

App Note

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Power Protection in Countries with Unstable Ac Mains Voltages

Coordination of Telecommunications Surge Protective Devices in Countries with Unstable Ac Power



Zoned protection strategy

Abstract

The rapid growth of the world market for telecommunications equipment will continue for the next several years. Manufacturers of radio infrastructure and switching equipment are based in the USA, Europe and Japan with some minor exceptions. Yet, these manufacturers are often not familiar with power quality in places far away from their home countries. The needs for surge protective devices vary from market to market and are especially challenging in the emerging countries. Why? Surge protection in the USA and Europe is based on the assumption that the ac power-line voltage is relatively stable. Developing countries, however, often have inadequate infrastructures for the generation and distribution of electric power. The lack of stable ac power complicates the selection and coordination of surge protective devices considerably. This paper will review the new IEC surge protection standards and discuss how to achieve coordination of surge protective devices in accordance with IEC 1312 principles.



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Introduction

IEC standards are used throughout Europe and in many other parts of the world. CE marking is based on such IEC standards. CE marking involves both equipment safety and electromagnetic compatibility while UL only involves safety. Thus, all electronic equipment that carry the CE label should have been tested to withstand static electricity, electric fast transients and surge voltages. This paper will focus on the surge voltage aspects.

IEC 1000-4-5 is a Combination Wave consisting of a voltage waveform of $1.2/50 \mu\text{s}$ with an amplitude of 2000 V in normal mode and 4000 V in common mode, and a current waveform of $8/20 \mu\text{s}$ at 2000 A. The Combination Wave is identical to the U.S. ANSI/IEEE C62.41-1991 Combination Wave with the following exceptions: the ANSI/IEEE voltage is 6000 V and the current is 3000 A.

In the IEC standard, the equipment that is tested for surge immunity is referred to as the "vulnerable equipment." Hence, the term "vulnerable equipment" will be used in this paper. All "vulnerable equipment" must be able to withstand IEC 1000-4-5 without upset, thus guaranteeing a certain level of surge immunity, which will be sufficient for most office environments. IEC has developed a series of standards that apply to enhanced surge protection of equipment and structures in cases where built-in equipment surge immunity is not sufficient. Telecom installations in outdoor shelters and enclosures are good examples of when enhanced surge immunity is required.

This paper will review key aspects of the following IEC standards:

- **IEC 1024-1:** 1990 Protection of Structures Against Lightning -- Part 1: General Principles
- **IEC 1312-3:** Protection Against Electromagnetic Impulse -- Part 3: Requirements of Surge Protective Devices.

SPECIAL PROBLEMS IN DEVELOPING COUNTRIES

Fluctuating power line voltage

Causes

Overloaded, inadequate power generation and distribution systems, particularly when large step load changes are present, result in large voltage sags and surges. Voltage fluctuations between 155V to more than 310V have been observed in the field. Differences between day- and night-time voltage of 40V have also been observed.

Such conditions are common in Africa, India, Pakistan and China, but can be found in many other areas. Additional power plants and distribution infrastructure is needed in many developing countries. Timely power plant expansion is prevented by political and economic issues, which means the problem is here to stay for the foreseeable future.

Effects

- **Sags and undervoltages** can cause component overheating or destruction, which reduces the life and deteriorates the real reliability as opposed to the estimated reliability, based on steady-state conditions of the power supply
- **Swells and overvoltages** can cause component overheating and destruction of MOVs, SCRs and input capacitors that are rated too close to the line voltage. It is fairly common for power supply and telecom rectifier manufacturers to rate



input MOVs at 275Vrms with the apparent objective of reducing the surge remnant voltage, thus providing better surge immunity of the power supply. The author of this paper has observed still-functioning telecom rectifiers where the input MOVs had been completely destroyed by high line voltage. Boost converters can be destroyed by voltage swells that cause increased energy storage in the input filter, which charges the output capacitor to an unsafe level. The charge level is dependent on the value of the output capacitor and the load levels for the dc to dc converter connected to the output of the boost converter.

- **Poorly damped EMI filters** can dramatically magnify the effects of voltage disturbances. The result can be oscillations inside the EMI filter during transitional conditions. Severe voltage surges may result from energy released when saturated inductors are looking for a path to release energy.

Frequent lightning conditions

Review of IEC 1024-01

This standard relates to the protection of structures against lightning. A structure can be anything from a high rise building to an outdoor shelter containing telecommunications equipment. IEC 1024 introduces the concept of Lightning Protection Zones (LPZ). Figure 1 below illustrates the basic zone concept.

Figure 1

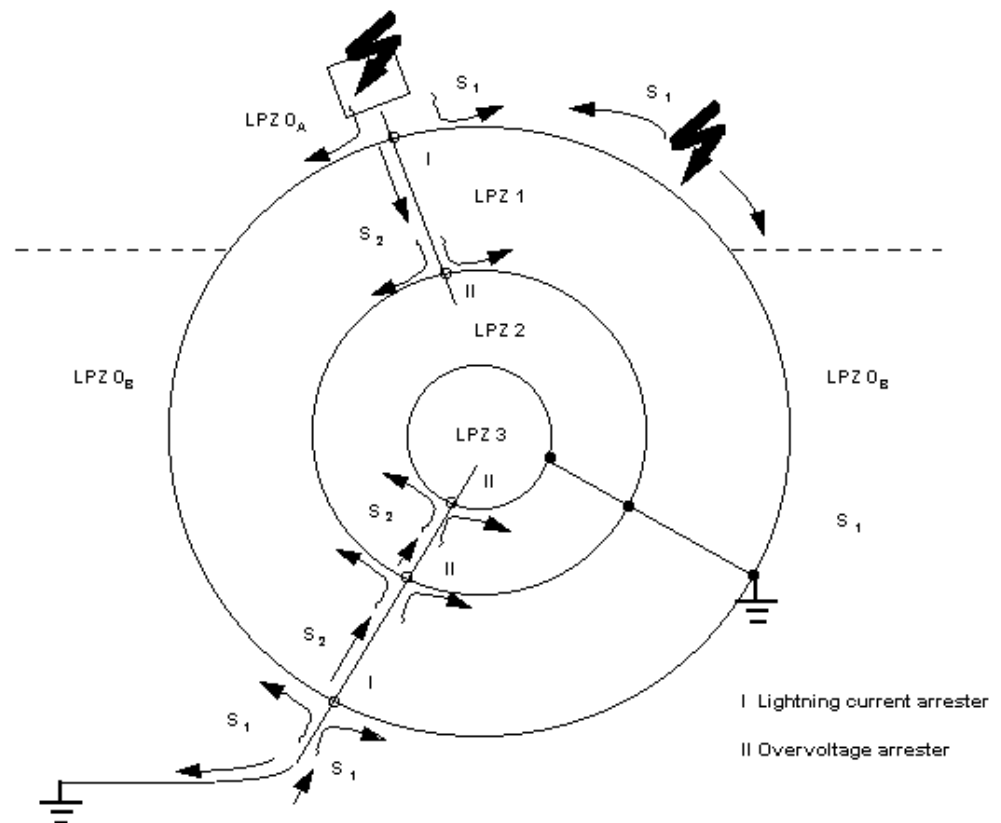


figure 1

The purpose of LPZs is to divert the surge energy from lightning and other disturbances away from the "vulnerable equipment." The majority of the energy should be diverted at the lowest zone boundaries. The number of required zones is determined by the physical properties of the structure and the sensitivity of the "vulnerable equipment."



Sensitive equipment installed in outdoor shelters, particularly when a poor physical ground is present, require a higher number of zones. Basic Lightning Protection Zones and surge current waveforms are explained below:

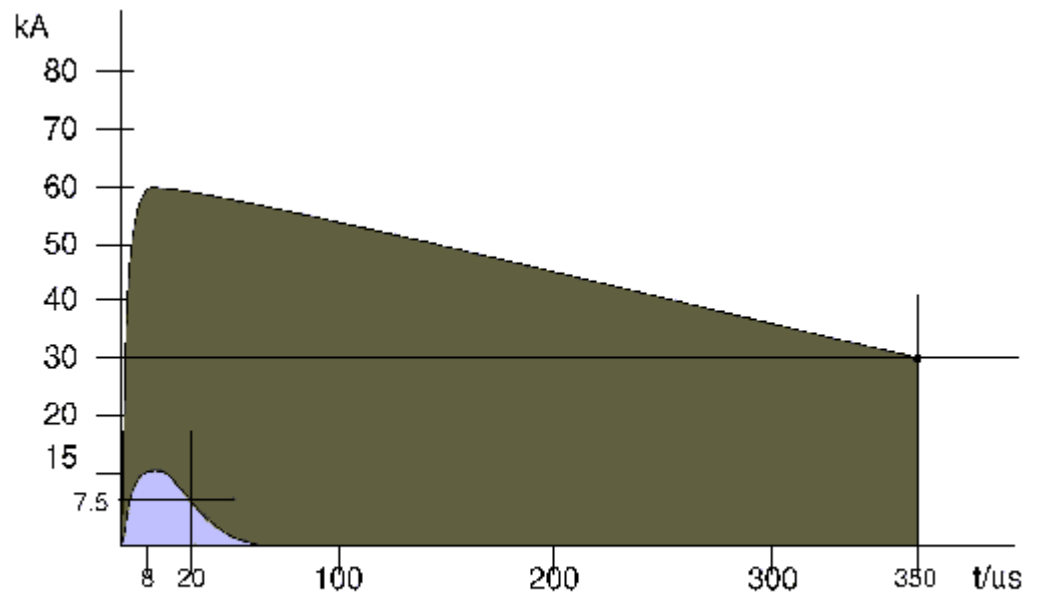
LPZ 0_A

This zone is subject to direct lightning strokes and may have to carry the full lightning current. The unattenuated electromagnetic field occurs here.

100 kA, 10/350 μ s 200 A, 0.5 s 25 kA, 0.25/100 μ s

Figure 2 shows a comparison between the 10 x 350 μ s test waveform and lower-energy Combination Wave.

Figure 2



LPZ 0_B

This zone is not subject to direct lightning strokes. The unattenuated electromagnetic field occurs here.

10 kV, 1.2/50 μ s 5 kA, 8/20 μ s

LPZ 1

This zone is not subject to direct lightning strokes and currents on all conductive parts within this zone are further reduced from previous zones. The electromagnetic field may also be attenuated depending on the screening measures.



LPZ 2

When a further reduction of conducted currents and/or magnetic field is required, subsequent zones can be introduced.

In general, the higher the number of zones, the lower the electromagnetic environment parameters.

LPZ 3

According to the author's interpretation of IEC standards, this zone should contain the protected equipment. The requirement for Zone 3 is that the remnant surge voltage does not exceed the test levels specified in IEC 1000-4-5:

Combination Wave, 1.2/50 μ s, 8/20 μ s 2000 A

Normal-Mode Voltage: 2000 V

Common-Mode Voltage: 4000 V

Review of IEC 1312-3

Lightning surges contain significant amounts of energy which needs to be diverted away from the "vulnerable equipment." Electronic equipment, if CE marked, is designed with a certain built-in surge voltage immunity in accordance with IEC 1000-4-5 — this level of immunity will be sufficient for the majority of office buildings when the "vulnerable equipment" is located far away from the electric service entrance. Thus, equipment that carries the CE mark will work well without surge protection in many environments.

However, when the "vulnerable equipment" is installed close to the electric service entrance, or in an outdoor enclosure, particularly in areas with a poor physical ground (dry sand, rock, etc.), it is often necessary to add external surge protective devices (SPDs). IEC recommends (IEC 1024) that lightning protection zones (LPZ) be established to successively reduce lightning currents, in stages, down to the built-in immunity of the "vulnerable equipment." The number of zones required depends on the structure containing the installation and the "vulnerable equipment." IEC 1024 requires that an SPD be installed at each zone boundary. The surge current and voltage ratings of individual SPDs must not be exceeded.

Purpose of coordination

To progressively reduce the lightning threat, in stages (SPD 1, 2 & 3) down to the surge withstand capability of the "vulnerable equipment," without exceeding surge current and voltage ratings of individual SPDs.

Coordination concepts

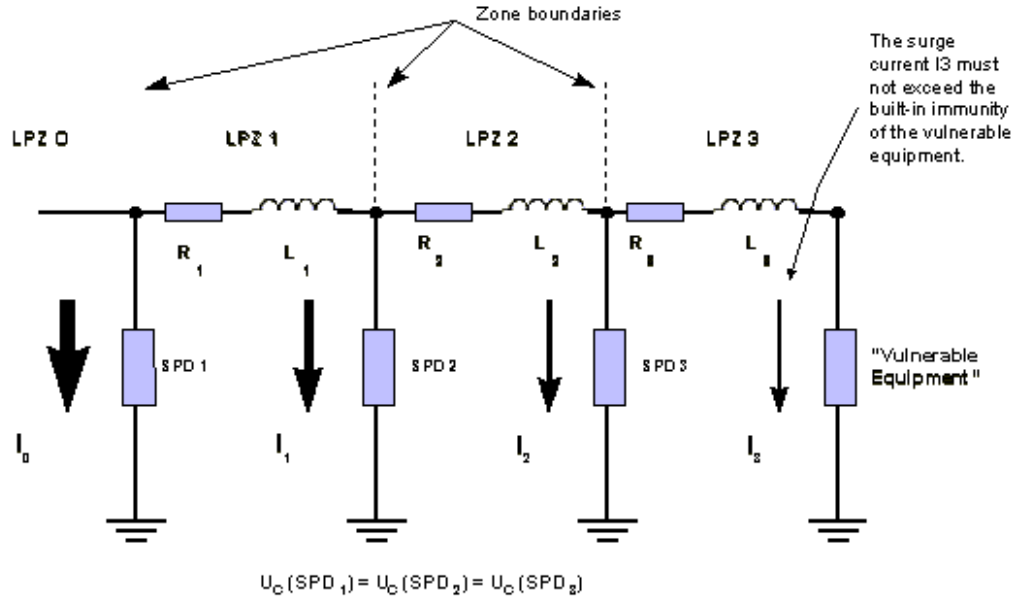
IEC 1312 defines four coordination "variants." The first three utilize individual single-port SPDs while the fourth variant is a two-port hybrid design.

Variant I

Shown in figure 3, the rated voltage of SPDs is identical and coordination is achieved by separating each SPD by means of series impedance.



Figure 3

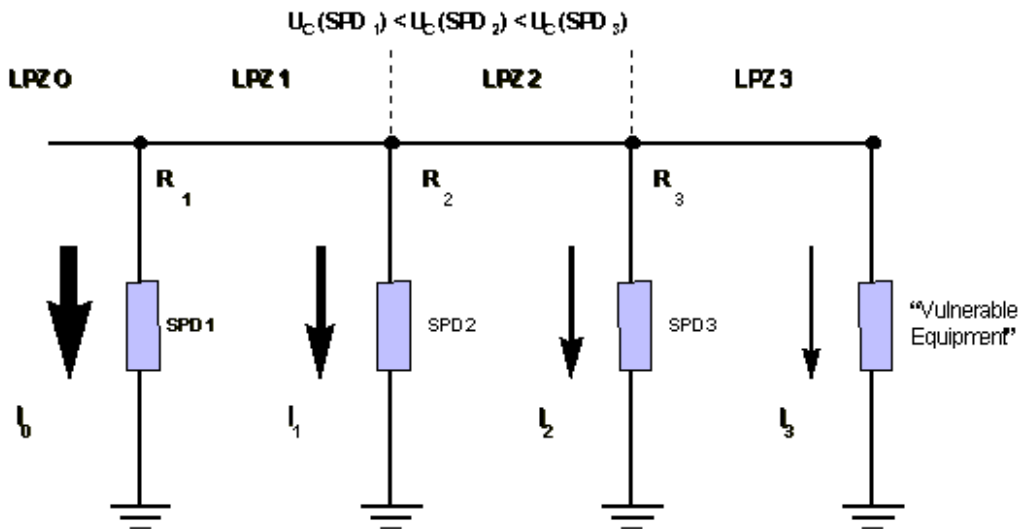


Variant I is not recommended by the IEC, probably because it would require approximately 30' (10 m) of wire or separate inductors between each SPD, which is not practical when installing equipment close to the electric service entrance or in outdoor enclosures.

Variant II

Shown in figure 4, the rated voltages of SPD's are stepped so that the SPD in the "vulnerable equipment" has the highest rated voltage and SPD 3, 2 & 1 have progressively lower rated voltages, thus assuring that each upstream SPD would divert progressively higher currents.

Figure 4



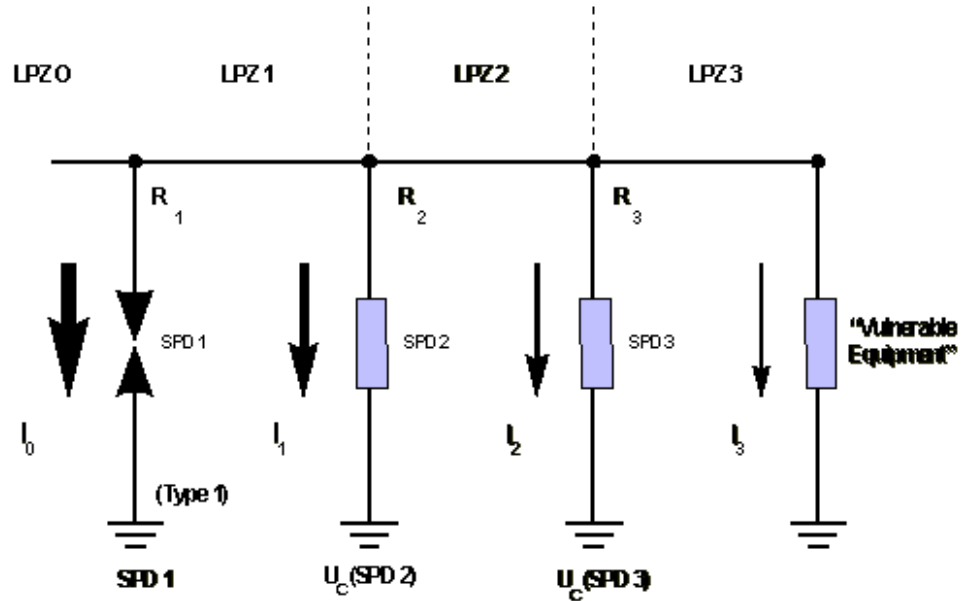
Variant II is difficult to implement as most power supplies, uninterruptible power systems and telecom rectifiers, rated for 230 Vac, use input SPDs with a 275 Vrms rating. Thus, stepping down rated voltage, would cause SPD 1 and 2 to be destroyed by normal line voltage fluctuations-experience has shown that fluctuations of plus 10% resulting in 250V is not unusual.



Variant III

Shown in figure 5, includes a component with a non-linear current/voltage characteristic, such as a spark gap. The SPD 1 spark gap would divert the majority of the surge current and output a Combined Wave, similar to ANSI/IEEE C62.41-1991, Category B3, Combination Wave, 3000 A, 6000 V, to downstream SPDs 2 and 3. The voltage ratings of SPD 2 and 3 are identical, but each device will handle considerably less current due to the much higher energy handling capability of spark gap SPD 1.

Figure 5



Variant III is a better choice than I or II as the spark gap is insensitive to fluctuations in line voltage. However, spark gap follow-on, short-circuit current may be an issue, and MOVs will still be sensitive to line voltage fluctuations.

Variant IV

Figure 6

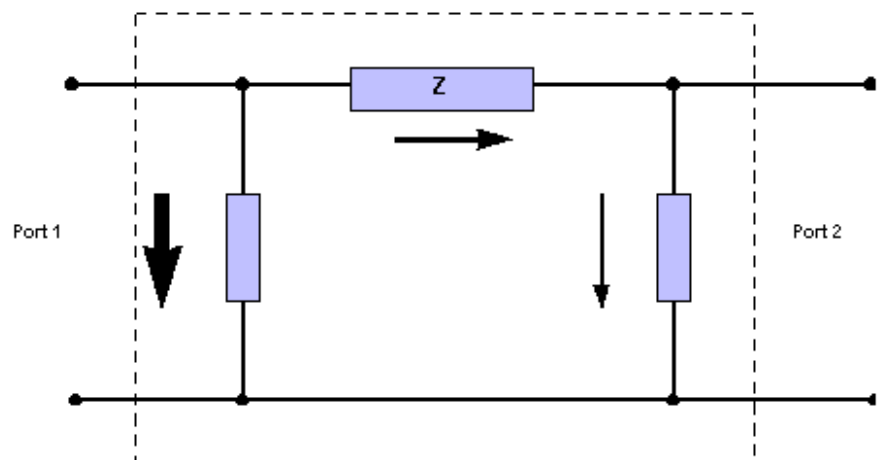


Figure 6 shows a two-port hybrid device that incorporates cascaded stages of SPDs internally coordinated with series impedance.



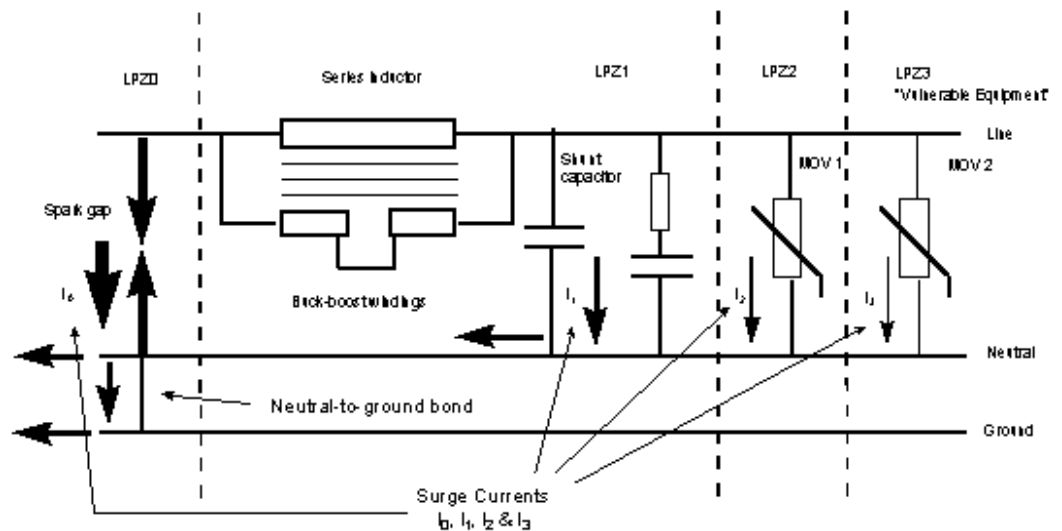
A hybrid device can be designed to maximize performance while reducing the undesirable characteristics of spark gaps and SPDs based on varistor or silicon-avalanche-diode technology. The use of a hybrid device eliminates the need to coordinate surge protective devices, but does not eliminate sensitivity to prolonged ac overvoltage.

Proposed hybrid device in accordance with Variant IV

The purpose of the circuit shown in figure 7 below is to provide, in a condensed space, the critical functions required for a universal ac power interface used in outdoor shelters for cellular, fixed wireless and other telecom equipment. The major functions required are outlined below:

- Surge protective device coordination for successive reduction of surge currents,
- High energy handling capability,
- Tolerance against high line voltage,
- Adjustment for local nominal voltage variation,
- Low dv/dt rise time,
- Function not dependent on performance of internal protection of "vulnerable equipment."

Figure 7



Discussion of circuit features shown in figure 7

The protection scheme is designed to work with an outdoor equipment shelter even when "vulnerable equipment" uses 275V MOVs as internal protection. In this case it is impossible to provide coordination in accordance with Variant II and Variant I is not practical, because the required wiring distances of 30' between SPD's are too short in an outdoor equipment shelter.

The spark gap is designed to provide primary protection within LPZ 0 and ignites when the surge voltage reaches approximately 2000V. The series inductance provided introduces the necessary coordination and reliable ignition of the spark gap. The output of the spark gap is a Combination Wave and is easily handled by the circuits in LPZ 1 and 2. Spark gaps can handle considerably more energy than MOV or SAD arrays and are not sensitive to line voltage fluctuations and are also more cost effective. The major disadvantage of a spark gap is the follow-on current which can cause tripping of upstream circuit protection devices. However, new-technology spark gaps based on the arc-chopping principle provide significant performance improvements.



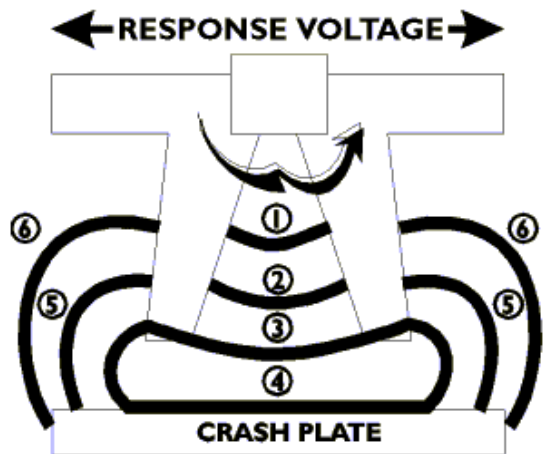
The new spark gap technology shown in figure 8 consists of two electrodes positioned opposite each other, held in place by a barrier and separated by a baffle. This arrangement and spacing of electrodes is called "arc chopping" and provides reliable ignition of the arc, which is then chopped by the baffle into several smaller arcs. Special versions with reduced follow-on current are available for branch circuits and services up to 75 kVA.

The neutral-to-ground bond provided at the service entrance or by a separate isolation transformer eliminates all surge voltages between neutral and ground and the requirement for SPD's between power carrying conductors and ground.

The series inductor with primary buck-boost windings provides static adjustment for different nominal voltages that can range from 200 to 250 V. The buck-boost windings can also be controlled automatically if the line voltage is chronically unstable. The series inductor also forms a two-pole filter together with the shunt capacitor. The filter reduces the surge voltage rise time (dv/dt) from 6 kV/μs to 10 V/μs thus providing considerable relief for the "vulnerable equipment." The filter which starts conduction well before MOV 1 also provides protection against electric fast transients and other line noise.

MOV 1, located within LPZ 2, is a 40-mm device rated for 275 Vrms, which is made possible due to the voltage adjustment provided by the buck-boost windings on the primary of the series inductor. In other words, MOV 1 is well-protected against premature failure caused by high nominal voltages. Now available in attractive packaging, easy-to-replace MOVs provide thermal disconnect and alarms in case of failure.

Figure 8



- ① Ignition at response voltage
- ② Electrical arc bridges the spark gap horns
- ③ Arc is forced down and outwards
- ④ Arc is chopped against the bottom crash plate
- ⑤ Formation of a partial arc
- ⑥ Breakdown and extinguishing of all arcs

Summary

This paper has reviewed IEC 1024 and 1312 standards for protection of structures against lightning and for coordination of surge protective devices (SPDs). Line voltage fluctuations outside of the typical regulation window of most power supplies have been observed in many developing countries. Methods for designing an economical power interface which provides hybrid surge protection for demanding international applications have been discussed. The hybrid circuit provides full coordination of SPDs while being tolerant to line voltage fluctuations.

About the Author

Mr. Peter Nystrom has been active in the power protection industry since 1979 and is the founder of two companies. He has also been active as a consultant to major telecommunication equipment manufacturers for several years. Since 1998, he has been the CEO of TSi Power Corporation (located in the state of Wisconsin, USA), a manufacturer of UPS, line conditioner, automatic voltage regulator, automatic transfer switches and dc to ac inverter systems designed to meet the challenging international power conditions.

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