Abstract
This paper provides an outline of a systematic approach to determine and apply lightning and surge protection to industrial plants such as water and sewerage and oil and gas facilities.

1. Introduction
All too often when lightning strikes an industrial plant, equipment is damaged and operations curtailed there is an initial rush to get the plant operational again. This is a reasonable response. Then comes the question of how to protect the plant against the next lightning strike. Inevitably the approach taken is ad hoc and the result is very often a lightning protection system that does nothing to protect the equipment that was originally damaged. Indeed by taking a systematic approach, applying the Australian standard, carrying out a risk assessment, then acting upon the results of that risk assessment both cost effective and successful solutions can be found.

2. Direct Strike and Inductance
Figure 1 sums this up. This plant took a lightning strike, control equipment was damaged and the result was that a tall mast with a non-conventional lightning protection system was installed. This was done despite the fact that the plant largely consisted of all metal buildings and a perfectly good conventional lightning protection system was already in place. No thought was given to protecting the actual control equipment itself.

The inevitable result was that the mast was struck by lightning, the LPS destroyed and the control equipment again damaged.

The reason for the LPS destruction and indeed the reason why equipment is damaged by lightning is due not only to induction in cables but to differences in potential across parts of the plant that appear to be solidly earthed and bonded together.

To understand this it is necessary to consider some of the electrical characteristics of a lightning strike. Lightning can be modeled by a current...
impulse. Whilst there are a number of waveforms that variously model direct strikes as well as induced voltages and currents in power and data lines, this paper will use the 8/20 microsecond current impulse to demonstrate the effects.

![Image](image1.png)

**Figure 1. LPS at Industrial Plant**

All conductors have inductance. Whilst this may be largely neglected at 50Hz, with a lightning impulse it is a different story.

The formula for the voltage across an inductor is:

\[ V = L \times \frac{dI}{dt} \]

Where L is the inductance and \( \frac{dI}{dt} \) the rate of rise of current.

Figure 2 shows the effect of applying a 10kA 8/20us impulse to one meter of various conductors.

![Image](image2.png)

**Figure 2. 10kA 8/20us impulse applied to various conductors**
The maximum rate of rise is at the start, from zero, of the impulse and here the inductive voltage is the greatest. At the peak of the current curve \( \frac{dl}{dt} \) is zero and the voltage due to resistance of the cable is apparent (apart from the 6sqmm conductor, it is almost zero). Thus for typical types of downconductor we can expect about 1KV per meter per 10KA.

So for the plant as shown in figure 3, we can conclude that, since it is all metal, it is self protecting and the best downconductors are the bodies of the tanks and vessels themselves.

However there must be a voltage rise at the top of any structure that is struck by lightning and therefore any instruments mounted on that structure will rise in potential along with the structure. Unfortunately a potential difference will then exist between the instrument and the I/O of the SCADA or PLC equipment in the control room. Damage to both instrument and I/O is inevitable and no amount of structural lightning protection will solve this problem.

![Figure 3. This plant is inherently self protecting but instruments and I/O are vulnerable.](image)

### 3. A Systematic Approach

The Australian and New Zealand standard on Lightning Protection, AS/NZS1768-2007 provides the means to analyse and design effective protection for industrial plants.

#### 3.1 Risk Assessment

A risk assessment will determine whether structural protection and/or surge protection is required. The assessment will also determine whether both primary and secondary surge protection is needed. The risk assessment procedure is provided in the standard as an Excel spreadsheet. Figure 4 shows the analysis applied to an extensive industrial plant. A number of assumptions have been made, one being that the buildings in the plant have metal frames, metal roofs and reinforced concrete panel walls. It is further assumed that
these connect to the building foundation steel, providing a suitable earth for lightning protection.

It is assumed that the plant is isolated and fed with a long transmission line. Whilst there will be a large number of signal cables within the plant only one underground service is shown, providing a very conservative assumption.

Without protection the acceptable risk is exceeded in three categories.

Figure 5 shows how these three categories of risk can be reduced to an acceptable level by the application of surge protection only. No structural protection is required. This result is so often the case yet the first impulse seems to be to protect structures. Indeed if the highest level of structural protection is applied the risk level still cannot be resolved.

Figure 5 shows that both primary and secondary surge protection is required in order to fully protect this plant. In other words this risk assessment is telling us to protect what was actually damaged by not only surge protection on main switchboards but also on every piece of vulnerable equipment on both power and signal lines.

![Risk Assessment for Lightning Protection]

**Figure 4. Risk Assessment, no protection**
3.2 Primary and Secondary Protection

Figure 6 is reproduced from AS/NZS1768-2007 and shows in simple terms what is meant by primary and secondary protection.

Primary protection is applied to incoming services such as power on the main switchboard and the telephone MDF. The dashed line within the “central facility” represents the control room or perhaps just one PLC cabinet. Whatever
it represents we need to provide protection such that everything within that dashed line referenced to the earth bar shown rises to the same potential. Thus every service crossing that dashed line requires surge protection.

The instrument in the field will rise to a totally different potential to the equipment in the control room. The SPD in the field serves one purpose: it ensures the potential of the signal line rises to the potential of the body of the instrument thereby preventing a flashover within the instrument. Thus the most important connection is the earth connection from the SPD to the body of the instrument.

### 3.3 Power Protection

AS/NZS1768-2007 provides guidance on the configuration of SPD devices suitable for both primary and secondary protection. Figure 7 shows the four most common configurations for power and signal line protection.

The surge diverter, SD, is shunt connected across the lines to be protected and is the most common type of primary protection. This is a one port device.

The series surge protector, SSP, is a series connected two port device which may protect individual circuits or a whole installation. Its value will become apparent.

The surge filter, SF, combines both primary and secondary protection in one unit. It too is a series connected two port device.

The signal line protector, SL, combines both primary and secondary protection. Signal protectors take many forms but are most effective when used as a series connected two port device.

![Figure 7. SPD Configurations from AS/NZS1768-2007](image)

Shunt connected surge diverters are almost invariably installed incorrectly and almost invariably do not provide effective protection. Whilst AS3000 clearly shows the recommended connection method and the need for overcurrent
protection, many are incorrectly installed and are simply connected from phase to earth.

![Figure 7. SPD installation, from AS3000](image)

Whilst it may not matter if the SPD is installed between phase an earth at a main switchboard, it certainly does matter at a sub board where the neutral also requires protection. Figure 8 shows an installation at a small sub board. This was supposed to protect a CCTV installation. It didn’t. The neutral was not protected and the MEN link in the main switchboard was hundreds of meters away.

![Figure 8. SPD at sub board. No protection for the neutral.](image)

At sub boards and final circuits all mode protection is required. Figure 9 shows how it should be done.
Inductance too plays its part. In a large switchboard it is difficult to avoid running long cables to install SPDs. Figure 10 shows the effect of the inductance of those connecting leads.

This is hardly going to protect sensitive electronics. Hence there is a need for both primary and secondary protection.

Now the purpose of the series surge protector, SSP, becomes clear. Being series connected there are no long shunt connected leads so the let through voltage of the device is exactly as per the manufacturer's specifications. Yet when an SSP is specified many suppliers simply substitute their surge diverter in an attempt to win the sale. Their ignorance is hard to comprehend.
Although a series surge protector has predictable performance its let through voltage may still not be low enough to protect sensitive electronics. That is why surge filters are used as secondary protection in PLC and other control equipment. Again series connected as shown in figure 12, typically with a guaranteed let through voltage of less than 600V, surge filters provide effective protection for sensitive electronics. Larger surge filters have even lower let through voltages.

The concept of primary and secondary protection is simple and when properly applied can provide most effective protection. The shame is it is rarely applied properly.
3.4 Signal Line Protection

Since it was PLC I/O that was damaged during the lightning strike one has to wonder why signal line protection is thought of last or often just ignored. Perhaps it is just too hard because there is no doubt it needs to be thought through; the correct signal line protector needs to be chosen because if wrong the signal will not even get through. Whether it be a 4/20mA loop, an Ethernet cable, RS485 signalling, analogue CCTV or a 900MHz RF signal every application requires the correct signal line SPD. This is a vast topic; this paper will concentrate on the principles of typical signals found in process control and field instruments.

Signal line protection for PLC I/O is relatively easy to fit in marshalling cubicles and can take the place of the usual rail mounted terminals. Figure 14 shows a typical retrofit installation. At this site a lightning strike to the ground some 500m from the plant destroyed all 9 PLCs in this, the oxygen plant. 50% of the analogue instruments were also destroyed. The plant was manufactured in Europe with no thought given to the fact that it was going to a tropical country and no thought given to surge protection.
It is important that earthing is considered. Inductance is the enemy. The SPD shown in figure 15 welded itself to the DIN rail despite the fact that there was 1m of earth cable connecting it to the earth bar.

Field instrument protection can be expensive with conventional signal line SPDs. This is especially so if the instrument is in an explosive or hazardous location. Fortunately with suitably rated instrument SPDs protection can be easily installed and cost effective.
Many instruments have two ports as shown in figure 16. The second port can be used to install the SPD and if suitably rated Exd and Exia, the SPD will not destroy the Ex integrity of the instrument. Even instruments with one port can be protected with a suitable adapter.

Protection is straightforward. The SPD can be screwed into the spare port and connected as shown in figure 17.

Note the green/yellow wire in figure 16. This is the cable screen, disconnected at the instrument end, connected in the marshalling cubicle. This wire requires protection because if left open it could cause an internal flashover. A properly designed SPD will allow for this.

There are many other examples of field instrument protection. An instrument with field power requires protection for both its signal and power conductors. A protected Magflo meter is shown in figure 18.
4. Conclusion

In industrial plants it is surge protection that is required to protect the equipment most frequently damaged. Most plant structures are inherently self protecting. A systematic approach using the risk assessment procedure set out in AS/NZS1768-2007 provides guidance on precisely where and how protection should be applied. It is such a shame that lightning protection is still thought of as structural protection only and the stuff that actually blows up is neglected.
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