UNIQUE PROBLEMS OF SURGE AND GENERIC PROTECTION TECHNIQUES FOR WIRELESS SITES

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Abstract – Although IEC 61312-3 clearly details the risk of a direct lightning strike to a consumers premises, use of this specification for wireless (GSM) installations is inappropriate and can be damaging to sites being protected. This paper discusses the lightning in Brazil, the influence of wireless towers, the surge protection technologies used and an understanding of the current flow from a direct strike.

1 INTRODUCTION

The past 50 years has seen surge protection devices (SPD's), along with international standards, evolve for application in buildings and domestic dwellings. The past 5 years however has seen a remarkable increase in the presence of wireless base station towers across the world. These sites offer unique protection challenges and the simple application of techniques developed for commercial buildings, for example, may not provide the optimum protection.

The purpose of this paper is threefold:

- Firstly to discuss the unique characteristics of a wireless site compared to a commercial building or domestic dwelling.
- Secondly to evaluate risk scenarios.
- Thirdly to briefly review available protection techniques and suggest optimum solutions

2 WORSE CASE LIGHTNING

IEC 61312 gives 200,000A (10/350µs) as the statistically severe peak current level discharged during a lightning strike. It is worthwhile noting that 99.5% of strikes will be less severe. CEMIG recently published the results of lightning strike activity in Brazil. The results are very informative. The median current magnitude was 44kA, with only 5% of strikes demonstrating a pulse width greater than 200µs.

Incidence of single stroke flashes	56%
Incidence of multiple stroke flashes	44%
Mean number of strokes in a flash	5.4
Mean inter-stroke time	54 ms
Mean flash duration	180 ms
First stroke median peak	43.1 kA
Subsequent stroke median peak	16.0 kA

Table 1
Researchers at Cemig, Brazil show the cumulative frequency distribution of peak current amplitudes for first strokes of a negative downward flashes recorded at Cachimbo Station and on the top of transmission towers.

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.

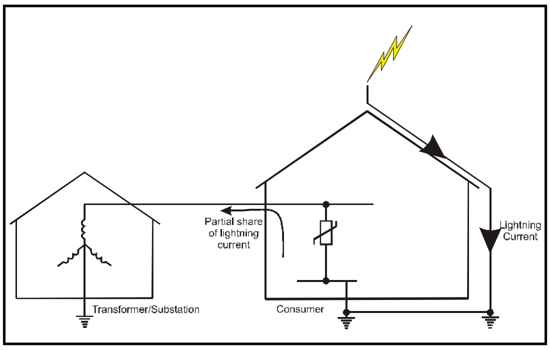

Figure 1 *10/350 µs Coupling Mechanism as defined in IEC 61312-3 for a typical domestic facility*

The mechanism by which a partial share of the 10/350µs lightning current passes through the SPDs is shown above. IEC provides simple rules based on a residential application. Here the approximation is that 50% of the lightning current flows to ground. Since the substation transformer is separately earthed some distance away from the facility, the remaining 50% share of the lightning current flows through the SPDs and out toward the transformer. The schematic in Figure 1 shows a typical power system for domestic consumers in Europe. Here, the risk of significant current flowing through the SPDs is high should the building take a worst case, 200kA strike. 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. Figure 2 shows the difference.

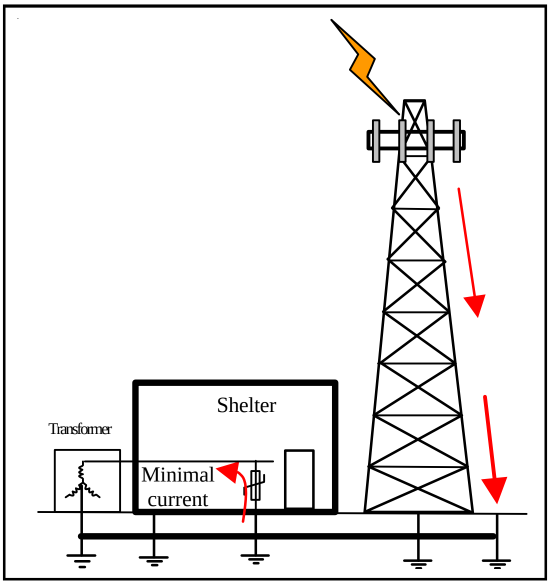

Figure 2

A typical wireless site (ground level or on the roof of a multistory building), has the transformer located close to the equipment and typically multi-story buildings have the transformer in the basement. 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.

3 TOWER STRIKE PROBABILITY IN BRAZIL

The actual flash density in Brazil is available from a number of sources, the paper by Diniz et al gives the flash density in Minas de Gerais as between 3 and 10 flashes to ground per km2 per year. Using this number we can estimate the number of times a tower of a given height will be struck.

Many papers have been published discussing the relationship between the height of a tower and the effective attractive radius. Pierce & Price indicate that the attractive radius (Ra), and it's associated attractive area $Aa = \pi Ra^2$ are primarily functions of the structure height H.

H (meters)	Ra (meters)
25	~150
50	~250
100	~350
150	~400
>150	~400

Table 2

The relationship between structure height (H) and Attractive Radius (Ra)

A 100m high tower in Brazil has an effective attractive radius of 350m. We can use this to approximate the number of flashes to the tower per year. In a region with a flash density of 10 flashes to ground per km^2 per year, we can expect the 100m tower to be struck approximately 4 times per year, or 38 times in a decade.

Number of flashes = $10\pi(0.35)2$ = 3.8 flashes

Number of flashes 3.8 x strokes 5.4 = 20.5 strokes / year per tower.

This clearly shows the probability of frequent direct strikes to wireless tower sites is significantly greater that a domestic facility mentioned in IEC61312-3.

First Strokes				
		% of cases exceeding tabulated values		
Parameter	Source	95%	50%	5%
Time to half value (us)	Berger	30	75	200
	Cemig	27	62	142
Charge ©	Berger	1.1	5.2	24
	Cemig	2.1	5.1	12.2
Energy Ci^2dt	Berger	6.0x 10_3	5.5x 10_4	5.5x 10_5
	Cemig	2.3x 10_4	10.0x 10_4	4.4x 10_5
Subsequent Strokes				
		% of cases exceeding tabulated values		
Parameter	Source	95%	50%	5%
Time to half value (us)	Berger	6.5	32	140
	Cemig	2.4	19	145
Charge ©	Berger	0.2	1.4	11
	Cemig	0.2	1.1	6.2
Energy Ci^2dt	Berger	5.5x 10_3	6.0x 10_4	5.2x 10_5
	Cemig	1.0x 10_3	8.0x 10_3	8.3x 10_4

Table 3

CEMIG's lighting research tower at Cachimbo, produced the following data from a total of 76 strikes

It can be seen from the CEMIG data that although there are a high incidence of strokes to towers, less than 5% have a time to half peak greater than 140µs. It is important to bear this in mind when designing protection systems. The CEMIG study shows that 95%+ of all strikes will have a duration shorter than the IEC standard suggests and 99% will have a lower amplitude.

4 SURGE PROTECTION OPTIONS

Various protection devices are available for use on wireless sites. Most devices will offer an improvement in protection levels over an unprotected site, however the purpose of this paper is to consider the optimum approach. To this end the various protection options will be discussed.
Protector devices are of two basic types, constant voltage and crowbar. The constant voltage devices will conduct very little at a steady state voltage, but above a certain voltage level will conduct very heavily. (Bent, unpublished).

A crowbar device in effect, short circuits a high voltage to ground. This short circuit will continue until the current is brought to a low level. A constant voltage device will never reduce the line voltage below it's steady state value but the crowbar device often will. This could be a problem if there is a continuing follow current

Technologies considered	
Metal Oxide Varistor (MOV)	Constant V
Silicon Avalanche Diodes (SAD)	Constant V
Hybrid MOV/SAD	Constant V
Gas Discharge Tube (GDT	Crowbar
Spark Gap	Crowbar

Table 4

4.1 Metal Oxide Varistor (MOV)

MOV's have been deployed in the power distribution system for decades providing adequate levels of protection and operational life. MOV devices are available in a wide range of ratings, however, devices rated 40kA (8/20µs) or less will invariably have limited 10/350µs capability. 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 to 20kA (10/350µs).
Advantages : Large Block MOV products are relatively inexpensive and provide excellent levels of protection for wireless sites in many high lightning activity areas of the world, while having few drawbacks.
Disadvantages: Choosing an inappropriately rated MOV device may lead to premature failure or failure to protect the equipment in the installation.

4.2 Silicon Avalanche Diodes (SAD)

SAD's are the most "constant voltage" devices available and the voltage is only slightly dependent on the current. These devices offer exceptional performance and low "let-thru-voltage" (LTV).

Individual components have very low surge current capacity and although assembled into series parallel networks, still offer low overall current capacity while being expensive.
Advantages: Excellent control of transient voltages, providing the associated current does not exceed the ratings of the device.

Disadvantages: Expensive: SAD devices are now available with 12 – 20 kA (8/20) of surge current capacity.

4.3 Hybrid MOV / SAD
Wireless sites are generally remote and unmanned. This has made the installation of SAD devices a high risk although offer the best LTV performance. Over the years, MOV / SAD hybrids have evolved based on the expected early failure of the SAD stage, while providing an MOV secondary stage as a back-up until a failed SAD module can be replaced.
Advantages: High performance with multiple levels of redundancy in the event of a failure.
Disadvantages: Expensive

4.4 Gas Discharge Tube (GDT)
An excellent description of the use of GDT's is given in a report by Hart & Higgins and their main conclusions will be briefly described here. Typical volt time curves of a GDT have a high initial clamping voltage. The arc region can be sustained at a low voltage, the AC voltage may be sufficient to allow a follow or holdover current, depending on the power source. This may be significant and may cause damage to the electrodes. As the voltage passes through the zero at the end of every half cycle, the GDT will extinguish, but at times, if the electrodes are hot and the gas ionized, it may re-ignite on the next half cycle. For these reasons GDT's are rarely used on power systems.
Advantages: Low cost
Disadvantages: "Crowbar" device often forbidden in national specifications due to the risk of follow-through currents. Slow response and high LTV.

4.5 Spark Gap Devices
Surge protectors based on 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. These are typically connected to a European type 220 / 380 power distribution system. However, spark gaps are being recommended for wireless sites.

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.

Advantages: Low cost
Disadvantages: "Crowbar" device often forbidden in national specifications due to the risk of follow-through currents. This is also a risk of premature in-line fuse rupture without any alarm indications. Slow response, high LTV and potential plasma damage.

5 PERFORMANCE OF THE DIFFERENT TECHNOLOGIES

Table 5 is information derived from the published documentation of various surge protection products that use these technologies.

Technology	Let-thru-voltage
SAD	500V
High capacity MOV	700V
Average MOV	1000 – 1500V
Spark Gap	3500 – 4000V
Triggered Spark Gap	1500V

Table 5
Typical protection performance of the different technologies

It can be seen, that for a 220/240 volt distribution system, there is a significant difference between the optimum and the worst technology. Obviously this does not consider other factors such as cost, surge current capacity and size.

6 POWER DISTRIBUTION IN BRAZIL

Figure 1 (derived from IEC61312-3) clearly shows the risk of 10/350 magnitude surges is the ground potential being elevated by a direct strike and the coupling of the current discharging back to a distant off site transformer, sited at a significantly lower earth potential. New installations in Brazil will follow the new code of practice. This code (NABR5410) calls for a ground or earth connection from the transformer to the wireless site ground. This changes the picture considerably. (Figure 6) Added to this is the fact that the earthing system of a tower is typically superior to that of a small building or house. We can conservatively assume that 60%+ of the lightning current flowing through the tower will flow into the earthing system on site (as compared to the 50% generalized in the IEC document). Further IEC61312-3 clearly shows that as much as 25% of the lightning current will flow on the ground wire back to the transformer. The

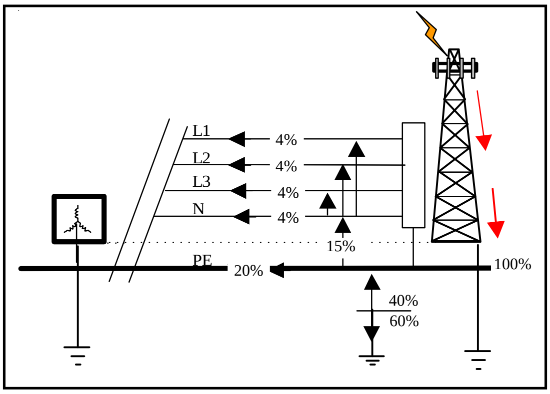

Figure 6

remaining 15% of the lightning current will be distributed between the phase and neutral conductors of the power system. For a 3-phase supply with neutral, the current flowing through each surge protector is 7.5kA (10/350µs). More importantly this is the order of magnitude that we would expect from a 200kA strike. We have already established that 99% of strikes will have a LOWER amplitude. Understanding this scenario should lead to surge protection designs more appropriate for wireless installations.

7 CONCLUSION

Wireless sites require a carefully designed surge protection scheme that takes into consideration the unique issues that effect their risk to direct lightning strikes. These are remote, located on high sites, tall towers that effect random lightning, unmanned and extensive grounding systems. As shown, although spark gap devices can handle the maximum IEC61312-3 surge on any given line, the real surge current is considerably lower per line. High capacity MOV's with ratings of 100-150kA (8/20µs) and 10-15kA (10/350µs) will provide better protection levels and provide decades of effective surge protection for wireless sites.

8 REFERENCES

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