



# Electric Power Conductors Volume IV: Low Voltage Cables

An Online Continuing Education Course for Engineers

**Course Number: E-2069**

**Credit: 2 Hours / 2 PDH / 2 CPD**

# Electric Power Conductors Volume IV: Low Voltage Cables

Lee Layton, P.E.

## Table of Contents

<b>Section</b>	<b>Page</b>
Introduction.....	2
Chapter 1: Conductor Types .....	3
Chapter 2: Insulated Cable Properties.....	9
Chapter 3: Application Issues .....	20
Summary .....	30

**This course is one of four courses on electrical power conductors.**

**The four courses are:**

**Volume I: Electric Power Conductors – Electrical Characteristics**

**Volume II: Electric Power Conductors – Mechanical Characteristics**

**Volume III: Electric Power Conductors – Medium Voltage Cables**

**Volume IV: Electric Power Conductors – Low Voltage Cables**

**Each course is written as a stand-alone course and it is not necessary to take them in order. Because they are written as stand-alone courses there is some duplication of material among the four courses.**

## Introduction

The electric utility system in the United States has over seven million miles of power lines, and this includes over 100 billion feet of electrical conductors. The industry uses a combination of overhead and underground conductors, the majority of which is made from aluminum and aluminum alloys. At one time, copper was the predominant conductor, though little is used today.

While aluminum is used because of its superior strength to weight ratio and its reasonable conductivity, it is often augmented with steel and special ceramics to enhance the conductor's mechanical properties. The steel and ceramic materials contribute little to the conductivity of the conductor.

When looking at the electrical characteristics of a conductor, it is important to know the conductors' resistance, reactance, fault current capability, and thermal current carrying capability. This begins by first calculating the DC resistance of the conductor based on the conductivity of the materials used in the conductor. Once the DC resistance is found, the AC resistance is based on system frequency and other factors. Conductor properties vary based on temperature, and the current-carrying capacity of a conductor is based on its ability to dissipate the heat generated by the current flowing through the conductor. Both continuous, steady-state currents and transient current carrying capabilities can be calculated for a conductor based on its physical properties.



This course explains the types of conductors used by electric utilities for low voltage service cables, which are defined as cables up to 600-volts phase-to-phase. The references, ratings, and installation practices mentioned herein applied to electric utilities whose practices are governed by the National Electric Safety Code (NESC). This information is in compliance with the National Electric Code (NEC) as necessary, except where specifically referenced.

# Chapter 1: Conductor Types

## Covered Conductors

The term *covered conductor* refers to any conductor having an integral, continuous cover or encasement over and around it of any non-conductive, non-metallic material. There are two classes of covered conductor for overhead applications:

- Weatherproof
- Insulated

The differences in weatherproof and insulated conductors are explained below.

### Weatherproof Conductor

Even though any polyethylene covering has some insulating value, weatherproof coverings do not imply any insulation characteristic and should not be considered electrically insulated. Weatherproof conductor does not have a voltage rating and is installed and handled the same as a bare conductor. It is manufactured to conform to applicable ASTM specifications for a weatherproof conductor.

The various materials for insulation or weatherproofing must have certain desirable characteristics to best withstand the field conditions that will be imposed upon them. Some deficiencies are apparent in all coverings, and some compromises must be made in selecting a covering with the most desirable characteristics for the intended service.

Desirable environmental, electrical, and physical characteristics for covering materials include:

- Environmental Characteristics
  - Heat resistance
  - Resistance to oxidation and ozone
  - Resistance to corona
  - Resistance to oil and chemicals
  - Good thermal conductivity
  - Non-combustibility

- Electrical Characteristics
  - High dielectric strength
  - High insulation resistance
  - Low dielectric losses
  
- Physical Characteristics
  - High tensile strength
  - Resistance to tearing, cutting, and abrasion
  - Resistance to compression
  - Adequate elongation with little set
  - Low specific gravity
  - Ease of stripping

This list is also applicable to insulated conductors; however, for weatherproof coverings, the physical and long-life characteristics apply most predominantly, while the electrical characteristics are of more importance for electrical insulation.

### Insulated Conductors

In contrast to weatherproof conductors, *insulated conductors* have a definite voltage rating for a given class of service. The thickness of insulation applied depends upon this rating as well as conductor size. All insulated conductor is subjected to dielectric testing according to applicable specifications.

The remainder of this course is focused solely on 600-volt insulated conductors.

In the past overhead service entrance cables were single conductors separated in air on stand-off brackets, as shown in Figure 1. Today, virtually all service entrance cables are *multiplexed cables* where the conductors are wrapped around a neutral cable, which also serves as the supporting wire for the cable. The assemblies consist of one, two, or three insulated phase conductors cabled around a bare neutral messenger and are known as duplex, triplex, or quadruplex cable, respectively. Phase conductors are commonly insulated with polyethylene or crosslinked polyethylene. Service drop cable is installed by and is generally within the jurisdiction of the utility company. (See NEC Article 230.)



**Figure 1**

## Mechanical Properties

This section describes some of the key calculations that are often encountered when applying secondary service cables.

### Conductor Sizing by Geometric Progression

Conductor sizes are identified by the American Wire Gage (AWG) for wire sizes up to 4/0 and in thousands of circular mils for conductors larger than 4/0. AWG sizing is based on a geometric progression from the smallest diameter wire size (36 AWG) to the largest (4/0 AWG). There is a total of 39 AWG wire sizes, and they are related based on a geometric progression, which results in a *progression factor* of 1.122932. All wire gauges between these two sizes are related by the progression factor. Using this progression, the formula to determine the conductor diameter for one wire size based on another wire size is,

$$\text{Dia}_{\text{Cond 2}} = \text{Dia}_{\text{Cond 1}} * 1.122932^N$$

Where,

$\text{Dia}_{\text{Cond}_2}$  = Diameter of the conductor in question, in

$\text{Dia}_{\text{Cond}_1}$  = Diameter of the known conductor, in

N = Number of AWG wire sizes between the two conductors

This formula is valid for solid conductors only. Stranded conductors can be converted to equivalent solid conductors for the calculation.

**Example.** A #2 AWG solid conductor has a diameter of 0.2576. What is the conductor diameter for a #4/0 AWG, stranded conductor?

There are five AWG wire gauges between #2 AWG and #4/0 AWG, so the diameter of #4/0 is,

$$\text{Dia}_{\text{Cond 2}} = \text{Dia}_{\text{Cond 1}} * 1.122932^5$$

$$\text{Dia}_{\text{Cond 4/0AWG}} = 0.258 * 1.122932^5$$

$$\text{Dia}_{\text{Cond 4/0AWG}} = 0.460 \text{ in}$$

## Conductor Diameter based on Strand Diameter and Number of Layers

For a stranded conductor, the overall conductor diameter is based on the number of strands in the conductor and the diameter of those strands. The formula is,

$$\text{Dia}_{\text{Cond}} = \text{Dia}_{\text{Str}} * (2 * \text{N}_{\text{Layers}} - 1)$$

Where,

$\text{Dia}_{\text{Cond}}$  = Overall Conductor Diameter, in

$\text{Dia}_{\text{Str}}$  = Diameter of an individual strand, in

$\text{N}_{\text{Layers}}$  = Number of layers in the conductor

**Example.** What is the overall conductor diameter for a 37-strand, 4-layer conductor with 0.1337 diameter strands?

$$\text{Dia}_{\text{Cond}} = \text{Dia}_{\text{Str}} * (2 * \text{N}_{\text{Layers}} - 1)$$

$$\text{Dia}_{\text{Cond}} = 0.1337 * (2 * 4 - 1)$$

$$\text{Dia}_{\text{Cond}} = 0.936 \text{ in}$$

## Equivalent Solid Diameter Given a Stranded Conductor

For making connections to a stranded conductor for a given application, it is important to know the equivalent size solid conductor for a given application. This is true for all aluminum (AAC) and steel (ASC) stranded conductors given the same application.

The equivalent size solid conductor is the size of a solid conductor for a concentric strand application—which only works for a concentric strand conductor for a concentric strand application.

Where,

$\text{Dia}_{\text{Solid}}$  = Equivalent Diameter, in

$\text{N}_{\text{Str}}$  = Number of individual strands

$\text{Dia}_{\text{Str}}$  = Diameter of the individual strand, in

**Example.** What is the equivalent solid diameter for a 37-strand, 4-layer conductor with 0.1337 diameter strands?

