Abstract

This paper provides an outline of how to effectively install surge protection to various elements of an industrial plant. The paper highlights the need to consider cable impedance and the importance of equipotential bonding.

1. Introduction

In designing lightning protection it is usual to carry out a risk assessment. A risk assessment procedure is described in the Australian standard on lightning protection, AS/NZS1768-2007. This is provided in the standard as an Excel spreadsheet. The risk assessment can identify the need for structural lightning protection and/or the need for surge protection. This need is assessed by considering the risks of damages caused by direct and indirect strikes. All too frequently insufficient consideration is given to the need for surge protection and the immediate reaction when lightning causes equipment damage is to install structural lightning protection. Usually protecting the very equipment that was damaged, usually some small signal device is considered last or not at all.

2. 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 1 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 2 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 2 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.
3. Cable Impedance

All conductors have inductance. Whilst this may be largely neglected at 50Hz, with a lightning impulse it is a different story. Lightning current is modeled as an impulse. Typically that impulse has an 8μs risetime and 20μs decay. This is called an 8/20μs impulse.

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 3 shows the effect of applying a 10kA 8/20μs impulse to one meter of various conductors.

![Figure 3. 10kA 8/20us impulse applied to various conductors](image)

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 \( \frac{di}{dt} \) 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 4, 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 4. This plant is inherently self protecting but instruments and I/O are vulnerable.

4. Primary and Secondary Protection

Figure 5 is reproduced from AS/NZS1768-2007 and shows in simple terms what is meant by primary and secondary protection.

![Diagram of Primary and Secondary Protection](image)

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.

### 4.1 Power Protection

AS/NZS1768-2007 provides guidance on the configuration of SPD devices suitable for both primary and secondary protection. Figure 6 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 one 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.

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

AS1768 rates SPDs in terms of their single shot 8/20μs rating. This is called $I_{\text{max}}$. Figure 7 shows recommended surge ratings for various locations in a typical LV distribution network.
Shunt connected surge diverters at main switchboards provide primary protection. They are installed as shown in figure 8 between each phase and neutral. The MEN link provides the path from neutral to earth. All SPDs must be protected with an over current fuse or circuit breaker. AS1768 provides guidance on this rating which relates to the surge rating, $I_{\text{max}}$, of the SPD. Figure 9 shows recommended fuse ratings.

<table>
<thead>
<tr>
<th>Coategory</th>
<th>SPD location</th>
<th>$I_{\text{max}}$ rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Long final subcircuits and electricity supply outlets</td>
<td>3 – 10 kA</td>
</tr>
<tr>
<td>B</td>
<td>Major submains, short final subcircuits and load centres</td>
<td>10 – 40 kA</td>
</tr>
<tr>
<td>C1</td>
<td>Service entrance, other than below</td>
<td>40 kA</td>
</tr>
<tr>
<td>C2</td>
<td>Service entrance, building fed by long overhead service lines, or is a large industrial or commercial premises</td>
<td>40 – 100 kA</td>
</tr>
<tr>
<td>C3</td>
<td>Service entrance, building in a high lightning area, or fitted with a LPS</td>
<td>100 kA</td>
</tr>
</tbody>
</table>

Figure 8. SPD installation main switchboard

<table>
<thead>
<tr>
<th>$I_{\text{max}}$ surge rating</th>
<th>Recommended fuse</th>
<th>Recommended CB</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kA)</td>
<td>(A HRC)</td>
<td>(A)</td>
</tr>
<tr>
<td>40</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>63</td>
<td>40</td>
</tr>
</tbody>
</table>
SPD manufacturers should nominate a maximum back up fuse rating for their products. This is the maximum fuse or circuit breaker rating that the SPD will safely clear should the SPD fail. This is a requirement of IEC. A typical SPD label is shown in figure 10. The fuse must also be able to pass the rated $I_{\text{max}}$ current without failure, although this is not a requirement of AS1768 because such a requirement is somewhat impractical.

![Figure 10. Typical label for an IEC compliant SPD](image)

At sub boards there is no MEN link so protection is necessary between phases and neutral and between neutral and earth. Omitting the neutral-earth component or directly connecting the SPD to earth does not provide effective protection. The correct method of installing a sub board SPD is shown in figure 11.

![Figure 11. SPD installation sub board](image)

The method of installation very much determines the performance of the SPD because the inductance of the shunt connected leads adds to and thus degrades the $U_p$ or let through voltage of the SPD. Figure 12 shows the effect of the leads on the let through voltage.
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. Figure 13 shows typical performance of an SSP used as secondary protection.

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. Series connected as shown in figure 12, typically with a guaranteed let through voltage, $U_p$, 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.

Figure 13. Surge performance of a surge filter used as secondary protection

Although small surge filters are typically used as secondary protection they also have a place as primary protection. If the risk assessment requires primary and secondary protection for a small site such as a telemetry site, cellular basestation etc a surge filter provides the solution. A surge filter can find application at a data centre where all equipment is considered sensitive. Figure 14 shows an optimum installation method. By creating two neutral bars the shunt connected lead inductance of the neutral connection is eliminated. The neutral - earth gas discharge tube is not required in this application.

Surge filters are available in current ratings from 2A to over 2000A per phase.
4.2 Signal Line Protection

Given that low level signal equipment is more easily damaged than power equipment the installation of signal line protection is as important if not more important than power protection. The choice of suitable signal line surge protection is a more difficult task than power equipment. The SPD must protect the equipment yet at the same time not degrade the signal. 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 15 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 16 welded itself to the DIN rail despite the fact that there was only 1m of earth cable connecting it to the earth bar.

![Image of a SPD welded to a DIN rail]

Figure 16. A lightning weld.

When protecting a device with both power and signal ports it is vital that the protective earths be common. Equipotential bonding is vital for effective protection. Figure 17 shows a typical example.

![Diagram of power and signal protection with equipotential bonding]

Figure 17. Power and signal protection with equipotential bonding.

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 18. 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 19.

Note the green/yellow wire in figure 18. 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.

A complete protection scheme for both I/O and instrument is shown in figure 20. In this example gas discharge tubes are used to provide the equipotential bonding so that the bond is only present under a lightning surge and noise that may otherwise be introduced is eliminated. Note that all earth symbols on the right indicate that these are bonded together. The instrument earth is connected to the instrument body.
5. Conclusion

Surge protection can be highly effective but only when installed correctly. An understanding of the importance of inductance is essential. Never assume that the installer knows this. Equipotential bonding is equally as important. The absolute earth resistance is never as important as equipotential bonding. The greatest impediments are inductance.

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Phillip currently sits on Australian Standards EL24 committee for lightning protection. He also represents Standards Australia on a number of IEC standards committees.

Phillip has been consulting in lightning and surge protection for over 20 years for industry and commercial organisations throughout the world. He established Novaris Pty Ltd in 1994. Novaris is an Australian manufacturer of surge protection products.