INVESTMENT IN LIGHTNING PROTECTION FOR EQUIPMENT SURVIVAL - WHAT COST ?

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There has been a substantial deployment of sophisticated electronics for ITS and traffic applications in the recent years. In both cases there is a significant mortality rate of equipment, due to a great extent, from lightning and electrical surges. The investment into protection systems can be directly related to the installed lifetime costs associated with failure. This article-discusses the issues to be considered for the investment required, as a function of the equipment capital cost for a surge and lightning protection system.

There are a number of subjects to be investigated when determining the amount to be spent on a protection system. Remember that the protection system is failure prevention, not insurance. To get to a logical conclusion, consideration must be given to the cost of the equipment being installed, the strategic importance of the equipment, ease of repair and the vulnerability to surge and lightning of the location. Lastly; if the systems fail during lightning activity associated with severe weather, it is probably one of the times that the system performance is critical.

In order to conclude a good investment strategy and cost for the protection system, we need to determine the "right" amount of protection to install.

A well designed protection system will prevent damage from lightning and surges:
Surge protection and earthing systems are proven to prevent the damage from lightning related surges in Florida USA over decades of electronic equipment deployments. So we know they work. User specifications of protection systems vary dramatically causing some equipment to be badly under-protected while others are a gross overkill. It is important to understand what needs to be installed and why. Unfortunately, the subject is considered low technology, not demanding enough detailed attention. As a result, it is often littered with myths and misunderstandings.

In order to determine the cost of a protection system we must clearly understand the functions of each part, and the maximum risk that can be encountered.

There are a number of issues to review for a system design that will be economic and adequately protect the equipment. We start by reviewing the functions of a surge protector and the relationship between the surge protectors and earthing system.

Types of failures
There are three consequences of surges on equipment; **first** is a catastrophic failure, **second** is eroding a product's MTBF (early failure), and the **third** is data disruptions or corruption.

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Gas-tube and MOV AC protection – grosslyinadequate

Functions of a surge protector:
A "voltage sensitive switch" is a simple description of an SPD. When a surge or over-voltage is detected, greater than it's maximum continuous operating voltage, (MCOV), the SPD will transition from a high impedance (passive) device into a low impedance conductive device. When this happens the SPD will "shunt" the current away from the equipment being protected, and "equalize" the voltage or potentials on the connected lines and earth. When the potential on the line returns to normal the SPD will return to a passive, high impedance state. "All of this happens in nano-seconds."

Equalizing the potentials on all associated lines removes the risk of "flash-over's" which is frequently the cause of fatal damage once the SPD has failed.

What is the significance of a low let-thru-voltage ?:
As you can deduce, the over emphasis on "let-thru-voltage " while under specifying surge current capacity is focused on the potential interruptions, and ignoring the expensive damaging issue. LTV is important, however, one has to understand that the LTV will increase with the amount of current in the surge. Therefore the question has to be, is an SPD rated by UL as a 330v better than a 400v device?" In terms of the UL 1449 2nd edition tests, using a 500A pulse, we can see that we are only reviewing a tiny portion of the risk. The LTV at 3,000A or even 10,000A, which are the IEEE C62-41 category B & C risks, can easily be over 600 volts for a 120 volt system. The easiest and most cost effective way to ensure a low LTV is to have two AC SPD's installed, a primary and secondary. This is a cascade that ensures the secondary can control the LTV to a low level, because it is dealing with a low energy surge current at optimum performance.

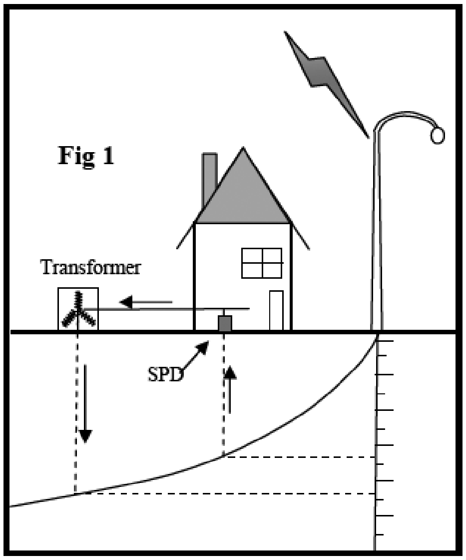

Fig 1

Bi-directional surges:
Most people understand about surges on a connected power or communications line. In this case, the SPD will divert the current component to earth while equalizing all potentials, thus preventing flash-over.

Now let us consider the lightning attachment point being nearby, such as the street light shown in Fig 1. The ground potential is elevated at the street light base, which can be 100's of kV and 10's of kA. This energy does not dissipate instantly, but charges the ground for some finite amount of time as if ground is a capacitor. The charge dissipates uniformly in all directions and will energize the ground rod of a nearby structure, which in turn is connected to the earth terminal of the installed SPD. In the case of a power line the neutral at the transformer is connected to ground at some distance away, which is at a lower relative potential than the house

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ground. Under these circumstances, the utility path to the transformer ground is a significantly lower impedance path than through the earth itself. The route through the SPD may be a few Ohms, whereas the route through the earth could be many megOhms. This is the popular idea that "lightning follows the route of least resistance". The energy will want to choose this low impedance path, via the surge protector to flow to the transformer earth. This is the surge wanting to leave the site, as opposed to the popular view that the surges a delivered on connected lines. The surge protection device used in this AC power example must be able to shunt or carry the huge kA's of current (charge) stored in the ground, and survive. If it should fail, the charge will flash over to some point in order to connect to the transformer ground causing catastrophic damage. It can be seen that the SPD is a bi-directional device, and that surge current capacity is key to SPD survival. Therefore the protection system's overall effectiveness.

Surge current capacity:

There is a lot of emphasis on the performance of the surge protector device, (SPD), in minimizing the let-thru-voltage, (LTV). This is related to data disruption and eroded MTBF, and not enough on the surge current capacity of the device chosen. Most catastrophic failures occur when the SPD fails, often because it just doesn't have enough surge current capacity to handle the surge. Once the surge protector has failed, the surge will cause fatal damage. Energy leaving the site via a connected line, is described in IEC 61312-3 which defines the maximum surge energy risk as 200 kA. IEEE C62-41 also refers to the mechanism as "scenario 2," but does not quantify the magnitude of the risk. Therefore, in order for site to survive a direct or nearby strike, the AC surge protector needs to have a surge current capacity of over 100 kA

Earthing and Grounding Systems:

Now we come to consider the earthing / grounding part of the lightning protection system. The surge protection and earthing system function as a fully integrated system. The SPD diverts current into the earth in one direction or shunts the earth charge off-site to a distant lower potential earth at the transformer or communications point in the other.

There are various specifications for the impedance of the earthing system ranging from 5 Ohms to 25 Ohms in some cases. There is usually extra-ordinary effort put into the design of earthing systems, often at the neglect of the SPD's.

One of the classic misunderstandings is that the performance of the earthing system is the only critical issue in a protection scheme. It is reasonable to postulate that this comes from the importance of a good safety earth in order to minimize the risks of injury to people, and damage to facilities from a direct strike. This is counterbalanced by the NEC Article 250 of a 25 Ohm earth for the N-G bond and safety earth, while the Lightning Protection Institute (LPI) suggests that up to 50 Ohms can be acceptable. How did we get to a specification requirement of 5 Ohms or less? One can only speculate that this relates to either a safety earth for a "Ground-fault current path," by utility transmission lines or older analog telecommunications equipment, with a concern that the 60Hz hum may get onto the transmission bridge. The reader is left with the decision to specify somewhere between 5 and 50 Ohms as acceptable.

Irrespective of the impedance specified the following rules must apply:

- Single point grounding is the only method to be considered. There can be multiple ground bars, but they must all be interconnected and bonded.
- All metal structures on the site must be interconnected. The interconnection should not exceed 0.1Ω(IEC 60950)
- Multiple ground rods must be spaced twice the length of an individual rod in order to optimize efficiency.
- Ideally use exothermic weld connections.
- Bond the electrical safety earth to the site earth system.
- Ensure that all SPD's are referenced to the single earthing system.

5 Ohms or 50 Ohms, what do you need ?

There is not one standard ground resistance threshold that is recognized by all agencies. However, the NFPA and IEEE have recommended a ground resistance value of 5.0 Ohms or less. The NEC has stated to "Make sure that system impedance to ground is less than 25 Ohms specified in NEC 250.56. In facilities with sensitive equipment it should be 5.0 Ohms or less." The Telecommunications industry has often used 5.0 Ohms or less as their value for grounding and bonding.

The proliferation of cellular transceiver sites throughout the USA have been a good model. Most major cellular companies used contractors to build out their systems with as many as 5,000 sites per year. It has been typical for the cellular engineers to design the earthing system by specifying the actual earthing design that would be installed at each site, irrespective of the location in the USA. This included the number and size of the ground rods, their spacing and the interconnection between them. Even

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NEC specifies a 25 Ohm earth but more importantly, 2 x 8 foot ground rods (250-56). If 2 rods are installed, there is no requirement to verify 25 Ohms or less. This indicates that the actual impedance of the earthing system for electronics is less significant than many believe, as long as it is matched with adequate surge protection. This also simplified the installation and inspection process by removing the requirement to measure the earth impedance at each site. It is clearly understood that the impedance will change with soil type, moisture content and temperature which mitigates the desire to bicker with a contractor over the end result being 1 or 2 Ohms over specification. In addition, this takes away the earthing design function from the contractor. Not everyone will agree with this process, however, it has been extremely successful in the construction of over 200,000 cellular sites across the USA.

This clearly shows that the system design, the SPD's and earthing system, MUST function as a complete integrated lightning and surge protection system. Remember, the SPD's divert the surge current from a connected line to the earthing system to be safely dissipated and the SPD's shunt or carry the current off site and equalize potentials when the ground potential is elevated from a nearby lightning strike.

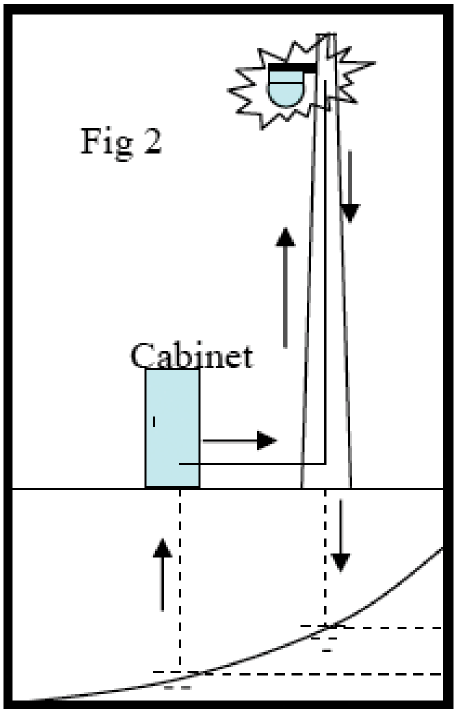
Fig 2

An example to consider:

Let us now consider an example of a protection system using a CCTV site. First review the three mechanisms that cause the damage as it relates to a camera pole installed on the side of the highway with the electronics mounted in a cabinet nearby. These fall into three basic areas, irrespective of the device being protected.

- A surge on a connected line, such as Power, Telco or Data.
- An induced surge, EMP from a nearby strike, into any one of these lines.
- Elevated ground potential from a direct or nearby strike. (see Fig 2) where there is a flash-over between camera and the pole.

The Engineer, when reviewing any site installation or protection design, needs to consider the risk of each of these mechanisms and ensure that each is adequately protected against.

In this example, (Fig 2 typical), we can see that all three risks are present. By mounting the electronics cabinet onto the pole, it will alleviate the risk of an earth potential difference and will greatly diminish total risk, but surges to the site on connected lines and induced surge risks are still present.

At this point the reader has a clear understanding of the magnitude of the maximum energy in a lightning related strike up to 200 kA, far beyond the IEEE C62-41 "C" class risk of 10kA, also a clear understanding of the functions of the surge protector and the coupling mechanisms that cause the damage.

Selecting and specifying surge protection:

Now we must consider a rational surge protector specification that will provide a high probability of survival. To do this we must separate the applications into the AC power and separately the communications, data, network or video.

Knowing that the energy in a lightning strike is a variable between 5 – 200kA and EPRI studies have shown that the median energy for a negative first stroke in a flash is 35kA, the AC power SPD needs to have at least 50kA of surge current capacity in order to be able to handle a reasonable elevated ground potential charge. The cost of an SPD that increases this capacity to 80 or 150kA is negligible and should be carefully considered. Serious consideration should be given to a primary / secondary AC SPD combination. The primary connected in parallel to the load and the secondary connected in series. This will minimize the let-thru-voltages, (LTV), that can occur with large surge currents. The motivations for two AC surge protectors is based on the knowledge that the higher the current in the surge, the higher the LTV of a single SPD device. A second SPD, of the same or similar technology will control the LTV down to a consistent, low level, very economically. The principle is to ensure that the surge protector survives and provides optimum performance.

Selecting a communications or data surge protector:

When selecting a SPD for communications, data or video we have a different issue to consider. This is the size or gauge of the wires being used. It is prudent to install series connected multi-stage hybrid SPD's with a surge current capacity of about 10kA. This ensures that the SPD is the weak link in the system. If the surge current exceeds 10kA the SPD will fail and isolate the equipment, because it is connected in series with the line. This will further protect the equipment. If the SPD is capable of handling larger surge currents, the risk is that the SPD will survive, but the site cabling will become the fuse link and melt the wiring. It is far more economic to replace the SPD, under warranty, than to rewire a site.

In all cases surge protection must be installed. What is often neglected is the need to install surge protection at both ends of EVERY circuit to/from a site, not just the video connection, but the camera power and PTZ data circuit as well. SPD's in the cabinet are referenced to the cabinet ground, while SPD's on a pole will be referenced to the pole ground. This mechanism can be seen clearly in Fig 1 & 2. If SPD's are mounted in a cabinet with the camera electronics, but neglect to install SPD's at the camera end, then all the elevated ground potential and current will be shunted in the cabinet by the SPD's and sent to the camera. This will cause a flash-over between some metallic part or port of the camera and the metal pole's ground reference. Often burn marks can be seen on the metal clamp of damaged cameras. Obviously mounting the camera on a concrete pole will reduce this risk and a wooden pole will reduce it even more. Unfortunately the complexity of many installations, including stay wires, span wires and lightning rods, (air terminals), with down conductors makes the need to have a standard SPD installation configuration a sensible solution.

The cost of failure:

This consists of both direct and indirect cost. The direct cost is relatively easy to estimate as there is generally enough history and records that can be used that

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are tied to the maintenance budget. From this, one can derive the failure rate, cost of replacement and labor costs for the repairs. This has to be separated from any “preventative maintenance” costs and costs attributed to non-lightning or surge related damage, but we do know that a typical “truck roll” costs about $375.00. The indirect costs are a little more complex and will need some creativity. When we consider that one of the main objectives of any ITS or traffic system is to optimize traffic flow and minimize congestion. Keeping the system functioning is a key issue. There have been many publications that provide the overall cost of congestion on the economy that are in billions. It is difficult to relate this down to a system or site outage cost per hour, but it may be enough just to acknowledge that there is an intangible cost, however, the American Road and Transportation Builders Association, (ARTBA), tells us “ The total cost of traffic congestion to the U.S. economy in lost productivity and wasted motor fuel is almost $68 billion—or $1,160 per traveler”. Using simple math and looking at the issue from another perspective, we can consider that a site, whose electrical and electronics cost $5,000, an investment of $500 for the earthing, grounding and surge protection is appropriate. Therefore we could forgo the complex math and abstract assumptions to conclude that 10% of the equipment value, is a sound minimum investment for protection. It is also a reasonable assumption that the investment will be saved multiple times during the installed life of the equipment.

Conclusion:

The design of the lightning protection scheme needs to take on as much detail as the selection of the equipment to be installed. This is an investment in failure prevention . Done correctly, it is economic and will significantly reduce the installed lifetime cost and ongoing maintenance costs.

In summary here are the considerations:

- Lightning and surge related damage can be prevented.
- Investment into a protection system is an investment into failure prevention.
- Both the earthing and surge protection system need equal design and investment consideration.
- The protection system must be at least 10% of the value of the electrical and electronics at the site, more can be invested, depending on the significance of the site.
- The AC power surge protector needs to have a surge current capacity in excess of 50,000 amps.
- It is essential to have a Primary & Secondary surge protection scheme. This will be a two devices in the case of AC power, or a multi-stage hybrid in the case of communications or data.
- The whole protection scheme consists of earthing and surge protection and both need equal attention and careful specifying.
- Both ends of any connecting circuit between devices on a site, MUST have surge protection. (e.g. camera to cabinet, DMS to cabinetised controller).

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Born and educated at Liverpool college in Britain, then working for British Telecom in Telecommunications for a number of years. My career has been deeply involved in Lightning and related subjects for over 27 years. This includes involvement in lightning research, development and deployment of real time lightning detection networks, both in the USA and Abroad. For the last 12 years I have been with Atlantic Scientific involved with the recommendation and sale of surge & lightning protection products. I have been privileged to present technical papers on the subjects of Lightning and Surge Protection both internationally and around the USA. These include national and regional meetings of ITS, ITE and IMSA.

Seminar synopsis :

The objectives of the technical session are to define the rational investment cost of protection as part of a preventative maintenance design. This will also cut through many of the misunderstandings of protection systems, the need and technologies. Delegates will have a clear understanding of the issues. The amount of effort and investment in the procurement and installation of protection systems varies dramatically across the USA. Some have very stringent, expensive specifications while others have virtually no requirement what-ever. Much of the variance is caused by a lack of understanding while often being driven by emotional decisions based on past experience. The session discusses the specific extremes of earthing and bonding systems, their implications and virtues. In addition, lightning protection is discussed in a similar manner, reviewing the pro's & con's of technologies, configurations, surge current capacity and let-thru-voltages. There are many variants of “specifying features” of items to be procured or installed which are similarly discussed and clarified pointing out the flaws and mistakes. The end conclusion is to review protection configurations and technologies related to the sites importance and vulnerability.

References:

The following organizations have recommendations and/or standards for grounding to ensure safety:

- OSHA (Occupational Safety Health Administration)
- NFPA (National Fire Protection Association) NFPA-77
- ANSI/ISA (American National Standards Institute and Instrument Society of America)
- TIA (Telecommunications Industry Association)
- IEC (International Electro technical Commission) IEC 60364
- CENELEC (European Committee for Electro technical Standardization)
- IEEE (Institute of Electrical and Electronics Engineers) IEEE Std 142-2007
- NEC Article 250

IMSA