

Multiple Protection Devices Guard Against Transients

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Several devices are available to suppress transients that occur in power electronic systems. By employing the appropriate devices, the suppression system can protect the entire power system against transients on ac and dc lines.

The rate of transient occurrences varies with every power system. Recent studies show that surges of 1kV or less are common—whereas 3kV surges are rare. Protecting against more frequent (internally produced) transients provides a likely return in terms of improved system performance, yet higher-level transients are potentially more costly in terms of damage. Fig. 1 depicts results of a study on building power system transient occurrences.

current flow. One such risk determination model is:

$$E = \int V_C I dt$$

where:

E = Transient energy

I = Peak transient current

V_C = Resulting clamping voltage

t = Time

τ = Impulse duration of the transient

You can divide the energy profile contained in a transient according to the impedance of the transient suppressor and the line on which it is traveling. A realistic assumption of the transient's source impedance ensures adequate surge handling capability. The surge suppressor must handle the current passed through it by the surge source. An assumption of too high an impedance may not subject it to sufficient stresses, while the assumption of too low an impedance may subject it to unrealistically large stress.

Table 1, on page 56, aids selection of surge suppressor protection levels. All indoor low-voltage ac power systems have an inherent protection system built into the wiring of the building (wiring systems used in 120V to 240V systems have a natural sparkover level of 6000V). This 6kV level was selected as the worst-case cutoff for the occurrence of transients in the indoor power system. The transient generated by sparkover (causing a low impedance path by exceeding the device's voltage rating) creates a high energy, low impedance pulse. The further away from the source of the transient the protected equipment is located, the more the energy is absorbed in the wiring impedance and the more the equipment is protected. This allows different size suppressors to be used at different locations in the system.

For example, using the graph shown in Fig. 1, on page 55, the investigation into the indoor low-voltage system encountered transients with oscillatory waveshapes in the 5 kHz to more than 500-kHz range, with 100 kHz being most

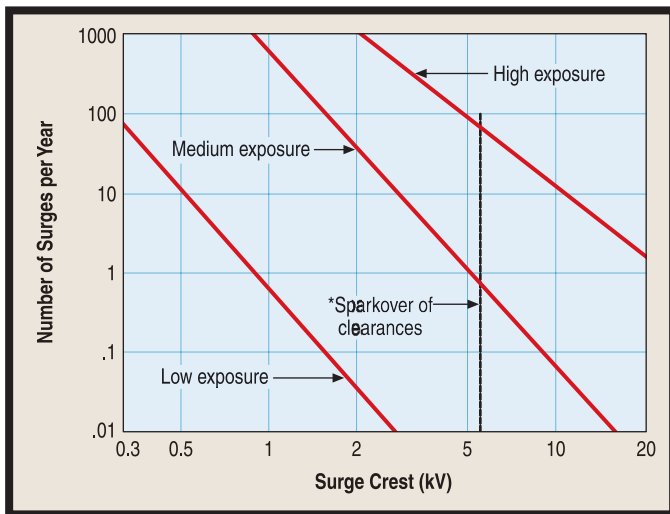
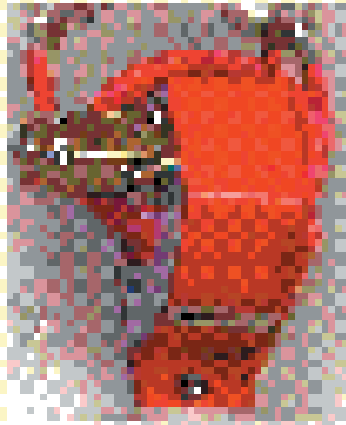


Fig. 1. Rate of transient occurrences vs. voltage level at unprotected locations. *Note: In some locations, sparkover of clearances may limit the overvoltages.

Transients due to inductive load switching and commutation voltage spikes are easy to suppress because their energy content is “known.” Externally generated and intermittent transients (such as high level ESD) are more difficult to identify, measure, and suppress. All must be weighted on the basis of destructive energy potential defined by their peak voltage, follow-on current, and time duration of

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Transient Protection

| Location Cat. Center | Comparable to IEC 644 Cat. | Impulse | | Specimen Type or Load Circuit | Joules deposited in suppressor with Clamping Voltage | |
|--------------------------------------------------------------|-------------------------------|------------------|----------------------------|----------------------------------|---------------------------------------------------------|-------------|
| | | Waveform | Med. Exposure Amplitude | | 500V | 1000V |
| Long branch circuits/offsets | II | 0.5µs to 100 kHz | 6kV | High Imp. *(1) | (120V Sys.) | (240V Sys.) |
| | | - | 200A | Low Imp. **(2) | 0.8 | 1.6 |
| Major feeders short branch circuits and load center | III | 1.2/50µs | 6kV | High Imp. (1) | - | - |
| | | 8/20µs | 3kA | Low Imp. (2) | 40 | 80 |
| | | 0.5µs to 100 kHz | 6kV | High Imp. (1) | - | - |
| | | - | 500A | Low Imp. | 2 | 4 |

Table 1. Surge voltages and currents deemed to represent the indoor environment and recommended for use in designing protective systems. *(1) For high-impedance test units or load circuits, the voltage shown represents the surge voltage. When conducting simulation tests, use that value for the open-circuit voltage of the test generator. **(2) For low-impedance test units or load circuits, the current shown represents the discharge current of the surge (not the short-circuit current of the system). When conducting simulation tests, use that current for the short-circuit current of the test generator.

common. The “lightning surge” has been established as 1.2/50µs voltage wave and 8/20µs current wave. Here, the TVS specifier should consider systems that provide a protection profile for long branch and outlet style circuits to protect against a 0.5µs 100 kHz, 6kV/200A level impulse. Also,

protection should be from a 1.2/50µs 100 kHz, 6kV/3kA level impulse for major feeders and short branch circuits. (The “1.2” of 1.2/50µs and “8” of the 8/20µs are waveform rise times. The voltage wave has a rise time of 1.2µs and a fall time of 50µs; for the 8/20 it’s a 8µs rise and a 20µs fall).

| V-1 Characteristics | Device type | Leakage | Follow on 1 | Clamping voltage | Energy Capability | Capacitance | Response time | Cost |
|----------------------------------------------------------|---------------------------------|-------------|--------------------------|-------------------------------------|-------------------|------------------|---------------|-------------|
| Clamping voltage Working voltage Transient current | Ideal device | Zero to low | No | Low | High | Low or high | Fast | Low |
| Working voltage | Zinc oxide varistor | Low | No | Moderate to low | High | Moderate to high | Fast | Low |
| Max I limit Working voltage | Zener | Low | No | Low | Low | Low | Fast | Hlgh |
| Peak voltage (ignition) Working voltage | Crowbar (Zener-SCR combination) | Low | Yes (Latching holding 1) | Low | Medium | Low | Fast | Moderate |
| Peak voltage (ignition) Working voltage | Spark gap | Zero | Yes | High ignition voltage low clamp | High | Low | Slow | Low to high |
| Peak voltage (ignition) Working voltage | Triggered spark gap | Zero | Yes | Lower ignition voltage low clamp | Hlgh | Low | Moderate | Moderate |
| Working voltage | Selenium | Very high | No | Moderate to high | Moderate to high | High | Fast | High |
| Working voltage | Silicon carbide varistor | High | No | High | Hlgh | High | Fast | Low |

Table 2. Transient voltage suppressor characteristics.

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Transient Protection

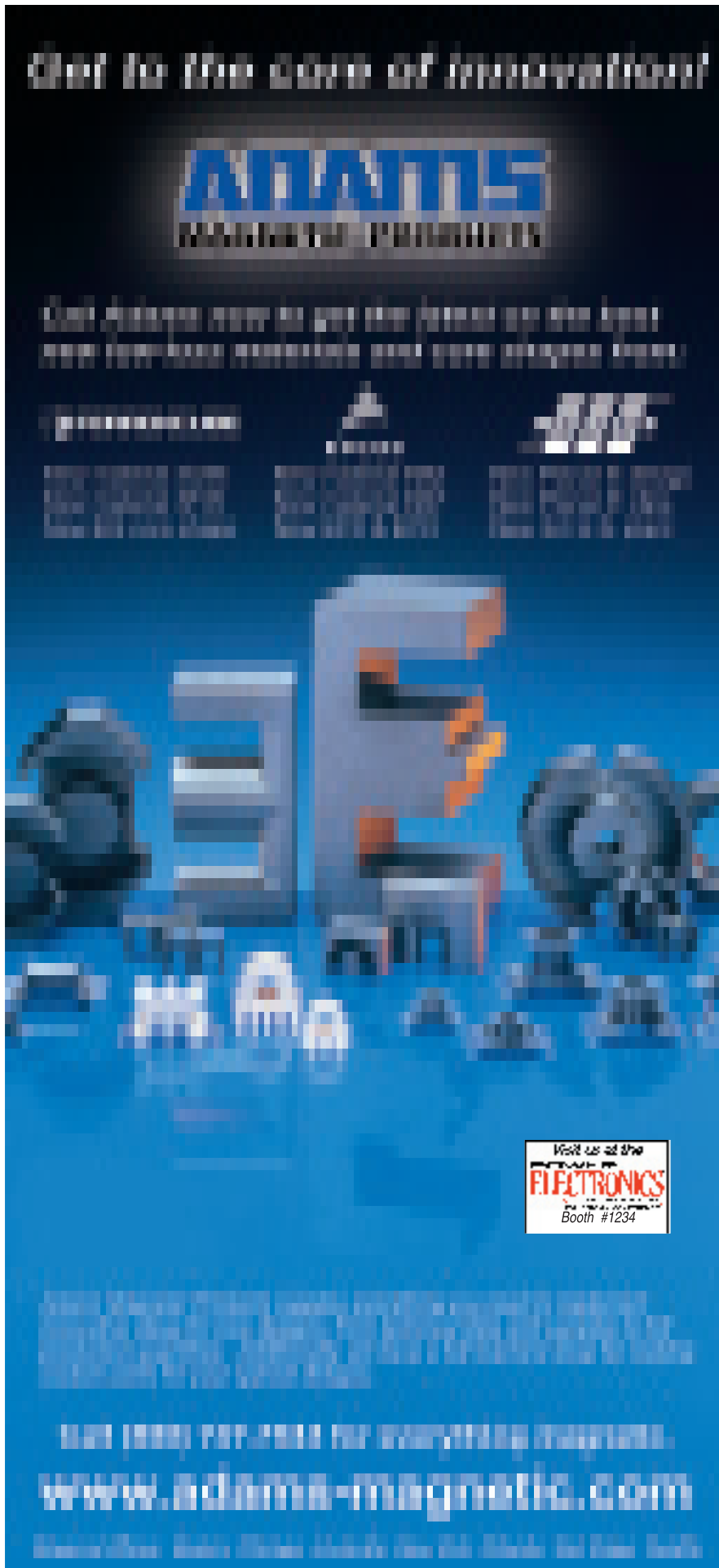
After creating the general power system transient suppression specification, the next step is to decide what protection technology to use and how to use it. Select a TVS that can suppress surges to levels below the failure threshold of the protected equipment; the suppressor must survive a definite number of worst-case transients. When comparing available devices, consider the required characteristics, such as protection levels, component survivability, cost, and size. Also, a number of agency requirements, such as UL1449 and 1020, require a TVS to be protected from potential short circuit from causes such as sustained overvoltage (caused by a loss of neutral connection). See the sidebar, on page 64, for a transient suppressor comparison.

Several technologies are available for use as a transient suppressor in the low-voltage ac mains system. Generally, you can group them into two categories:

- Those that attenuate transients, preventing their propagation into the sensitive circuit; and
- Those that divert transients away from sensitive loads and so limit the residual voltage.

By placing either filters or isolating transformers in series within a circuit, you can attenuate a transient, keeping it from propagating away from its source or from impinging on a sensitive load. The isolator attenuates the high frequency transient and allows the signal or low frequency power flow to continue undisturbed.

You can also divert the transient with a crowbar or a voltage-clamping device. A crowbar device involves a switching action—either the breakdown of a gas between electrodes or the turn on of a thyristor. After switching on, they offer a very low impedance path that diverts the transient away from the parallel-connected load. Clamping devices have a varying impedance that depends on the current flowing through the device or on the voltage across the terminals. These devices exhibit a nonlinear



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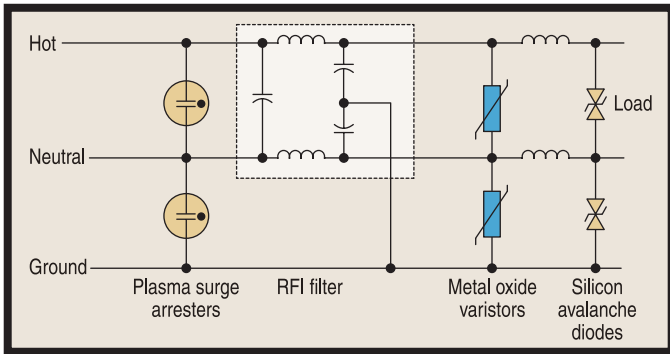


Fig. 2. Hybrid transient protection circuit.

impedance characteristic. The variation of the impedance is monotonic; that is, it doesn't contain discontinuities in contrast to the crowbar device, which exhibits a turn on action. Because of a diversity of characteristics and nonstandard manufacturer specifications, transient suppressors aren't easy to compare. Among many other factors, it is necessary to know the device energy-absorption and peak-current capabilities when comparisons are made. Table 2, on page 56, includes other important parameters of commonly used suppressors.

Besides the criteria noted in Table 2, the power consumed by the suppressor unit at normal line voltage is an impor-

tant selection criterion. Peak standby current is one factor that determines the standby power of a suppressor. Though certain devices have low standby power at the nominal design voltage, a small line-voltage rise can cause a dramatic increase in the standby power. For example, in a zener-diode based suppressor, a 10% increase above rated voltage increases the standby power dissipation above its rating by a factor of 30. But for a less reactive device, such as silicon carbide, the standby power increases by only 1.5 times.

From a designer's point of view, surge suppressor component selection accounts for the base technology strengths and weaknesses outlined in Table 2, plus a variety of environmental, performance, and trade-off issues such as:

- Maximum system rms voltage.
- How will the suppressor be used in the TVS circuit?
- Component sizing (e.g. selecting the suppressor with a working voltage 10% to 25% above system operating voltage).
- Worst-case transient energy suppressor must absorb.
- Clamping voltage required for system protection.

Hybrid Protection Schemes

An ideal surge protector overcomes the current handling and energy diverting characteristics of the crowbar with the speed of the clamp-type device. Fig. 2 shows a typical

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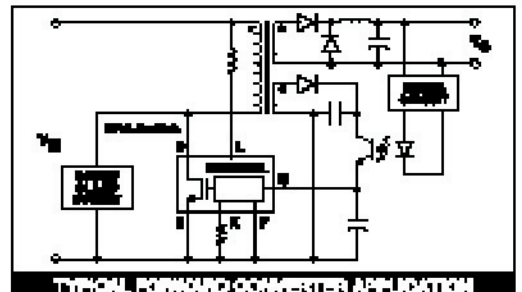
- Eliminates 20-30 external components—saves space, cost
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- Eliminates all external current sensing circuitry
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- Pin selectable 300/400 kHz fixed frequency
- Wide input (line) voltage range: 18-75 VDC

| OUTPUT POWER TABLE | | | | | | |
|--------------------------|-------|------|-------|------|------|-------------------|
| 18-75 VDC INPUT RANGE | | | | | | |
| Total Device Dissipation | 0.5 W | 1 W | 2.5 W | 4 W | 8 W | Max. Power Output |
| PN6001 | | | | | | |
| DPW32R | 12 W | 18 W | — | — | — | 18 W |
| DPW36R | 15 W | 23 W | 30 W | — | — | 30 W |
| DPW42R | 23 W | 32 W | 50 W | 63 W | — | 70 W |
| DPW42R | 23 W | 35 W | 55 W | 70 W | 83 W | 100 W |

Note: Data based on 18 V and 20 V minimum input and for Pulse and Steady-State.



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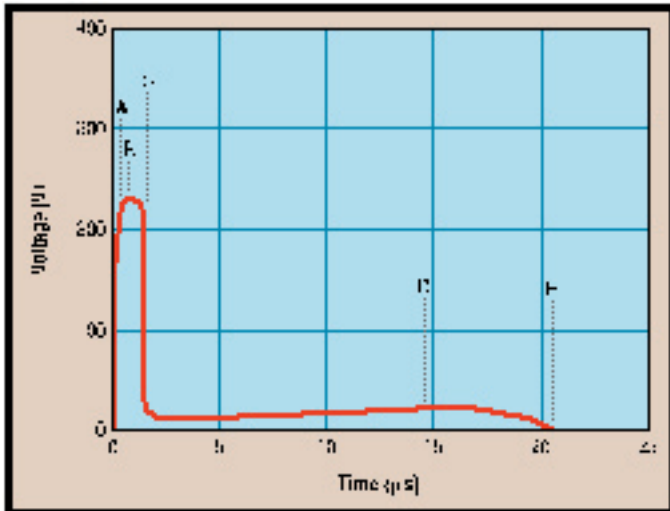


Fig. 3. Transient response time of hybrid circuit.

installation that is a three-stage hybrid circuit consisting of a gas tube surge arrester as the primary protector, a metal oxide varistor (MOV) as the secondary protector, and a silicon avalanche diode (SAD) as the tertiary protection. These elements must be separated by an isolating impedance that is resistive (>10W) or inductive (>0.1mH) to ensure proper coordination of the protective devices. Most ac applications

use an inductive element to minimize power dissipation and voltage drop during normal operation. The inductor used in this example is part of the EMI filter already required by the design. Fig. 3 illustrates the output of the protection circuit during a transient.

In a gas-tube arrester, the low impedance of the arc after sparkover causes dissipation of most of the energy elsewhere, for example, in a power-following, current-limiting resistor added in series with its gap.

A voltage clamping suppressor, such as an MOV, must absorb a large amount of transient surge energy. Its clamping action does not involve the power-follow energy resulting from a gap's short-circuit action.

The letters below correspond to Fig. 3, which depicts the sequence of events for the transient suppression:

A. The SAD clamps the leading edge of the transient to a value just above the normal operating voltage.

B. As the transient voltage continues to rise, it enters the operating range of an MOV sized with a peak current handling capability higher than the SAD.

C. As the current through the MOV increases, a voltage develops across the inductor, which causes the gas tube surge arrester to fire, shunting the transient's energy through the gas tube surge arrester and away from the protected circuit.

D. The gas tube surge arrester remains in full conduction for the duration of the transient.

E. After the transient passes, the gas tube surge arrester extinguishes—ready for the next transient.

This circuit uses each component to do what each does best: The gas tube surge arrester diverts the high-energy portion of the transient, the MOV provides intermediate power handling and protection of the SAD, which accomplishes accurate clamping of the low-energy leading edge.

The following factors enhance the cost effectiveness of this protection circuit:

1. Use of an ac line gas tube surge arrester eliminates the need for additional components to ensure turnoff.
2. An existing component (EMI filter) supplies the isolating impedance.
3. It uses a small diameter MOV because the gas tube surge arrester handles the highest-energy portion of the transient.
4. It uses a small avalanche diode cluster because the MOV dissipates the transient's energy level, protecting the SAD from potential overexposure and self-destruction.
5. The SAD begins reacting to the transient within 5ns vs. approximately 25ns before the MOV could respond, improving overall transient response time.
6. The hybrid design begins to reduce the excess transient energy at a lower voltage than the MOV by approximately 15% to 20%, subjecting the circuit to less total transient overvoltage.
7. The secondary protection MOV matrix activates as

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Transient Suppressor Comparison

Filters installed in series with equipment is one solution to overvoltage conditions. The impedance of a low pass filter (a capacitor) forms a voltage divider with the source impedance. As the frequency components of a transient are several orders of magnitude above the power frequency of the ac circuit, the inclusion of the filter attenuates high frequency transients. Unfortunately, this simple approach may have some undesirable side effects: unwanted resonances with inductive components located elsewhere in the system leading to high voltage peaks, high inrush currents during switching, and excessive reactive load on the power system voltage. You can reduce these problems by adding a series resistor—hence, the use of RC snubber networks.

Isolation transformers usually have an electrostatic shield between their primary and secondary windings. It provides isolation from transients when placed between the source and the equipment requiring protection. No transient conduction path is between primary and secondary windings. A widely held belief is that isolation transformers attenuate voltage spikes and that transients do not pass through the transformer windings. When properly applied, an isolation transformer prevents ground loops by blocking common-mode voltages. However, a simple isolation transformer provides no differential-mode attenuation, so a differential-mode transient will pass through its windings.

Spark gaps and gas tubes are crowbar devices that change from an insulator to an almost ideal conductor during an overvoltage. In a non-conducting mode, the impedance of the gas is in the gigaohms region with the gas set to ionize at a predetermined voltage that provides an extremely low impedance path to ground. After removing the overvoltage condition the gas deionizes and the circuit restores itself to its normal operating condition. Gas tubes have typical dc firing voltages between 150V and 1000V. They have the smallest shunt resistance of all nonlinear transient suppressors, typically in the milliohm range. Their capacitance is low—between 1pF and 5pF. An advantage of this technology is its ability to handle large currents (up to 20kA).

Selenium transient suppressors apply the technology of selenium rectifiers in a special process that allows reverse breakdown current at high energy levels without damage to the polycrystalline structure. These cells employ rectifier elements on the surface of a metal plate substrate, which gives them good thermal mass and energy dissipation performance. Some have self-healing characteristics that allow it to survive energy discharges in excess of the rated values for a limited number of operations, characteristics that are useful, if not “legal” in the unsure world of voltage transients. Selenium cells, however, do not have the clamping ability of the more modern MOVs or avalanche diodes. Consequently, their application is diminished.

Silicon carbide varistors were the most common type of “varistor” before MOVs. Made from specially processed silicon carbide, they handle high-power, high-voltage surge arrester applications. However, the relatively low impedance values of this material produce one of two results. Either the protective level is too high for a device capable

of withstanding line voltage or, for a device producing an acceptable protective level, excessive standby current would be drawn at normal voltage if directly connected across the line. Therefore, they require a series gap to block the normal voltage.

Silicon avalanche diodes find use in both low-voltage dc applications and in higher voltage ac mains protection. Avalanche diodes have a wider junction than a standard zener diode, which gives them a greater ability than a zener to dissipate energy. Avalanche diodes offer the tightest clamping voltage of available ac protection devices. Applying a voltage greater than the device breakdown, the diode conducts in the reverse direction. Diode data sheets usually give a peak pulse power rating. Common values are 600W and 1500W. This peak pulse power is the product of the maximum peak pulse current, I_{pp} , and the maximum clamping voltage, V_C , at a current of I_{pp} during a 10/1000 μ s transient duration. The avalanche diode has an excellent clamping voltage capability, but only over a small range of current (one decade). The biggest disadvantage to using the avalanche diode as a transient suppressor on an ac mains line is its low peak current handling capability.

Metal oxide varistors (MOVs) are nonlinear devices that have the property of maintaining a relatively small voltage change across its terminals while a disproportionately large surge current flows through it. This nonlinear action allows the MOV to divert the current of a surge when connected in parallel across a line and hold the voltage to a value that protects the equipment connected to that line. Since the voltage across the MOV is held at some level higher than the normal line voltage while surge current flows, there is energy deposited in the varistor during its surge diversion function. When exposed to surges, the MOV's zinc oxide material exhibits a “bulk action” characteristic, permitting it to conduct large amounts of current without damage. MOVs are cost and size effective, are widely available, and do not have a significant amount of overshoot. They have no follow-on current and their response time is often sufficient for the types of transients encountered in the ac mains environment. Subjecting an MOV to continuous abnormal voltage conditions rather than short duration transients may cause the MOV to go into thermal runaway, resulting in overheating, smoke, and potentially fire. To prevent this condition, many modern MOVs include an internal thermal fuse or thermal cut-off (TCO) device. Some even extend this capability with an internal indicator that provides a logic output if the device's thermal protection is engaged.

Surge fuses protect the surge suppression component from overcurrent protection. Specially designed, they provide a failsafe capability beyond the current rating of the device. As opposed to a standard current fuse, they can be configured to trigger if the TVS component's rated surge current handling is exceeded in the industry standard test pattern of an 8/20 μ s waveform, representing the variable pulsed energy as might be received in an actual lightning-induced surge. Fuses are typically mated to specific surge devices and can be used as a one-to-one protection scheme or in a one-to-many configuration.

the transient energy approaches the level at which the SADs cannot operate safely, greatly increasing the surge rating (kA) of the circuit and protecting the SADs from overcurrent exposure.

8. The potential exists for extending MOV life cycles,

particularly in situations where it may be exposed to constant overvoltage cycles that may put the MOV into a thermal overload state.

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