



Electric Power Conductors Volume I: Electrical Characteristics

An Online Continuing Education Course for Engineers

Course Number: E-2068

Credit: 2 Hours / 2 PDH / 2 CPD

Electric Power Conductors Volume I: Electrical Characteristics

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**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 provides detailed calculations to determine the electrical characteristics of power conductors. DC resistance, AC resistance, inductive reactance and capacitance, steady-state and transient ampacities, as well as fault current calculations are presented in this course. Chapter one begins with the properties of materials used in conductors.



Chapter 1: Electrical Properties

Conductivity is the basic characteristic upon which all conductor electrical characteristics are based. Conductivity is a measure of the amount of current that will flow in a length and diameter of solid wire onto which is impressed a direct current (DC) voltage.

The International Annealed Copper Standard (IACS) uses *annealed copper* as the reference for a conductor's conductivity. With annealed copper as the reference (i.e., 100% conductivity), we can say that the conductivity of *hard-drawn copper* has a conductivity that is 97% of the IACS standard and 1350-H19 aluminum has a conductivity that is 61.2% of the conductivity of the standard. The IACS standard uses a 20C temperature reference for all conductivity and resistivity values.

Conductivity is the ability of current to flow through a material; therefore, the resistance to the flow of current through a material is the reciprocal of conductivity. The resistivity of annealed copper is 0.008145 ohms per 1,000 feet, and the resistance of 1350-H19 aluminum—which 61.2% of the conductivity of annealed copper — is,

$$R_{1350-H19 AL} = 0.008145 * \frac{1}{0.612} = 0.013310 \text{ ohms}/1,000'$$

Table 1 shows the resistivity, conductivity, and the thermal coefficient of resistance for several conductor materials.

Table 1 Electrical Properties of Materials			
Material	Conductivity	Resistivity (Ω-in²/1000')	Temperature Coefficient of Resistance per C
Annealed Copper	100%	0.008145	0.00393
Hard-Drawn Copper	97%	0.008397	0.00381
1350-H19 AL	61.20%	0.013310	0.00404
6201-T81 AL	52.50%	0.015515	0.00347
Steel Core	8.00%	0.101819	0.00327

The *thermal coefficient of resistance* is a factor that explains how the resistance of a material changes with temperature. As you can see in Table 1, 1350-H19 aluminum has the largest variance in resistance for changes in temperature (0.00404 per degree C).

The resistance of a conductor at a temperature other than 20 degrees Celsius can be found by using the temperature coefficient of resistance and this formula,

$$R_{Temp} = R_{Ref} * [1 + \alpha * (T - T_{Ref})]$$

Where,

R_{Temp} = Resistance at new temperature, ohms/mile.

R_{Ref} = Resistance at the reference temperature (usually 20C), Ohms/mile.

α = Temperature coefficient of resistance.

T = New temperature, degrees Celsius.

T_{Ref} = Reference temperature, degrees Celsius.

Example. What is the resistance of a hard-drawn copper conductor at 75C if it has a DC resistance of 0.042354 ohms/mile at 20C?

From Table 1, the temperature coefficient of resistance of hard-drawn copper is 0.00381 per degree Celsius. At 75C, the resistance is,

$$R_{Temp} = R_{Ref} * [1 + \alpha * (T - T_{Ref})]$$

$$R_{75} = 0.042354 * [1 + 0.00381 * (75 - 20)]$$

$$R_{75} = 0.05123 \text{ ohms/mile}$$

In this example, the resistance is 20% higher at 75C.

When the resistance of a conductor is at a temperature other than the standard IACS temperature (i.e., 20C), the temperature coefficient of resistance must be determined for this temperature. A temperature coefficient of resistance can be for the new temperature using the standard 20C reference temperature using this formula,

$$\alpha_{new} = \frac{1}{\left[\frac{1}{\alpha_{20C}} + (T_{new} - T_{20C}) \right]}$$

Where,

α_{new} = Temperature coefficient of resistance at new temperature, per degree C.

$\alpha_{20\text{C}}$ = Temperature coefficient of resistance at 20C.

T_{new} = New temperature, degrees C.

$T_{20\text{C}}$ = Reference Temperature, 20C.

Example. What is the temperature coefficient of resistance, based on a 20C reference, for a known resistance of a hard-drawn copper conductor at a temperature of 75C?

The temperature coefficient of resistance for hard-drawn copper 20C is 0.00381 per degree Celsius.

$$\alpha_{\text{new}} = \frac{1}{\left[\frac{1}{\alpha_{20\text{C}}} + (T_{\text{new}} - T_{20\text{C}})\right]}$$

$$\alpha_{75} = \frac{1}{\left[\frac{1}{0.00381} + (75 - 20)\right]}$$

$$\alpha_{75\text{C}} = 0.00315$$

The resistance of a conductor is based on a specific length. Table 1 has the resistivity shown as ohms per 1000 feet. Throughout this course, however, the unit of length will be ohms per mile unless otherwise noted.

The following tables have conductor specifications for several common sizes and types of conductors. Table 2 is for solid aluminum conductors using 1350-H19 aluminum.

Table 2 Solid Aluminum Conductors							
Size	Diameter		GMR (ft)	Resistance (ohms/mile)			
	Diameter (in)	Weight (lbs./ft)		20C		25C	50C
				R _{dc}	R _{ac}	R _{ac}	R _{ac}
4	0.2043	0.0385	0.00663	2.144	2.148	2.192	2.409
2	0.2576	0.0609	0.00836	1.348	1.352	1.379	1.515
1/0	0.3249	0.0970	0.01050	0.848	0.850	0.867	0.953
4/0	0.4600	0.1940	0.01490	0.423	0.424	0.433	0.476

Table 3 is for all aluminum conductors (AAC), which also use 1350-H19 aluminum.

Table 3 All Aluminum Conductors (AAC) Conductors							
Size	Code	Str	Diameter			Resistance (ohms/mile)	
						25C	50C
						R _{ac}	R _{ac}
4	Rose	7				2.237	2.458
2	Iris	7				1.405	1.544
1/0	Poppy	7				0.884	0.972
4/0	Oxlip	7				0.441	0.485
266	Laurel	19				0.351	0.385
336	Tulip	19	0			0.2779	0.0.3052
795	Arbutus	37	0			0.120	0.132

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Table 4 is for Aluminum conductors with steel cores. This product uses 1350-H19 aluminum too.