A SIX POINT PROTECTION APPROACH FOR LIGHTNING PROTECTION, SURGE PROTECTION AND GROUNDING FOR LOW VOLTAGE FACILITIES

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Abstract

High energy over-current and over-voltage transients induced by direct lightning strikes or conducted into a site by power and telecommunication lines cause millions of dollars damage each year. Whilst no single technology can prevent damage, a six point protection approach provides a comprehensive check list covering all damage mechanisms. Commencing with effective means to capture, conduct and then safely dissipate the energy in direct lightning strikes to ground, the plan continues with clamping and diverting transients arriving at the site via external cables.

The importance of capturing the drect lightning strike on a purpose designed air terminal is explained. Lightning currents (up to 200 kA) can then be conducted directly to ground via purpose designed down conductors, while minimising the dangers of "side flash".
In addition to surge protection and transient product technologies, the need to provide a low impedance ground plane throughout the site is emphasised. A single point ground connection for all equipment within a facility is recommended. This reduces the likelihood of earth loops or "sneak" potential gradients induced by the high frequency, high dI/dt and dV/dt transients.

Transient protection technologies for equipment connected to mains power are discussed. Communications equipment, data processing and signal equipment has additional protection requirements.

1 - THE PROBLEM

Lightning and over-voltage transients cause millions of dollars damage to low voltage installations each year. Damage to equipment in the US alone was estimated to US$1.8 billion annually, before including the loss of productivity from industrial and business downtime.

High energy over-voltage transients may be derived from direct lightning strikes to building structures or they may be conducted on power and telephone cables entering buildings and facilities. Induced transient over-voltages may also originate from near strikes due to capacitive or inductive coupling.

- Peak currents can exceed 200 kA with 10/350 µs waveshape (I.E.C. 1024-1).
- Current rise times vary between 0.1 - 100 µs.
- Multipulse surges are experienced in over 70 per cent of direct strike situations. This is a naturally occurring phenomenon where up to 20 restrikes may follow the path of the main discharge at intervals of 10-200 milliseconds.
- Continuing currents of 200-500A lasting 1-2 seconds may also occur.

2 - SIX POINT PROTECTION PLAN

There is no single technology that can eliminate the risk of lightning and its transients. A holistic systems approach is required. From over 20 years experience in examining the nature and extent of damage created by lightning transients, ERICO Lightning Technologies has developed a comprehensive Six Point Plan to minimise exposure to damage.

The **Six Point Plan** recommends

1. *Capture the direct lightning strike* at a preferred point on purpose-designed air terminals;
2. *Conduct the lightning current to ground safely* via a purpose-designed downconductor system to minimise the dangers of side-flashing;
3. *Dissipate the energy into the ground* with minimal rise in ground potential through a low impedance grounding system;
4. *Eliminate earth loops and differentials* by creating an equipotential grounding plane under transient conditions;
5. *Protect equipment from surges and transients on power lines*; and
6. *Protect equipment from surges and transients on communications and signal lines* to prevent equipment damage and costly operational downtime.

Figure 1 shows a schematic representation of comprehensive lightning and surge protection for a typical low voltage facility.

2.1 - Point 1: Capture the lightning strike

The first point of the Six Point Plan involves capturing the lightning strike to a preferred point on purpose-designed air terminals.

In general, the most vulnerable point to direct strike is located at the highest point or corner of a structure where some electric field intensification will occur under storm conditions. Satellite or microwave dishes and communications antenna systems and their control equipment are typically vulnerable to direct strikes.

By correctly installing a purpose-designed air terminal on the top of the structure, direct lightning strikes can be attracted to a preferred point which is away from antennae and cabling to minimise the risk of damage to equipment from the direct force and energy of a lightning discharge.

The patented Dynasphere is an effective air terminal which intercepts lightning discharges at a preferred point ***earlier*** than conventional lightning protection techniques. This air terminal was developed from research into the formation of corona and space charge effects around grounded points during the millisecond time-frame prior to the development of lightning upward streamers.

The Dynasphere's floating sphere construction is passive on approach of a storm, and produces minimal corona.

In the milliseconds prior to the approach of a lightning down leader it becomes active through capacitive coupling, it absorbs energy and assists in triggering an upward intercepting discharge to capture and control the main downleader.

Lightning can then be drawn to the downconductor system to enable the safe transfer of energy to ground.

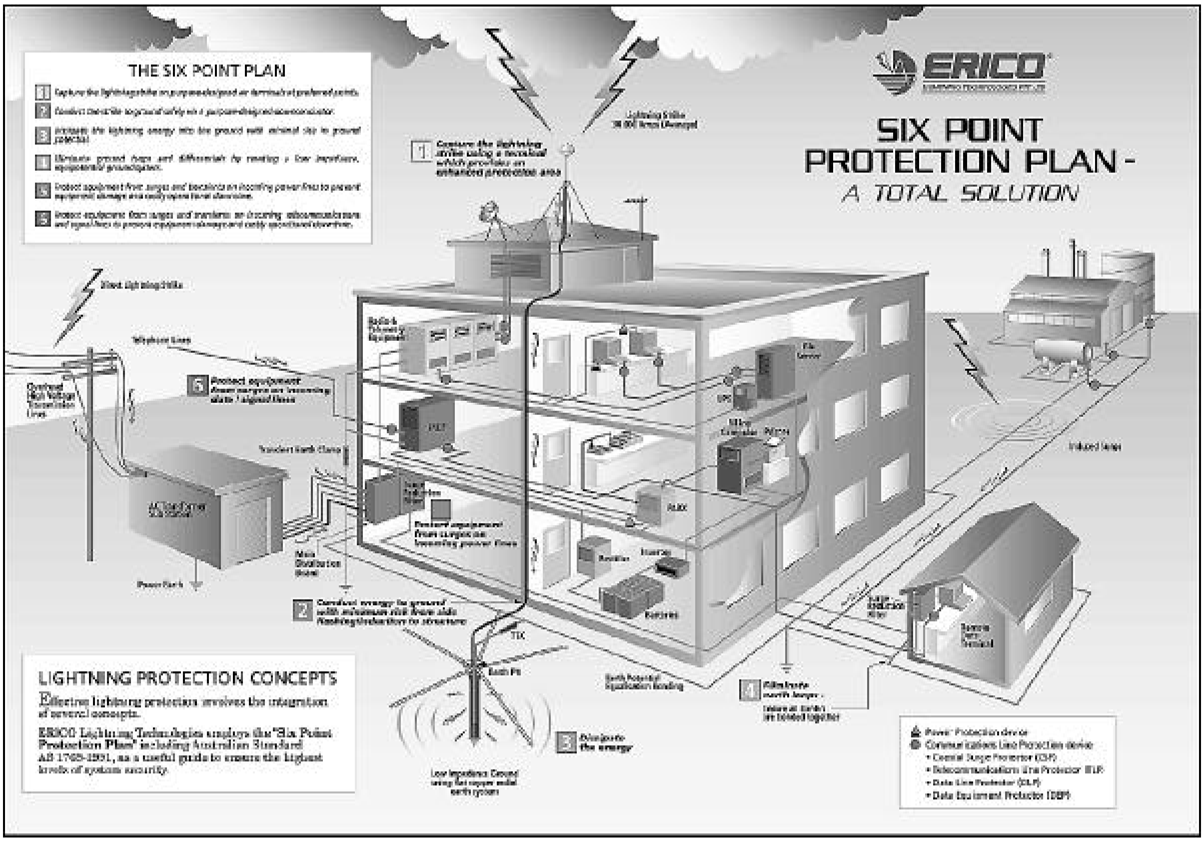

Figure 1 -Comprehensive lightning and surge protection for a typical low voltage facility.

2.2 - Point 2: Conduct the lightning current to ground safely

Once the lightning has been captured at a preferred point, it is necessary to convey the discharge current safely to ground, and to minimise the conduction of lightning currents on ancillary conductors such as coaxial feeder cables as these can carry dangerous lightning energy directly to equipment racks.

ERICO has developed a purpose-designed, screened, downconductor cable to reduce the risk of "side-flashing and to contain the discharge to a central core conductor during a strike. In a radio base situation, this purpose-designed downconductor has the ability to reduce risks associated with conducted currents entering equipment rooms via RF feeder cables.

2.3 - Points 3 and 4: Dissipate the energy into the ground and eliminate ground loops and differentials

Once the energy is conducted to ground level, a low impedance ground is essential to dissipate the lightning energy into the earth mass as effectively as possible. The grounding systems for dedicated lightning protection terminals, tower footings and electronic equipment rooms or control centres are critical design elements.

Attributes of an ideal grounding arrangement are considered in Figures 2 and 3 and below:

- Each grounding system (lightning, electrical, communications, and equipment room) must be individually of high integrity, as well as being considered a component of an overall grounding network. Where separate grounds exist, they should be bonded together (especially under transient conditions). Bonding of all grounding systems is required by Code in the US.

- Because lightning is a high frequency event, it is the high frequency "impedance" that is the critical design element, not the D.C. resistance.

- A ground ring should surround sensitive electronic equipment rooms, industrial plants and telecom facilities. This will reduce the risk of potential gradients across the facility.

- The lightning protection ground should be directly bonded to the facility ground ring.

- There should be a **"single"** point connection to the ground network from all equipment within a facility. Figure 2 shows an example of a well-designed grounding system with a "single" point connection of mains power and communications equipment ground wires to the ground ring. If a surge arrives at the facility via the mains power supply, the surge protection equipment will divert excessive energy to ground, and the telecommunications and lightning protection grounds will rise equipotentially with all other grounding / ground points as they are closely bonded together. There is therefore little opportunity for potential differences between ground points creating earth loops, or causing sparking or sideflashing.

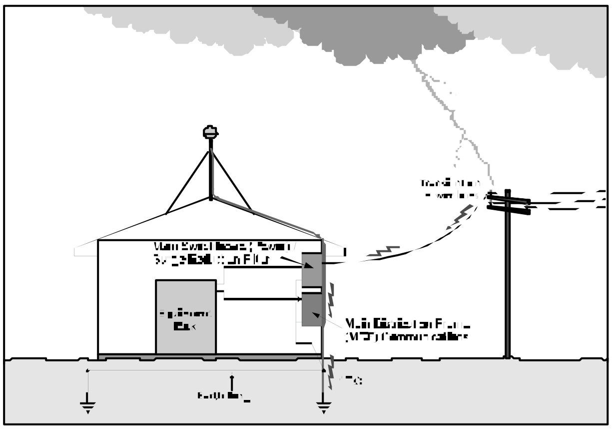

Figure 2 - Preferred grounding system.

Figure 3 case shows a "non-preferred" system with multiple connection points to the ground-ring. Although adequate protection equipment on both the power and communications interfaces is provided, the separated electrical and communications grounds are located some distance apart (as shown by the parameter 'd'.) Regardless of the impedance of each individual ground, for a very short time the potential of the electrical ground will be higher than the communications' ground. As a result the excess energy has two potential paths to follow to reach the lower potential communications' ground, thus creating a dangerous 'earth loop' that will damage sensitive electronic equipment in the equipment room.

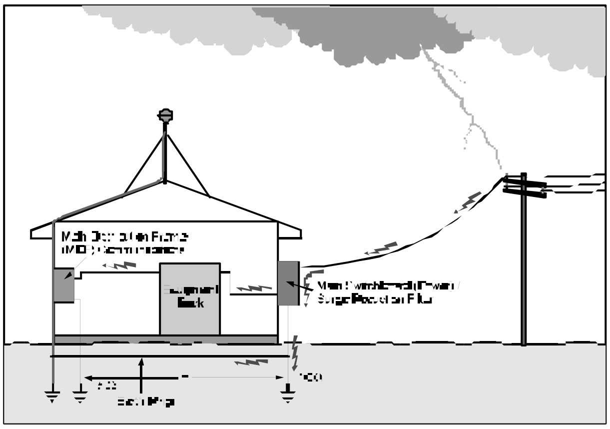

Figure 3 - "Non-ideal" grounding system - currents in an earth loop can damage sensitive electronics through magnetic induction.

- The use of "crows foot" radial grounding techniques for the lightning protection ground allows the lightning energy to diverge as each conductor takes a share of the current. This can lower impedance and means that voltage gradients leading away from the injection point will be lower and there will be reduced danger from "step potentials" affecting equipment or people.

- Electrolytically copper-plated steel, galvanised steel or stainless steel ground rod provide cost-effective grounding anchor points and electrodes for most standard applications. Solid ground plates, steel grates, safety mats, ground (mesh) grids, custom-designed terminals, braids and bridges are used in grounding and bonding applications for high-voltage or heavy current environments such as near industrial furnaces or around electrical substations.

- Special compounds can be used to reduce grounding impedances at locations where the ground resistivity is high such as in rocky, sandy or mountainous areas with large particle soil sizes. Ground impedances can be reduced by measures in excess of 50 per cent when GEM (ground enhancement material) or EEC (earth enhancing compounds) are used to form conducting masses or non-soluble gels around ground rods and tapes. Approved non-leaching compounds, which do not contaminate ground water or surrounding soils by releasing conductive ions (salts), are available in order to meet environmental standards.

A number of technologies are available, to assist in the construction of effective "best practice" ground grids or grounding systems.

- CADWELD® - exothermic molecular bonding processes (copper-to-copper or alloys and copper-to-steel or alloys) for grounding, lightning protection and cathodic protection systems provide connections that are
  - permanent, robust;
  - low impedance;
  - corrosion-free;
  - and cannot loosen or weaken with age.

  The CADWELD molecular bonding process (including over 35,000 different applications) means full current carrying (fusing) capacity for connections **at least equal** to the capacity of conductors in a grounding network. These connection processes satisfy IEEE Standard 80 - 1986 (Grounding) and IEEE Standard 837 - 1989 (Connectors).

- The use of a pre-fabricated, low-impedance signal reference grid (SRG) grounding network inside a specialised shelter is highly recommended to create an equipotential plane for high frequency, low voltage digital signal installations. Typical examples of such applications include intensive computer, telemetry and telecommunications facilities. Because digital signal line voltages are typically low, their sensitivity to transient noise is very high: typically 1 volt for some digital systems.

The SRG should provide bonding between interconnected computer, switching, transmission and power supply equipment to provide an equipotential "ground" at frequencies from DC to over 30 MHz. All SRG connections should be welded because even a momentary loosening or separation of a mechanical connection can create high noise voltages which may introduce false data or destroy circuits. The SRG complies with IEEE Standard 1100-1992 for grounding practices in sensitive electronic environments. (AT&T recently specified SRG when consolidating more than 400 computers and other equipment in their Denver "hub" to service Western USA customers, and Goldman Sachs & Co., the New York City investment banking firm, similarly installed SRG when re-locating its data centre to new facilities in Brooklyn.)

A number of indicative tests are available to diagnose grounding problems and to evaluate the true transient performance of a grounding system prior to a real lightning event.

The ERICO Earth Systems Analyser™ can provide data in assessing the performance of a grounding system by :

- providing a measure of soil resistivity;
- providing a measure of grounding system resistance (in low frequency DC test mode);
- providing a measure of impulse impedance which will indicate the peak voltage rise expected for a given lightning (transient) current; and by
- providing diagnostic path tracing capability to determine the relative magnitude and direction of lightning currents passing to ground. The aim here is to ensure that the majority, if not all, of the transient current travels to ground via a preferred path, which will not cause damage to equipment or be a risk to personnel.

These tests using the Earth Systems Analyser provide a comprehensive indication of the likely performance of an integrated grounding system.

2.4 - Point 5: Protect equipment from surges and transients on power lines

Even if a structure is provided with an integrated direct strike protection system, there remains the risk that overvoltage transients may arrive via external cables. High energy over-voltage transients can arise from capacitive and inductive coupling from nearby lightning strikes in addition to power switching and from irregular power distribution. Efficient clamping and filtering of power transients at the point-of-entry of power lines to facilities is essential to minimise the risk of physical equipment damage, loss of operations and economic loss.

Simple surge diverters installed at the mains switchboard may not provide adequate protection. In order to protect sensitive equipment, it is necessary to limit residual voltages to within the immunity level of the internal equipment. For equipment operating on a 230 V_{RMS} system, component damage may result from transients with peak values as low as 700 V. Many manufacturers of battery chargers and rectifiers state a peak tolerance under 800 V.

Whilst some shunt-only devices can clamp at below the recommended voltages, they do little to limit the fast rising wavefront energy (dI/dt and dV/dt) prior to the onset of clamping. Rates of current rise can be as high as 10 kA/µs (10^{10} A/s) from the initial discharge of lightning and an order of magnitude higher for subsequent restrikes in multiple strike lightning. These very high dI/dt and dV/dt values can induce destructive high voltages across components, leading to equipment damage and failure.

Suitably designed low pass filter technologies following the primary shunt diverter will reduce the peak residual voltage and dramatically reduce the rate of current and voltage rise reaching the equipment. Proline Surge Reduction Filters (SRFs) and DINLINE filters (for sites with smaller current loads) provide multistage surge attenuation by clamping and then filtering transients on power lines.

Proline SRFs manufactured by ERICO Lightning Technologies feature Movtec™ primary transient protection. Movtecs incorporate arrays of Zinc Oxide Varistors (MOVs) with individual end-of-life disconnect fuses. Continuous monitoring on a 5-segment LED panel shows the life-time status of the device. In the SRF, an efficient low-pass filter follows the Movtec to modify the rates of current and voltage rise reaching downstream equipment.

Table 1 shows typical residual voltages and rates of change of voltage for various technologies.

This superior level of protection offered by Surge Reduction Filters means enhanced operational reliability for electronic and telecommunications equipment connected to mains power supplies downstream from the surge filter.

2.5 - Point 6: Protect equipment from surges and transients on communications lines

Coaxial surge protector (CSP) devices are important to protect against transients tracking from towers directly to transmission and telemetry equipment via radio feeder cables. Although a purpose designed downconductor confines the vast majority of the lightning current, some induction to coaxial feeder cables will occur with strikes to towers or as a result of magnetic and capacitive coupling from the air channel component of a lightning strike.

CSPs are based on gas arrester devices housed in a chrome plated brass block. These devices are precision machined for impedance matching with the coaxial cable. They provide protection at typical power ratings of 50 W (continuous) and operate at frequencies up to 3 GHz. Typically, CSPs should be mounted directly into grounded bulkheads at the point of entry of feeder cables into the facility to provide maximum protection. Other installation arrangements are however possible.

Protection of land based telephone, signal and data lines into the facility may also be an issue for comprehensive protection. Transients up to 20 kA (8/20µs) injected onto telecommunications and signal lines can damage and destroy sensitive terminal equipment and lead to facility down time.

Telecommunications line protectors (TLPs) are designed to protect terminal and interface equipment from transients conducted on telecommunications lines.

- Single-stage, "gas arrester only" circuits provide cost-effective protection for less sensitive electro-mechanical or discrete component-type terminals and supplement circuits with "built-in" protection.
- Multistage stage protectors employing primary gas arrester and secondary decoupled semi-conductor protection stages can provide lower clamp (let-through) voltages than single-stage protectors. These devices are suitable for more sensitive analog equipment and for PCM digital circuits operating at up to 8 Mbits/s or 12 MHz.

3 - SUMMARY

Direct lightning strikes and over-voltage transients create major equipment failures and cause downtime at telecommunications and radio sites where there is little or no purpose-designed protection fitted.

Analysis of damage has shown that no one protection device can provide lightning immunity. Comprehensive protection is provided only by employing an integrated Six Point Plan approach.

ERICO Lightning Technologies has over 20 years experience in examining the nature and extent of lightning and transient damage to equipment and are pleased to offer more detailed advice on lightning and transient protection solutions. Prevention is better than cure.

Technology	Residual Voltage (V) Applied Impulse 20 kA 8/20µs	Applied Impulse 70 kA 8/20µs	dV/dt applied to equipment at 20 kA 8/20µs (V/µs)
32 mm “25kA” Block MOV	1,400 V	Failure	1400
60mm “70kA” Block MOV	1,050 V	1,500 V	1100
Critec “135 kA” Shunt Movtec	790 V	1,100 V	700
SRF363F “135kA” Proline Movtec Filter	510 V	700 V	6 to 9

Table 1 - Typical Residual Voltages and Rates of Change of Voltage.