Save Energy and Improve Power Quality!

A Case Study – 75 kVA Transformer

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Synopsis

Harmonic generating loads, also known as nonlinear loads, distort the current waveform and can even affect the voltage waveform. These harmonics can create a variety of power quality problems. Harmonics also increase losses in transformers and produce heat that must be removed from the building via the HVAC system.

This paper is a case study where a 75 kVA transformer was replaced with a new, higher-efficiency unit that has a special winding that reduces the effects of these harmonics. The transformer reduces the negative effects of 3^{rd} harmonic currents on the secondary distribution system. This case demonstrates how a new type of transformer can reduce the effects of harmonics and save energy as well.

About the Author

Robert Fuhr graduated with a B.S.E.E. from the University of Wisconsin in 1980. Before graduating, Mr. Fuhr worked for Madison Gas and Electric in Madison, WI and Tennessee Valley Authority in Knoxville, TN.

After graduation, he worked for the General Electric Company from 1980 to 1986 as a Field Engineer, performing commissioning and start up tests on many different types of power distribution equipment.

Mr. Fuhr worked as a Senior Facilities Engineer at the University of Washington from 1986-1989. There he re-commissioned the electrical power distribution system for University Hospital.

In 1986, Mr. Fuhr established Power Systems Engineering (now called PowerStudies, Inc.), a consulting firm that specializes in power systems studies, power quality services, and commissioning services. He also teaches classes in protective relaying, electrical systems, safety, power factor correction, harmonics and filter design. Mr. Fuhr is a Professional Engineer registered in Washington, Oregon, California, and Alaska.

Mr. Fuhr has been actively involved in the Institute of Electrical and Electronic Engineers (IEEE) and the Industrial Applications Society (IAS) since 1986. He served as an officer for the IAS from 1988 to 1992, was the 1991-92 Chairperson of the IAS, and was a Member-at-large for the Seattle Section of the IEEE from 1992-93. Mr. Fuhr is an IEEE Senior Member and a member of the Electric League of the Pacific Northwest.

Harmonic Loads and Their Effect

Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 60 Hz, then the 5th harmonic is five times that frequency, or 300 Hz. Likewise, the 7th harmonic is seven times the fundamental or 420 Hz, and so on for higher order harmonics.

Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 300 Hz on a 60 Hz system. The 5th harmonic current flowing through the system impedance creates a 5th harmonic voltage. Total Harmonic Distortion (THD) expresses the amount of harmonics. The following is the formula for calculating the THD for current:

$$I_{THD} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} x100\%$$

For example...

I_1 = current at 60 Hz = 250 Amps
I_5 = current at 300 Hz = 50 Amps
I_7 = current at 420 Hz = 35 Amps

Then...

$$I_{THD} = \sqrt{\frac{(50^2 + 35^2)}{250}} \quad x \;\; 100 = 24\%$$

When harmonic currents flow in a power system, they are known as poor "power quality" or "dirty power". Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as a steady-state cause of poor power quality.

Devices that draw non-sinusoidal currents when a sinusoidal voltage is applied create harmonics. Frequently these are devices that convert AC to DC. Listed below are some of these devices.

- Adjustable Speed Drives (ASDs)
- DC Drives
- Variable Frequency Drives (VFDs)
- 6-pulse Converters
- Power Rectifiers (e.g., plating systems)
- Uninterruptible Power Supplies (UPSs)

These devices use power electronics like SCRs, diodes, and thyristors, which are a growing percentage of the load in industrial power systems. The majority use a 6-pulse converter.

Most loads which produce harmonics, do so as a steady-state phenomenon. A snapshot reading of an operating load that is suspected to be non-linear can determine if it is producing harmonics.

Normally each load would manifest a specific harmonic spectrum. A switch-mode power supply used for personal computers has a common spectrum – all odd harmonics, with the largest being the 3^{rd}, followed by the 5^{th} and 7th.

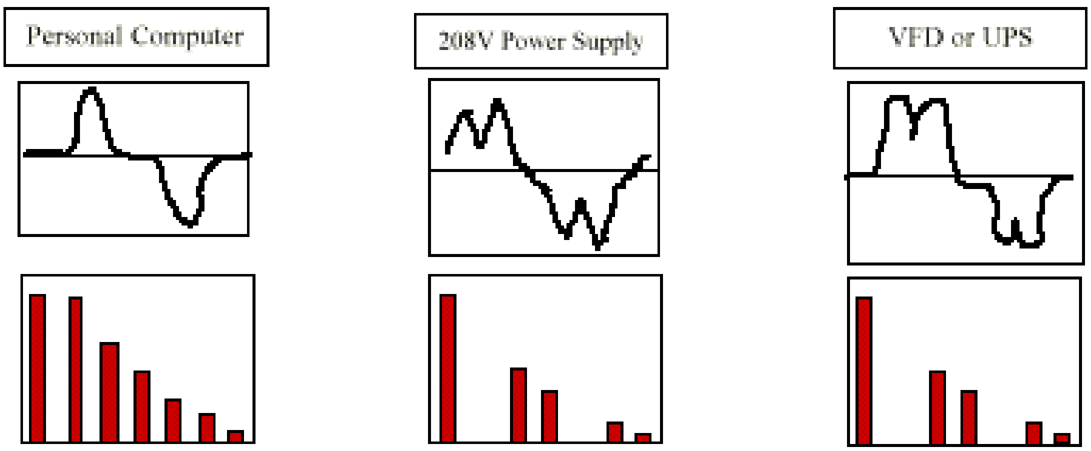
Many problems can arise from harmonic currents in a power system. Some problems are easy to detect; others exist and persist because harmonics are not suspected. Higher RMS current and voltage in the system are caused by harmonic currents, which can result in any of the problems listed below:

- Failed Power Factor Correction Capacitors
- Blown Fuses (no apparent fault)
- Misfiring of AC and DC Drives
- Overheated Transformers
- Tripped Circuit Breakers
- Overheated Conductors
- Voltage distortion
- Overheated conductors
- High neutral currents
- High neutral to ground voltages
- Increased system losses (heat)
- Rotating and electronic equipment failures
- Capacitor bank over-load and failures
- Reduced power factor

Harmonic Loads and Associated Harmonic Current Spectrums

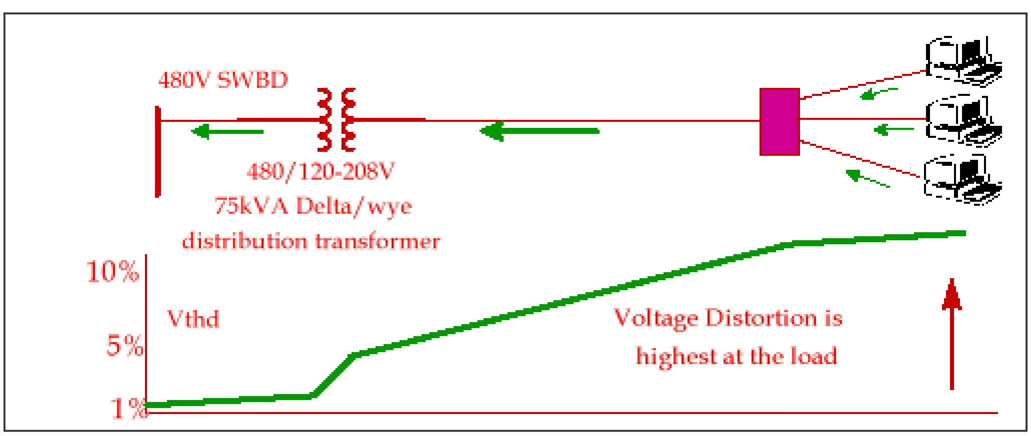
Harmonic current and voltage profiles can be represented by a bar chart. These charts are a visual method of showing the harmonic components making up the total voltage or current. The figures below show various current spectrums for three different types of harmonic loads. Single phase loads tend to have the following characteristics:

- There will be a high range of harmonics (3,5,7,9, & 11)
- The 3rd harmonic will be in-phase in all three phases and will not cancel out in the neutral
- The triplen harmonic (3,9,15,21...) currents will raise the neutral to ground voltage.
- The triplen harmonic (3,9,15,21...) currents will couple and circulate in the primary delta windings of delta-wye transformers causing voltage distortion and losses (heat).



Graph 1 - Current Spectrums for Equipment

Voltage Distortion



Graph 2 - Voltage Distortion from Source to Loads

Voltage distortion and current distortion will be highest where the non linear equipment is connected to the power system. This typically is at the receptacle. Typical voltage distortion levels range from 1-2% at building main services to as high as 15% at the loads. (The figure above illustrates this graphically.) This high voltage distortion can cause equipment failures and mis-operations.

IEEE Standards for Limits of Harmonics

IEEE standard 519-1992 "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems" has suggested limits on the amount of harmonics that a customer or facility should produce. There are important items that are discussed in the article, and they are listed below:

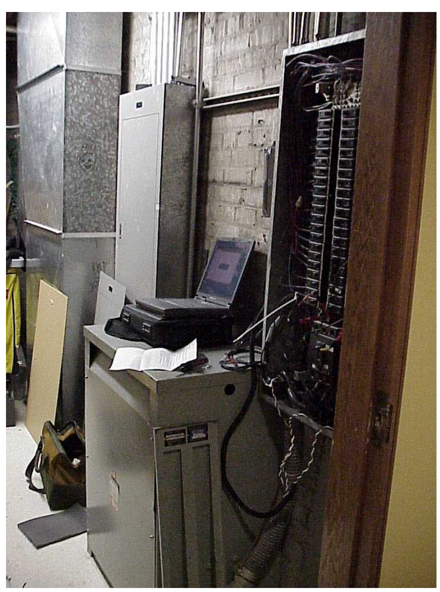
"…power electric equipment is susceptible to mis-operation caused by harmonic distortion.."

"...computers and allied equipment such as programmable controllers frequently require ac sources that have no more than a 5% harmonic voltage distortion factor, with the largest single harmonic being no more than 3% of the fundamental voltage…"

"…critical applications like hospitals and airports should have no more than 3% harmonic voltage distortion…"

Case Study – 75 kVA Transformer

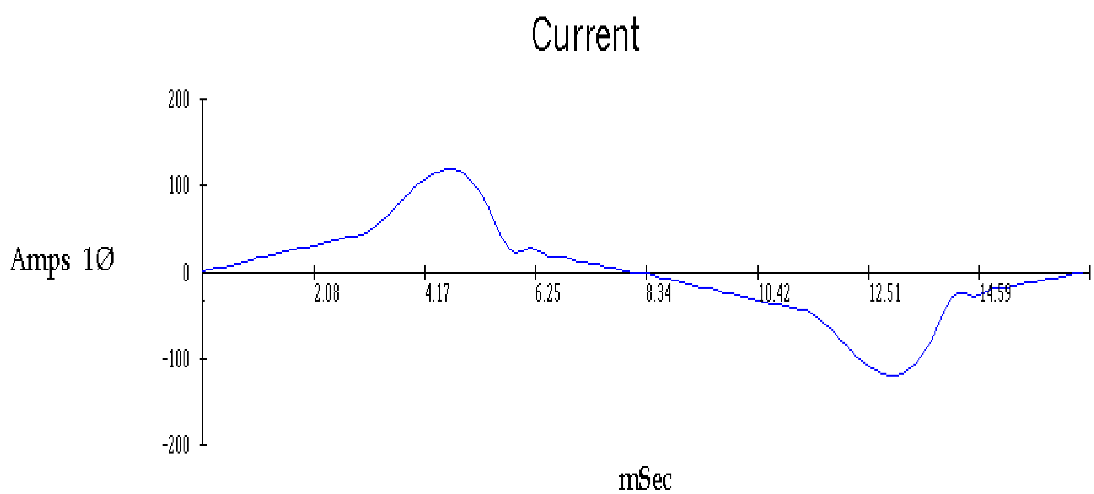
A commercial building in Seattle, WA housed several clients with high computer densities. The electrical room on the 4th floor contained a 75 kVA transformer that was extremely hot. The transformer was so hot that it was difficult to keep your hand on top of the case for more than a few seconds. This transformer heat filled the electrical closet, which in turn was removed by the building Heating Ventilation and Air Conditioning (HVAC) system.

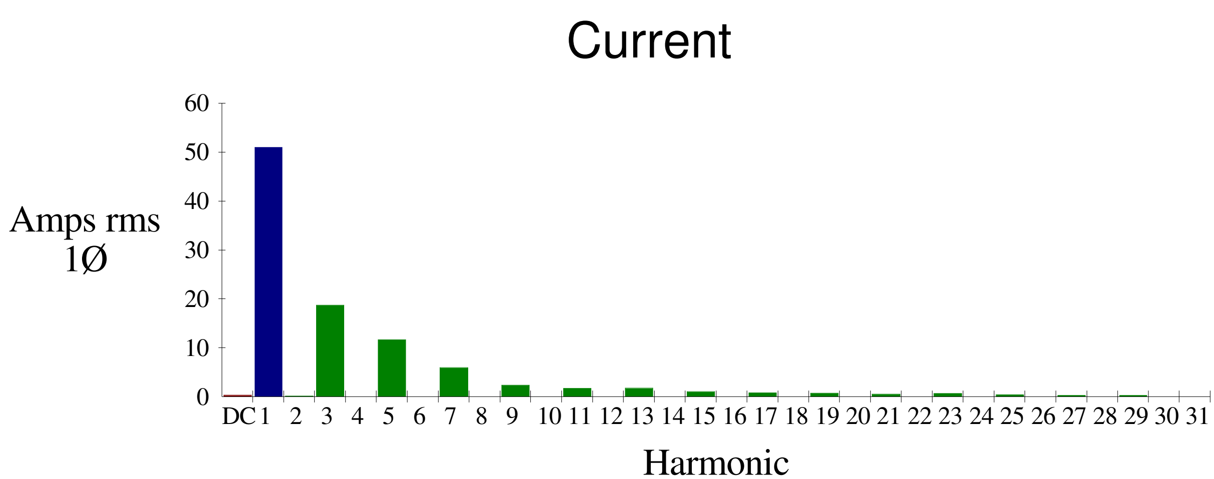


Picture 1 - Electrical Closet, Transformer, and Panelboards

The transformer load was measured in the mid afternoon. The measurements showed that the transformer was only 27% (29 kVA) loaded. However, the current wave shape and spectrum revealed that the content was a mix of linear and nonlinear loads, resulting in current THD of 45%. The measurements showed that the transformer overheating was caused mainly by the 3rd, 5th and 7th harmonic currents generated by the nonlinear loads, with the 3rd harmonic circulating in the transformer primary winding.

Because this conventional delta-wye transformer did not have 3rd harmonic cancellation windings, the voltage distortion on the secondary side of the transformer was 3%. This means that at the loads, the voltage distortion would be greater than 3%, which is above the IEEE recommended value for critical applications.





Graph 3 & 4 - Existing Xfmr Secondary Current Waveform and Harmonic Spectrum

Due to the excessive heating and poor voltage distortion, the owner approved installation of a new 75 kVA, T1000 high-efficiency harmonic canceling transformer manufactured by Powersmiths. This unique transformer incorporates a low zero-sequence impedance* that will cancel the 3rd harmonic (& other triplens) flux in the secondary of the transformer. This cancellation means they no longer circulate in the primary winding. The transformer also uses high quality core steel that further reduces losses and is Energy Star Rated. The transformer will be more efficient (cost less to operate), and cancellation of the 3rd harmonic will improve the secondary voltage distortion. For more information about this transformer, please refer to the Powersmiths web site @ www.powersmiths.com .

After the transformer was replaced with the new T1000 unit, the secondary load was again measured. This second measurement was taken during mid-morning, and the load was slightly lower than previously (20 kVA Vs 28 kVA). The voltage distortion at the transformer secondary dropped substantially, from 3.0% to 1.0%.

Energy Usage

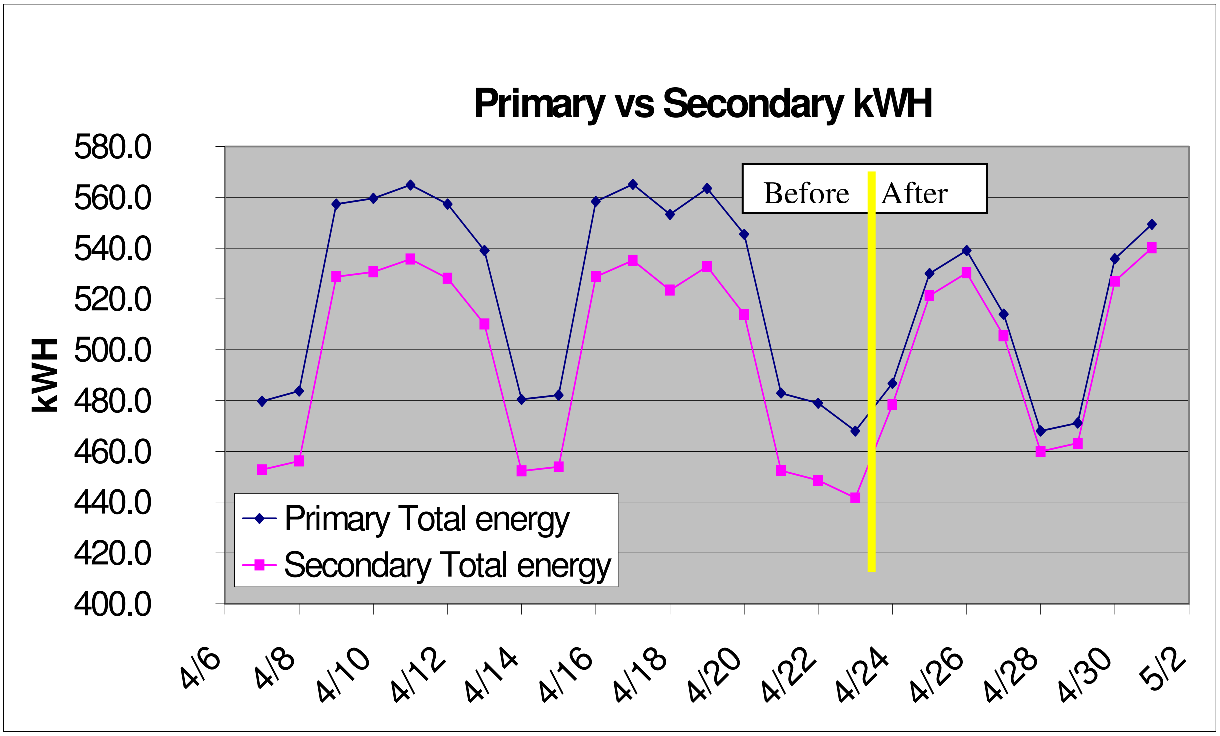
Before the transformer was replaced, we placed a revenue grade kWh meter on both the primary and secondary sides of the transformer. The meters were left connected during the replacement, and they recorded the energy consumption of both the existing and new transformers. Subtracting the secondary readings from the primary readings resulted in the energy (kWh) loss of the transformers.

The graphs below show the kWh losses, efficiency, and cost to operate over time. Each graph shows the values using the original transformer and the replacement transformer. Graph 5 shows the kWh readings for both the primary and the secondary. The efficiency graph (Graph 6) shows a significant reduction after the transformer was changed out. The efficiency rose from 94-95% to 98%. The cost graph (Graph 7) shows the electrical cost for the transformers each day. This graph does not include the cost of energy for heat removal via the HVAC system.

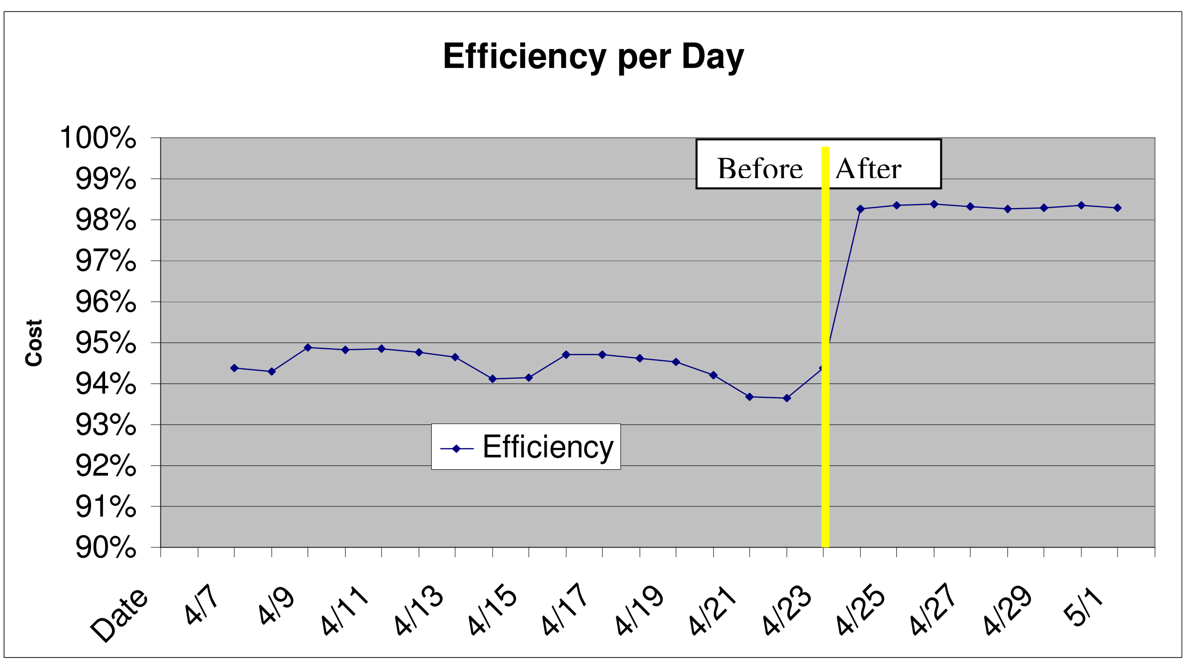
Conclusion

This case study has demonstrated that energy savings can be realized by installing Powersmiths' new high-efficient, harmonic-cancellation transformers. These new transformers reduce the electrical losses and generate less heat that must be removed by the building HVAC system. These transformers also have a special winding that cancels out the 3rd harmonic in the transformer so it no longer circulates in the primary winding. The result is cleaner power and lower operating costs.

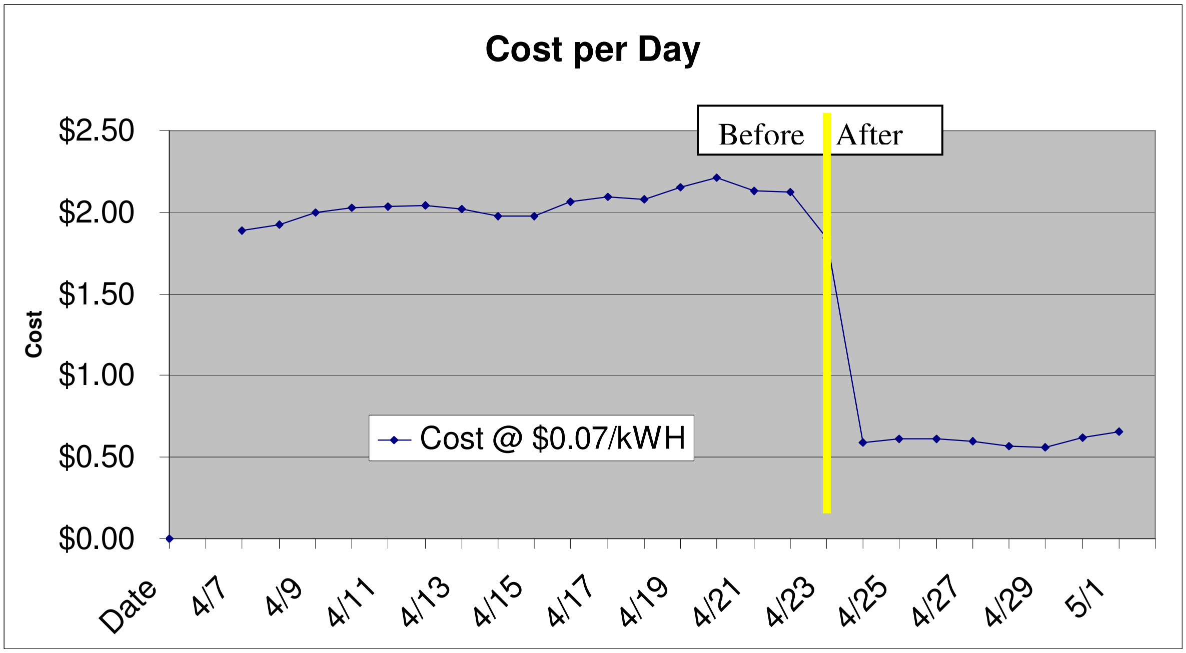
* - The low zero-sequence impedance of these transformers are key to reducing the effects of the harmonics and energy consumption. However, this low impedance can create higher than expected fault currents on the secondary side of the transformer. When using these transformers, the available secondary short circuit current should be compared to the secondary protective device short circuit ratings.



Graph 5 - Primary and Secondary kWH



Graph 6 - Transformer Efficiency



Graph 7 - Transformer Cost