<Back to Questions>

13. How do Harmonic Mitigating Transformers reduce voltage distortion?

Delta-wye transformers, even those with a high K-factor rating, generally present high impedance to the flow of harmonic currents created by the non-linear loads. Question 8 showed that the non-linear loads are current sources that push the harmonic currents through the impedances of the system. Any voltage drop across the impedance of the transformer at other than the fundamental frequency (60 Hz) is a component of voltage distortion.

Because of its higher impedance to harmonic currents, the voltage distortion at the output of a delta-wye transformer often reaches the 5% maximum voltage distortion limit recommended by IEEE Std. 519-1992 by the time that the secondary side load has reached just one-half of full-load RMS current. At closer to full-load, these transformers can produce critically high levels of voltage distortion and flat-topping at their outputs and at the downstream loads.

To minimize the voltage distortion rise due to the transformer itself, Harmonic Mitigating Transformers (HMTs) are designed to reduce the impedance seen by the harmonic currents. This is accomplished through zero sequence flux cancellation and through phase shifting - a combined strategy pioneered by MIRUS. The secondary winding configuration of the HMT cancels the zero sequence fluxes (those produced by the 3^{rd}, 9^{th}, 15^{th} (triplen) current harmonics) without coupling them to the primary windings. This prevents the triplen current harmonics from circulating in the primary windings as they do in a delta-wye transformer. The flux cancellation also results in much lower impedance to the zero sequence currents and hence lower voltage distortion at these harmonics. In addition, the reduced primary winding circulating current will lower losses and allow the transformer to run cooler.

The remaining major harmonics (5^{th}, 7^{th}, 11^{th}, 13^{th}, 17^{th} & 19^{th}) are treated to varying degrees through the introduction of phase shifts in the various HMT models.

Single output HMTs are offered in 0° and 30° models to provide upstream cancellation of 5^{th}, 7^{th}, 17^{th} and 19^{th} harmonic currents on the primary feeder.

In a dual output HMT, 5^{th}, 7^{th}, 17^{th} and 19^{th} harmonic current fluxes are cancelled by the 30° phase shift between the secondary windings so that only residual amounts of 5^{th}, 7^{th}, 17^{th}, and 19^{th} current harmonics will be found in the primary side windings.

A three output HMT is configured such that the relative phase shift between the three sets of secondary windings will cancel 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonic fluxes without coupling them to the primary windings.

<Back to Questions>

14. How do Harmonic Mitigating Transformers save energy?

Harmonic Mitigating Transformers save energy by reducing losses in the following ways:

1. Zero phase sequence harmonic fluxes are canceled by the transformers secondary windings. This prevents triplen harmonic currents from being induced into the primary windings where they would circulate. Consequently, primary side I^2R and eddy current losses are reduced.
2. Multiple output HMT's cancel the balanced portion of the 5^{th}, 7^{th} and other harmonics within their secondary windings. Only residual, unbalanced portions of these harmonics will flow through to the primary windings. Again I^2R and eddy current losses are reduced.
3. Many HMT designs are highly efficient at 60Hz as well as at harmonic frequencies. Energy Star compliant models meet NEMA TP-1 energy efficiency minimums at 35% loading. This is typically achieved by reducing core losses to further improve efficiencies under lightly loaded conditions. For optimum energy efficiency performance, Mirus' Energy Star compliant Harmony™ Series HMT's are designed to meet NEMA TP-1 minimum efficiencies not only at 35% but in the entire operating range from 35% to 65%.

Figure 14-1 provides an example of the energy savings that can be realized when HMT's are used in lieu of conventional or K-rated transformers. A K-9 load profile, typical of a high concentration of computer equipment (Ithd = 83%), was selected for the analysis. Losses were calculated for various types of 75 kVA transformers at varying load conditions. In the graph, Conv is a conventional delta-wye transformer, K-13 is a K-13 rated delta-wye and H1E is a Harmony-1E™ single output Energy Star compliant HMT.

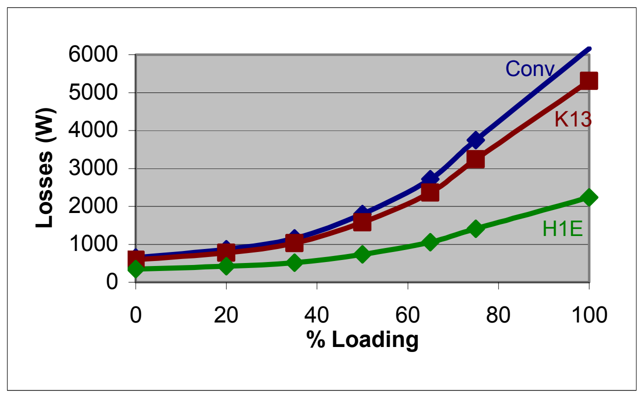

Figure 14-1: 75 kVA Transformer losses at various loading conditions with non-linear K-9 load profile.

The chart shows how energy savings become more and more substantial as a transformer's load increases. This is logical since it is the load losses which are most affected by the harmonic currents and these are proportional to the square of the current (I^2R and I^2h^2).

Figure 14-2 further emphasizes how transformer efficiencies are affected by non-linear loading. It compares the performance of various types of transformers with linear loading (K-1) and non-linear loading (K-9). The efficiencies of the conventional and K-13 transformer are much lower when they are subjected to a load with a K-9 profile, especially under the heavier loading conditions.

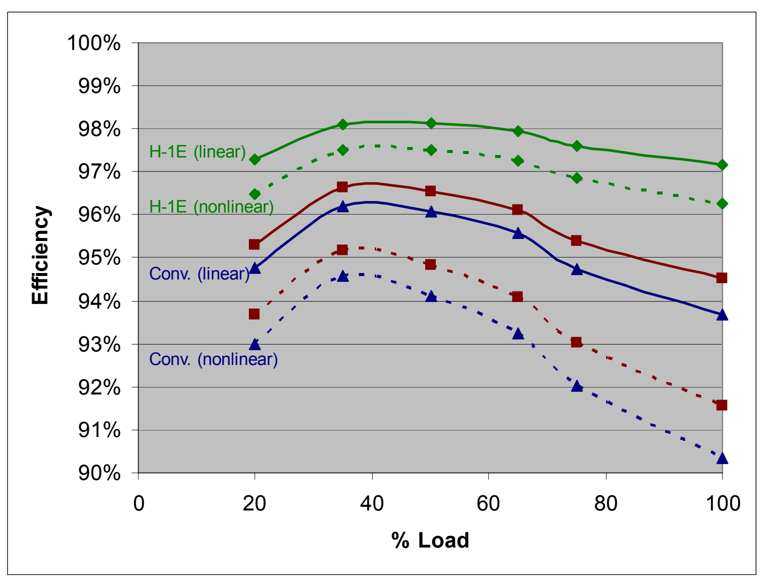

Figure 14-2: Energy Efficiencies for various types of 75 kVA transformers supplying linear (K-1) loads and non-linear (K-9) loads under varying load conditions.

Determining the amount of energy savings associated with a reduction in harmonic losses requires information on the Electric Utility rate and the load's operating profile. These parameters can vary quite substantially depending upon the location of the facility and the specific application. Table 14-1 shows the energy savings that can be realized when a Harmony-1E HMT is compared with a typical K-13 transformer. As in the previous examples, the transformers are 75 kVA and the non-linear load profile is that of a typical K-9 load.

Transformer	% Load	Losses (Watts) NLL	LL	Total	Annual Consumption (kWhrs)	($ / yr)	Transformer Cost (Est.)	Payback on HMT Premium
K-13	35%	590	411	1001	3,866	$365	$2,750	
	50%	590	928	1518	5,478	$518		
	65%	590	1668	2258	7,787	$736		
	100%	590	4445	5035	16,453	$1,555		
Harmony-1E	35%	345	165	510	2,025	$191	$3,530	
	50%	345	373	718	2,674	$253		
	65%	345	671	1016	3,606	$341		
	100%	345	1794	2139	7,109	$672		

Table 14-1: HMT energy savings and payback estimate comparing a 75 kVA HMT to a K-13 transformer in a typical office environment with a high concentration of computer equipment

The monetary savings are based on the equipment operating 12 hours per day, 260 days per year at an average Utility rate of $0.07 per kWhr and assumes that additional cooling energy is required by the building's air conditioning system to remove the heat produced by the transformer losses. The calculation is as follows:

Annual Consumption = (Total losses in kW) x (hrs/day) x (days/yr) + (NL loss in kW) x (24 – hrs/day) x (365 – days/yr))
$/yr Savings = (H1E Annual Consumption – K13 Annual Consumption) x 1.35 x (rate in $/kWhr)

This previous example could be typical of an office environment with a high concentration of computer loads and with the transformer located in air conditioned space. The requirement to cool the heat produced by the transformer's losses is typically 30% to 40% of the power in the losses (thus the 1.35 multiplier in calculation of $/yr Savings). Paybacks were calculated based on estimated transformer costs and would result in recovering the Harmony-1E premium many times over based on the transformer's life expectancy of 30 to 40 years.

Table 14.2 provides another example. In this case, a lower harmonic content K4 load profile was used with the equipment operating 24 hrs/day, 365 days a year and the transformer located in air conditioned space. An example of such a location might be a Broadcasting Facility or Data Center. As can be seen, paybacks are even more attractive.

Transformer	% Load	Losses (Watts) NLL	LL	Total	Annual Consumption (kWhrs)	($ / yr)	Transformer Cost (Est.)	Payback on HMT Premium
K-13	35%	590	367	957	8,381	$792	$2,750	
	50%	590	835	1425	12,482	$1,180		
	65%	590	1508	2098	18,381	$1,737		
	100%	590	4054	4644	40,681	$3,844		
Harmony-1E	35%	345	164	509	4,458	$421	$3,530	2.1 yrs
	50%	345	374	719	6,302	$596		1.3 yrs
	65%	345	678	1023	8,958	$847		0.9 yrs
	100%	345	1827	2172	19,024	$1,798		0.4 yrs

Table 14-2: HMT energy savings and payback estimate comparing a 75 kVA HMT to a K-13 transformer in a typical Broadcasting Facility or Data Center

In summary, the inherent ability of Harmonic Mitigating Transformers to cancel harmonic currents within their windings can result in quantifiable energy savings when compared with the losses that would exist if conventional or K-rated transformers were used. If we consider the average premium cost of an HMT over a K-13 transformer, the typical payback in energy savings is 1 to 4 years when loading is expected to be in the 50% to 65% range.