LIGHTNING coupling mechanisms, the 10/350µs Waveform and Protection Techniques for Wireless Sites

1. Introduction

For the past 50 years surge protection devices (SPD's) have been rated and specified using the 8/20µs current waveform. This practice was born out of decades of experience with overhead line surge protectors for the power systems. Experience dictated that a surge protector capable of withstanding 100kA (8/20µs) will typically provide a satisfactory (20-30 year) life expectancy. The fact that the real electrical environment contains surge currents shorter and significantly larger than 20µs was always accepted. More recently, standards such as IEC TS61312 have introduced the 10/350µs waveform as a standardized (maximum threat) profile for the current in the lightning channel itself.

The purpose of this paper is threefold.

- Firstly to review the coupling mechanisms that give rise to 10/350µs currents.
- Secondly to evaluate how differences in power supply systems and applications affect the magnitude of current penetration
- Third to briefly review available protection techniques.

2. Worse Case Lightning

IEC 61312 gives 200,000A (10/350µs) as the statistically severe peak current level discharged during a lightning strike.

The question that designers of protection systems must answer is: "how much of that surge current will flow to earth and how much will stress surge protectors installed in the facility being struck by lightning?" Understanding the coupling mechanism is key to understanding the level of threat.

10/350 µs Coupling Mechanism defined by IEC 61312-3

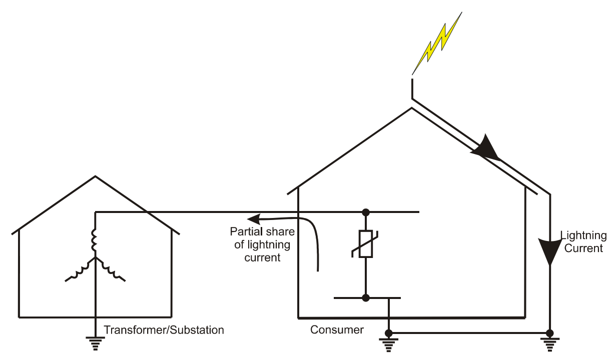

Figure 1 Typical domestic facility as shown in IEC 61312-3

The mechanism by which a partial share of the 10/350µs lightning current passes through the SPDs is described above. This is derived from the IEC specification and clearly shows the threat. Since the substation transformer is separately earthed some distance away from the facility, a partial share of the lightning current flows through the SPDs and out toward the transformer. The schematic in figure 1 describes a typical power system for domestic consumers in Europe. Here, the risk of significant current flowing through the SPDs is high. SPDs with 10/350µs current ratings of at least 20kA would be recommended.

It is critical however, to draw the distinction between figure 1 and a remote wireless site or one installed on the rooftop of a multi story building. Figures 2 & 3 shows the difference.

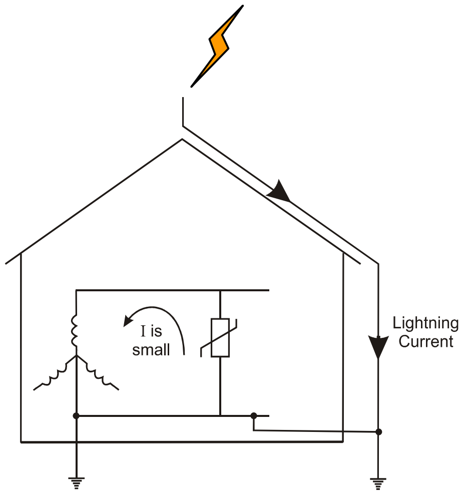

Figure 2

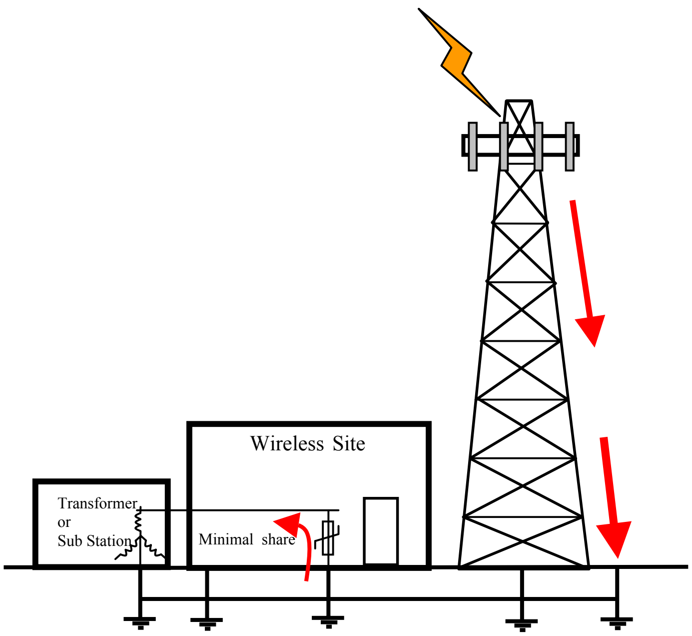

Figure 3

A typical wireless site (ground level or on the roof of a multistory building), has the transformer located close to the equipment. The earthing system of the transformer is equipotentially bonded into the facility earthing system. In contrast to a residential or small commercial site, great effort and expense is used to ensure the earthing system at a wireless site has a low impedance. Every effort is made to bond all metal surfaces, telecommunications and power, with the minimum of impedance. This act of bonding the transformer earth to building or site earth, completely changes the coupling mechanism. A larger share of the lightning current will flow to earth than is dictated in the IEC guide. The transformer now no longer acts as a remote earth. Very little, if any, surge current flows through the SPD, since the voltage to drive this current is the voltage developed across the equipotential bond.

In such wireless applications, a spark gap based device could be an inappropriate choice (see later).

3. <u>Wireless Specific Scenarios</u>

The applicability of the coupling mechanisms outlined in the IEC document can be dictated by the power distribution system in a given country or application. As an example, many wireless facilities will have a transformer located in or next to the premises and so fall into the Figure 2 & 3 configuration. The surge current flowing in the surge protectors is no longer a partial share of the lightning current, but a secondary effect.

Even when the transformer is located some distance away, the superior earthing and bonding practices at wireless sites will dramatically lower the magnitude of 10/350µs current flowing through the SPDs. Remember, the IEC guidelines are based on a typical domestic building. Improving the earthing will lead to a greater share of lightning current flowing to earth.

4. What is the <u>10/350µs Threat</u>

Summarizing the concepts presented in this document, the magnitude of the lightning threat can be estimated. The following table shows the wireless site configurations ordered in terms of the risk that SPDs will carry a significant share of lightning current.

High risk: Wireless sites, where the transformer is distant from the site and neutral is not earthed at the service entrance.

Expected currents <20kA (10/350µs)

Medium/low risk: Wireless sites where the transformer is located close to the wireless site, neutral is grounded at the transformer and at the service entrance.

Expected currents <5kA (10/350µs)

Low risk: Wireless sites or rooftop installations where the transformer is located adjacent to, or within the facility and shares a common earth with the facility.

Expected currents <<5kA (10/350µs)

Finally, it should be noted that the most common path, identified in many standards, for surge currents to enter the facility is through the power system. These surge currents, due to secondary effects of lightning and switching events, will be of shorter duration characterized by the standard 8/20µs. The risk categories described here are specifically related to a lightning strike to the tower, which feeds a partial share of the lightning current back through the SPDs and out of the building on power lines.

A basic misunderstanding of the coupling mechanism has led some to specify surge protection devices capable of handling 50 to 100kA (10/350µs) in all applications. The theory being that a SPD capable of 100kA (10/350µs) will work fine in a low risk environment where expected currents are <5kA. The fundamental flaw in this approach is that the specification of 100kA (10/350µs) SPDs implies Spark Gap Devices, (SGD's**). In wireless facilities with limited space, this choice may not be appropriate**. To understand why, the operation of spark gaps must be reviewed.

5. Spark Gap Devices and Their Applications

Surge protectors based on the simple spark gaps have become a popular technique to protect against a high magnitude 10/350µs threat. Spark gaps provide useful protection for residential dwellings that fall into the high-risk category. However, spark gaps are being recommended for wireless sites that present a low risk for the coupling mechanism that is described here and in IEC TS 61312. The application of spark gaps in low risk scenarios could be disadvantageous compared to proven protection techniques.

6. Spark Gaps and Their Disadvantages

Although there are several variations, spark gaps are basically two pieces of metal (electrodes) in close proximity to one another. A transient of sufficient magnitude to breakdown the insulation of air causes a spark to jump between the electrodes. The resulting electric arc is quite conductive, discharging the partial lightning surge current. Unfortunately, the same conductive arc that discharges surge current also short-circuits the AC power system. The AC current that continues to flow through the spark gap after the initiating transient is called "AC power follow current". This can result in fuse blowing and/or the venting of flames an ionized gases. Hot ionized gases will cause normal insulation and creepage spacing to breakdown. **Extreme care is required in locating a spark gap to avoid triggering arcs throughout a power panel or in the confines of a wireless equipment cabinet**. Such an event could be disastrous.

To avoid the expulsion of flames, some spark gaps are encapsulated. However encapsulation does restrict the capability of the spark gap to extinguish the arc and stop the flow of AC power current. To prevent a disaster where the spark gap does not "turn off" series fuses are required.

Spark gaps, encapsulated or not, often require series fuses, the purpose is to interrupt the fault current should the spark gap fail to extinguish. It is important to realize that a spark gap needing the assistance of a series fuse to extinguish the AC power follow current, could be a weak link in the protection system. A single lightning strike is comprised of several (3-20) individual current impulses. This can be seen as a flicker in the lightning channel itself.

As an example, a lightning strike comprising of four current pulses could pose quite a problem. The first impulse fires the spark gap, but the resulting AC power follow current blows the series fuse. The subsequent lightning current pulses can now flow into the facility unhindered.

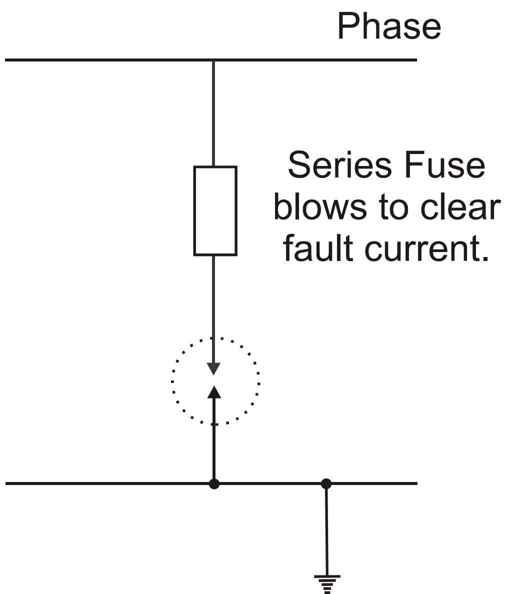

Figure 4 Spark gaps often require series fuses.

The series fuse requirement introduces a weak link in the protection system. In fact, the series fuse would need a rating of 400A or more to pass 50kA (10/350µs). Ironically spark gap manufacturers often recommend series fuses with ratings of 100A to 200A. Fuses with these ratings will blow (operate) with surge currents of 10 to 20kA (10/350µs)!

Wireless sites are typically remote and unmanned, how long does it take before a maintenance engineer notices that the fuse has indeed blown and the facility is unprotected ?

Care must be taken to install a spark gap "system" correctly to get the benefit of its 10/350 u/s performance. The let-thro-voltage (LTV) of a SGD is unacceptably high. The manufacturers recommend that a secondary MOV device is installed to reduce the LTV to a level that electronic equipment can survive. The MOV has a much faster response time, therefore the correct sequence of operation is extremely important, otherwise the MOV will do all the work and the SGD will be in-operable. To achieve this, some distance must separate them. The manufacturers recommend the distance to be at least 10 meters (32 ft) between spark gap and MOV. Wireless sites are small and compact and do not have such physical space available. In such cases, loading coils are recommended by the SGD manufacturers, installed in series with the AC power, to simulate distance. All of this equipment becomes an expensive and bulky installation, for a site that is determined as technically a low 10/350 u/s pulse, risk.

If the correct spacing or sequence of operation is not engineered properly, then the MOV device will do all the work and the SGD will never operate.

One final twist in the development of spark gap technology is the triggered spark gap. Electronics are used to fire the spark gap at a voltage level below that which the gap would normally operate. This overcomes the high (4-6kV) firing voltage, but does nothing to help the spark gap turn off. This new development carries added concerns for electrical engineers. A triggered spark gap could be fired by a relatively small (1.5kV) transient, the ensuing short circuit as the arc is developed could be more stressful to the power system than the transient itself!

The short term power interruption, as the spark gap clears the AC power fault, could cause 63A or 100A inline fuses or circuit breakers to blow. Power would then be removed from the site until repairs could be made.

For the above reasons, the use of these products at wireless (GSM) sites be carefully considered; particularly in view of the fact that such installation represents a very low risk of partial lightning current (10/350µs) problems

7, <u>Large Block MOV Devices a Proven Alternative</u>

Quality surge protectors using large block MOV technology are available with the recommended 10/350µs ratings as defined in

IEC 61643-1. Specifically MOV based products are available rated for 10kA (10/350µs) and 20kA (10/350µs).

Such products provide excellent levels of protection for wireless sites in many high lightning activity areas of the world, while having none of the drawbacks associated with spark gaps.

Specifically, MOV based SPDs avoid the following drawbacks of spark gaps:

- AC power follow current due to the operation of the spark gap.
- Shorting out (temporarily) the AC power system.
- Additional equipment to reduce the LTV
- Additional equipment to simulate distance between SPD devices.
- Flames and ionized gases, exhausted from some spark gaps during clearing of the AC fault current.
- The mechanical shock a short circuit fault places on a high current power system.
- The high initial let-through voltage of a spark gap, which can be as high as 4-6kV.

8. Conclusion

Standards such as IEC 61312 have shown that lightning striking a typical domestic building can cause surge currents to flow "out" of the building through surge protectors, toward a remotely earthed transformer. In effect the SPDs carry a partial share of the lightning current.

Wireless sites will be inherently less susceptible to this coupling mechanism. Earthing and bonding techniques and the location of the transformer all serve to mitigate the risk and magnitude of 10/350µs current flowing on surge protectors.

Given the reduced threat, the characteristics inherent in spark gap technology are not well matched to the requirements of a wireless site. High let through voltages, hot ionized exhaust gases and potential fuse blowing are problems that MOV devices will remove.

Finally, proponents of spark gap devices have stated that MOV devices cannot withstand 10/350 pulses and would provide a limited service life. Clearly this is incorrect. Indeed, the best manufacturers of quality **large block MOV based products, offer a 10 year, unconditional, free replacement, warranties, with nearly a decade of protected wireless sites, as evidence of performance.**

References:

IEC 61312
IEC 61643
BS 6651
ANSI/IEEE