Structure and Operation Method of Surge Arresters

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INTRODUCTION

Safe and reliable lightning protection for a system requires proper installation and planning. Coordination of main lightning current arresters to reduce damaging voltage to branch circuit arresters is essential for consistent surge protection performance.

To eliminate the surge voltages in a particular area, a protection circuit must be set up around the entire area being protected (Figure 1). This protection zone is designed to stop surge voltages from coupling from external sources, and to prevent various electrical circuits such as power cables and data leads inside it from influencing each other. To accomplish this, floor duct installations with grounded conduit can be used instead of window ducts in plastic channels. Power cable and data leads should be shielded and routed in separate ducts. Once all electrical circuits which enter or leave the protection zone have been fed through the appropriate surge arresters, all other electrically conductive components, such as pipe work, should be connected to the equipotential bonding ground systems.

Depending on how soon the surge voltage protection concepts are included in construction and electrical planning, a surge voltage protection zone can be used to protect an entire building, a room, or part of a room. The zone can also comprise an individual computer, such as in cases where a computer is operated and it is not economical to extend the surge voltage protection zone to an entire room or building. Of course, consideration should always be given to any future expansion of the electrical equipment.

Comprehensive surge voltage protection can be achieved with a combination of arresters.

PROTECTION CLASSES

Surge voltage protection for AC power and I/O data communication equipment is divided into the following classes:

- Coarse protection (100 kA)
- Medium protection (10 kA)
- Fine protection (0.5 kA)

The various circuit types for different protection levels are significant. A comprehensive surge voltage protection program can only be achieved if all electrical circuits entering a surge voltage protection zone are equipped with suitable surge arresters to eliminate surge voltages.

COARSE-PROTECTION ELEMENTS

Gas-filled surge voltage arresters (gas arresters, surface discharge tubes and chopping devices) are used for coarse protection. Both the surface discharge tubes and chopping technology devices, which produce a practically static characteristic for ignition, are voltage-dependent devices; the voltage has to reach a certain level before the devices react to the surge voltage. Currents of up to 100 kA or more can be handled by surface discharge tubes and chopping technology devices. The most common version of gas-filled surge arresters can handle 10 kA surge currents (Figure 2). Discharge currents above 10 kA should not arise in conductors such as data cables because the cross sections of the cables which are connected are relatively small, and they often do not have the capacity to conduct large current transients.

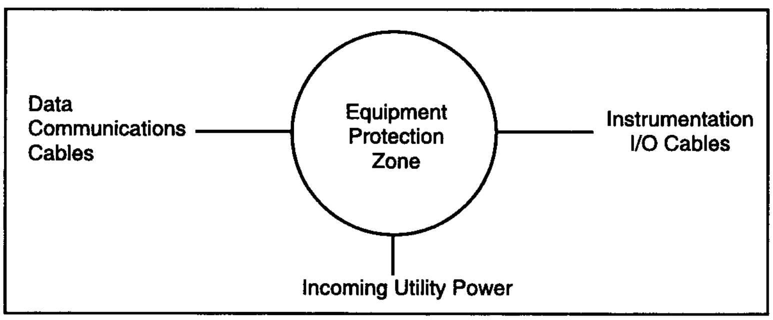

Figure 1. *Equipment Protection Zone.*

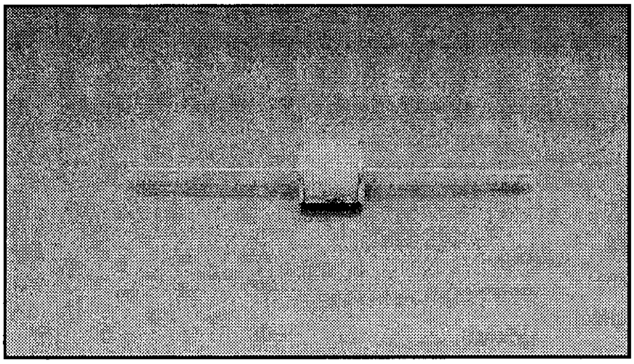

Figure 2. *Gas-filled Surge Arrester.*

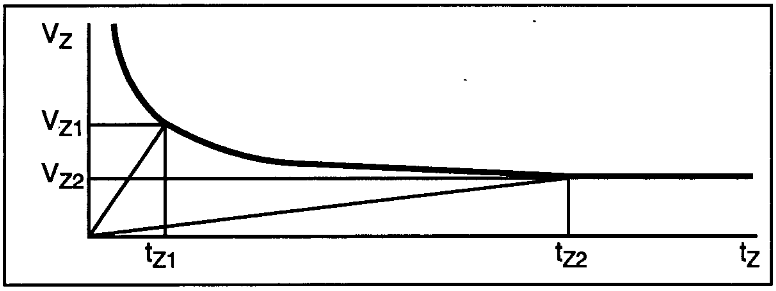

Figure 3. *Characteristic Curve of Gas-filled Arrester Ignition.*

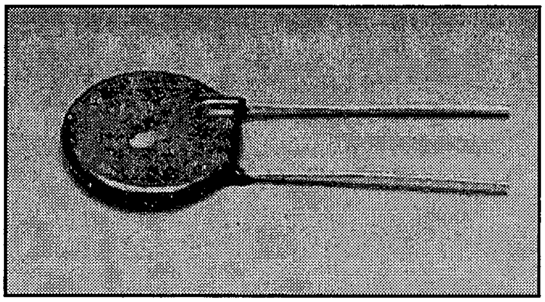

Figure 4. *Metal Oxide Varistor.*

Gas arresters have response times in the medium nanoseconds range and have been used for several decades in the telecommunications industry. They do, however, have drawbacks, such as ignition behavior in response to rise times of transients (Figure 3). Transients with long rise times (e.g. dv/dt ≈100 V/s) intersect the ignition characteristic curve in the area where the curve runs almost parallel to the time axis. For this reason, a protection level of approximately that of the nominal voltage of a gas arrester can be expected. However, particularly high-energy transients with fast rise times intersect the ignition characteristic curve at a point where the voltage can be as much as 10 times above the nominal voltage of the gas arrester. Taking the smallest nominal voltage of a gas arrester to be 90 V would still mean a residual voltage of 900 V.

The possibility of a line follow current is another disadvantage. If the gas arrester has ignited, a low-impedance circuit with operating voltage above 24 V is capable of maintaining the short circuit, which is only required for a few microseconds, but would result in the gas arrester exploding within a fraction of a second. For this reason, surge voltage protection circuits which use gas arresters must be fitted with a safety fuse in front of the gas arrester in order to interrupt the circuit very quickly. Another alternative is to place a metal oxide varistor (MOV) in series with the gas tube, but this approach requires some engineering in order to produce the right voltage combination between the two surge components.

MEDIUM-PROTECTION ELEMENTS

A medium-protection component allows the level of the residual voltage from the coarse device to be further reduced after the high-energy currents have been discharged. Varistors provide this medium protection (Figure 4). Varistors of approximately the same size as the gas arresters are not capable of discharging the same high current levels. To compensate for this, their reaction time is in the low nanosecond range, so they have a quicker reaction time and do not suffer the same problems with line follow currents in the 2.5 kA to 5 kA range. These varistors are physically larger than the gas arresters used for 10-kA transient leakage currents.

Disadvantages of varistors include aging and relatively high capacitance. Aging is caused by the failure of diode elements inside the varistor. The p-n junctions usually create a short circuit when an overload occurs, so a varistor will start to draw leakage currents depending on how frequently it is stressed. This can lead to incorrect measurement values in sensitive measurement circuits and can cause a considerable build-up of heat, particularly if the nominal voltages of the circuits are quite high.

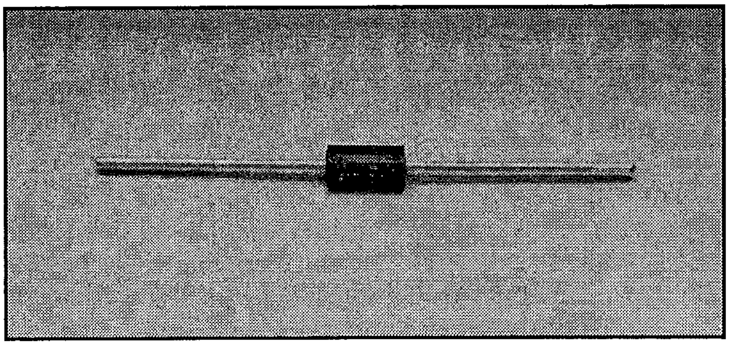

Figure 5. *Suppressor Diode.*

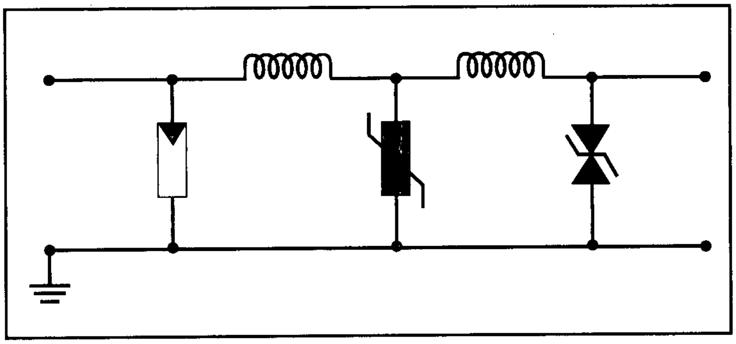

Figure 6. *Inductive Decoupling of Surge Elements.*

The high capacitance of a varistor means that in many cases it is not suitable for use in data transmission cables which operate using high frequencies. Together with the inductance of the cable, these capacitances produce a lowpass filter which results in considerable signal attenuation. However, with frequencies below approximately 30 kHz, this attenuation is practically insignificant.

FINE PROTECTION

Despite the use of a medium-protection element, the poor dielectric strength of sensitive electronic circuits often means that the protection level is still too high. For this reason, a further stage, fine protection, must be included in the protection circuit.

Fine-protection methods generally employ circuits in which components are also connected between the current-carrying conductors for ac, and between the signal conductor for data or I/O applications.

Fine protection surge arresters can be diodes in combination with varistors or gas-filled surge arresters or a suppression diode used only for equipment protection. Fine surge arresters should always contain extremely fast-reacting suppressor diodes (Figure 5).

The advantage of diodes is that they can react within a matter of picoseconds. Voltage limitation is another advantage. The proper threshold voltage should be about 1.8 times the nominal voltage. However, diodes also have disadvantages, namely their limited current-carrying capacity and relatively high capacitance. The maximum discharge current for nominal voltages of 5 Vdc is approximately 600 A, although special diodes can reach 900 A. Higher nominal voltages only permit increased currents of a few tens of amps.

The inherent capacitance of the suppressor diodes is also dependent on the nominal voltage. As with varistors, this capacitance combines with the inductance of the connected cables to make a lowpass filter. The result is excessive attenuation during the transmission of high-frequency signals. However, the use of special diode arrays can reduce the capacitance to zero except during a transient surge, when it is functioning.

In accordance with various national and international standards, varistors used in ac voltage applications must be continuously checked for temperature increases caused by leakage current flows. Because of this, varistors for protecting the ac voltage supply should always be fitted with thermal monitoring components.

COMBINED PROTECTION CIRCUIT

Ultimately, the goal of the transient protection engineer is to exploit the advantages of each individual suppression component (gas arrester, surface discharge tube, varistor, suppressor diode and chopping principle device) and to circumvent their disadvantages. In order to achieve this, the components are connected indirectly in parallel circuits using decoupling impedances (Figure 6).

By limiting the conductor paths between the various surge arresters to minimum defined distances, a voltage arises whenever the conductor path is subjected to transient currents due to the self-inductance of the cables. This voltage, together with the voltage which arises in

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a similar way from the weaker surge arrester on the circuit, provides the necessary response voltage for the stronger surge arrester (medium- or coarse-protection) to function. In this way, the discharge current mitigates from the weaker to the stronger surge arrester, and therefore the stronger surge arrester protects the weaker surge arrester from destruction.

The suppressor diode is the fastest component and reacts first whenever a surge voltage occurs. The circuit is designed so that as the discharge current gains in strength, it will mitigate through the varistor before the suppressor diode can be destroyed in accordance with the following formula:

$$V_s + \Delta V \geq V_v$$

When the surge arresting capacity limit of the varistor is reached, the discharge current mitigates again, this time through the gas arrester, according to the following formula:

$$V_v + \Delta V \geq V_g$$

However, if the discharge current does not reach such a level, the gas arrester does not respond. This procedure combines the advantages of rapid component response time, low-level voltage limitation and high surge arresting capacity. The procedure also eliminates the disadvantages of overloading the suppressor diode and of frequent circuit interruption by the fuse in the case of a line follow current.

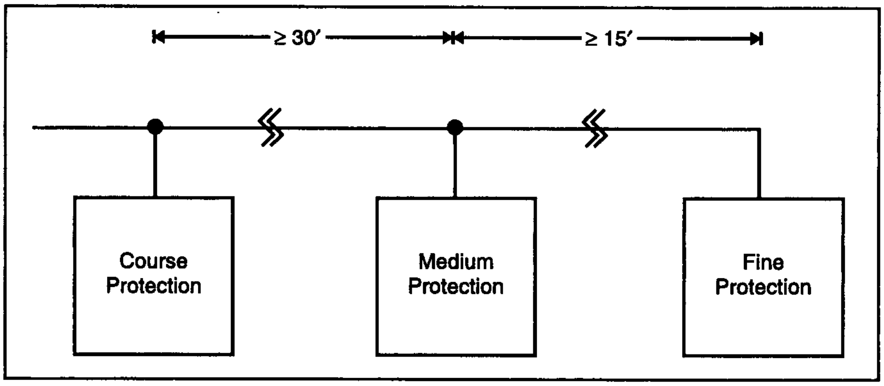

Figure 7. *Minimum Suggested Distances Between Protection Devices.*

Other circuits for high frequencies cannot use varistors or have high line inductance. Instead, they have ohmic resistance as decoupling elements and operate using low-capacity bridge circuits.

When surge arresters are connected in series for applications in measurement and data processing technology, the inputs and outputs of the protection product must be installed so that the components are in the proper order according to the source of the surge. The arrester package must have the gas tube on the input side (the direction from which the surge is expected to come) and the diode on the output or protected equipment side.

MINIMUM CABLE DISTANCES

The minimum cable lengths in the ac voltage feed have a corresponding relationship to the inductive elements fitted in surge arresters for the fine protection of electronic equipment.

The distance between a coarse protector (such as hybrid circuit containing surface discharge and varistor devices, or products employing the chopping principle) and a fine protector should not exceed 30′ to 35′. If the distance is greater than 30′ to 35′, a medium-protection device is required in the circuit. The cable length between coarse protection and medium protection should be at least 30′ to 35′ (or approximately 10 µH of inductance). One note of caution: a medium protector should always be used with an arc chopping principle device if the arc chopping principle device is used as the only coarse-protection device. The distance between medium- and fine-protection devices should be at least 15′ (or approximately 5µH of inductance) (Figure 7).

In addition to this line voltage protection, protection should be fitted to data, measurement and control cables and also — wherever possible — to antenna cables. Most of the electronic equipment connected to these cables requires coarse, medium and fine protection.

The discharge current mitigates from the weaker to the stronger surge arrester, and therefore the stronger surge arrester protects the weaker surge arrester from destruction.

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$$SET_n := -10 \cdot \log\left(10^{\frac{-SE1_n}{10}} + 10^{\frac{-SE_{slot_n}}{10}} + 2 \cdot 10^{\frac{-SE1_n - SE_{slot_n}}{20}}\right)$$

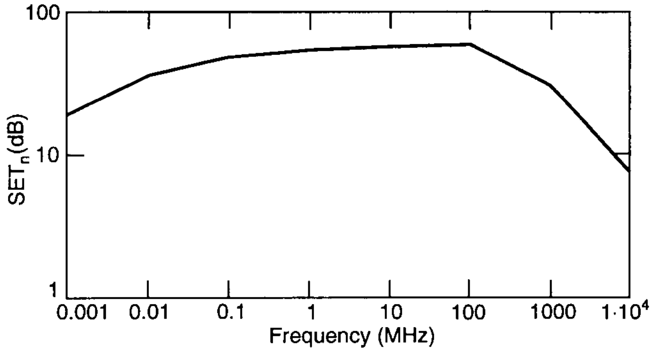

Figure 9. *Total Box Shielding Effectiveness.*

Table 5 represents the projected SE of the enclosure without gaskets. This SE calculation does not include all potential contributors to the SET (e.g., cables, air inlets, honeycomb, and other penetrations). It does not take into account the polarization and angle of the incident field, but rather assumes worst-case conditions. It does not take into account any box resonances. These other contributors to the overall SE may improve or reduce the final calculated SE, and need to be considered in the final SE analysis.

SET_n	Freq. (MHz)
19.221	0.001
35.777	0.01
54.575	0.1
58.345	1
57.191	10
46.39	100
27.819	$1 \cdot 10^3$
7.83	$1 \cdot 10^4$

Table 5. *Shielding Effectiveness without Gaskets.*

CONCLUSION

An effective first approximation methodology for calculating the shielding effectiveness of an arbitrary enclosure has been presented. This basic technique can be applied to many varied conditions to allow approximation of a box's top level EMI/EMC performance.

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NUMEROUS ADVANTAGES

The entire protection circuit is then incorporated in a housing which is designed to offer the user all possible installation and maintenance advantages. These include:

- Two-part construction made up of a base element and plug section, so that the surge-arresting components installed in the plug can be replaced without interrupting the circuit if they are overloaded
- Ease of component testing using a special test device, avoiding lengthy laboratory tests
- Installation of the final coupling impedances in the base element, so that they remain neutral in the measurement circuits even during the test procedure or when replacing the component
- Asymmetrical plug pins which preclude incorrect IN/OUT alignment
- Use of a grounding foot which makes the ground potential connection to DIN rails while it is being installed

Other surge arrester types are notable because they use the same physical connection technology as the units they are protecting. This is generally the case for surge arresters which are inserted in the cabling, and which use the same connectors, such as BNC connections on shielded cables.

Experience has shown that two steps are advisable for the planning and installation of surge voltage protection. The surge arrester must be selected in accordance with the dielectric strengths of the electronic and electrical equipment. The correct installation location must be specified by dividing the entire area requiring protection into surge voltage protection zones.

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