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POWER LOSSES AND THEIR SIGNIFICANCE

There are four major types of power loss in an energized power cable: I^2R loss in the conductor, Power Factor (PF) loss in the insulation, IR loss in the insulation, and I^2R loss in the shield (if one is present and it is multi point grounded). Each type of power loss and its relative cost is described below.

Conductor Loss

Power loss in the conductor results from "friction" between the current (i.e., moving electrons) and the copper (or aluminum) atoms in the conductor. A water pipe analogy is helpful in understanding the situation. As water flows through a pipe, friction between the moving water and the walls of the pipe generate heat. This heat raises the temperature of the water a small amount. In a power cable, friction between the moving electrons and the atoms of the metal conductor produces heat which raises the temperature of the conductor. The amount of heat produced is proportional to the resistance of the conductor (R), and the square of the current (I) flowing through it, i.e., power loss = I^2R.

For example, if the current flowing in a conductor is 100 amps and the resistance is 0.02 ohms/1000 ft. (the approximate resistance of a 500 kcm copper conductor), the power loss is 200 watts/1000 ft.

In fully loaded power cables, the electrical cost of conductor loss is typically in the range of $1000 to $10,000 per 1000 ft. of cable per year (based on an electric power cost of 7¢ per kilowatt-hour). The cost is, of course, proportionately less in a partially loaded cable.

Shield Loss

Shield loss results from the same basic mechanism as conductor loss. That is, electrons moving through a conductor against the electrical resistance of that conductor. The current that flows in the shield of a medium voltage power cable that is grounded at more than one point is primarily the result of magnetic coupling with the current flowing in the center (or phase) conductor of the cable. Thus, shield loss increases as current in the phase conductor of the cable is increased. The cost of shield losses in a well designed power system can range from zero for a shield with single point grounding to as much as 25% or more of the phase conductor loss. If the system is poorly designed, shield loss can actually be as great or greater than the power loss in the phase conductor!

Insulation PF Loss

Insulation Power Factor (also called Dissipation Factor) loss occurs in the insulation of the cable and is due to a somewhat different mechanism than conductor and shield losses. To visualize this loss mechanism, imagine that there are thousands of microscopic dumbbells located throughout the cable insulation. Each of these dumbbells has a positively charged end and a negatively charged end. When voltage is applied to a cable, the electric field causes the dumbbells to align with the electric field, i.e., it causes the dumbbells to rotate until the positive end of the dumbbell is closer to the negative side of the insulation and the negative end is

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nearer the positive side (remember opposite charges attract—like charges repell).

Since AC voltage reverses polarity 60 times every second, these dumbbells "flip-around" 60 times a second, always trying to catch up with the electric field. The movement of the dumbbells (actually polar molecules of the insulation) against restraining forces in the insulation results in a power loss. This power loss is proportional to the applied voltage, power factor and SIC (dielectric constant) of the insulation. This power loss typically consumes $1 to $10 worth of electric power per 1000 ft. of cable per year in medium voltage power cables.

Insulation IR Loss

Ordinarily, the smallest power loss in power cables is due to insulation resistance (IR) losses. Applying the water pipe analogy again, IR loss can be visualized as the power loss resulting from water leaking through thousands of pinholes in the pipe wall. Friction between the water and the wall of each pinhole generates heat which is lost to the environment. In actual power cable, it is electrons being forced through the insulation by an applied voltage. As the electrons work their way through the atomic structure of the insulation, they are deflected and bounced around by the atoms which make up the insulation. This results in a power loss which is inversely proportional to the insulation resistance of the cable. It is proportional to the square of the applied voltage. Medium voltage power cables typically consume 1¢ to 10¢ worth of electric power per 1000 ft. of cable per year due to this mechanism. If the IR of any particular insulation is doubled, the power loss due to IR losses will halve.

Total Power Loss

The total power loss in an operating power cable is simply the sum of the conductor loss, shield loss, insulation PF loss and insulation IR loss. Although the loss from each source varies considerably depending on conductor size, conductor metal, insulation type, applied voltage, cable loading, installed configuration and other factors, the approximate range of cost of these losses are summarized in the table below. ≶

Source Of Power Loss	Typical Cost Of Power Loss*
Conductor loss	$1000 to 10,000
Shield loss	$10 to 1,000
Insulation PF loss	$1 to 10
Insulation IR loss	$0.01 to 0.10

*Per 1000 ft. of cable per year. Based on a properly installed cable operating at 90°C with the shield grounded at multiple points.