J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*

CABLE INSULATION

There basically are two means by which electric power is transmitted and distributed—by overhead lines and underground cables. In the United States, most electric power still is transmitted by overhead lines between the generating plants and load areas. Only about 1% of the US transmission lines are underground. Most of these are in urban areas where overhead rights of way are unavailable or where local ordinances mandate undergrounding. On the other hand, underground cables are used more frequently in distribution systems, due to safety, security, reliability, and ordinance requirements.

Cable Construction

In general, three conditions must be met in cable design. First, a material of high electrical conductivity must be provided for transmitting the energy. Second, it must be insulated electrically from its return circuit. Third, the insulating material must be protected from mechanical injury, and if it is hygroscopic, it must be protected from moisture. Figure 1 shows a conceptual cable design. The two main components of a cable are the conductor and the insulation. The conductor and insulation shields are used to reduce electrical stresses at the metal-to-insulation boundaries. The cable sheath is used to carry the fault current and in some cable types also provides corrosion and moisture protection. Mechanical protection normally is provided by the cable jacket.

Conductor

Cable conductors normally are made of either electrolytically refined, tough-pitch copper or 1350 grade aluminum. Conductor material selection is based on the following considerations: (1) cable rating (ampacity), (2) mechanical strength and flexibility, (3) cable size and weight limitation, (4) chemical stability, and (5) cost. Copper conductor is either soft, medium-hard drawn, or hard drawn. Aluminum conductor is either hard, three-quarters hard, or half-hard. The conductivity of the conductor is often increased by annealing it. However, this also lowers its tensile strength.

Copper has the advantage of having the lower resistivity; however, it also has the higher cost and weight. The dc resistivities of copper and aluminum at 20 °C are 1.72 μ /cm and 2.82 μ /cm, respectively. The electrical conductivity of aluminum is critically dependent upon minute chemical and metallurgical impurities, which are difficult to eliminate in practical production (1). Impurities such as Ti and Mn will cause a large decrease in the electrical conductivity of aluminum. The variation in the dc resistivity with temperature is different for copper and aluminum and is given in the following equation (2):

$$R_T(\mathrm{dc}) = R_r \frac{T_r + T}{T_r + t}\ \mu\Omega/\mathrm{m} \qquad (1)$$

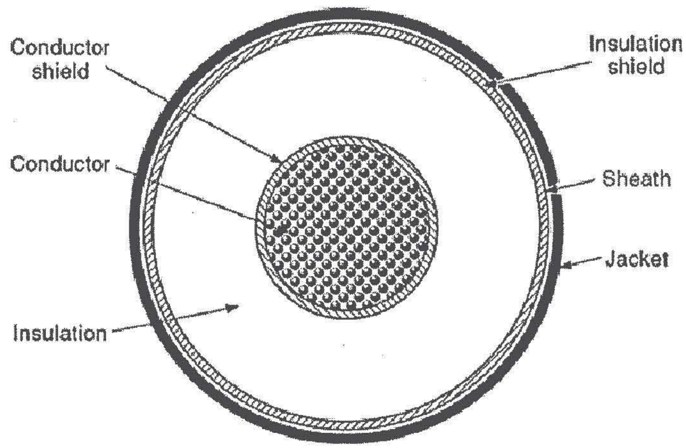

Fig. 1. Basic cross-section of a power cable.

where

R_T = resistance at temperature T, μ/m
R_r = resistance at the reference temperature T_r, μ/m
t = temperature of inferred zero resistance

In ac operation, the conductor dc resistance is increased by the skin and the proximity effect. The skin effect is the tendency of the ac current to crowd toward the surface of the conductor. The proximity effect is the distortion of current distribution due to the magnetic effects of other nearby currents. Other contributors to increases in the ac resistance are hysteresis and eddy-current losses in nearby ferromagnetic materials and induction losses in short-circuited nearby conducting materials. In general, the ac resistance of a conductor can be calculated using the following equations (2):

$$R(\mathrm{ac}) = R(\mathrm{dc}) \times K_1 \times K_2 \qquad (2)$$

where

$R(\mathrm{dc})$ = dc resistance at 20 °C, μ/m
K_1 = ratio of dc resistance at the maximum permissible conductor temperature to that at 20 °C
K_2 = ac/dc resistance ratio

Here

$$K_1 = 1 + \alpha\,(T_1 - 20) \qquad (3)$$

where

α = temperature coefficient of resistance
T_1 = maximum permissible conductor temperature