Designing for Power-Line Surge Immunity

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Line transients, whether caused by lightning strikes or the switching of reactive loads, are ubiquitous. Surge protection, therefore, must be viewed as an essential part of the design of all modern electronics. The approach used to achieve AC line-transient immunity involves three principal components. There are devices that crowbar when exposed to a brief, excessive voltage; gas tubes are one example. Other devices such as metal-oxide varistors and avalanche diodes clamp the signal at a predetermined level. Finally, the high-frequency transients that remain after such crowbar and clamping actions can be filtered out by low-pass filter circuits.

Surge-Protector Types

Until recently, surge-protection elements could be divided conveniently into two classes: crowbars and clamps. Recent innovations have added to these venerable classes new hybrids such as the SSTVS device described below.

Crowbar devices have an action illustrated in Figure 1. When a striking potential is achieved, the device, usually a gas tube or a carbon-block arrester, switches on and drops the potential across it to a low holding voltage dependent on its design. The voltage remains fixed until the current through the device falls to a level that causes the holding action to be extinguished. During the next cycle, normal operation is resumed.

Clamp-type devices, typified by metal-oxide varistors or silicon avalanche suppressors, simply clamp the voltage to a maximum level.

Crowbar devices are designed to handle extremely high surge current, sometimes on the order of tens of thousands of amps, and they end up reflecting much of the incident energy back into the source. Clamps, in contrast, dissipate the energy on the spot, though their current-handling ability is lower.

Gas Tubes

A gas tube consists of specially designed electrodes within an envelope filled with various gases at a defined temperature. Once a threshold voltage across the device is exceeded, an arc occurs in the gap, causing the crowbar effect. In standby mode, the impedances of gas tubes are greater than 10 gigohms. When an arc is formed, the impedance drops to a few milliohms; the voltage across the device falls to the arc-holding voltage and remains there until the current level through the gas tube is reduced to a few milliamps. At that point, the arc extinguishes and the gas tube returns to its high-impedance state.

In specifying a gas tube, care must be taken to select the proper voltage. To protect a 117 AC volt-nominal line, for example, the peak voltage should be calculated. Given a 10% tolerance, such a line could be expected to reach 182 volts peak. Considering that gas tubes have a 20% tolerance, a gas-tube voltage of at least 262 volts AC should be selected. For 220-volt applications, the voltage of the gas tube should be at least 475 volts.

While gas tubes are rated for extremely high instantaneous surge current capabilities (20 kiloamps or more), they can dissipate such currents only for relatively brief impulses, such as the 8 x 20 microsecond impulse specified in IEEE C62.41 (formerly IEEE 587). Where the gas tube must fire continuously through half an AC line cycle, a second rating for the "follow-on current" must be considered. Generally, a gas tube's follow-on current rating will be on the order of 300 amps. Most residential circuits can source only about 100 amps; hence, the gas tube will operate safely under these conditions. Certain industrial applications, however, comprise circuits of higher current capability, and here a series resistance must be placed between the AC line and the gas tube. A good choice is a 2-ohm, 2-watt metal oxide film resistor.

Gas tubes have excellent characteristics for standby drain. In the off state, their leakage current is usually less than 1 x 10-20 amp. Their capacitance is low, between 1 and 5 picofarads. As transient suppressors they are fairly slow, typically reacting in 100 nanoseconds. (This is still fast compared to a typical 8 x 20 microsecond AC transient waveform.) When faced with repeated surges, gas tubes tend to wear out slowly over time. Most gas tubes are specified by the maximum number of current pulses of a specific duration they can withstand—usually 50 strikes of a 500-amp, 10 x 1000 microsecond current pulse.

In the end, the gas tube does not fail catastrophically but rather suffers a gradual shift of breakdown voltage to a lower value.

Silicon Avalanche Suppressors

Avalanche suppressors are specially designed wide-junction zener diodes. They are different from standard zener diodes in that they quickly dissipate the energy to which they are

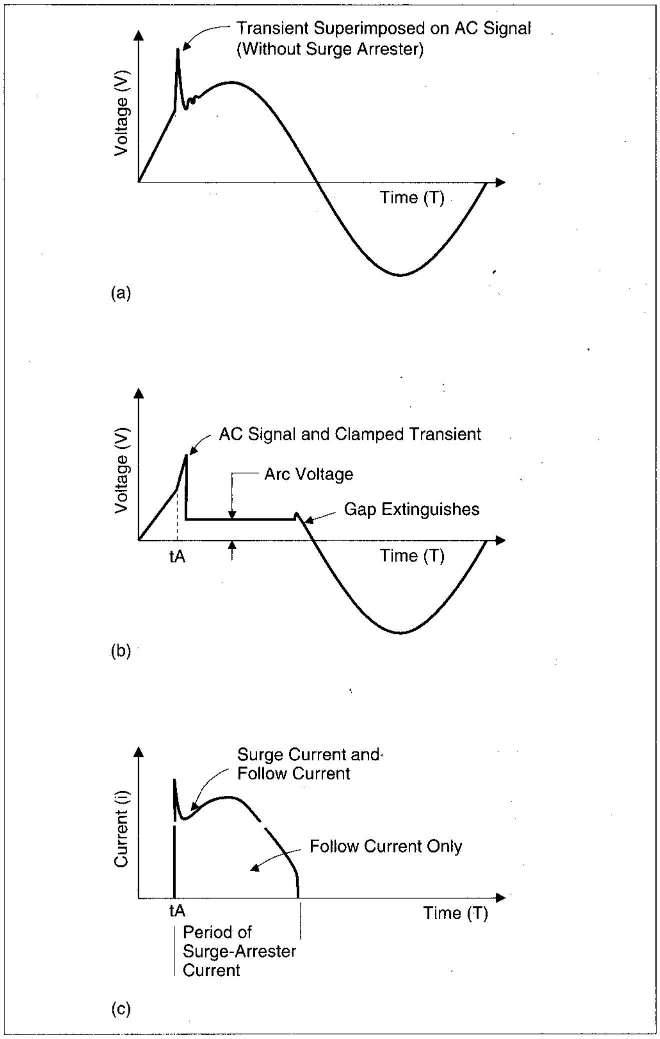

FIGURE 1: Appearance of follow-on current. Without surge protection, a transient appearing within the first 8.3 ms or first half-cycle of the 60 Hz sine wave can disrupt the signal (a). With surge protection, this spike is clamped (b), and the gap extinguishes near the zero crossing, at the point where gas-tube conduction stops in the surge arrester. The follow-on current (c) begins after the large spike of transient current passes through the surge arrester.

exposed; regular zener diodes do not have that capability and are often soon destroyed when used in transient-surge applications. Avalanche diodes' I-V characteristics, however, are very similar to those of regular zener diodes.

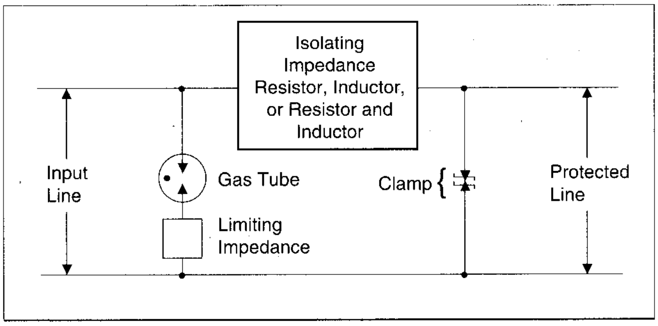

FIGURE 2: Hybrid surge protection. A gas tube with series limiter, an isolating impedance, and a clamp are the components necessary for surge protection. Gas discharge tubes with a wide range of breakdown voltages are available from manufacturers.

Leakage current in the off state for such devices runs between 0.5 and 10 microamps, and capacitance ranges between 1,000 and 10,000 picofarads. They can be selected for voltage ranges from 6.8 volts to 400 volts and have extremely fast reaction times, often less than 1 nanosecond. Their maximum pulse current is specified by the manufacturer and can be estimated by dividing the wattage by the clamping-voltage rating.

Avalanche diodes can also be used for clamping applications in DC circuits. Note that gas tubes should never be used for DC applications because once they crowbar, the current will never fall to the point where the tube will extinguish.

Metal Oxide Varistors

Like silicon avalanche suppressors, metal oxide varistors rely on a clamping action. They are slower but have considerably higher peak-current and energy ratings. The leakage current of a metal oxide varistor can range from 5 to 250 microamps, and its capacitance from 10 to 20,000 picofarads. Such varistors come in voltage ratings from 14 to 1,200 volts and generally react in less than 50 nanoseconds. They are rated to suppress high current levels from 40 to 25,000 amperes from a single pulse of an 8 x 20 microsecond waveform. Note, however, that these devices' peak-current capabilities will be reduced if they are exposed to a rapid sequence of multiple shocks. The lifetime curve ratings supplied with these devices must be observed.

Each metal oxide varistor has an associated joule rating, but its allowable surge energy may be more accurately specified by observing the published maximum-current-versus-pulse-width curves. Typically, a 130-volt metal oxide varistor rated at 40 joules can withstand a 3,000 amp peak 8 x 20 microsecond current pulse.

Solid-State Transient Voltage Suppressors (SSTVSs)

SSTVSs borrow the best of both worlds from gas tubes and silicon avalanche suppressors. In its off state, the SSTVS sits across the line with a near-infinite resistance and is transparent to the circuit. Once the breakover voltage is exceeded, however, the initial response of the SSTVS is to clamp the transient voltage much as a silicon avalanche suppressor would, thus preventing the fast rising edge of the waveshape from damaging the sensitive ICs and transistors (clamping typically occurs within nanoseconds). The second action for an SSTVS is to crowbar if the transient has enough energy in it. Once the transient current drops below the SSTVS's holding current (typically 200 mA), the device resets to the off-state condition.

SSTVSs have leakage-current ratings under 5 A and a low off-state capacitance of 40 pF. Unfortunately, state-of-the-art technologies cannot withstand the 20,000 A peak surges that a gas tube can survive; hence, most SSTVS applications may be found in the telecommunications industry. Due to their rapid response time, reliability, wide range of breakdown-voltage ratings (12 to 600 V), and available surface-mount packaging, they are becoming the protection of choice for many telecommunications engineers.

Implementing Surge Protection

Protection schemes often involve hybrid circuits. One such circuit is shown in Figure 2. A gas tube is placed immediately across the AC line, and some type of clamping, either a silicon avalance diode or a metal oxide varistor, is isolated from the gas tube by an isolating impedance. This allows the voltage across the gas tube to approach its striking level without being "shorted out" by the clamp.

This hybrid protection scheme, while popular, has two principal drawbacks. First, its suppression characteristics will differ in the window between the clamp voltage and the striking voltage of the gas tube. In evaluating its performance through tests such as those embodied in ANSI C62.41 and C62.45, care should be taken to apply transients at various voltage levels. Second, the switching action of the clamp in the gas tube will leave behind high-frequency transients that can themselves disrupt circuit function. In order to relieve the latter, a standard EMI line filter consisting of LC sections should be installed between the clamp and the input to the power supply.