Distribution Losses In Industrial Facilities

There is a dramatic difference in an AC power distribution system between the simple DC resistance values of the various conducting elements, and the actual apparent AC resistance, under heavy current load, of these same elements. Motors, lighting systems, wiring, mechanical terminations, distribution panels, protective devices, transformers, switchgear, and all end of circuit equipment experience a variety of resistance increasing inefficiencies that combine to create an average wattage loss in a typical industrial facility of from 10% to 25% of total demanded power. Identifying and calculating the sum of the individual contributing loss components is a challenging engineering specialty, requiring extensive experience and knowledge of all the factors impacting the operating efficiencies of each of these components.

The following list is a simplified overview of several of the more important loss factors in an industrial facility, including a broad range estimate of reasonable loss values attributable to each stated effect. Note that all of these are current dependent, and can be readily mitigated by any technique that reduces facility current load.

Hysteresis Losses

Hysteresis loss is a heat loss caused by the magnetic properties of the armature in an AC motor. When an armature core is in a magnetic field, the magnetic particles of the core tend to line up with the magnetic field. When the armature core is rotating, its magnetic field keeps changing direction. The continuous movement of the magnetic particles, as they try to align themselves with the magnetic field, produces molecular friction. This, in turn, produces heat. This heat is transmitted to the armature windings. The heat causes armature resistances to increase.

• *Typical hysteresis losses as a percentage of building demand: 2% to 5%*

Skin Effect Losses

The apparent resistance of a conductor is always higher for AC than for DC The alternating magnetic flux created by an alternating current interacts with the conductor, generating a back EMF which tends to reduce the current in the conductor. The center portions of the conductor are affected by the greatest number of lines of force, the number of line linkages decreasing as the edges are approached. The electromotive force produced in this way by self-inductance varies both in magnitude and phase through the cross-section of the conductor, being larger in the center and smaller towards the outside. The current therefore tends to crowd into those parts of the conductor in which the opposing EMF is a minimum; that is, into the skin of a circular conductor or the edges of a flat strip, producing what is known as 'skin' or 'edge' effect. The resulting non-uniform current density has the effect of increasing the apparent resistance of the conductor and gives rise to increased losses.

Harmonic loading increases skin effect losses by the square of the increase in frequency above nominal line frequency, and so is responsible for a substantial lost wattage in any facility with large populations of nonlinear equipment loads, such as VFDs, DC drives, rectifiers, induction heating or other arcing or switching power supply devices.

• *Typical skin effect losses as a percentage of building demand: 2% to 8%*

Proximity Effect Losses

Proximity effect is a property existing when conductors are close together, particularly in low voltage equipment, where a further distortion of current density results from the interaction of the magnetic fields of other conductors.

In the same way as an EMF may be induced in a conductor by its own magnetic flux, so may the magnetic flux of one conductor produce an EMF in any other conductor sufficiently near for the effect to be significant.

If two such conductors carry currents in opposite directions, their electromagnetic fields are opposed to one another and tend to force one another apart. This results in a decrease of flux linkages around the adjacent parts of the conductors and an increase in the more remote parts, which leads to a concentration of current in the adjacent parts where the opposing EMF is a minimum. If the currents in the conductors are in the same direction the action is reversed and they tend to crowd into the more remote parts of the conductors.

This effect, known as the 'proximity effect' (or 'shape effect'), increases the apparent AC resistance. If the conductors are arranged edgewise to one another the proximity effect increases. In most cases the proximity effect also tends to increase the stresses set up under short-circuit conditions and this may therefore have to be taken into account.

• *Typical proximity effect losses as a percentage of building demand: 1.5% to 3%*

Transformer Losses

The two primary types of transformer losses are core losses and load losses. The core loss of a transformer arises because the core must be taken through its alternating cycles of magnetization. Core losses occur because there must exist a magnetizing current in the primary winding of a transformer which is additional to that current which flows to balance the current in the secondary winding. The magnetizing current is required to take the core through the alternating cycles of flux at the rate determined by system frequency. In doing so, energy is absorbed. This is known as the core-loss. The core-loss is present whenever the transformer is energized.

Transformer load losses occur because the flow of a current in any electrical system also generates loss dependent upon the magnitude of that current. Transformer windings are no exception and these give rise to the load loss of the transformer. Load loss is, of course, present only when the transformer is loaded and its magnitude is proportional to the load squared.

There are three categories of load loss which occur in transformers :

- · Resistive losses, often referred to as I^2R losses.
- · Eddy-current winding losses due to the alternating leakage-fluxes
- · So-called stray losses in leads, core-framework and tank due to the action of load-dependent stray alternating fluxes.

Resistive losses, as the term implies, are due to the fact that the windings cannot be manufactured without electrical resistance (at least, until commercial superconductors are successfully developed) and are therefore a "fact of life" which cannot be eliminated for the transformer designer.

The leakage-flux occurring in transformer windings is greatest at the winding ends, but is present throughout the entire winding body. Consequential eddy currents are set up that oppose the natural direction of current flow and greatly increase the transformer's apparent AC resistance.

Stray losses exist in all transformers, but present more of a problem on larger transformers, because the physical size of the leads and the currents they carry are greater.

Typical transformer losses as a percentage of building demand: 1% to 2%

Line Losses

In addition to I^2R losses and dielectric losses, cables have other losses such as skin-affect and proximity-effect developed by magnetic induction. For single conductor cables, however, where conductors are not operating close to each other, proximity effect is negligible. Skin-effect loss is caused by the reversing magnetic field, about the cable, which tends to concentrate the current toward the periphery of the conductor. This affect then reduces the effective carrying capacity of a conductor in its central portions. Proximity-effect loss is caused by the opposing force of magnetic fields set up by neighboring conductors. This displaces the points of maximum reactance to a maximum distance from each other, resulting in maximum current density at the nearest surfaces of the two conductors. Operating together in a typical industrial conduit enclosed distribution system, these various loss factors can sufficiently increase the building wiring's apparent AC resistance to more than an order of magnitude above nominal DC resistance values. Thus, typical I^2R wiring losses are often far greater than simple chart-based values.

With the above, recall that I^2R losses occur in *ALL* distribution system conducting components, not only the wire.

• *Typical line losses as a percentage of building demand: 1% to 3%*

Eddy-Current Losses

With any electrical system component comprising an iron or steel frame and an electrical coil, flux will flow in the steel as a result of the alternating current in the coil. The flux in the steel will itself induce an EMF in the material following the basic laws of induction. Since the material is essentially an electrical circuit closed on itself, the induced EMF will cause a circulating electrical current called an eddy-current. Its value is dependent on the value of EMF and on the resistivity of the path of current. As in any other electrical circuit the power loss is the product of the square of the current times the resistance. In a similar manner to hysteresis losses, the eddy-current loss manifests itself as heat, contributing to the maximum operating temperature limit of the device.

Eddy current losses occur in protective circuit breakers, lighting ballasts, power supply transformers, magnetic motor starters, voltage reducing or isolation transformers, current overload relays, control contactors and relays, all motor windings, and even building wiring, when the wiring is in circular proximity to steel or iron structures, such as electrical enclosures, distribution panels, or terminal or distribution blocks.

• *Typical eddy current losses as a percentage of building demand: 1.5% to 4%*