MOV or SASD — Which Surge Suppressor is Right for You?

By Kenneth J. Brown, Leviton Manufacturing Co., Chula Vista, Calif., and Mark McGranaghan, Electrote Power Quality, Dec 1, 2001

Damage from transient overvoltages is one of the leading causes of equipment failure. Although some pieces of equipment may come equipped with transient protection, others will need some form of external protection. Surge protection devices (SPDs), or transient voltage surge suppressors (TVSSs), fulfill that need. In this article, we'll discuss the causes and characteristics of transient overvoltages and focus on two types of clamping devices: metal-oxide varistors (MOVs) and silicon avalanche suppression diodes (SASDs).

When people hear the term “transient overvoltages,” lightning usually comes to mind. A lightning stroke is a transient current with a rise time ranging from 1 µs to 10 µs and a subsequent decay lasting hundreds of microseconds. The current can have peak values from a few kiloamps to 200 kA.

When a lightning current hits a power line, it's conducted to ground through a surge arrester or a flashover on the power system. The current flowing through the system's line and ground impedance causes a high-voltage transient (rise time of a few microseconds and a tail of tens of microseconds). This transient couples through transformers and can excite natural resonances within low-voltage systems, which results in transient voltages that look significantly different than the original lightning transient (see Fig. 1).

Lightning isn't the only cause of transients. In fact, other causes are much more frequent and equally damaging to sensitive electronic equipment. Any switching operation can result in transient voltages. Here are a few examples:

- Switching capacitor banks on the utility supply system or within a facility. When a capacitor is energized, the initial step change in the voltage can couple through transformers and cause high-frequency transients in a facility.
- Line and cable switching. This can be important when a circuit is reenergized after an interruption. The circuit-switching operation causes oscillations and traveling waves that couple through the transformer into a facility.
- Motor- and load-switching operations within a facility. Any switching operation that causes an abrupt change in current will cause a corresponding transient because of the inductive characteristic of the system impedance (L di/dt transient). Important transient voltages can even result from the normal operation of electronic equipment, such as power supplies.

It's important to provide some type of protection so that these normal switching operations and lightning transients don't cause sensitive electronic equipment to fail.

Protection for Transients
SPDs or TVSSs are used to limit the voltage at protected equipment during transient conditions. These pieces of equipment employ several methods to suppress high-energy voltage transients. Filtering uses capacitive and inductive elements to reduce noise and assist a clamping device.

Most TVSS devices use clamping elements to limit the transient-voltage magnitude. In some surge suppressors, clamping elements can be combined with filtering components for more complete protection (see Fig. 2).

Since most of the surge current is diverted to ground, it's important that your facility has a good, low-resistance grounding system. This system should include a single ground-reference point that connects the grounds of multiple building systems.

It is sometimes possible to protect equipment by applying a SPD at the service entrance. A service-entrance SPD provides the first line of defense against electrical transients by diverting high-energy, outside surges to ground. This may be sufficient because the equipment may be able to handle the reduced transients that result at the actual equipment locations. In addition, a properly applied service-entrance SPD means surge suppressors installed closer to the load can have lower energy ratings.

There are many types of clamping devices available. The two most common are MOVs and SASDs. Let's take a closer look at some of their characteristics.

**Metal-Oxide Varistors**

MOVs are bipolar, ceramic semiconductor devices designed to sense and limit transient voltage surges. The term varistor is a generic name for voltage-variable resistor. The resistance of an MOV is nonlinear and decreases as voltage magnitude increases.

The distinguishing feature of a zinc oxide varistor is its exponential variation of current over a narrow range of applied voltage (see Fig. 3). Within the useful varistor voltage range, the voltage-current relationship is approximated by the expression $I = AV^a$, where:

- $I$ = the current in amperes, $V$ = the voltage, $A$ = a material constant, and $^a$ = an exponent defining the degree of nonlinearity.

Varistors have a maximum continuous operating voltage (MCOV) rating, which indicates the maximum voltage the device is expected to see. The MCOV represents the active nonlinear region of the MOV, generally referred to as the “knee” of the curve (see Fig. 3).

When applying MOVs, it's very important to provide some margin between the MCOV and the actual maximum system operating voltage. The most common cause of MOV failures is high steady-state voltages that cause the MOV to operate in the conducting region and then eventually fail due to thermal overloading.

One advantage to using MOVs is their relatively large surge-current and energy ratings. When SPDs are functioning in the active region, they divert energy by conducting current to ground or neutral and absorbing energy by converting it to heat.

Given a properly designed SPD, a 40 mm MOV can generally withstand several $8 \times 20 \mu$s standard impulses at 10 kA (with little, if any, change in characteristics). Most MOV manufacturers will rate a
40 mm MOV’s surge-current level at 40 kA.

In parallel-connected MOV circuits, the surge current is distributed through each of the MOVs, which results in an improved circuit with higher surge-current capability. You can achieve a similar effect in an SASD circuit, but at a higher cost.

**Silicon Avalanche Suppression Diodes**

SASDs operate in a similar manner to MOVs. Instead of metal oxide, this type of surge suppressor uses a silicon-based diode, similar to a zener diode. SASDs are inherently unidirectional. Therefore, two SASD devices in a back-to-back configuration are required to clamp AC voltages.

SASDs have some characteristics that can be advantageous in comparison to MOVs. Most important, they have a sharper bend in the curve around the breakdown voltage. As a result, they can be specified to clamp closer to the normal peak voltage of the AC waveform.

For most equipment connected to the AC power system, this isn't a significant advantage because the surge-withstand capability of the equipment is well above the protection levels of MOVs. However, this advantage may be important when protecting data lines and other sensitive electronic equipment at the low-voltage level, where the transient voltage magnitude may be more critical.

The response time is another difference between SASDs and MOVs. Generally, SASD response times are faster: 1 ps to 10 ps, compared to 1 ns to 10 ns for MOVs.

This may be important for surge suppression on electronic circuit boards with sensitive components and high-frequency signals, but it doesn't provide any advantage for applications within a facility or on the power system.

The characteristics of the power system and a facility's wiring limit the rise times of transients to hundreds of nanoseconds, which is well within the range for MOVs to provide instantaneous protection.

Two standards (the IEEE C62.41 standard and the IEC 61000-4-5 standard) specify a 1.2 × 50 µs test wave to represent the surges that can enter facilities as a result of lightning transients. For fast rise times — where the characteristics of the surge suppressor could be an issue — the effect of voltage differences across short lead lengths (inductance of the lead) can be much more important than the response time of the actual surge-suppression device.

**Summary**

Transient overvoltages can be caused by external disturbances, such as lightning, or a wide variety of system and load-switching operations. Sensitive equipment should be protected by appropriate TVSSs. High-frequency transients can be coupled through transformers so it is important to provide transient protection at each voltage level within a facility (see Fig. 4, on page 15).

TVSSs can include series elements to block transients, filtering to handle a transient's high-frequency components, and clamping devices to limit the peak voltage magnitude.

In general, MOVs provide the most cost-effective means of limiting the transient voltage magnitude. SASDs are typically not needed for AC mains applications, but they can be very useful for protection in...
high-speed data transmission or low-voltage DC applications. Purchasing TVSS devices with the appropriate UL 1449 listing (see the sidebar) will help insure that appropriate design considerations have been incorporated into the product and that the product can be applied safely.

Kenneth J. Brown is the director of engineering for power quality at Leviton Manufacturing Co. in Chula Vista, Calif. You can reach him at kbrown@leviton.com.

Mark McGranaghan directs power quality projects and product development at Electrotek Concepts in Knoxville, Tenn. You can reach him at mark@electrotek.com.

UL Standard 1449

Underwriters Laboratories' Standard 1449, the “Standard for Transient Voltage Surge Suppressors,” provides some guidance on surge-suppressor usage. Although this standard focuses on the safety issues associated with surge-suppressor applications, it also addresses protection characteristics and evaluates responses using specific test waveforms.

UL 1449 defines transient voltage surge suppressors (TVSSs) or surge protection devices (SPDs) as equipment intended for electrical connection on the load side of the main overcurrent protection, in circuits not exceeding 600V rms. According to IEEE Standard C62.41, a well-designed surge-suppression system follows a cascade protection scheme, which incorporates a lightning arrester, a service-entrance SPD, and downstream SPDs.

The UL standard assigns suppressed voltage ratings (SVRs) based on subjecting products to combination wave impulses of 6kV at 500A. The rise and decay waveforms are 1.2 × 50 µs for open-circuit voltage and 8 × 20 µs for short-circuit current. The clamped voltage values for hardwired products are measured at the end of 6 in. of lead length, as recommended by manufacturers.

TVSS characteristics are evaluated with a specific duty cycle. A duty cycle involves 20 shots of the combined voltage and current test waves (different current magnitudes are used for panel devices, strips, and plug-ins). Three samples are tested before and after the duty cycle. These six measurements should not deviate by more than 10%. The rating is then based on the average of the six measurements.

The latest version of UL 1449 also includes a surge current test. This test checks to see if TVSSs can handle a relatively high surge current without degrading enough to cause fire or shock. Panels and receptacles are subject to two shots of a 10 kA/6kV impulse. Strips and plug-ins are subjected to a 3 kA/6kV impulse.

Also included in the latest version is a series of tests designed to ensure that TVSSs can handle abnormal overvoltage conditions in a safe manner. The temporary overvoltage test connects a TVSS to 110% of the normal system voltage for 7 hr. The full-phase system overvoltage test subjects a TVSS to a simulated “loss of neutral.” For example, a device intended for 120/240V systems is connected to 240V. Finally, the limited current overvoltage test subjects TVSSs to increasing levels of “standby current” through each mode where an MOV is connected within the device. This test basically simulates thermal runaway. All of these test results, which include checking for dielectric withstands (hipots) and leakage currents, should show no evidence of fire or shock hazards.

After all the UL testing has been completed, each mode of operation for a TVSS is assigned an SVR rating. This rating is obtained by taking the test results and rounding up to one of the SVR values in the table (above).
In the table, you'll notice that the lowest clamping rating assigned by UL 1449 is 330VAC. There are two good reasons for this. One is that a 330VAC clamping level protects downline equipment from most surge conditions. The second is that the standard's authors don't want to see equipment manufacturers design products with voltage-protection levels too close to the nominal line voltages (as indicated by the new tests for abnormal voltage conditions).

Many TVSS systems feature multiple parallel MOVs. As the voltage reaches the MOV's rated voltage level, the MOV's impedance changes state, providing a low-impedance path for the transient to follow. This allows excess energy to be diverted away from the protected load. However, if the MOV sustains an overvoltage or a large transient exceeding its capacity, it can go into thermal runaway condition. This means the zinc oxide material breaks down and initiates a short-circuit condition.

Manufacturers can design TVSSs to meet these conditions through proper fusing of MOVs, the use of thermal cutoffs (TCOs), or by overrating the MCOV rating for the MOVs employed in the device. The latter approach results in a safe device but a higher SVR, or clamping voltage.