Wide Voltage Range
Surge Protection Break-through

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Introduction

Most powerline surge suppressors use fixed clamping level components and therefore function over a very narrow voltage range (typically +/- 10%), going into thermal run-away for higher voltages and losing effectiveness for lower voltages or brown-out conditions.

Such surge suppressors are generally sacrificial and degrade with use, with very few meeting US Government CID 1,000 surge endurance requirements[1]. In fact, anticipating failure, most of these products come with lights, buzzers, thermal fuses or other circuits to indicate the anticipated failure! A surge suppressor worn out from numerous internal surges loses its ability to protect against larger, more dangerous external surges. This fact is often discovered only when the unit fails, since there is no practical way to determine the life left in such suppressors, or whether they are capable of stopping a dangerous surge!

For important applications, use of sacrificial and obviously failure prone products can only mean undesirable down-time and productivity loss. This productivity loss can greatly exceed the initial cost of more reliable, more effective protection.

New Technology

Zero Surge was asked to develop a supplement to their proven series-mode surge suppression technology that not only was very reliable, effective and safe but that would work over a voltage range of 85 to 265 volts rms with no performance degradation. Were we able to meet these requirements, it became apparent that such a product would be ideal for a wide range of applications and be especially suitable for use under brown-out conditions and with stand-by generators. Stand-by generators used by hospitals and other critical applications can experience brief voltage overshoot during start-up, load changes, and with contaminated fuel. Voltage overshoot will overstress fixed clamping level suppressors, leading to premature and unpredictable failures.

Since many other important applications for a wide voltage range product became evident, we opened a project to develop a suppressor that:

- Would operate effectively over the entire 85 to 265 volt range.
- Was not sacrificial; would not fail for even 1,000 worst case surges.
- Would provide exceptional surge protection for even the most sensitive equipment.
- Would operate effectively under brown-out and voltage overshoot conditions.

Imagine: A single surge suppressor that works equally well at 120 volts, 208 volts and 240 volts rms!

During the development program, eight important elements for effective surge suppression were identified. These eight items are all important and can be applied to all powerline surge suppressors generally.

An important outcome of the development program was a new patent pending technology which addresses all 8 surge suppression elements identified herein, and results in products with uncompromised, unmatched performance and endurance.

Products incorporating this new technology have been in use for over 6 months now, and they have proven to work effectively over the entire powerline voltage range of 85 to 265 Volts. Furthermore, no surge induced degradation is evident after testing to US government CID 1,000 worst case ANSI C62.41 Category B3/C1 surges, assuring at least 10 years of extremely effective protection, truly break-through performance!

Industry Standard Surge

The worst case industry standard surge energy within a building is about 90 Joules[2]. This is less energy than consumed by a 100 watt light bulb turned on for only 1 second.

How can such little surge energy cause so much trouble?

The answer lies in the ***rate*** that the energy arrives (di/dt and dv/dt).

As the rate increases (duration decreases) for a given energy level, the peak power must increase. One key to effective surge suppression therefore is reducing the rate (hence reducing the peak power) of any residual surge energy that is passed on to protected equipment.

Not just "Suppressed Voltage"

- **Damaging surge energy is the product of the surge voltage, surge current and surge duration.**

The surge "suppressed voltage" is most often the only performance parameter offered by many surge protection products, but is just one component of the damaging surge energy! Most suppressors only clamp surge voltage, but do not reduce the surge current and duration.

- **Surge voltage does not cause surge damage!**

Surge damage only occurs if surge current flows for a long enough time!

Since switch-mode power supplies take their power from the power wave peak, and voltage clamping suppressors do not even *begin* to suppress a surge until their clamp voltage is *exceeded*, it becomes obvious that the power supply voltage must climb all the way up to that clamp voltage before suppression begins to take place. Until the clamp voltage is exceeded, **all the available damaging surge current flows into the "protected" power supply!**

By attacking all three principal surge energy components for the most dangerous surges: **surge voltage, surge current and surge duration**, the greatest protection can be achieved.

- A 6,000 volt powerline surge without sufficient current and duration will do absolutely no harm!

New testing procedures were developed to evaluate this technology since simple no-load "suppressed voltage" or "let-through voltage" tests as commonly used were found to be incomplete and totally inadequate for characterizing a surge suppressor with comprehensive suppression technology.

The 8 Surge protection elements

This paper identifies and addresses the 8 elements of effective surge protection:

1. Surge voltage slew rate (dv/dt) limiting.
2. Surge current slew rate (di/dt) limiting.
3. Peak let-through voltage limiting.
4. Peak let-through current limiting.
5. Surge duration limiting (surge inversion).
6. Dynamic surge energy sensing.
7. Dynamic surge voltage clamping and inversion.
8. 1,000 surge endurance for worst case surges.

Unlike fixed voltage clamping elements, dynamic sensing and dynamic suppression results in no performance compromises with powerline voltage variations or clamping component voltage tolerances. Sensing and suppression occur as soon as a surge exceeds the power wave peak voltage, (zero threshold) independent of the actual powerline rms voltage, resulting in optimum protection for all relevant voltages.

Worst surges

Industry standards indicate that a worst case 90 Joule surge, consisting of 3,000 Amperes short circuit current, 6,000 Volts open circuit voltage with a short-circuit current duration of 20 microseconds can be expected within a building[3]. Matched impedance power from this surge would be 1,500 amperes x 3,000 Volts, or 4.5 million watts.

A sample shunt-mode MOV (Metal Oxide Varistor) with a nominal clamping onset level of 200 volts at 1 milliampere does not offer a matched impedance, and would dissipate about 600 Volts x 3,000 Amperes, for a dissipation of 1.8 million watts.

This 1.8 million watts applied to a component the size of a nickel often results in an internal “hot spot” where melting and re-crystallization takes place, forever altering the affected component. Occasionally the “hot spot” not only melts, but vaporizes and the vapor pressure actually explodes the MOV.

90 Joules applied to the same component at a much slower rate of 9 watts for 10 seconds would result in no melting or component degradation, showing the importance of controlling the rate of applied energy.

WVR™ Block diagram

This new Wide Voltage Range (WVR™) technology uses reliable linear and non-linear filter concepts and consists of several building blocks:

1. A high voltage, high current linear input inductor is used to provide surge current limiting, control di/dt and offer a controlled input impedance for carrier current environments.
2. A filter capacitor works in conjunction with the input inductor to provide low pass filter noise filtering for noise and surges within the power wave voltage envelope.
3. A bridge rectifier functioning as a peak detector detects surges which exceed the power wave peak voltage.
4. A peak detecting capacitor associated with the bridge rectifier limits the surge peak voltage, controls dv/dt and integrates the incoming surge energy for subsequent signal processing.
5. A multiple section filter is connected to the peak detector with the bandwidth and thresholds set to sense dangerous surge energy levels.
6. Once the filter circuit determines a surge is potentially dangerous, a surge inverter activates at a pre-determined safe incremental voltage level to actually invert the surge and bring it below the power wave voltage peak, rendering the rest of the surge benign.

All the above components are chosen to operate within their safe surge ratings for at least 1,000 surges, so no performance degradation takes place, assuring the designs can exceed the US government CID 1,000 surge endurance requirements.

No thermal fuses, alarm circuits or other “catastrophic failure” fuses are required since no sac-

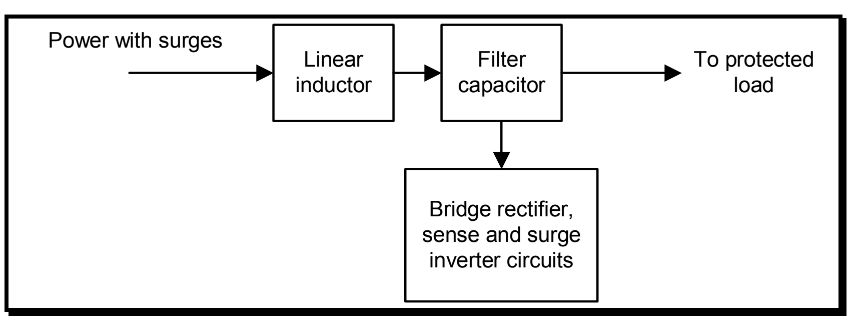

Figure 1 WVR™ Simplified Block Diagram

rificial components are used. The risk of surge suppressor failure down-time is therefore eliminated. This technology has no known surge related failure mechanisms.

How it works

See Figure 1, WVR™ simplified block diagram. The incoming surge first encounters the linear air-core inductor (choke). Inductors augmented with magnetic materials are avoided since such inductors tend to "saturate" at the higher currents, just when the inductance is most required. Since an inductor has the property of inhibiting higher frequencies more than lower frequencies, the most dangerous, fastest surge components are most severely restricted. This inductor must be designed to handle the large surge current linearly and high voltage without breaking down.

For small surges and noise within the power wave voltage envelope, the inductor works in conjunction with a first filter capacitor in a low pass filter configuration to attenuate surges and noise above 5 kHz, with 26 dB minimum attenuation typical at 100 kHz.

Incoming surges which exceed the power wave peak voltage must overcome the much larger capacitor within the diode bridge (see the waveforms in Appendix A1). The capacitor within the bridge integrates the incoming surge voltage, controlling the peak let-through voltage, dv/dt, and offering a measurement of the residual surge energy ($1/2C\Delta V^2$) passing through the inductor. A very large dv/dt developed across this large capacitor indicates a large surge.

A signal from the capacitor is fed to the sense circuits, and should the signal pass through the selective filter indicating a large surge is present, the surge inverter activates. This effectively eliminates the surge.

We can therefore see that the circuit acts to reduce di/dt, reduce the peak surge current, reduce dv/dt, reduce peak surge voltage and also reduce surge duration, attacking ALL dangerous surge energy components. The actual surge energy reduction level achieved is entirely up to the designer by choice of the component values. The waveforms in the Appendix show examples of performance available from practical production products.

Although some of the parts used for higher voltage operation at 265 Volts rms are more expensive than those for 120 Volts, there is no inherent voltage sensitivity to performance, and the circuits work just as effectively during brownout conditions, and even over the entire 85 Volts rms to 265 Volts rms powerline voltage range, as shown by the responses in Appendix A3.

Power supply diode	**No protection**	**Shunt clamp**	**WVR™ System**
Peak current through diode (Amps)	2,200	750	180
Peak voltage across diode (Amps)	100	32	5
Peak power in diode	220,000	24,000	900
dv/dt	4,000 V/us	4,000 V/us- 24 V/us	4 V/us
di/dt	360 A/us	50 A/us	7 A/us
Power supply input			
Peak surge voltage	1,130	410	210
Peak surge current (Amps)	2,200	750	180

Performance Testing
Since Zero Surge WVR™ products limit surge current and duration in addition to surge voltage, and common peak "Suppressed Voltage" tests do not account for these important improvements, Zero Surge testing necessarily is much more comprehensive.

To measure surge suppression effectiveness, testing is done with a load similar to a 250 watt switch-mode power supply, since these power supplies are very common, are essentially peak detectors and take their power in "gulps" from the peak of the power wave, making them particularly susceptible to surges which exceed the power wave peak voltage.

The 250 watt test supply uses an NTC inrush current limiter thermistor with a 0.1 ohm "on" resistance, and 2 uh normal mode parasitic inductance.

To determine the effectiveness of a surge suppression technology, we monitor the current, voltage, voltage drop across the test power supply rectifier diode (one of the first components to be stressed by the surge), power dissipated in the rectifier diode, input dv/dt, and input di/dt to the test supply.

APPENDIX A1
Appendix A1 shows the voltage response at the input to our test 250 watt power supply, for a 6,000 Volt 3,000 Amp Category B3 surge.

No Protection
Peak voltage above power wave: 950 Volts
dv/dt: 4,000 volts per microsecond

Shunt Protection
Peak voltage above power wave: 240 Volts
dv/dt: initially 4,000 volts per microsecond, then 24 volts per microsecond.

WVR™ Protection
Peak voltage above power wave: 50 volts.
dv/dt: 4 volts per microsecond.

APPENDIX A2
Appendix A2 shows the current response into our test 250 watt power supply, for the same 6,000 Volt, 3,000 Amp Category B3 surge.

No Protection
Peak input surge current: 2,200 Amps.
di/dt: 360 amps per microsecond.

Shunt Protection
Peak input surge current: 750 Amps.
di/dt: 50 amps per microsecond.

WVR™ Protection
Peak input surge current: 180 Amps.
di/dt: 7 amps per microsecond.

Appendix A3
Appendix A3 shows the surge performance for 85 volts rms, 120 volts rms and 265 volts rms. Dv/dt, incremental surge voltage rise, and surge inversion are virtually identical, showing the performance is unaffected by the actual rms voltage. With no inherent voltage limitation (no fixed clamping components), products not only perform well under brown-out condition, but work equally well for 120, 208, and 240 volts rms.

Comparative protection
When compared to no protection at all, shunt mode protection offers considerable improvement for a ANSI C62.41 Category B3 (6kV, 3kA) surge, reducing the peak power dissipated in the input diode from 220,000 watts to 24,000 watts, nearly a 10 to 1 improvement! But 24,000 watts in a small rectifier diode is still likely to be destructive.

The WVR™ system reduces this peak power to only 900 watts, a 240 times improvement over no protection and a 27 times improvement over shunt protection!

When you realize that semiconductors have a sharp threshold for damage, we must protect a wide range of products of varying loads and sensitivities, and that powerline voltage can vary considerably, the improvement offered by the WVR™ technology is dramatic.

Further compounding the surge protection situation generally is the ever decreasing low voltages and low noise voltage thresholds being used by computer ICs, making surge and noise protection more critical to reliable operation.

Audio and video products have even lower noise susceptibility thresholds and greatly benefit from this new technology. Except for some models developed for ship-board applications, the technology operates in Mode 1 (no ground wire surge contamination), eliminating this source of noise.

Summary

A new surge suppression technology has been described. This technology was developed to eliminate several deficiencies found in most conventional powerline surge suppressors.

Most 120 VAC MOV based suppressors:

Voltage range: 108-132 volts rms- thermal runaway above 132 volts.

Endurance: Sacrificial nature of the MOVs limits endurance to relatively few worst case surges. There is no practical way to determine the remaining life of a worn suppressor. Very few have been certified to 1,000 surge endurance.

Suppression: Voltage clamping, with clamping onset fixed at a level well above the nominal power wave peak voltage to prevent thermal runaway over normal voltage ranges. This high clamping level onset reduces suppressor effectiveness for lower powerline voltages.

Catastrophic shut-down:
Various shut-down circuits (fuses, thermal cutouts) are required for safety reasons. These remove power from the "protected" equipment when the suppressor fails, leading to "protected" equipment down-time.

WVR™ technology:

Voltage range: 85-265 volts. No thermal runaway, as fixed clamping is not used.

Endurance: 1,000 worst case (6kV, 3kA) surges, certified by an independent lab. No sacrificial components. At least 10 year life even in worst-case surge environments.

Suppression: Voltage limiting with zero voltage threshold, current limiting, surge inversion, di/dt reduction, dv/dt reduction.

Catastrophic shut-down: Not needed; 1,000 surge endurance. "Protected" equipment has minimum "down time".

Testing

Common "Suppressed Voltage" testing is incomplete for testing this new technology since important surge suppression parameters such as current limiting, surge inversion, di/dt reduction and dv/dt reduction, all factors which can contribute to surge induced degradation and damage, are ignored. A "test" power supply which has the input characteristics of a switch-mode power supply was incorporated into the design and testing phase of the project so relative improvements can be accurately gauged for real world situations. By testing for, and minimizing all elements of a surge, performance and endurance levels have been established that should make this technology the technology of choice for most critical applications.

References:

[1] US government CID A-A-55818 (commercial surge suppressor purchase specification- can be downloaded from www.zerosurge.com).

[2] ANSI C62.41 defines a Category B3,C1 surge which has a matched impedance energy of 3,000 Volts x 1,500 Amps x 20 microseconds = 90 Joules (watt seconds).

[3] ANSI C62.41 defines a Category B3,C1 surge as 6,000 Volts open circuit, 50 microseconds duration, 3,000 Amps short circuit current, 20 microseconds duration.