APPLICATION NOTES

Combining GDTs and MOVs for Surge Protection of AC Power Lines

AC power line disturbances are the cause of many equipment failures. The damage can be as elusive as occasional data crashes or as dramatic as the destruction of a power supply, computer terminal, or television set. Power line disturbances go by many names -- transients, surges, spikes, glitches, etc. -- but regardless of the name, an understanding of their characteristics and the operation of the various protection devices available is necessary to design an effective protection circuit. This Application Note will illustrate how to design high performance, cost-effective surge protection for equipment connected to AC power lines. The role of gas discharge tube (GDT) surge arresters specifically designed for AC power line protection will also be discussed.

The first step in providing an effective defense against power line transients is to accurately characterize the transients. One good reference is IEEE C62.41-1991 entitled "IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits" (formerly IEEE Standard 587). This standard defines the open circuit voltage and short circuit current waveforms which can be expected to occur on AC power lines of 1000 Volts (RMS) or less. The standard defines three levels of increasing transient activity, labeled

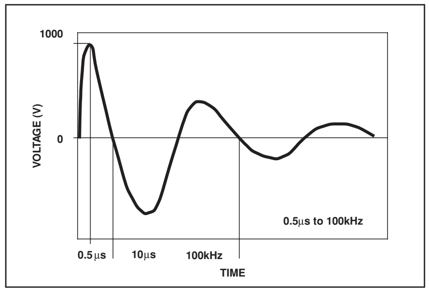

Figure 1a. IEEE C62.41

Location Categories A through C, dependent on the distance of the equipment from the service entrance. Line cord-connected equipment will usually be covered by Location Category A or, occasionally, Location Category B. There

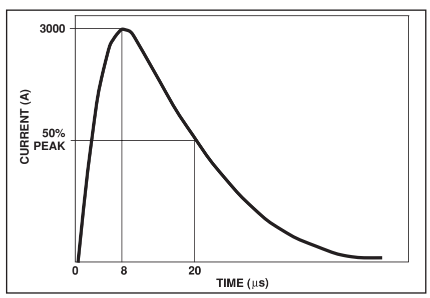

Figure 1b. IEEE C62.41

are two standard waveforms which define the types of transients expected in these Location Categories:

- 0.5µs-100kHz Ring Wave (Figure 1A) — an oscillatory waveform having a peak open circuit voltage of up to 6kV (Note 1), a risetime of 0.5µs, a ring frequency of 100kHz, and a "Q" of three. Though a short-circuit current is not specified, peak currents of up to 0.5kA can be expected (Note 1).
- 1.2/50µs-8/20µs Combination Wave (Figure 1B) — a unidirectional impulse waveform having a peak open-circuit voltage of up to 6kV (Note 1) with a rise time of 1.2µs and a duration of 50µs (Note 2) AND a peak short-circuit current of up to 3kA (Note 1) with a rise time of 8µs and a duration of 20µs (Note 3).

Test waveforms for evaluation of a surge protection system should conform to these standard waveforms as closely as possible to ensure valid results. The use of test waveforms having slower rise times or lower peak currents/voltages may result in a false sense of security concerning the level of protection actually provided under field conditions.

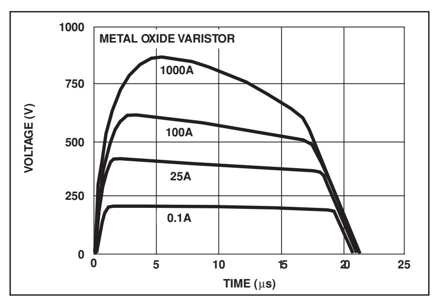

Figure 2a. MOV clamping voltage at various current levels

The second step in designing an effective surge protection circuit is to choose which type(s) of surge protector to use. Surge protection devices can be divided into two basic types: Crowbar-type devices such as gas tube surge arresters, spark gaps, and SCRs; and Clamp-type devices such as avalanche diodes, transient absorption zener diodes, and metal oxide varistors.

The clamp-type devices have faster response times but are limited in their current handling ability because most of the energy of the transient must be dissipated by the clamping device. Also, the voltage drop across a clamp-type surge protector

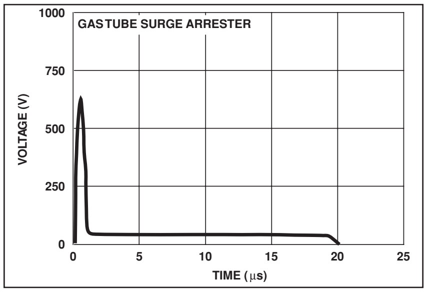

Figure 2b. Transient response of a plasma surge arrester

increases with the conducted current as shown in Figure 2A.

Crowbar-type devices such as gas tube surge arresters have slightly slower response times but can handle much higher current because they act as a low impedance switch which diverts the transient energy away from the protected equipment to be dissipated externally. While the peak voltage experienced by the protected circuit during the leading edge of some transients may be higher than with a clamp-type device; the duration, and thus the total energy delivered to the protected circuit, is much lower when using a crowbar-type device as shown in Figure 2B.

This peak voltage is a function of the rise time of the leading edge of the transient. Faster rise times will result in higher peak voltages due to the response time of the protector. Although Zener-gated SCRs and thyristors are available which offer faster response times, their use is limited to telecom and signal line applications due to their relatively low peak current ratings. A major benefit of the gas tube surge arrester is that the voltage drop across the device remains essentially constant (<20V) regardless of the conducted current.

The ideal surge protector would overcome the current handling and energy diverting characteristics of the crowbar type device with the speed of the clamp type device. This approach has been difficult and expensive to realize with traditional crowbar type devices because their designs were optimized for the ability to turn off in the presence of a low-current DC bias. While that is appropriate for protecting a telecom line, additional components (such as

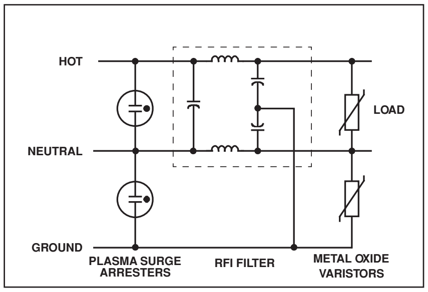

Figure 3a. Hybrid surge protection circuit

a series resistor or parallel connected series-RC network) were required to ensure that the gas tube surge arrester would extinguish when placed across an AC power line with its relatively low source impedance and the resultant follow-on currents (Note 4). These components invariably decreased the performance of the protector while increasing its installed cost.

Gas tube surge arresters specifically designed for AC power line applications provide the low impedance switching action and high peak current capabilities of traditional gas tube surge arresters while optimizing the ability to extinguish in the

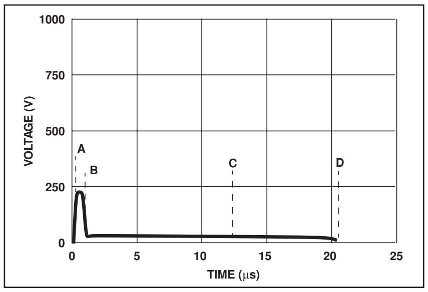

Figure 3b. Transient response of hybrid circuit

presence of AC follow-on currents in excess of 300A. In most applications, no additional components are required other than those of the basic surge protection circuit. A surge protection circuit with sub-nanosecond response time, precise control of transient energy let-through, and a peak current rating of 20,000A is now practical even for cost-sensitive applications such as power supplies, home stereos, monitors, and printers.

A typical installation is illustrated in Figure 3A. This is a two stage hybrid circuit consisting of a gas tube surge arrester as the primary protector and a Metal Oxide Varistor (MOV) as the secondary protector. These elements must be separated by an isolating impedance. This impedance may be either resistive (>10Ω) or inductive (>0.1mH) to ensure proper coordination of the protective devices. Most AC applications utilize an inductive element to minimize power dissipation and voltage drop during normal operation.

The inductor used in this example is part of the RFI filter already required by the design. The output of the protection circuit during a transient is illustrated in Figure 3B.

The following sequence of events is depicted in Figure 3B:

A. The leading edge of the transient is clamped by the MOV to a value just above the normal operating voltage.

B. As the current through the MOV increases, a voltage is developed across the inductor which causes the gas tube surge arrester to fire. The energy of the transient is now quickly shunted through the gas tube surge arrester and away from the protected circuit.

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

D. When the transient has passed, 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 and the MOV provides the fast, accurate clamping of the low energy leading edge.

The cost effectiveness of this protection circuit is enhanced by three factors:

1. The use of an AC line gas tube surge arrester eliminates the need for additional components to ensure turnoff.

2. The isolating impedance is supplied by an existing component (the RFI filter).

3. A small diameter MOV (LA or UltraMOV™ varistors) is used since the gas tube surge arrester handles the high-energy portion of the transient.

The example duplicates the circuit between Neutral and Ground in addition to the Hot-to-Neutral circuit. This provides protection against Common Mode (both lines surged relative to ground) as well as Normal Mode (Hot-to-Neutral) transients. This is important because both types of transients are frequent occurrences in the real world. The failure to provide Common Mode protection is one of the leading causes of failure in many otherwise solid designs.

The critical points in the selection of the gas tube surge arrester are the minimum DC breakdown voltage (which must be higher than the highest normal voltage expected on the protected line) and the follow-on current rating (which must be higher than the expected fault current of the incoming supply line). In this example, the minimum DC breakdown voltage is calculated by multiplying the normal line voltage ($120V_{RMS}$) by 1.414 to obtain the peak voltage and then adding an appropriate guard band to allow for normal variations in the supply voltage.

The MOV should be selected using the same formula. When used in a properly designed hybrid circuit, a 7mm or 10mm device is normally adequate to handle the small leading-edge currents until the gas tube surge arrester goes into conduction.

The inductor should have a value of at least 0.1mH. If the inductance is too low, the MOV may clamp the transient voltage at a level that does not allow the gas tube surge arrester to go into conduction. This would result in energy beyond the ratings of the MOV. Tests have been conducted using several common RFI filters having inductances or 1-2mH with excellent results.

Hybrid surge protection circuits incorporating HAC Series gas tube surge arresters can provide cost-effective protection against transients that exceed even the tough guidelines of IEEE C62.41-1991 for Location Categories A and B.

Notes

1. The exact value is a function of the Location Category and System Exposure level. See the IEEE spec for more detailed information.

2. The rise time for an open-circuit voltage waveform is defined as $1.67 \times (t_{90} - t_{30})$ where t_{30} and t_{90} are the 30% and 90% amplitude points on the leading edge of the waveform. The duration is defined as the time from the virtual origin, t_0 (where a line through t_{30} and t_{90} intersects the zero voltage axis), to the 50% amplitude point of the trailing edge of the waveform, t_{50}.

3. The rise time for an short-circuit current waveform is defined as $1.25 \times (t_{90} - t_{10})$ where t_{10} and t_{90} are the 10% and 90% amplitude points on the leading edge of the waveform.

The duration is defined as the time from the virtual origin, t_0 (where a line through t_{10} and t_{90} intersects the zero current axis), to the 50% amplitude point of the trailing edge of the wave-form, t_{50} .

4. If the current supplied by the AC power line exceeds the maximum follow-on current of the gas tube surge arrester (typically, ~20A), the device will continue to conduct, even at a zero crossing of the AC voltage signal, causing the gas tube surge arrester to overheat and fail.

Littelfuse, Inc.
800 E. Northwest Highway
Des Plaines, IL 60016
www.littelfuse.com

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