Harris Semiconductor

APP NOTE

No. AN9308.2 January 1998

Harris Suppression Products

AC Line Voltage Transients and Their Suppression

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Introduction

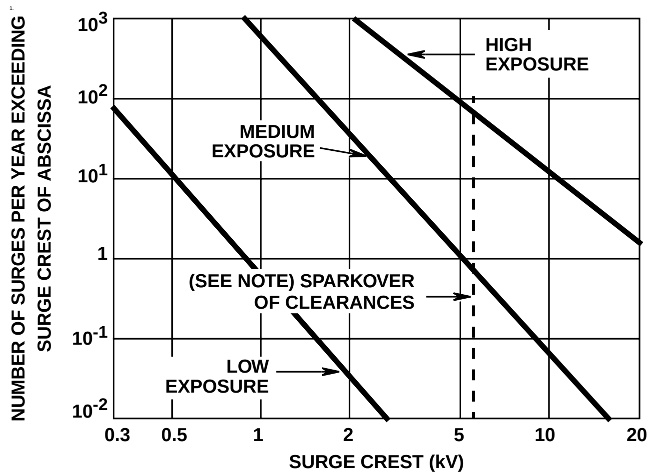
The increasing usage of sensitive solid state devices in modem electrical systems, particularly computers, communications systems and military equipment, has given rise to concerns about system reliability. These concerns stem from the fact that the solid state devices are very susceptible to stray electrical transients which may be present in the distribution system.

The initial use of semiconductor devices resulted in a number of unexplained failures. Investigation into these failures revealed that they were caused by transients, which were present In many different forms in the system. Transients in an electrical circuit result from tile sudden release of previously stored energy. The severity of, and hence the damage caused by transients depends on their frequency of occurrence, the peak transient currents and voltages present and their waveshapes.

In order to adequately protect sensitive electrical systems, thereby assuring reliable operation, transient voltage suppression must be part of the initial design process and not simply included as an afterthought. To ensure effective transient suppression, the device chosen must have the capability to dissipate the impulse energy of the transient at a sufficiently low voltage so that the capabilities of the circuit being protected are not affected. The most successful type of suppression device used is the metal oxide varistor. Other devices which are also used are the zener diode and the gas-tube arrestor.

The Transient Environment

The occurrence rate of surges varies over wide limits, depending on the particular power system. These transients are difficult to deal with, due to their random occurrences and the problems in defining their amplitude, duration and energy content. Data collected from many independent sources have led to the data shown in Figure 1. This prediction shows with certainty only a relative frequency of occurrence, while the absolute number of occurrences can be described only in terms of low, medium or high exposure. This data was taken from unprotected circuits with no surge suppression devices.



NOTE: In some locations, sparkover of clearances may limit the overvoltages.

FIGURE 1. RATE OF SURGE OCCURRENCES vs VOLTAGE LEVEL AT UNPROTECTED LOCATIONS

The low exposure portion of the graph Is derived from data collected in geographical areas known for low lightning activity, with little load switching activity. Medium exposure systems are geographical areas known for high lightning activity, with frequent and severe switching transients. High exposure areas are rare, but real systems, supplied by long overhead lines and subject to reflections at line ends, where the characteristics of the installation produce high sparkover levels of the clearances.

Investigations into the two most common exposure levels, low and medium, have shown that the majority of surges occurring here can be represented by typical waveform shapes (per ANSI/IEEE C62.41-1980). The majority of surges which occur in indoor low voltage power systems can be modeled to an oscillatory waveform (see Figure 2). A surge impinging on the system excites the natural resonant frequencies of the conductor system. As a result, not only are the surges oscillatory but surges may have different amplitudes and waveshapes at different locations in the system. These oscillatory frequencies range from 5kHz to 500kHz with 100kHz being a realistic choice.

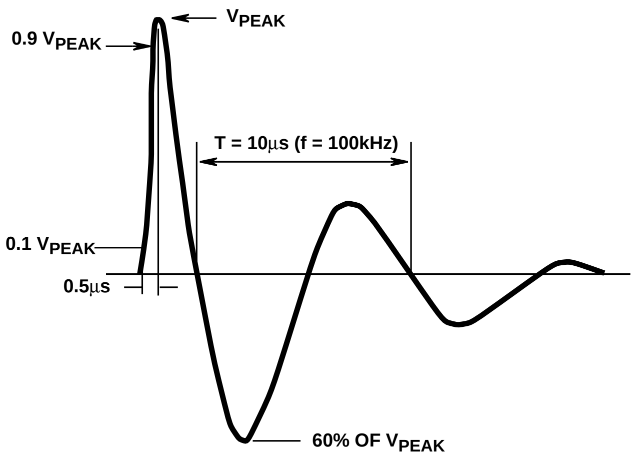


FIGURE 2. 0.5µs - 100kHz RING WAVE (OPEN CIRCUIT VOLTAGE)

In outdoor situations the surge waveforms recorded have been categorized by virtue of the energy content associated with them. These waveshapes involve greater energy than those associated with the indoor environment. These waveforms were found to be unidirectional in nature (see Figure 3).

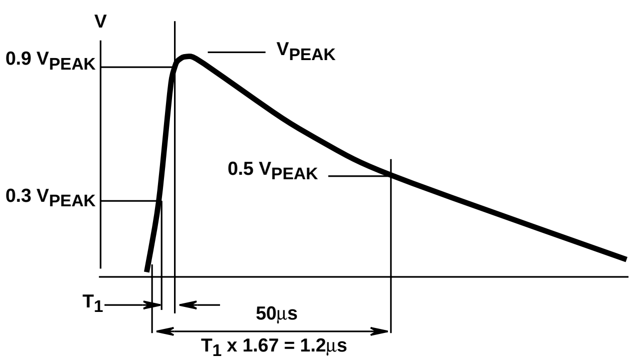


FIGURE 3A. OPEN-CIRCUIT WAVEFORM

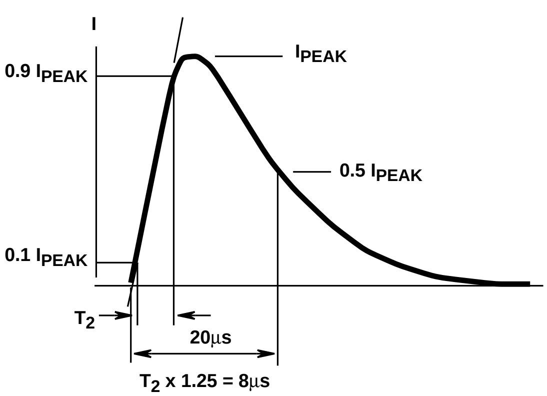


FIGURE 3B. DISCHARGE CURRENT WAVEFORM

FIGURE 3. UNIDIRECTIONAL WAVESHAPES (OUTDOOR LOCATIONS)

Transient Energy and Source Impedance

Some transients may be intentionally created in the circuit due to inductive load switching, commutation voltage spikes, etc. These transients are easy to suppress since their energy content is known. It is the transients which are generated external to the circuit and coupled into it which cause problems. These can be caused by the discharge of electromagnetic energy, e.g., lightning or electrostatic discharge. These transients are more difficult to identify, measure and suppress. Regardless of their source, transients have one thing in common - they are destructive. The destruction potential of transients is defined by their peak voltage, the follow-on current and the time duration of the current flow, that is:

$$E = \int_0^{\tau} Vc(t) \bullet I(t)\, dt$$

where:

E = Transient energy

I = Peak transient current

Vc = Resulting clamping voltage

t = Time

τ = Impulse duration of the transient

It should be noted that considering the very small possibilities of a direct lightning hit it may be deemed economically unfeasible to protect against such transients. However, to protect against transients generated by line switching, ESD, EMP and other such causes is essential, and if ignored will lead to expensive component and/or system losses.

The energy contained in a transient will be divided between the transient suppressor and the line upon which it is travelling in a way which is determined by their two impedances. It is essential to make a realistic assumption of the transient's source impedance in order to ensure that the device selected for protection has adequate surge handling capability. In a gas-tube arrestor, the low impedance of the arc after sparkover forces most of the energy to be dissipated elsewhere - for instance in a power-follow current-limiting resistor that has to be added in series with the gap. This is one of tile disadvantages of the gas-tube arrestor. A voltage clamping suppressor (e.g., a metal oxide varistor) must be capable of absorbing a large amount of transient surge energy. Its clamping action does not involve the power-follow energy resulting from the short-circuit action of the gap.

The degree to which source impedance is important depends largely on the type of suppressor used. The surge suppressor must be able to handle the current passed through them by the surge source. An assumption of too high an impedance (when testing the suppressor) may not subject it to sufficient stresses, while the assumption of too low an impedance may subject it to unrealistically large stress; there is a trade off between the size/cost of the suppressor and the amount of protection required.

In a building, the source impedance and the load impedance increases from the outside to locations well within the inside of the building, i.e., as one gets further from the service entrance, the impedance increases. Since the wire in a structure does not provide much attention, the open circuit voltages show little variation. Figure 4 illustrates the application of three categories to the wiring of a power system.

These three categories represent the majority of locations from the electrical service entrance to the most remote wall outlet. Table 1 is intended as an aid in the selection of surge suppressors devices, since it is very difficult to select a specific value of source impedance.

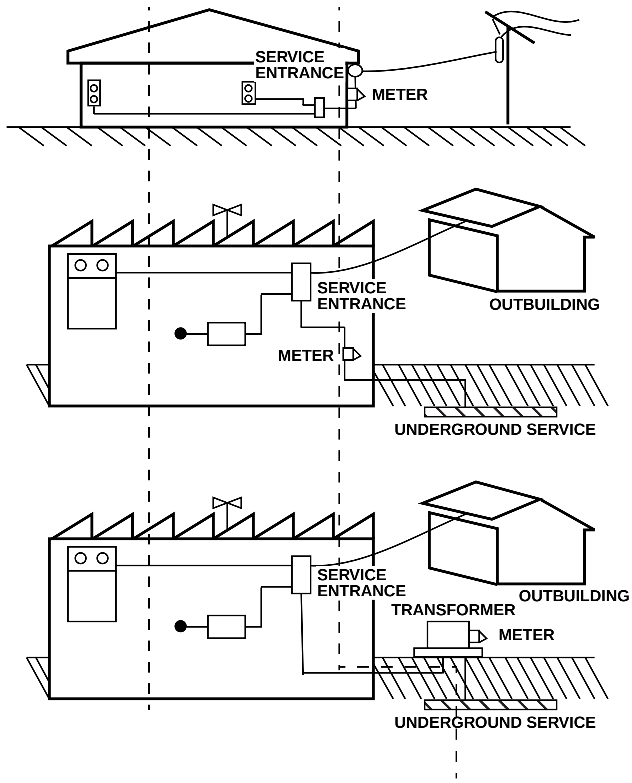
Category A covers outlets and long branch circuits over 30 feet from category B and those over 60 feet from category C. Category B is for major feeders and short branch circuits from the electrical entrance. Examples at this location are bus and feeder systems in industrial plants, distribution panel devices, and lightning systems in commercial buildings. Category C applies to outdoor locations and the electrical service entrance. It covers the service drop from pole to building entrance, the run between meter and the distribution panel, the overhead line to detached buildings and underground lines to well pumps.

TABLE 1. SURGE VOLTAGES AND CURRENTS DEEMED TO REPRESENT THE INDOOR ENVIRONMENT AND RECOMMENDED FOR USE IN DESIGNING PROTECTIVE SYSTEMS

LOCATION CATEGORY CENTER	COMPARABLE TO IEC 664 CATEGORY	IMPULSE		TYPE OF SPECIMEN OR LOAD CIRCUIT CIRCUIT	ENERGY (JOULES) DEPOSITED IN A SUPPRESSOR WITH CLAMPING VOLTAGE	
		WAVEFORM	MEDIUM EXPOSURE AMPLITUDE		500V	1000V
					(120V Sys.)	(240V Sys.)
A. Long branch circuits and outlets	II	0.5µs - 100kHz	6kV	High Impedance (Note 1)	-	-
			200A	Low Impedance (Note 2)	0.8	1.6
B. Major feeders short branch circuits, and load center	III	1.2/50µs	6kV	High Impedance (Note 1)	-	-
		8/20µs	3kA	Low Impedance (Note 2)	40	80
		0.5µs - 100kHz	6kV	High Impedance (Note 1)	-	-
			500A	Low Impedance	2	4

NOTES:

1. For high-impedance test specimens or load circuits, the voltage shown represents the surge voltage. In making simulation tests, use that value for the open-circuit voltage of the test generator.
2. For low-impedance test specimens or load circuits, the current shown represents the discharge current of the surge (not the short-circuit current of the power system). In making simulation tests, use that current for the short-circuit current of the test generator.
3. Other suppressors which have different clamping voltages would receive different energy levels.



A	B	C
Outlets and long branch circuits. All outlets at more than 10m (30ft.) from Category B. All outlets at more than 20m (60ft.) from Category C.	Feeders and short branch circuits Distribution Panel Devices Bus and feeder in industrial plants Heavy appliance outlets with “short” connections to service entrance Lighting systems in large buildings	Outside and service entrance Service drop from pole to building. Run between meter and panel. Overhead line to detached building. Underground line to well pump.

FIGURE 4. LOCATION CATEGORIES

Transient Suppression

The best type of transient suppressor to use depends on the intended application, bearing in mind that in some cases both primary and secondary protection may be required. It is the function of tile transient suppressor to, in one way or another, limit the maximum instantaneous voltage that can develop across the protected load. The choice depends on several factors, but the decision is ultimately a trade-off between the cost of the suppressor and the amount of protection needed.

The time required for a transient suppressor to begin functioning is extremely important when it is used to protect sensitive components. If the suppressor is slow acting and a fast-rise transient spike appears on the system the voltage across the protected load can rise to damaging levels before suppression begins. On AC power lines the best type of suppression to use is a metal oxide varistor. Other devices occasionally used are the zener diode and the gas-tube arrestor.

Gas-Tube Arresters

This is a suppression device which finds most of its applications in telecommunication systems. It is made of two metallic conductors usually separated by 10mils to 15mils encapsulated in a glass envelope. This glass envelope is pressurized and contains a number of different gases. Types specifically designed for AC line operation are available and offer high surge current ratings.

Zener Diodes

One type of clamp-action device used in transient suppression is the zener diode. When a voltage of sufficient amplitude is applied in the reverse direction, the zener diode is said to break down, and will conduct current in this direction. This phenomenon is called avalanche. The voltage appearing across the diode is therefore called the reverse avalanche or zener voltage.

When a transient propagates along the line with a voltage exceeding the reverse-based voltage rating of the diode, the diode will conduct and the transient will be clamped at the zener voltage. This clamping voltage is lower than that of an equivalent varistor. Some manufacturers have claimed that the response time of a zener diode is 1ps to 2ps. In practice, the speed of response is greatly determined by the parasitic inductance of the package and the manner in which the device is connected via its leads. Although zener diodes can provide transient protection, they cannot survive significant instantaneous power surges. Larger diodes can be used to increase the power rating, but this is only at the expense of increased costs. Also, the maximum tolerable surge current for a zener diode in reverse breakdown is small when compared to tolerable surge currents for varistors. Due to the fact that there is only the p-n junction in a zener diode, it will need to have some additional heat sinking in order to facilitate the rapid build-up of heat which occurs in the junction after it has encountered a transient.

Metal Oxide Varistor

As the name suggests, metal oxide varistors (MOV) are variable resistors. Unlike a potentiometer, which is manually adjusted, the resistance of a varistor varies automatically in response to changes in voltages appearing across it. Varistors are a monolithic device consisting of many grains of zinc oxide, mixed with other materials, and compressed into a single form. The boundaries between individual grains can be equated to p-n junctions with the entire mass represented as a series-parallel diode network.

When a MOV is biased, some grains are forward biased and some are reverse biased. As the voltage is increased, a growing number of the reversed biased grains exhibit reverse avalanche and begin to conduct. Through careful control in manufacturing, most of the nonconducting p-n junctions can be made to avalanche at the same voltage. MOVs respond to changes in voltages almost instantaneously. The actual reaction time of a given MOV depends on physical characteristics of the MOV and the wave shape of the current pulse driven through it by the voltage spike. Experimental work has shown the response time to be in the 500 picosecond range.

One misconception about varistors is that they are slow to respond to rapid rise transients. This “slow” response is due to parasitic inductance in the package and leads when the varistor is not connected with minimal lead length. If due consideration is given to these effects in its installation, the MOV will be more than capable of suppressing any voltage transients found in the low voltage AC power system.

The MOV has many advantages over the zener diode, the greatest of which is its ability to handle transients of much larger energy content. Because it consists of many p-n junctions, power is dissipated throughout its entire bulk, and unlike the zener, no single hot spot will develop. Another advantage of the MOV is its ability to survive much higher instantaneous power.

Summary

When designing circuits of the complex nature seen in todays electrical environment, the initial design must incorporate some form of transient voltage surge suppression. The expense of incorporating a surge protection device in a system is very low when compared with the cost of equipment downtime, maintenance and lost productivity which may result as a consequence of not having protection. When selecting surge suppressors for retrofit to an existing design, one important point to remember is that the location of the load to be protected relative to the service entrance is as important as the transient entrance which may be present in an overvoltage situation.

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