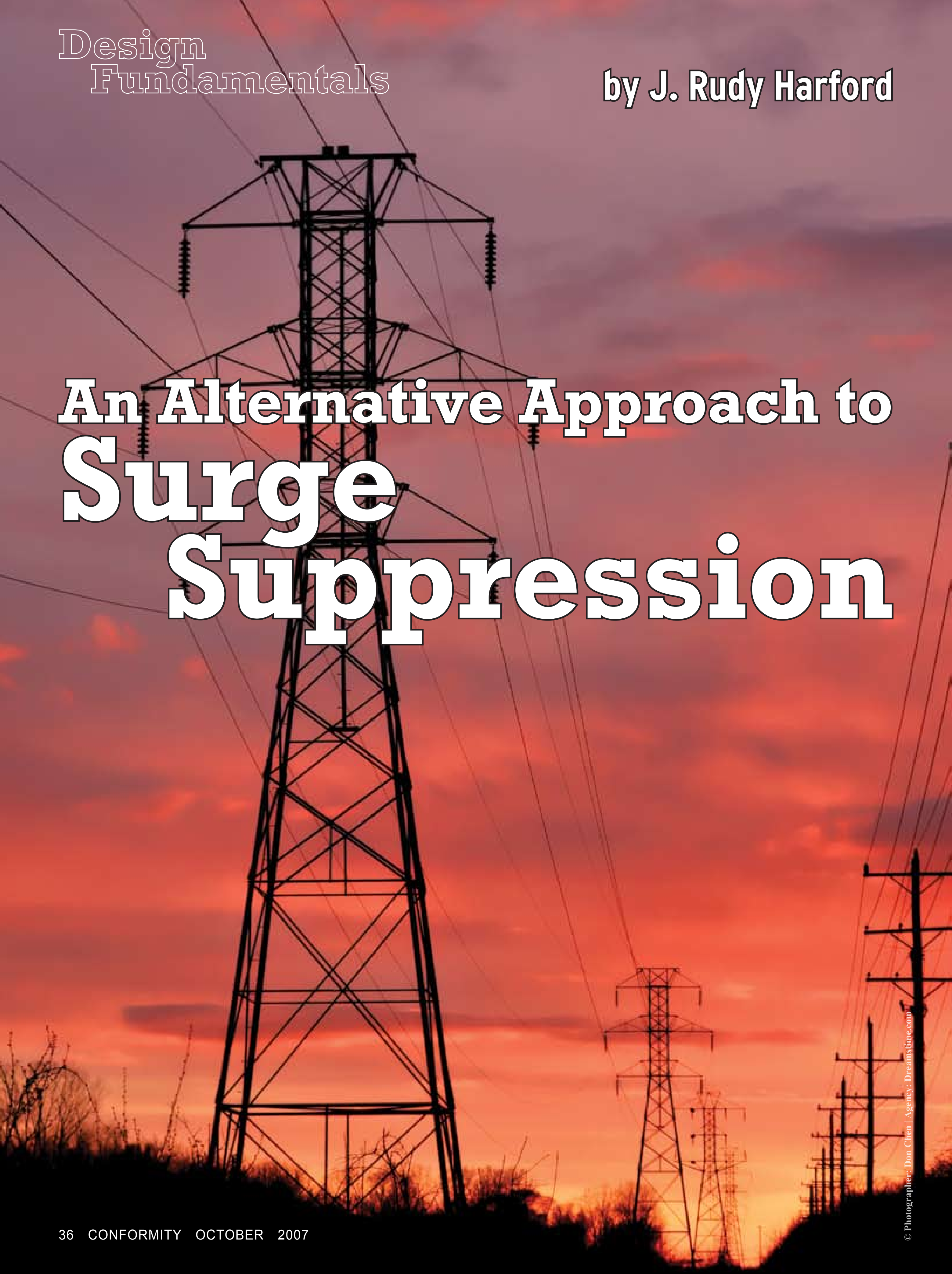
by J. Rudy Harford

An Alternative Approach to Surge Suppression



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UL 1449 "Transient Voltage Surge Suppressors" has been the safety standard for powerline surge suppressors for over 20 years, but changes to the UL1449 standard have opened the door to a viable alternative for surge suppression products.

UL 1449 has recently been significantly revised, and will be introduced as a Third Edition and renamed "Surge Protective Devices." Manufacturers will be required to be in compliance with the changes by October 2009. The focus of UL 1449 Third Edition has been on assuring the safety of products which principally used fixed clamping components such as MOVs (metal oxide varistors) and SADs (silicon avalanche diodes) as their primary surge suppression component.

Since the safety testing assumes that products operate in a shunt mode and have a fixed voltage clamping element, filters which operate in a series mode and do not contain fixed voltage clamping elements, but were previously UL 1449 Listed, would be subjected to tests that are not relevant to determining the safety of the electromagnetic interference filter technology.

As a direct result of many of the new shunt-mode safety tests being directed principally toward fixed clamping component technology, products which suppress surges and noise but use only electromagnetic interference filter technology have necessarily moved away from UL 1449. These products are now certified under UL 1283, since the UL 1449 safety testing is no longer relevant to the electromagnetic interference filter technology, even though a principal function of an electromagnetic interference filter may be to filter off undesirable noise and remove the damaging high frequency surge energy.

The Importance of Surge Suppression

A moment of reflection will show that powerline surges are nothing more than a short burst of high frequency energy, with the dangerous surge frequencies orders of magnitude higher in frequency than the 60 Hz power frequency. Therefore, a well-designed electromagnetic interference filter should be able to remove powerline surges by filtering off the high frequency energy, noting the large frequency separation. Electromagnetic interference filter designs become much simpler for a given desired rejection as the frequency separation increases. Of course, the powerline is a low impedance, high energy environment, which puts special requirements on the design components.

While a basic electromagnetic interference filter can dramatically reduce the surge voltage, modern computing systems have become increasingly sensitive, and are being used in increasingly important applications. For example:

- With so much electronic equipment in operation, it is hard to determine exactly how much surge suppression is required to assure optimum protection of the various systems;
- Every system is no better than the weakest link;
- We know that, if the worst-case surge can be suppressed to a level at or below the power wave peak voltage, downstream equipment will be unaware a surge event occurred, so even the most susceptible products will be protected;
- If surge voltage let-through can be dramatically reduced, there will be no degradation, no disruption, and no damage.

With these issues in mind, the total elimination of dangerous surge energy even with the worst-case surges becomes an important design goal.

Filtering to Achieve Total Surge Cancellation

Since a good electromagnetic interference filter should be able to remove surge energy from the powerline, we undertook to develop a different approach to surge suppression. To assure ourselves we were addressing the worst-case situation, we first consulted IEEE/ANSI C62.41. C62.41 describes locations within a building and anticipated surge dangers at those locations. Although many UL 1449 products have

been characterized as protection for IEEE/ANSI Category A1 locations, these locations are described as being 60 feet or more from the service entrance. We wanted an electromagnetic interference filter that could be placed anywhere within a building, even close to a branch service panel or the main service entrance wiring.

According to C62.41, worst-case surges inside a building (IEEE/ANSI Category B3 locations) could be a pulse as large as 6,000 volts peak, 3,000 amps peak with a half amplitude duration of 50 microseconds. An electromagnetic interference filter designed for this Category B3 location would have to reduce this 6,000 volt pulse to less than 170 volts peak to pull it within the normal dynamic range of 120 Vac power. This level of performance would qualify the electromagnetic interference filter to be used anywhere within the building. A low pass electromagnetic interference filter with 32 dB attenuation could accomplish this task.

Since it is desirable to minimize the electromagnetic interference filter "standby" current, the bulk of the filtering is put within a full wave bridge, which offers several advantages. First, it allows the use of large value electrolytic capacitors, needed to operate at the low impedances required. Second, it also peak rectifies on the power wave, and therefore the bulk of the filtering occurs for voltages (surges and noise) that exceed the power wave peak voltage, without adding significant "standby" current flowing from the normal 60 Hz power (which would otherwise be characteristic of a low impedance filter).

After several months of reviewing various electromagnetic interference filter configurations and parameters for optimum performance, a "Eureka" moment came when we considered the following:

- Many years ago, in the design of an integrated circuit filter, we used phase cancellation to improve a low pass filter design. An anti-phase signal was added to the main signal path to result in significant (20 db) additional rejection of the undesired signals, leading to a significantly more stable integrated circuit.
- Audio cancellation using anti-phase paths for noise reduction is fairly common today. Was it possible to apply the same principles to the power line?

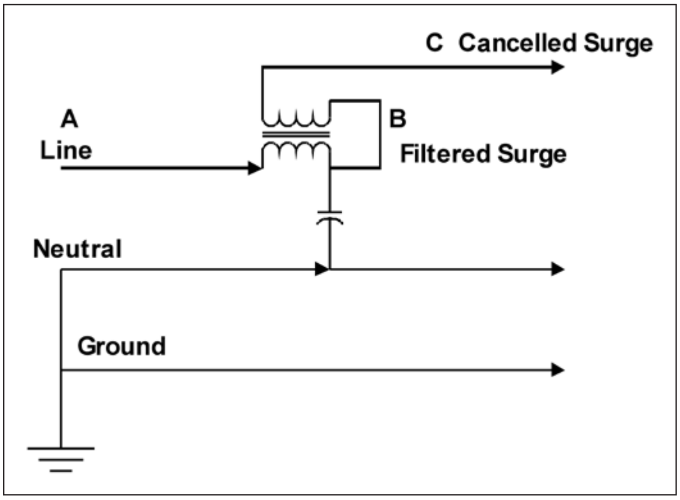

Figure 1

Computer Analysis to the Rescue

Computer analysis showed that the basic low pass filtering removed the dangerous higher frequency components, but there was still a low frequency pulse of about 150 volts above the power wave peak voltage. The issue then became one of deriving a cancelling voltage. The input inductor bears the brunt of the surge voltage and current. Could a cancelling voltage be derived from the input inductor?

We found that, by optimizing the turns ratio, coupling, and damping, the input inductor could be tapped and properly phased to provide a 150 volt cancelling phase voltage for the worst-case surge. Indeed, the residual low frequency pulse could be cancelled to below the power wave peak for even worst-case conditions.

Since computer simulations verified the complete design, we built a sample unit. Optimizing the input inductor to meet the computer design parameters was challenging, but the first samples were fine tuned to perform even better than the computer simulations, since the computer simulations used worst-case design parameters.

As a result, we've engineered what we believe is a different approach to surge suppression, one that removes dangerous surge energy from the downstream protected equipment using practical components. The approach utilizes a low pass electromagnetic interference filter that first filters off the higher surge frequencies. Then, the residual low frequency components are cancelled using well-established phase cancellation principles to provide total surge protection from even the worst-case surge energy. The result is a UL 1283 Listed electromagnetic interference filter that cancels out dangerous surge energy, while also filtering annoying powerline noise.

How Total Surge Cancellation Works

Although the actual circuit is complex, a simplified schematic shown in Figure 1 clearly illustrates the critical functions. (The tapped inductor is shown as an autotransformer, as the function is easier to understand with this configuration.) While functionally described previously in this article, the schematic will clarify the signal flow, as follows:

- A surge enters at point A;
- The tapped cancelling winding immediately begins to develop a cancelling voltage due to the surge current flow in the primary winding;

- The incoming surge voltage is filtered and delayed by the winding primary inductance and the capacitor. Some residual low frequency surge components appear at point B, but are delayed in time due to the filtering action of the input inductance and filter capacitance;
- The canceling voltage from the tapped coil is added to the point B filtered surge, with the resultant surge cancelled voltage sent to the output;
- Adding the cancelling voltage to the delayed residual surge voltage prevents even the residual surge voltage from exceeding the power wave peak voltage, reducing the surge voltage let-through to zero. (See the oscillograms later in this article for performance to worst-case surges).

Since the electromagnetic interference filter uses non-sacrificial filter capacitors and inductors, and no fixed clamping components, we predict that this type of device should have a long service life.

Total Surge Cancellation: Oscillogram Responses at Two Surge Levels

Figures 2, 3 and 4 represent a series of oscillograms showing a brief history of 120 volt AC power quality electromagnetic interference filter surge protection responses for both a reference electromagnetic interference filter (introduced in 2002) and the total surge cancellation filter described in this article.

UL 1449 Second Edition uses a suppressed voltage rating (SVR), with a minimum value of 330 volts established with a 500 ampere peak current surge, for transient voltage surge suppressor performance characterization.

UL 1449 Third Edition performance characterization will use a voltage protection rating (VPR—also with a 330 volt minimum) established with a 3,000 peak ampere surge. Since UL 1449-3 assumes a fixed clamping element(s), the power wave peak voltage may be as high as 132 volts rms or 187 volts peak (multiply the rms value by 1.414 to determine the peak voltage--surges must be evaluated against the power wave peak voltage). With allowances for component tolerances and the dynamic impedance of the clamping components, a 330 volt lower limit as specified in the standard makes technical sense for products using fixed clamping voltage components.

To characterize the performance of a UL 1283 Listed surge suppressing electromagnetic interference filter, we used a surge let-through voltage. The surge let-through voltage is the surge voltage that exceeds the powerline peak voltage. This measurement was used for this technology since the electromagnetic interference filter technology is dynamic, and the technology does not have a fixed voltage clamping element. The actual suppression level "tracks" the incoming power wave voltage, so the protection is optimized independent of the power line voltage. Designs are available that operate from 85 vrms to 265 vrms. This is possible since there are no fixed clamping voltage components to limit the voltage range. However, the filter components must be rated for the highest design voltage.

A 4,000 volt, 2,000 amp surge was applied to the baseline electromagnetic interference filter product for reference. The two horizontal dotted lines shown on each of the oscillograms represent the normal peak positive and peak negative power wave voltage extremes. Any significant surge voltage that exceeded the horizontal dotted lines (surge voltage let-through) could harm down-stream products. At the same time, if either the peak surge voltage let-through or its duration was reduced, the protection would be improved. Likewise, if the surge voltage was contained within the horizontal dotted lines, down stream equipment would be unaffected.

Electromagnetic Interference Filter Surge Protection Performance

Figure 1 illustrates the performance of a reference electromagnetic interference filter. This electromagnetic interference filter had a 100 volt surge voltage let-through pulse lasting only 17 microseconds, a significant improvement in both peak voltage and duration over conventional UL 1449 Listed technologies.

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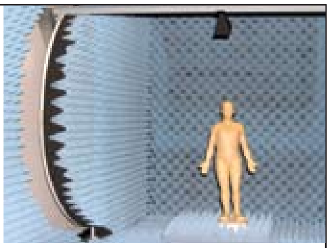

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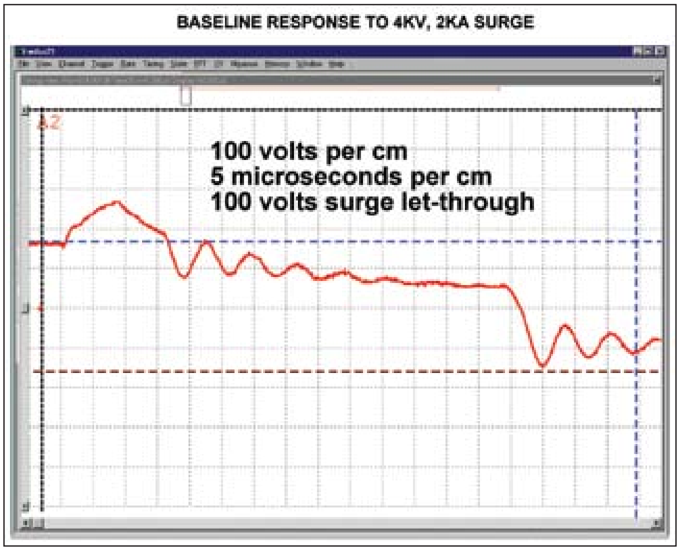

Figure 2: Baseline response to 4KV, 2KA surge

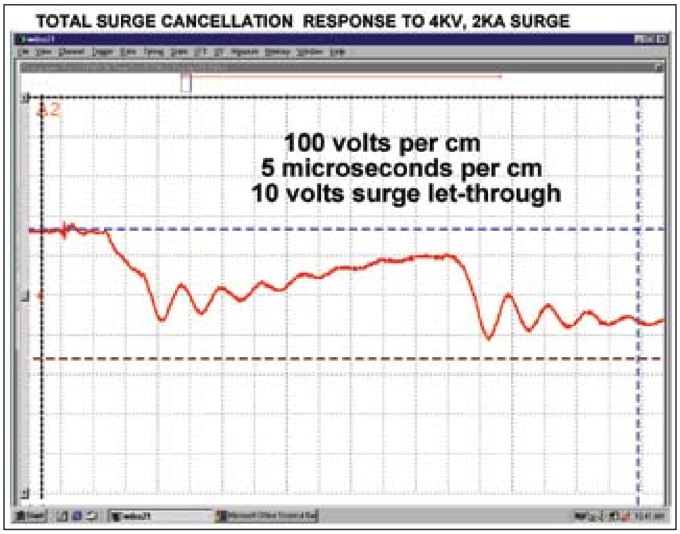

Figure 3: Total surge cancellation response to 4KV, 2KA surge

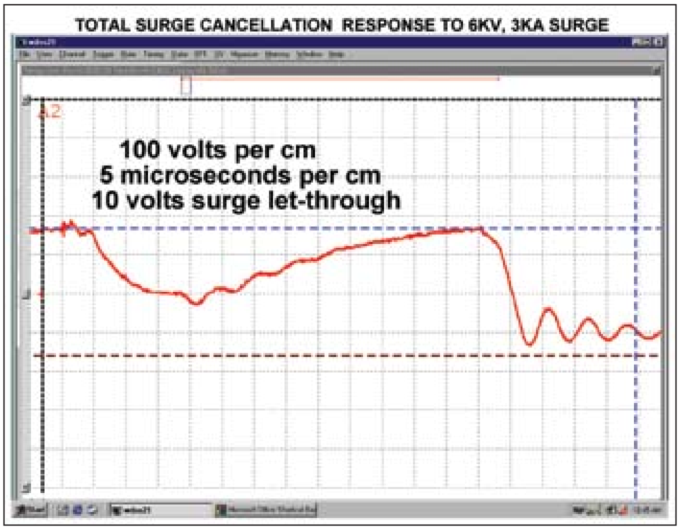

Figure 4: Total surge cancellation response to 6KV, 3KA surge

While the reference electromagnetic interference filter offered a significant improvement over UL 1449 suppressors, the total surge cancellation electromagnetic interference filters had less than a 10 volt surge voltage let-through lasting only 2 microseconds for dangerous surge input levels. Oscillograms of voltage responses at 4,000 volts, 2,000 amps and 6,000 volts, 3,000 amps are shown in Figure 3 and Figure 4. In essence, all the surges applied to the total surge cancellation electromagnetic interference filters were kept within the normal 120 volt ac voltage variations, and any downstream equipment would have been unaffected by any surge.

UL 1449 or UL 1283 Safety Listing?

Both UL 1449 and UL 1283 are safety standards. The safety testing in both documents is similar where wire sizes, temperature rating of components, allowable temperature rise, exposure to anticipated failure modes, etc. are concerned. However, a principle difference between UL 1283 and UL 1449 occurs when tests are applied which evaluate clamping components such as MOVs. These tests are very specific to the components that are representative of the dominant technologies used in the marketplace.

While UL 1449 Third Edition will be the prevailing standard for surge protection devices, certain filters with a UL 1283 Listing may be more effective at removing dangerous surge voltage from protected equipment. The core technology behind some of these filters has a proven long-life expectancy, and such devices can remove both the surge danger and associated noise. Therefore, where vital or sensitive equipment needs the best available protection from surges and noise, such total surge cancellation electromagnetic interference filters may be a better choice than the conventional UL 1449 Listed products. ☐

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Note: The filter described in this article is protected by U.S. Patents: 4,870,528, 4,870,534, 6,728,089, 7,068,487 and 7,184,252.

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