Chapter 7

Review of Types and Applications

In their broadest application, electrical conductors are designated as (1) bare, (2) covered, or (3) insulated. In the preceding chapters, bare conductors have been described. This and several following chapters will deal with covered and insulated conductors.

Conductors for Use with Covered or Insulated Wires or Cables

Aluminum conductors for insulated and covered power cables are most commonly 1350 aluminum, especially when used in overhead applications. However, conductors fabricated with an 8XXX series electrical grade alloy are now common among most building wire types in both AWG and kcmil sizes. The 8XXX series electrical grade alloys are a relatively new class of alloys notable for excellent thermal stability and creep strain resistance. Details on the various sizes of this type of conductor in the bare stranding are given in Table 4-27. ASTM Standards B 800 and B 801 cover other details of this alloy group in both the bare wire and stranded condition.

The hard-drawn, or H-19 temper, is acceptable for most stranded applications, with intermediate tempers half and three-quarters hard also being employed for some applications. Added flexibility may be obtained by various strandings using a larger number of smaller wires for a given cable size. Where extreme flexibility is desired, as for portable cords, bunched or rope lay strandings are used.

Bare and covered conductors generally have Class AA or A stranding; insulated power cables employ Class B, C or D stranding, except for portable cords with Class G or H. The number of strands varies with conductor size and Class of stranding. (See Table 4-8)

Descriptions of stranding Classes, including bunched and rope lay, are contained in Chapter 3. ASTM B 231 specifies details of the various strandings for all common wire sizes.

Insulated conductors are generally concentric stranded, with each succeeding layer of strands laid in the opposite direction and designed so the outer layer has left-hand lay. The direction of lay is defined as the direction the strands diverge when the cable is viewed from the end, looking along its axis.

Concentric conductors for insulating are increasingly compressed or compacted. For compressed stranding, the concentric conductor strands are compressed to reduce the cable diameter by approximately three percent. Compact conductors, such as those used in most building wire types, have diameters approximately nine percent less than that of standard concentric cables and are the result of fully compressing the successive strand layers and eliminating most voids within the conductor. Generally in compact round construction, the concentric strands are all helically applied in the same direction (unilay).

Bare and covered overhead cables are generally of concentric construction with right-hand lay.

The Distinction Between Covered and Insulated Conductors*

It is important to distinguish between an insulated conductor and a covered conductor.

Insulated conductors are designed to confine electrical charge within the conductor at a predetermined maximum voltage gradient and operating temperature under wet or dry conditions. The ratings of insulated conductors are determined by appropriate tests and established in applicable industry standards.

Insulated conductors are generally designed as single conductors for direct burial or use in raceways, or as components for multiple-conductor cables. Temperature ratings of conductors range from 60°C to 105°C, with some cables designed for higher ratings dependent on the type of insulation used. Insulated conductor temperature ratings in the NEC are based on use in wet or dry locations. (See Section 310-13)

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* The National Electrical Safety Code defines covered conductor as “a conductor encased within material of composition or thickness that is not recognized by this code as electrical insulation.” Insulated conductor is defined as “A conductor encased within material of composition and thickness that is recognized by this code as electrical insulation” (NESC 1987). Also see definitions in Article 100 of 1987 NEC.
Covered and insulated wire and cable

Covered conductors, in contrast to insulated conductors, are used mostly by the utility industry under conditions where insulation is not required, and covering is applied for weatherability.

Used by utilities as open secondary distribution cable, covered conductors are installed on insulators and otherwise treated and respected as bare conductor. The coverings help reduce faults due to weather and wind where objects may contact the lines, or the lines come into close proximity with one another. Testing is designed only to establish physical properties and continuity of coverings.

Tree wire and spacer cable are also in the same category as covered line wire, but designed with considerably thicker coverings. These conductors, too, are installed on insulators and treated as bare conductors.

Covered Aluminum Line Wires and Cables

Covered Line Wires

Covered aluminum conductors are generally all-aluminum 1350, alloy 6201, ACAR or ACSR.

The specification generally referenced for covered line wire is ANSI C8. 35. Conductors used in line wire (as with tree and spacer cable) meet the relative ASTM specifications for the conductors used. Conductor coverings have no associated voltage rating and are usually black polyethylene or crosslinked polyethylene. Occasionally high density polyethylene and gray coverings are applied.

Tree Wire

These conductors, with thicker covering than line wires, are used to permit utility companies’ secondary line installation without extensive tree trimming, minimizing outages resulting from occasional tree contacts due to weather conditions.

Spacer Cable

Conductors described above as tree wires may be used as spacer cables by utilities though spacer cable does not require the heavy covering of abrasion-resistant compound used in tree wires. Spacer cables are installed with non-conducting spacers to reduce the amount of space and hardware needed. Plastic or ceramic spacers with provision for attachment to a messenger support maintain the conductors in a fixed relationship, allowing close spacings without shorts or flashovers. Depending on conductor size and length of run, spacers are usually placed 30 to 40 feet apart.

Insulated Conductors and Cables (0-600 Volts)

The following brief descriptions of insulated aluminum conductors for use on circuits not exceeding 600 volts, either as single conductors, unjacketed assemblies of conductors, or as components of multiple-conductor cables, are to provide a general overview. For more information on selection and use, see succeeding chapters.

Cables of this category are of two types: 1) conductors predominantly used by utility companies, and 2) those better known as premise-type wiring or building wire. Conductors of the first type are generally specified by utilities to comply with an industry specification, whereas building wire products are manufactured to comply with specifications of testing laboratories such as Underwriters Laboratories. The minimum requirements for building wire applications are given in the NEC, while utility companies are generally governed by the National Electrical Safety Code.

Use and application of building wire is usually governed by NEC, while utility companies are generally governed by the National Electrical Safety Code.

Aluminum Power and Lighting
Insulated 600-Volt Cables

Aluminum conductors of this classification are employed in the circuits in buildings, structures, yards and other low-voltage distribution systems for which the previously described covered cables are not suitable. Depending upon design, they may be installed in duct, trays, conduits or air. Insulated conductors where approved for that use are suitable for direct burial in earth.

The conductors range from No. 8 AWG to 2000 kcmil, Class A strandings, with various kinds of insulation, and with or without metallic or non-metallic outer sheaths or armor. The insulation required is governed by the specific application and will include both temperature and moisture conditions. Ampacity ratings for a given cable of a particular voltage and construction will vary with type of insulation and installation conditions.

For the reader’s convenience, we will consider 600-volt wires and cables in three separate categories—single conductors, single conductors in unjacketed assemblies, and multiple-conductor cables surrounded by overall jacket, sheath, or armor.

Single Conductors (0 to 600 Volts)

Single conductors of standard insulation types in most cases must meet the requirements of the National Electrical Code. Conductors are required to be either direct buried in earth, or installed in conduits or other recognized raceways, except as permitted in specific NEC Articles.

Conductors manufactured to comply with the requirements of testing laboratories such as UL include types RHH, RHW, TW, THW, THHN, THWN, and XHHW, and are generally available in sizes through 2000 kcmil. Conductors are selected on the basis of application considerations such as temperature rating as related to ampacity, type of raceway, and installation location. In conductor selection, reference should be made to the NEC and Chapter 10 of this book.

Single 600-volt aluminum conductors are also widely used as underground service entrance, distribution, and feeder cables. (Covered in underground section, page 7-4).
Six-hundred-volt aluminum-armored cables are also available in single conductor constructions and are discussed on page 7-4. (See also NEC Article 334)

**Aerial Cable Assemblies (0 to 600 Volts)**

Messenger-supported aerial cables may be field assembled from single conductors. Factory assemblies in sizes through 4/0 AWG are generally available.

**Parallel Aerial Cables (PAC)**

These cables, manufactured to ICEA specifications, are rated at 600 volts phase-to-phase. Assemblies are either three- or four-conductor, with two or three insulated phase conductors assembled with a bare neutral messenger. These conductors are used to supply power to a limited number of customers and provide for “T”-type taps.

**Reverse Twist Secondary Cables (RTS)**

RTS cable meets the same ICEA specifications for 600 volt phase-to-phase conductors as PAC (above). Its basic design of reverse-layer twisting of phase conductors about the neutral messenger builds in additional length and eases separation of phase conductors for “T” taps.

**Service Drop Cables**

Service drop cables, sometimes referred to as multi-plexed cable, are manufactured to meet the applicable requirements of ICEA specifications for neutral-supported service drop cables. They are used on circuits not exceeding 600 volts phase-to-phase to supply power from the utility source to the user’s attachment point, where it is connected to the service entrance conductors. Assemblies consist of one, two, or three insulated phase conductors cable around a bare neutral messenger. Phase conductors are commonly insulated with crosslinked polyethylene or polyethylene. Service drop cable is installed by and is generally within the jurisdiction of the utility company. (See NEC Article 230.)

Service drop conductors are also used by utility companies and other users to power security light systems or distribute power overhead from one structure to another.

**Multiple Conductor Power Cables (0-600 Volts)**

**Aluminum Interlocked or Seamless Armored Cables**

Metal-clad cable designated Type MC by the NEC (Article 334) consists of one or more insulated conductors, plexed under a binder tape. The assembly is covered by a metallic armor of interlocking tape, or by a smooth or corrugated tube. Aluminum sheathed cable consists of one or more insulated conductors enclosed in an imperious, continuous, closely fitting tube of aluminum.

Metal-clad cables are installed in racks, trays, troughs, or baskets, or are suspended from messengers. Type MC cable is generally available in sizes Nos. 6 through 1000 kcmil. A protective thermosetting or thermosplastic outer covering may be added where corrosive or other conditions warrant its use or for direct buried application.

Aluminum armor is nonmagnetic and thus does not add to the inductive reactance of the conductor as does galvanized steel. Because of this, the characteristic use of aluminum armor is favorable in ampacity and voltage drop comparisons. Aluminum armor is also particularly resistant to corrosion in many industrial atmospheres and is significantly lighter in weight, weighing about one-third the weight of steel.

Metal-clad cable principally is used in lieu of cable in conduit and where significant labor savings, provision for rearrangement, flexibility and installation, mechanical protection of the conductors, and small available space are factors.

**Aluminum Service-Entrance Cables (600-volt)**

The most commonly used service-entrance cables are designated Type SE-Style U (SEU), Fig. 10-4, or Type SE-Style R (SER), Fig. 10-5. Both styles are recognized for service entrance circuits and also for sub-service and branch circuits within a building. In SEU cables, one or two insulated conductors form the base around which bare aluminum strands are concentrically wrapped to make the uninsulated neutral conductor. A layer of moisture-seal tape covers the concentric wrap, and the entire assembly is protected by an overall jacket of polyvinyl chloride.

The Type SE-Style SER cable differs from the oval style SEU in that all conductors, neutral and phase, are cable together to make a round construction. The three-conductor type includes two insulated phase wires and an insulated grounded conductor that serves as the circuit neutral as well as an equipment grounding wire (where codes permit dual use). The four-conductor type includes two insulated phase wires, one insulated conductor, and one bare grounding conductor, thereby separating the circuit neutral from the equipment grounding wire. The conductors are spirally assembled, wrapped with moisture-seal tape, and covered with a jacket.

NEC-recognized for single-unit dwelling services through 200 amperes, SER and SEU cables are available in sizes No. 8 AWG through 4/0 AWG. Conductors used in service entrance cable are generally RHH, RHW or XHHW.

Because these cables are also approved for certain interior circuits, they are used where many distribution panels and branch meters are connected to a single service entrance, such as in apartment buildings, and to equipment for which a three-wire service is required, such as electric ranges, laundry-room appliances, etc. Many UL-listed aluminum accessories are available for use with Type SE circuits.
covered and insulated wire and cable

Aluminum Cables For Underground Installation (600-Volt)

Insulated 600-volt aluminum cables are widely used for both secondary distribution feeders and service entrance conductors.

Both single conductors and preassembled cables, designated Type USE for service entrance and Type UF for underground feeders are available for this service.

Underground services — Type USE cables are available as single conductor, multiple conductor, and multiple conductor with an outer jacket. All are suitable for direct earth burial to complete the circuit from the utility source to the customer’s meter. Single conductors and multiple-conductor cables without jackets must be protected by conduit upon emerging from the earth, while USE with an outer jacket may be installed as Type SE cable.

Multiple-conductor 600-volt underground cable constructions come in several forms. Among the most common:

1. The most frequently used arrangement is made up of two separately-insulated aluminum phase conductors twisted with a solid or stranded insulated reduced-neutral conductor, Fig. 10-9C. These cables also are available preassembled in plastic pipe, plain or corrugated, for duct installation, Fig. 10-9E.

2. Two separately insulated aluminum phase conductors are laid parallel, and covered overall with bare round or flat-ribbon copper wires, applied helically and of such size that they comprise the equivalent of a reduced neutral, Fig. 10-9B. Copper wires are used for the spiraled neutral bare conductors.

3. A single insulated reduced-neutral conductor is centered between insulated phase conductors, in parallel or “ribbon” configuration, Fig. 10-9D. The insulation is extruded over the three conductors simultaneously. A thin web of insulation is left between the conductors. The web is easily separated for making terminal connections, and it aids in handling and stringing.

Developments by the aluminum industry of such specialized conductors as those described have greatly aided the conversion to underground residential distribution by reducing conductor and installation costs, narrowing the margin between URD and conventional overhead construction.

Underground feeders — Type UF cable is similar to Type NMC cable, but has additional jacket thickness making it suitable for direct burial. UF is available in single, two- or three-conductor cable, with or without grounding, and is approved for installation as underground feeders on circuits not exceeding 600 volts.

Insulated Conductors—Above (600 Volts)

Although bare aluminum conductors are extensively used for transmission and distribution circuits at all voltages, insulated aluminum conductors have not yet come into general use at transmission voltages 230 kV and above. However, installation in conduit as well as direct burial of insulated aluminum conductor at 69 kV, 115 kV and 138 kV (and all intermediate and lower voltages) has been in successful use for many years.

Power Cables (above 600 volts)

The general description of cables rated 600 volts with rubber or thermoplastic insulation on page 10-5, also applies to cables up to and including 2 kV, except for insulation thickness. However, for cables of the most-used types in the range 2001 V to 5 kV, NEC-designated Type MV (Medium Voltage), a layer of semi-conducting material known as conductor shielding is applied directly over the conductor and in contact with the inner surface of the insulation, Fig. 10-12. For most cable rated 5 kV and higher, an additional insulation shield of semiconducting material is applied directly over and in contact with the outer surface of the insulation.

Insulation and conductor shielding are used to create a uniform voltage gradient within the insulation about the conductor. A metallic shield, which is to be suitably grounded, is always applied over a semi-conducting insulation shield. The metallic shield may be used as part of a relaying circuit and occasionally as a neutral.

The described customary shielding practice for the various voltages are subject to exceptions as described in NEC and ICEA standards, as further noted in Chapter 10.

The most commonly used insulated aluminum medium-voltage cables are in the range of 5 kV through 35 kV (phase-to-phase) for installation in air, or duct-bank, as two-conductor or three-conductor cables, Figs. 10-15 and 10-17. Special reference to their use as preassembled aerial cable, cable conductors attached to a messenger, or as protected by interlocked or continuous armor, is in Chapter 8. See Fig. 10-16.

Conductors used in high voltage cable construction are generally Class B concentric or compressed stranded, though some solid conductors in the size range of No. 2 through No. 4/0 AWG are used. Chapter 8 of this book details types of insulation used in high and medium voltage cable constructions.

Cable constructions are sometimes tailored for specific use and the basic design modified to meet particular requirements.

Primary URD Cables for Underground Residential Distribution (5 kV to 35 kV)

In general, the two-conductor, concentric-neutral type is standard for primary URD cable, Fig. 10-18. The design is comprised of a standard medium voltage type cable (conductor, semi-conducting strand shield, insulation, and semi-conducting insulation shield) over which a bare concentric neutral is helically applied.

Primary URD cable is generally available in solid dielectric design with extruded insulation shielding. The
helically applied concentric neutral is generally composed of coated or uncoated copper strip or wires. Cable designs through 4/0 AWG often include a neutral, sized to match the conductance of the phase conductor, with one-third neutrals common for larger sizes.

Medium-Voltage Shielded Single-Conductor Power Cables (5kV to 35 kV)

Cables of this class are used principally for relatively high-voltage power distribution, and are suitable for installation in underground duct, direct earth burial, used as aerial cable conductors, and often as components in armored cable. The overall jacket of this construction provides protection for the metallic shielding and makes the cable suitable for a wide variety of uses, Fig. 10-13.

Interlocked-Armor Cables

Cables of this class installed on racks or cable trays provide ease of installation and re-routing of circuits where necessary.

Armored-conductor cables are available utilizing shielded conductors as described above. These conductors are cabled together with the necessary components to construct a round cable over which is applied a moisture barrier separator and the armor. Some constructions are designed with grounding conductors placed in the cable interstices. Cables of this class are generally available in 5 kV to 15 kV ratings and may have either aluminum or steel armor.

In general, cable armor in previous years was of the interlocked type, where metallic strips were shaped and spirally applied about the cable in an interlocking design. Today this design basically applies to cables with steel armor. Cables with aluminum armor are now generally of corrugated design. Aluminum strip is applied longitudinally about the cable, continuously welded and corrugated to provide flexibility. In contrast to the interlocking design, the corrugated armor seals the constructions from the ingress of moisture.

Jackets of polyethylene or polyvinyl-chloride applied over both types of armor provide protection against corrosive environments and seal the interlocking type armor. Mechanical protection can also be provided by the use of concentrically applied round-wire armor, usually galvanized steel, for applications such as submarine and bore-hole cables, or cables in vertical risers where longitudinal stress is a factor.

Preassembled Aerial Cables (to 35 kV)

Preassembled self-supporting aerial aluminum conductors for primary distribution are available for voltage ratings through 35 kV. Shielded and jacketed conductors as described above are used in these constructions. Individual phases are cabled together and bound to a supporting messenger.

These cables are designed for aerial installation on poles, towers, or between buildings where the cost of underground duct installation cannot be justified, or where aerial space and safety does not permit bare overhead conductors, or where congestion overhead or underground prohibits conventional installations.

Cables may be preassembled in the factory or field-spun using a binder applicator, Fig. 10-14.

Aluminum Insulated Conductors for Special Conditions

In addition to the applications previously described, there are other uses of aluminum conductors that require special consideration, because they differ in certain respects from the usual permanently installed circuits for power and lighting.

Aluminum Pole-and-Bracket Cables for Series Street Lighting

Cables for this service are usually single-conductor solid, with individual-conductor and belt insulations suitable for operation up to 9000 volts open circuit to ground, though the individual conductors may be insulated only to 600 volts, as required across a single fixture.

The conductor size for aluminum usually is No. 6 or No. 8 AWG either as single conductor or parallel two-conductor type. Cables are available for installations overhead, in underground ducts or conduit, and for direct burial.

Aluminum Mine Power Cables

The circuits in mines usually must be frequently relocated as mining progresses. The runs often are in cramped locations and also the supply often is through a vertical bored hole. Aluminum single and preassembled 3-conductor properly jacketed cables are excellent for this service because they provide needed flexibility, light weight for ease of handling, and the exterior jackets resist abrasion while being moved about.

Mine power cables, suitable for permanent or temporary installations, are available with rubber or cross-linked polyethylene insulation as single or 3-conductor aluminum phase cable which includes three copper grounding conductors (one of which may be insulated), for 600 V, 5 kV, 8 kV, 10 kV and 15 kV. The cables may be clamped without insulators to mine walls, run along the ground, or dropped vertically through a bore hole. For long drops, wire- armored cables are used. The insulated ground conductor, if used as a ground-check, is a safety feature that facilitates removal of power from the circuit if the other grounding conductors become broken. Three-conductor cables of this type also are supplied with an armored outer covering of steel wires to resist abrasion when the cables are dragged over the ground.

Preassembled aluminum self-supporting high-voltage aerial cables, as previously described, are often used for general supply on mining properties.
covered and insulated wire and cable

Aluminum Portable Cables

This highly specialized classification of electric conductors has heretofore mostly been available in copper, but more recently aluminum portables have become available in the heavy-duty sizes No. 6 AWG to 4/0 for 600-volt service, with single, two, three, or four conductors (and into the kcmil sizes for certain types). Also available are shielded portable cables to 5000 volts. Special extra-flexible light-weight portable single cables are also available for use with welding equipment. Flexibility is obtained by using Types G, H, or I stranding of ¾-hard, hard-drawn, or fully annealed aluminum, depending on requirements. The unidirectional method of stranding, as used for some designs, also aids flexibility; that is, all strands spiral in the same direction regardless of which layer they are a part.

Insulated molded fittings and couplings are available for many of the sizes so that quick connections can be made to terminals, electrode holders (of welding cable), and between cable sections.

The insulation and jackets are of materials that will withstand rough abuse when the cable is bent or dragged. Bending radii of eight times overall diameter are generally accepted for single- and multi-conductor cables over 5 kV, six times overall diameter for multi-conductor cables rated 5 kV and less.

Some of the uses of aluminum portable cables, in addition to the welding-equipment use mentioned, are those for locomotive reel equipment, mining machinery, magnetic hoists, dredges, motor leads, plug-in power drops from busways, and in and around shipyards.

Aluminum Submarine Cables

Submarine cables have moisture-resisting insulation and sometimes are protected by lead sheaths. Heavy mechanical protection is required to prevent damage from ship anchors, sharp rocks, and river or tide currents. These cables usually consist of three thermosetting or thermoplastic insulated conductors cabled together and protected by a tape, jute bedding, and galvanized-steel-wire armor.

Special Applications Cables

These cables usually consist of comparatively small conductors, often many within a single sheath. As current carrying requirements usually are small, little economic advantage accrues from the use of aluminum.

However, recent years have seen increased use of aluminum conductors in communications cables and automotive wiring harnesses, where weight is an important factor. Aluminum conductor manufacturers should be consulted for further information on this subject.