The Answer to Harmonics: Is It Mitigation or a Robust Transformer?

With its ability to treat both power quality and overheating harmonic concerns, a harmonic mitigating transformer may significantly outperform its K-rated cousin.

When a Chicago banking facility experiences consistent failures of equipment power supplies in one of its critical communications rooms, it considers poor power quality as a potential culprit. However, the 75kVA UPS powering the load should address all the equipment's power quality needs. What's behind this puzzling PQ problem?

The bank calls Charles Andersen of ATA, a local electrical testing company, to monitor the site and find the cause of the equipment failures. Andersen continually monitors the bank's power distribution system over a period of 20 days, but finds no troublesome impulses, surges, sags, or power interruptions. During this investigation, the equipment failures curiously continue. Next, he extensively reviews the grounding system—again, nothing significant. However, he does identify one anomaly during the monitoring process: the voltage downstream of the UPS is severely flattopped, with voltage total harmonic distortion (V_{thd}) consistently above 8%.

To resolve the high-voltage distortion problem, he installs a 75kVA, three-output harmonic mitigating transformer (HMT) downstream of the UPS. By treating the entire spectrum of odd order harmonics (up to and including the 15th), the HMT reduces the current distortion of the load from 65% to less than 10%. The direct result of this

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The Thinking Behind K-Factor Transformers

Harmonics generated by nonlinear loads can cause serious overheating problems in standard distribution transformers. Even under much less than fully loaded conditions, transformers can fail catastrophically. One of the main reasons for this is harmonic currents dramatically increase the eddy current losses in a transformer.

This condition prompted transformer manufacturers to build more robust designs that can tolerate the additional harmonic losses. In the interest of standardization, they adopted a rating scheme known as K-factor. Basically, K-factor reflects the increase in eddy current losses. So a K-rated transformer is one you can load to its full load rating when powering a nonlinear load having a K-factor rating no greater than the transformer's K-rating. Standard K-factor ratings are 4, 9, 13, 20, 30, 40, and 50.

With K-factor transformers, more is not necessarily better. Specifying too high a K-rating will result in an oversized transformer that can introduce problems such as very high inrush currents, excessive fault levels, higher core losses, and a larger footprint. For example, you would need a K-30 transformer only if the load it services is actually a K-30 load (and if you expect the transformer to operate near full load rating).

The use of K-rated transformers has become a popular means of addressing harmonic-related overheating problems where personal computers, telecommunications equipment, broadcasting equipment, and other similar power electronics are in high concentrations. These nonlinear loads generate harmonic currents that can substantially increase transformer losses.

The K-rated transformer has a more rugged design intended to prevent failure due to overheating. Unfortunately, a transformer designed simply to protect itself fails to address the other important problems associated with harmonics. Specifically, to prevent high-voltage distortion levels from adversely affecting the equipment loads, the transformer must be capable of canceling harmonic currents and fluxes within its windings.

current distortion reduction is a dramatic drop in voltage distortion to less than 4%. With the installation of the HMT, power supply failures drop from an average of five per month to less than one. In time, the bank expects this to reduce even further as the residual effect of the long-term exposure to distorted voltage begins to subside.

In another application, a major silicon chip manufacturer uses dual output HMTs to service a test area. Prior to installing the HMTs, consistent equipment failures caused annual repairs totaling $200,000. The improvement in voltage distortion that accompanies the HMT installation virtually eliminates the equipment failure, therefore, the savings

Harmonics Currents Do More Than Overheat Equipment

When servicing a high concentration of nonlinear loads, power distribution systems can experience a wide variety of problems, such as:

- Failure of power factor correction capacitors due to overloading and/or system resonance;
- Overheating of cables, transformers, and other distribution equipment, reducing their life span;
- High-voltage distortion (typically in the form of flattopping), especially when operating on weak sources, such as emergency generators or UPS systems;
- False tripping of breakers;
- Premature failure of rotating equipment (motors, generators, etc.); and
- Misoperation or component failure in PLCs, computers, or other sensitive loads.

Of all the problems listed above, those resulting from high-voltage distortion are often the most severe and generally the most difficult to identify.

Power distribution systems designed with HMTs are capable of servicing any level of nonlinear loading without suffering negative consequences. This should justify more widespread use of the HMT in applications where high concentrations of nonlinear loads are found.

in maintenance costs alone more than justify the HMT purchase.

These two case histories point out the capabilities of this relatively new product. But what exactly is an HMT, and how does it work?

Using HMTs to prevent voltage flattopping. Manufacturers designed HMTs to reduce system voltage distortion in addition to reducing the heating effects caused by the harmonic currents. The equipment does this by canceling load-generated harmonic fluxes and currents within the transformers windings. The benefits of HMTs are numerous:

- You prevent zero sequence harmonic currents, which include the 3rd, 9th, and 15th, from circulating in the primary windings by canceling their fluxes within the secondary windings.
- Single output HMTs are available in two models with differing phase shifts. When paired, these will induce cancellation of 5th, 7th, 17th, and 19th harmonic currents upstream.
- Dual output HMTs phase shift to cancel the balanced portion of 5th, 7th, 17th, and 19th harmonic currents within their secondary windings.
- Three output HMTs phase shift to cancel the balanced portion of 5th, 7th, 11th, and 13th harmonic currents within their secondary windings.
- Reduction of harmonic currents in the primary windings and upstream of the HMT reduces the harmonic voltage drops and distortion the drops produce.
- You also reduce losses because you subject the transformer and upstream distribution equipment to less harmonic current.

This means an HMT will produce significantly less voltage distortion than a conventional or K-rated transformer (see **sidebar**, "The Thinking Behind K-Factor Transformers," on page PQ14) when servicing similar nonlinear loads. In the **table**, on the following page, we compare the performance of various HMT models with a typical K-13 transformer. We also include a simple dual output phase shifting transformer (forked wye), which also finds application as a harmonic canceling transformer. It has dual outputs that are phase shifted by 30° to cancel the balanced 5th and 7th harmonic currents in much the same manner as the dual output HMT. The principal difference from the HMT is in the treatment of the 3rd and other triplen harmonics. Where the HMT prevents these currents from circulating in its primary windings, the forked wye does not. This means voltage distortion at the 3rd harmonic will be just as high as it would be in the K-13 and conventional transformer.

We used computer modeling to determine the voltage distortion that would appear at each transformer's output when servicing a K-13 nonlinear load

How Harmonic Currents Create Voltage Distortion

Why do harmonic currents generated by nonlinear loads create voltage distortion as they pass through the impedance of a power distribution system?

Current, at any frequency, flowing through an impedance will result in a voltage drop in the system at that frequency. This is a simple application of Ohm's Law. The cumulative effect of the voltage drops at each frequency produces voltage distortion.

A common term used to denote the amount of waveform distortion is *total harmonic distortion*, or *THD*. It's expressed in percent. You can apply THD for power systems to both voltage and current. *Voltage* THD (V_{thd}) is the root mean square of all the harmonic voltage drops, or more simply:

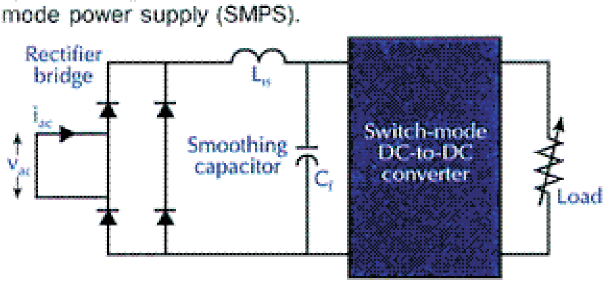
$$V_{thd} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + \ldots}}{V_1} \times 100\%$$

Current distortion is a measure of the combined effect of the various harmonic currents present:

$$I_{thd} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \ldots}}{I_1} \times 100\%$$

Voltage distortion then is a function of both the system impedance and the amount of harmonic current in the system. High system impedance due to long cable runs, high impedance transformers, generators, UPS systems, etc. usually causes high-voltage distortion levels.

You can see the basic relationship between current and voltage distortion by examining the waveforms themselves. The **diagram** below shows a switch-mode power supply (SMPS).



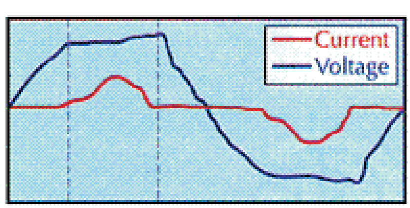
Typical Circuit Diagram of Switch-Mode Power Supply

Voltage Flattopping

Pulsed current creates voltage drop at peak of voltage waveform

Pulsed Current

Switch-mode draws current only while capacitor is charging



This switch-mode power supply (SMPS) is a typical nonlinear load. It draws current only during the peaks of the voltage waveform while charging the smoothing capacitor. As the applied voltage drops during the rest of the cycle, the capacitor discharges to support the load. The pulses of current that recharge the capacitor cause voltage drops, which clip-off or flattop the voltage peaks.

having a *current* THD (I_{thd}) of 88%. As you can see, the HMT transformers produce lower voltage distortion than both the K-13 and the forked wye. The multiple output HMTs achieve the best results, by treating 5th, 7th, and other higher order harmonics in addition to the triplens (3rd, 9th, and 15th).

With this load profile, the K-13 transformer will meet the 5% *voltage* THD (V_{thd}) limit only when loaded to less than 50%. On the other hand, you can fully load the multiple output HMTs without overly distorting the voltage waveform, and load the single output HMT to 75% before exceeding 5% V_{thd}.

This analysis supports the use of multiple output HMTs when you have a distribution system servicing a high concentration of nonlinear loads. This includes computer rooms, call centers, broadcasting studios, telecommunications sites, Internet service providers, and hospitals, to name a few. If you don't expect severe loading, the single output HMT may be enough to prevent problems. In any event, the K-13 transformer isn't a suitable alternative. **EC&M**

	V_{thd} at Transformer Output		
	Full load	75% load	50% load
K-13 transformer	10.5%	7.8%	5.2%
Forked wye	7.9%	5.9%	3.9%
Single output HMT	6.9%	5.2%	3.4%
Dual output HMT	3.8%	2.8%	1.9%
Three output HMT	3.6%	2.7%	1.8%

Listed are comparison performance data of various HMT models, a typical K-13 transformer, and a simple dual output phase shifting transformer (forked wye), which is also finding application as a harmonic canceling transformer. It has dual outputs that are phase shifted by 30° to cancel the balanced 5th and 7th harmonic currents in much the same manner as the dual output HMT.

Suggested Reading

- IEEE Std. 1100-1992, *Recommended Practice for Power and Grounding Sensitive Electronic Equipment*, (The Emerald Book).
- IEEE Std. 519-1992, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.*

For ordering information, call (800) 678-IEEE.

- *Practical Guide to Quality Power for Sensitive Electronic Equipment*, 2nd Edition.

For ordering information, call *EC&M* Books, (800) 543-7771.