantee the electrical and physical characteristics of a cable described as "RG-# type." Today, RG designators are mostly used to identify compatible connectors that fit the inner conductor, dielectric, and jacket dimensions of the old RG-series cables. Because of these issues, care should be used to select the proper cable based on the application and installation requirements for temperature and other environmental factors.

Most coaxial cables have a characteristic impedance of 50 Ω , 52 Ω , 75 Ω , or 93 Ω . [See Table 2 for RG types and uses.](#)

Table 2—Common coaxial RG designations

Cable type	Use
RG-6	A 75 Ω cable type. Commonly used for satellite clock antennas. Commonly used for cable television (CATV) distribution coax, used to route cable television signals to and within homes. CATV distribution coax typically has a copper-clad steel (CCS) center conductor and an aluminum foil/aluminum braid shield with coverage around 60%. RG-6 type cables are also used in professional video applications, carrying either base band analog video signals or serial digital interface (SDI) signals; in these applications, the center conductor is ordinarily solid copper, the shielding is much heavier (typically aluminum foil/95% copper braid), and tolerances are more tightly controlled.
RG-8	RG-8 is a 50 Ω cable used in radio transmission or in computer networks.
RG-11	A 75 Ω cable type.
RG-58	RG-58 is a 50 Ω cable. Commonly used for IRIG-B distribution, radio transmission, computer networks, or power line-carrier applications. RG-58 is a smaller cable than RG-8.
RG-59	A 75 Ω cable originally used for CATV, but is being replaced by RG-6.
RG-213	A 50 Ω cable used for power line carrier (PLC) applications.

(New)

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RG-6	A 75 Ω cable type. Commonly used for satellite clock antennas. Commonly used for cable television (CATV) distribution coax, used to route cable television signals to and within homes. CATV distribution coax typically has a copper-clad steel (CCS) center conductor and an aluminum foil/aluminum braid shield with coverage around 60%. RG-6 type cables are also used in professional video applications, carrying either base band analog video signals or serial digital interface (SDI) signals; in these applications, the center conductor is ordinarily solid copper, the shielding is much heavier (typically aluminum foil/95% copper braid), and tolerances are more tightly controlled.
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RG-59	A 75 Ω cable originally used for CATV, but is being replaced by RG-6.
RG-213	A 50 Ω cable used for power line carrier applications.

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Advantages of coaxial cable include the following: high bandwidth, low signal distortion, low susceptibility to cross-talk and noise, low signal losses, and greater information security. However, coaxial cable is more difficult to install, heavier, and does not have the flexibility offered by twisted pair cables.

The shield of a coaxial cable is normally grounded, so if even a single bit of shield touches the center conductor, the signal will be shorted causing significant or total signal loss. This occurs at improperly installed end connectors and splices. In addition, the connectors require proper attachment to the shield, as this provides the path to ground for the interfering signal. Despite being shielded, coaxial cable can be susceptible to interference, which has little relationship to the RG designations (e.g., RG-59, RG-6) but is strongly related to the composition and configuration of the cable shield. Foil shielding is typically used with a tinned copper or aluminum braid shield, with anywhere from 60% to 95% coverage. The braid is important to shield effectiveness, because of the following braid:

- a) It is more effective than foil at helping to prevent ~~preventing~~ low-frequency interference. 7
- b) It provides higher conductivity to ground than foil. 7 ~~and~~
- c) It makes attaching a connector easier and more reliable.

For better shield performance, some cables have a shield with only two braids as opposed to a thin foil shield covered by a wire braid. Another form of construction used in applications involving interference is “quad-shield” that uses ~~cables use~~ four alternating layers of foil and braid. Some 7 ~~which is typically used in situations involving troublesome interference. Quad shield is less effective than a single layer of foil and single high-coverage copper braid shield. Other~~ shield designs reduce flexibility ~~in order~~ to improve performance.

Typical uses of coaxial cable are for transmission of radio frequency signals. The most common uses in substations are for antenna connections to satellite clocks and satellite clock timing signal distribution using IRIG-B communication. Other substation uses include microwave radio and ~~power line carrier (PLC)~~ applications. Equipment manufacturers should be contacted to provide guidance on application-specific cable selection.

5.2.3.7 Terminations

Terminations are used to connect communication cables to the various IEDs for the purpose of communications. There are various types of terminations. A different type of termination can be used on either end of the cable. Regardless of the terminations used for communication cables, care should be taken to match each signal assigned to each conductor, terminal, or pin on each end of the communication cable. This helps ensure that the communications work properly. Terminals and signals should be identified clearly on drawings, typically in common details, especially when a custom cable and termination are required for the application. These are typically referred to as pin-out diagrams. Also note that while there are common connectors for serial cables and Ethernet cables as discussed, the presence of ~~the~~ one of these connectors does not guarantee the port signaling is the typical type. This is especially true for RJ45 ports, which are commonly used for Ethernet, RS232, or RS485 communications.

5.2.3.8 Punchdown blocks

Phone cables are typically terminated to a 66-block punchdown block, common to telephone systems, or a 110-block punchdown block, common to higher-speed cable terminations for CAT 5 and CAT 6 cables. A punchdown block is so named because the solid copper wires are “punched down” into short open-ended slots that are a type of insulation-displacement connectors. These slots typically cut crosswise across an insulating plastic bar, with two sharp metal blades that cut through the wire’s insulation as it is punched down. These blades hold the wire in position and make the electrical contact with the wire as well. A punchdown tool is used to push the wire firmly and properly into the slot, making the termination easy because there is no wire stripping and no screw terminals. Patch panels are commonly replacing punchdown blocks for non-voice applications because of the increasing performance demands of Ethernet cabling.

5.2.3.9 Terminals

5.2.3.9.1 General

A terminal strip may be used to land the communication conductors. These types of connections are typically used for terminating RS485 cables, but may also be seen for RS232 connections and rarely for Ethernet connections or coaxial connections. Care should be used to properly identify the conductor signals and terminal block labels so as to properly associate them with the signals for the terminal connection being used.

5.2.3.9.2 DB connectors

RS232 cables are typically terminated in connectors commonly called DB9 or DB25 today. The original RS232 connector was a 25-pin connector, but that connector is much larger than the connector associated with the DB25 connector seen today. The D-subminiature connector was invented by Cannon in 1952 with an operating temperature between -54°C and 150°C . The product had a standard series prefix of "D" and different shell sizes (A, B, C, D, E) followed by the number of pins/sockets. Connectors of six different sizes were later documented in MIL-C-24308 ([B172 B145], now withdrawn), with a temperature range from -55°C to $+125^{\circ}\text{C}$. A similar 25-pin connector is defined in IEC 60211 [B65 B57] without any temperature range. The DB connectors with crimp connectors are standardized in IEC 60807-3 [B84 B71] and solder style connectors in IEC 60807-2 [B80 B70], both with five shell sizes for 9, 15, 25, 37, and 50 pins. The temperature ranges from -55°C to 125°C and -55°C to $+100^{\circ}\text{C}$ for IEC 60807-3 [B84 B71]. IEC 60807-2 [B80 B70] adds another temperature range from -40°C to 100°C .

Each DB connector is designated as male (plug) or female (jack). The pins may be crimped or soldered onto the conductors in the cable. The most common connectors are 9 pins (DB9), 15 pins (DB15), 25 pins (DB25), 37 pins (DB37), and 50 pins (DB50), although others are used. Serial cables have various combinations of gender and pins, such as a DB9 female connector on one end (DB9F) and a DB25 male connector on the other (DB25M). In addition, just because a cable has connectors with nine pins on both ends, this does not mean all nine pins are actually connected through the cable. How the pins are connected through the cable may only be discoverable by pinning out the cable with a simple ohm meter to test connectivity between one pin on one end with each pin on the other end. The pin out may be specified on a specification sheet or drawing. Providing a pin-out diagram is typically required when requesting a custom cable from a cable manufacturer. A pin-out diagram also validates that the selected cable will actually work with the signals on the pins for the connected IEDs. [See Figure 2 for typical serial DB-style connectors.](#)

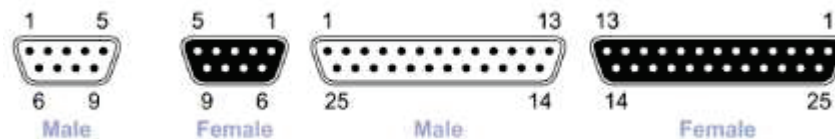


Figure 2—Typical serial DB-style connectors

Use care when connecting serial ports together via serial cables because the signal pins may not be properly connected by the cable, possibly resulting in damage to the communication port that may not be readily repaired.

Please reference the vendor's documentation to properly identify the pin signal definitions for both cable connectors and IEDs.

5.2.3.9.3 RJ (registered jack) connectors

Registered jack (RJ) connectors typically terminate communication cables and jacks located on devices. The RJ designation describes the physical geometry of the connectors and a wiring pattern in the jack. Inspection of the connector will not necessarily show which [RJ registered-jack](#) wiring pattern is used. The same modular connector type can be used for different registered jack connections. While [RJ registered-jack](#) refers to both the female physical connector (modular connector) and its wiring, the term is often used loosely to refer to modular connectors regardless of wiring or gender. The six-position plug and jack commonly used for telephone line connections may be used for RJ11, RJ14, or even RJ25, all of which are names of interface standards that use this physical connector. The RJ abbreviations only pertain to the wiring of the jack (hence the name registered jack); it is commonplace, but not strictly correct, to refer to an unwired plug connector by any of these names. See Table 3 for typical RJ characteristics and uses.

The types of cable connectors are a plug type of connector when the device has a receptacle. They are typically used for telephone and network type applications, but can be used for serial ports and other ports as well. Some common designations are shown below. TIA-1096-A [\[B210\]](#) specifies a temperature range for the connectors based on change in contact resistance between -40°C and 66°C under varying humidity conditions. There is no specification for vibration, only mating and unmating cycles.

IEC 60603-7 [\[B76 B66\]](#) specifies a temperature range and vibration conditions. The temperature range is between -40°C and $+70^{\circ}\text{C}$ for 21 [d days](#) based on climatic category 40/070/21 from IEC 61076-1:2006 [\[B94 B75\]](#). The vibration requirements are taken from IEC 60512 [\[B74 B64\]](#) with a frequency range between 10 Hz to 500 Hz, amplitude at 0.35 mm, acceleration at $50\text{ m} \times \text{s}^{-2}$ and 10 sweeps per axis.

For Ethernet cables, ANSI/TIA-598-C [\[B12 B9\]](#) requires connecting hardware [to](#) be functional for continuous use over the temperature range from -10°C to 60°C .

Table 3—Characteristics of RJ connectors

Common name	Wiring	Connector	Usage
RJ11	RJ11C/ RJ11W	6P2C	For one telephone line (6P4C if power on second pair). RJ11W is a jack from which you can hang a wall telephone, while RJ11C is a jack designed to have a cord plugged into it.
RJ45		8P8C	8P8C modular connectors are typically known as "RJ45," an informal designation for TIA-568A or TIA-568B jacks, including Ethernet that is not the same as the true RJ45/RJ45S. The shape and dimensions of an 8P8C modular connector are specified in TIA-1096-A[B210], but this standard does not use the term 8P8C (only as a miniature 8 position plug, unkeyed and related jack) and covers more than just 8P8C modular connectors; however, the 8P8C modular connector type is described in TIA-1096-A[B210] with eight contacts installed. The international standard for the 8P8C plug and jack for integrated service digital network (ISDN) is ISO-8877[B157]. For Ethernet cables, the IEC 60603-7[B76] series specifies not only the same physical dimensions as the 8P8C for shielded and unshielded versions, but also high-frequency performance requirements for shielded and unshielded versions of this connector for frequencies up to 100 MHz, 250 MHz, 500 MHz, 600 MHz, and 1000 MHz.
RJ48	RJ48	8P8C	Used for T1 and ISDN termination and local area data channels/subrate digital services.
RJ48	RJ48C	8P8C	Commonly used for T1 lines and uses pins 1, 2, 4, and 5.
RJ48	RJ48S	8P8C, keyed	Commonly used for local area data channels/subrate digital services, and carries one or two lines.
RJ48	RJ48X	8P8C with shorting bar	A variation of RJ48C containing shorting blocks in the jack, creating a loopback used for troubleshooting when unplugged. The short connects pins 1 and 4, and 2 and 5. Sometimes this is referred to as a "smart jack."

(New)

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RJ11	RJ11C/ RJ11W	6P2C	For one telephone line (6P4C if power on second pair). RJ11W is a jack from which you can hang a wall telephone, while RJ11C is a jack designed to have a cord plugged into it.
RJ45		8P8C	8P8C modular connectors are typically known as "RJ45," an informal designation for TIA-568A or TIA-568B jacks, including Ethernet that is not the same as the true RJ45/RJ45S. The shape and dimensions of an 8P8C modular connector are specified in TIA-1096-A, but this standard does not use the term 8P8C (only as a miniature 8 position plug, unkeyed and related jack) and covers more than just 8P8C modular connectors; however, the 8P8C modular connector type is described in TIA-1096-A, with eight contacts installed. The international standard for the 8P8C plug and jack for integrated service digital network (ISDN) is ISO-8877. For Ethernet cables, the IEC 60603-7 series specifies not only the same physical dimensions as the 8P8C for shielded and unshielded versions, but also high-frequency performance requirements for shielded and unshielded versions of this connector for frequencies up to 100, 250, 500, 600, and 1000 MHz.
RJ48	RJ48	8P8C	Used for T1 and ISDN termination and local area data channels/subrate digital services.
RJ48	RJ48C	8P8C	Commonly used for T1 lines and uses pins 1, 2, 4, and 5.
RJ48	RJ48S	8P8C, keyed	Commonly used for local area data channels/subrate digital services, and carries one or two lines.
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Figure 3 shows a generic 8P8C receptacle.