Power Quality Solutions

Technical Note

Energy Savings/Loss Reduction Opportunities

Overview: Distribution Losses

There are fundamental differences between simple DC resistance values of various conducting elements and actual 'apparent' AC resistances of the same elements. Motors, lighting, facility wiring, distribution panels, protective devices, transformers and switch gear all experience a wide range of phenomena that combine to create wattage (energy) losses. Identifying and calculating the total of all losses is an extremely challenging engineering proposition that requires knowledge of all factors that impact operating efficiencies. The following document provides a simplified overview of the most common and important loss factors in a typical facility. Note that all of these are current (Amps) and frequency (Hz) dependent, and can be reduced by utilizing techniques that reduce facility current usage and filter harmonics.

Hysteresis Losses

Hysteresis losses are heat losses associated with the magnetic properties of an AC motor armature. 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 magnetic particles as they try to align themselves with the magnetic field produces molecular friction, causing heat. This heat is transmitted to the armature windings, increasing armature resistance.

Skin-Effect Losses

The apparent resistance of a conductor is always higher for Alternating Current (AC) than for Direct Current (DC). The magnetic flux created by AC interacts with the conductor, generating a back Electro-motive Force (EMF), tending to reduce the current in the conductor. The center portions of the conductor are affected by the greatest number of lines of this force. The EMF produced in this manner (self-inductance) varies both in magnitude and phase through the cross-section of the conductor, being greater toward 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. This phenomenon is known as 'skin' or 'edge' effect. The resultant non-uniform current density has the effect of increasing the apparent resistance of the conductor, causing increased losses. Harmonic loads amplify skin effect losses by the square of the increase in frequency above nominal line frequency. Because of this, harmonics are the cause of substantial energy losses in any facility with nonlinear equipment loads, such as VFDs, DC drives, rectifiers, induction heaters or other arcing or switching power supply devices.

Proximity Effect Losses

Proximity effect exists when conductors are close together, particularly in low voltage equipment, where the interaction between the magnetic fields of conductors causes further distortion of current density. In the same way as an EMF can be induced in a conductor by its own magnetic flux, another conductor can produce an EMF in any other conductor.

If two such conductors carry currents in opposite directions, their electromagnetic fields are opposite, tending 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. This forces a larger concentration of current to the adjacent parts where opposing EMF is at a minimum. If the currents in the conductors move in the same direction, the above action is reversed. 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. As an additional note, in many cases the proximity effect will also tend to increases distribution network stresses under short-circuit load conditions.

Transformer Losses

The two primary types of transformer losses are core losses and load losses. Core losses occur because a magnetizing current must exist in the primary winding of a transformer. This current is additional to 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. Core-losses are present whenever the transformer is energized.

Transformer load losses occur because of current flow in an electrical system and depend on the magnitude of that current. Load losses are caused by the windings in the transformer, and are only present when loaded. The magnitude of losses is proportional to the load squared. The three categories of load losses that occur in transformers are:

- *Resistive losses - often referred to as I2R losses.*
- *Eddy-current losses due to the alternating leakage fluxes*
- *Stray losses in leads, core-framework and tank due to the action of load-dependent stray alternating fluxes.*

Line Losses

In addition to skin-effect and proximity-effect losses discussed on the first page, cables also exhibit the same I2R resistive/heating losses reviewed in the Transformer section above and dielectric losses. However, for single conductor cables, where conductors are not operating close to each other, proximity effect can be considered to be negligible.

Operating together in a typical industrial conduit-enclosed distribution system, these various line loss factors can sufficiently increase the facility electrical distribution wiring's apparent AC resistance to more than an order of magnitude above nominal DC resistance values. As a result, typical I2R wiring losses are often far greater than simple chart-based values. With the above, recall that I2R losses occur in ALL distribution system conducting components, not only the cable.

Eddy-Current Losses

Flux will flow in any electrical system component comprising an iron or steel frame and an electrical coil 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 itself, the induced EMF will cause a circulating electrical current called an eddy-current. Its total magnitude is dependent on the value of EMF and on the resistivity of the current path. As in any other electrical circuit, the losses can be calculated as the square of the current times the resistance. In a similar manner to hysteresis losses, the eddy-current loss manifests itself as heat, and contributes 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 reduction or isolation transformers, current overload relays, control contactors and relays, and motor windings. They can also exist in facility wiring if it is in proximity to steel or iron structures such as electrical enclosures, distribution panels, or terminal or distribution blocks.

Summary

As evidenced throughout this document, necessary components of an electrical system are contributors to energy losses in any facility. Measures can be taken to reduce current and harmonics in many facilities that will help minimize distribution losses and save energy. I2R heating losses in many facilities contribute from 1 - 3% of a facility's overall kW usage. Hysteresis and skin-effect losses are greatly impacted by current harmonics, and in facilities with high harmonic content, can add 1 – 5% to overall facility kW usage. Overall, employing devices such as real-time harmonic and reactive power compensation systems can help a facility reduce their energy consumption.
Further, real-time systems help a facility achieve:

- *Improved voltage stability*
- *Reduced Power Factor penalties (if any)*
- *Reduced kVA demand charges*
- *Increased production thru-put*
- *Lower overall maintenance costs*
- *Reduced electrical-related down-time*
- *Improved utilization of electrical infrastructure*

Useful Formulas

1) Loss Reduction:

$$\%Loss = 100 * \left[1 - \left(\frac{P.F.old}{P.F.new} \right)^2 \right]$$

$$\Delta P = (1 - \%\Delta V)^2 \Leftrightarrow P = \frac{V^2}{R}$$

2) Transformer Losses:

$$P_{LL} = P + P_{EC} + P_{OSL}$$

3) Eddy Current Losses:

$$P_{EC} = P_{EC-R} \sum_{h=1}^{h=\max} \left[\frac{I_h}{I_R} \right]^2 * h^2$$

$$P_{EC-R} = RatedEddy - CurrentLoss$$

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