<Back to Questions>

10. How do harmonics increase power losses and overheat transformers?

Harmonics generated by non-linear loads substantially increase the losses in conventional or K-rated delta-wye distribution transformers. This increase in losses will increase operating costs and can shorten transformer life. The main thrust of the K-rated design is not to lower the increased losses caused by harmonics but rather to withstand them without overheating.

Transformer loss components include no load (P_{NL}) and load losses (P_{LL}). The no load losses are transformer core losses. They depend mainly upon the peak flux levels reached in the core so the increase in no load losses due to harmonics is usually negligible. On the other hand, load losses are significantly increased by harmonic currents created by non-linear loads.

Load losses consist primarily of I^2R copper losses (P_R) and eddy current losses (P_{EC}). Harmonics increase these losses in the following ways:

1. Copper Losses, I^2R
   Harmonic currents are influenced by a phenomenon known as skin effect. Since they are of higher frequency than the fundamental current they tend to flow primarily along the outer edge of a conductor. This reduces the effective cross sectional area of the conductor and increases its resistance. The higher resistance will lead to higher I^2R losses.

2. Eddy Current Losses
   Stray electromagnetic fields will induce circulating currents in a transformer's windings, core and other structural parts. These eddy currents produce losses that increase substantially at the higher harmonic frequencies. The relationship is as follows:

$$P_{EC} = P_{EC-1} \sum_{h=1}^{h_{\max}} I_h^2 h^2$$

Where:
P_{EC} = Total eddy current losses
P_{EC-1} = Eddy current losses at full load based on linear loading only.
I_h = rms current (per unit) at harmonic h
h = harmonic #

For linear loads, eddy currents are a fairly small component of the overall load losses (typically about 5%). With non-linear loads however, they become a much more significant component, sometimes increasing by as much as 15x to 20x. A transformer can easily be subjected to losses exceeding its full load rating even though the RMS value of the non-linear load current indicates only partial loading.

Because Harmonic Mitigating Transformers (HMT) cancel certain harmonic fluxes without coupling them to the primary windings, their primary winding currents are lower than those found on conventional transformers having the same level of non-linear load currents on the secondary side. This means that the I^2R losses and eddy current losses on the primary of an HMT are considerably reduced compared to those in a conventional transformer.

The conventional and k-rated delta-wye transformers have the same level of 3rd, 5th, 7th, and 9th harmonic currents in their primary windings as in their secondaries. Do not be misled by the low level of triplen harmonics in the feeder conductors to a delta-wye transformer. Checking the delta primary winding itself will show that the same percentage of 3rd and 9th harmonic currents (compared to the fundamental current) are circulating in the delta primary as is present on the wye secondary. This increases the losses and voltage distortion on a delta-wye transformer compared to an HMT.

Checking the primary of an HMT will reveal only residual amounts of 3rd and 9th harmonic current. Even better, checking the primary of a dual output HMT (MIRUS Harmony-2 for example) will show only residual amounts of 3rd, 5th, 7th, and 9th. Hence lower harmonic losses and lower voltage distortion when HMTs are used to feed non-linear loads.

References:

1. Thomas S. Key, *Costs and Benefits of Harmonic Current Reduction for Switch-Mode Power Supplies in Commercial Office Building,* IEEE Transactions on Industry Applications, Vol. 32, No. 5 Sept/Oct 1996, pp. 1017-1024
2. ANSI/IEEE C57.110-1986, Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents, American National Standards Institute