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LIGHTNING PROTECTION
of SCADA AND TELEMETRY SYSTEMS

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Abstract - *This paper examines the characteristic current and waveform of a typical lightning discharge and suggests methods of protection for SCADA and telemetry system components using these characteristics to drive the need for that protection. The paper demonstrates why building protection alone is not enough and shows how the importance of earth conductor impedance influences earthing design.*

INTRODUCTION

In the process control and utility industries such as electricity, gas and water supplies, remote monitoring and control are commonplace. SCADA systems are increasingly finding use in providing these functions. From simple PLC's to fully implemented plant automation systems, their use in now widespread.

To provide protection for these SCADA systems an understanding of the way direct or induced remote lightning strikes can induce surges into sensitive control electronics is an essential requirement.

This paper discusses the induction mechanism and examines methods of prevention. Protection for power supplies, both AC and DC, plus the more sensitive I/O and signalling equipment associated with SCADA and telemetry is discussed as well as an appreciation of correct earthing practices.

SCADA SYSTEMS

SCADA, meaning Supervisory Control and Data Acquisition is a term generically applied to systems which may be used to collect data and acting upon that information control some process function. The controlling intelligence may be remotely located from the process under control or it may be shared in the case of distributed control systems. However the system is configured, its essential elements are:

a) *Field sensors*. These convert physical quantities into electrical signals which then form the raw data input for the remote terminal units.

   Field sensors may be digital, in their simplest form are contact closures which sense a change of state; or they may be analogue, converting a varying signal into a 4-20mA loop signal. Quantities such as pressure, temperature, flow etc may be measured.

b) *Field actuators*. These convert electrical signals from the RTU to mechanical actions to operate solenoid valves (digital), or actuator positioners (analogue), for example.

c) *Remote Terminal Units*. RTU's process the field inputs and outputs and feed this information via a communications link to the master controller. Depending upon their configuration RTU's may provide a local controlling function such as a programmable logic controller, PLC, or they may depend entirely upon the master station.

d) *Communications systems*. The RTU's are linked to the master station controller via a communication system. This may be a wire loop carrying RS232, RS485 or other proprietary protocols. Alternatively it may be a fibre optic loop or a microwave radio link.

e) *Master Station*. The master station is the central data collection point and processor which provides overall process control of the plant, power system or gas pipeline to name a few.

LIGHTNING DAMAGE

Many SCADA systems consist of long runs of field cabling, sensitive signalling lines from the RTUs and communications systems with microwave links on tall towers. Lightning strikes, whether direct or induced, can cause damage to sensitive electronics in many parts of the system.

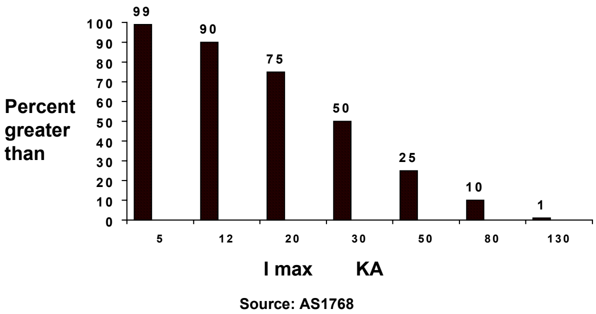

Fig 1. First stroke return current

Before looking at the mechanism of lightning damage to SCADA systems in detail, consider two typical characteristics of a lightning strike. Figure 1 shows the magnitude of current in a typical return stroke. It is statistically distributed with 99% of all strikes exceeding 5KA, 25% of all strikes exceeding 50KA and so on. So the magnitude is large.

Consider a lightning strike to a protected building as in figure 2. The lightning energy will be conducted into the earth termination and dissipate the charge into the mass of the earth.

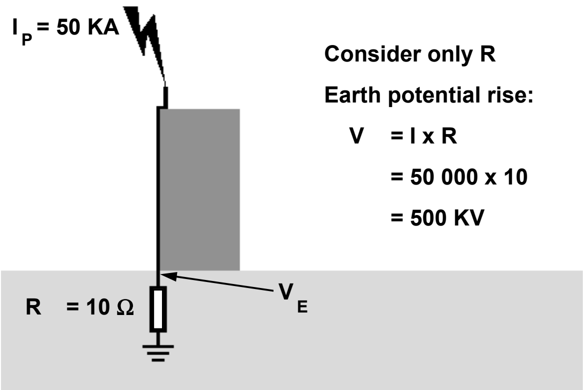

Fig 2. Earth potential rise

The effect of this current is to raise the earth potential of the building itself. For example if the earth resistance is 10 ohms and the lightning current 50KA (both typical values) the resulting earth potential rise will be 500KV. If all equipment within the building is correctly bonded and single point earthing techniques applied, there should only be small potential differences within the building and equipment should be safe.

This situation is complicated by the presence of external cabling. A field sensor is referenced to its own local earth, and probably has a breakdown voltage of around 500V. The sensor now has to withstand the transient voltage between the elevated building potential and its local earth potential. Many transducers can be destroyed in this way even though the strike was to a protected building. In addition this voltage stress is also applied to the RTU field input terminals.

Now consider the waveform of the lightning current. As figure 3 shows the current rise time is very fast, in the order of 1 us.

This means that not just the resistance of conductors is important, their inductance is important as well. The voltage drop across an inductor is given by the expression:

$$V = I \times R + L \times dI/dt$$

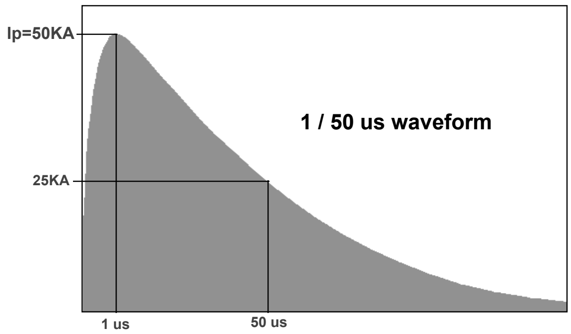

Fig 3. Lightning current waveform

For induced voltages in conductors it is generally recognised that a waveform like the more familiar 8/20us impulse with a rise time of 8us is typical. Actual experiments clearly demonstrate the effect of this risetime on voltage drops across relatively short lengths of conductor. Figure 4 shows the voltage across a straight length of $4mm^2$ conductor when a 3KA 8/20us impulse is applied.

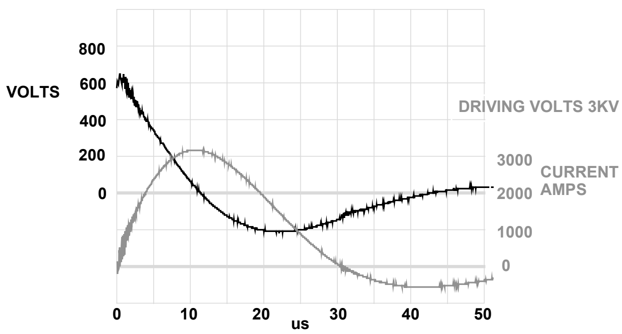

Fig 4. Voltage across 1m of $4mm^2$ conductor

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Even across a 1m length the voltage peak measured 600V. So protection devices must be earthed with short leads to minimise inductance. Long earth leads do not ensure equipotential bonding, there may be significant potential differences between points relatively close together.

PROTECTION COMPONENTS

Several components are available which can prevent excessive transient energy from reaching sensitive electronics. These operate by diverting the energy to ground yet if properly chosen have no effect on the signal path during normal operation. There are three main classes of such components.

Gas arresters

Gas arresters are typically connected across the line or from line to ground to divert transverse and common mode transients. Two element arresters are suitable for single wire circuits but the three element versions should be used on balanced circuits. With a three element arrester both halves of the arrester fire simultaneously hence both lines will be clamped to ground together.

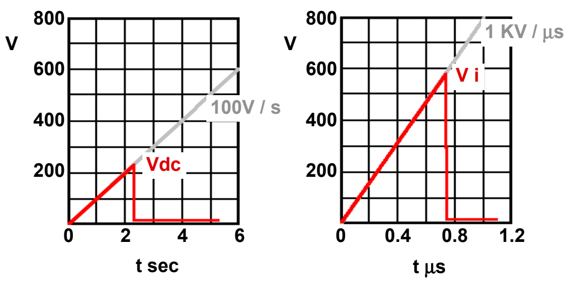

Fig 5. Gas arrester performance

Gas arresters have a high current carrying capacity but have a relatively slow response time to fast risetime signals. As figure 5 shows a common 230V gas arrester may fire at 230V for slow rise time pulses but for faster risetimes the firing voltage may be as much as 600V. For this reason they are rarely used alone on sensitive circuits, rather in combination with other transient protection components.

Gas arresters are unsuitable for power circuits above around 24VDC because of the risk that they may not extinguish in the presence of a low impedance voltage source. They are most commonly used to protect communications and signal line circuits.

Varistors

A varistor is a voltage dependent resistor with a non-linear current/voltage characteristic. Figure 6 shows the typical characteristic curve of a varistor.

Varistors are fast to operate and are able to handle moderate amounts of surge current. For this reason they are used almost exclusively for power circuit protection in surge diverters or power filters or they may be used in conjunction with gas arresters to provide fast response and lower voltage clamping than the gas arrester alone is able to provide.

Figure 7 shows the characteristic of a large metal oxide varistor with a surge handling capacity of 70KA for an 8/20us impulse. This current rating is guaranteed once by the manufacturers. The second 70KA impulse may damage the device. At lower impulse currents, the MOV may be able to absorb tens, hundreds or thousands of impulses, depending upon the impulse current. The B60K275 for example has a single impulse rating of 70KA, ten impulses 25KA, 100 impulses 8KA and 1000 impulses 2.5KA.

For this reason, metal oxide varistors are chosen to operate in their mid current ranges where a reasonable life can be expected.

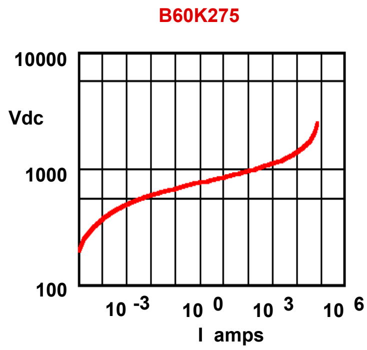

Fig 6. V/I characteristics of Siemens B60K275 MOV

Solid state diodes

A special class of zener diode, called "transzorb diodes" are used for transient protection. These components have enhanced junction areas and a stable, well defined V-I characteristic as figure 7 shows. Their energy handling capacity is limited so they are commonly used in conjunction with gas arresters and varistors to provide precise clamping voltage characteristics.

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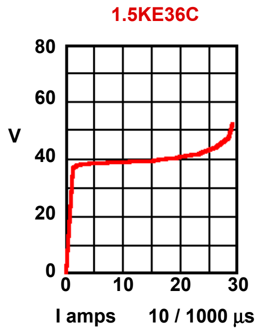

Fig 7. V/I characteristics of 36V bidirectional transzorb diode

Transzorb diodes have only limited surge ratings and under no circumstances should devices employing these components be utilised for high energy surge diversion. Despite claims to the contrary these devices are not suitable for high energy locations.

PROTECTION METHODS

Using the devices describes above, there are a range of protection products which may be utilised to provide protection for SCADA systems.

For AC power protection, surge diverters and mains power filters are two common products.

Surge Diverters

Surge diverters, consisting of metal oxide varistors are shunt connected from the power active leads to earth. They are simple and relatively effective so long as their lead lengths are kept short to minimise inductance. Their voltage clamping characteristics may not be sufficiently low for sensitive electronic power supplies.

Figure 8 shows tests conducted on a commercial surge diverter with zero connecting lead length. With a 7KV, 7KA 8/20us impulse applied, the diverter clamped at 900V.

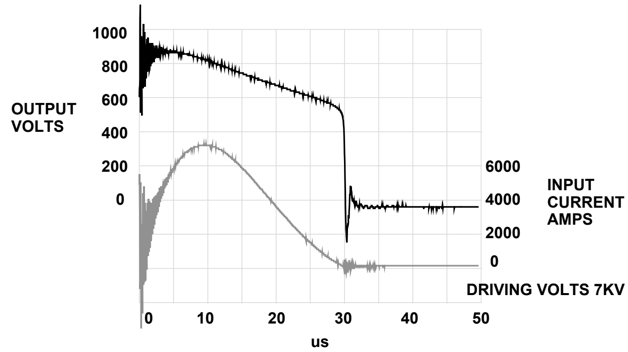

Fig 8. Let through voltage 70KA surge diverter, 900V

With a total lead length of only 600mm, the let through voltage doubled to almost 1800V. The necessity for short connecting leads becomes clear.

Mains Power Filters

Filters designed for surge protection are generally simple low pass types following a stage of metal oxide varistors as shown in figure 9. This filter provides for both common mode and transverse mode protection and would be used on power distribution circuits or on individual sensitive loads like RTU's, PLC's etc.

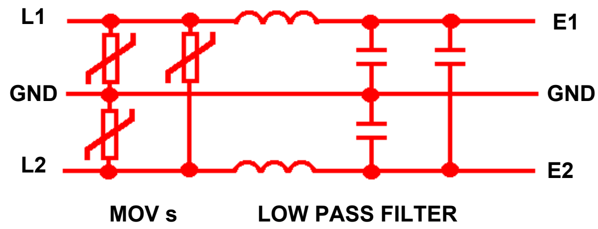

Fig 9. Mains power filter configuration

Being series connected, lead length is not a concern and the performance of a well designed power filter is far superior to surge diverters. Figure 10 shows the let through voltage of a 200A three phase filter, manufactured by Tercel Pty Ltd.

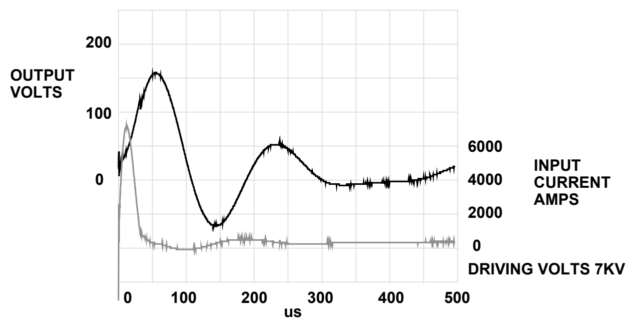

Fig 10. Mains power filter, let through 160V

Signal Line Protection

To protect low voltage signalling and control circuits, multistage protectors are often employed. A typical three stage protector for balanced line is shown in figure 11. This consists of a three terminal gas arrester to absorb the majority of the energy followed by a stage of metal oxide varistors and finally transzorb diodes.

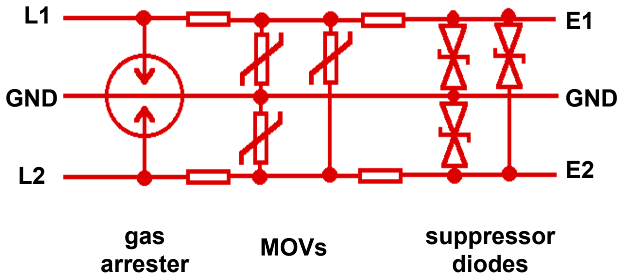

Fig 11. Multistage signal line protector

The choice of signal line protection depends upon factors such as:

a) *Operating voltage*. The transient protection must be chosen such that its clamping voltage is greater than the peak operating voltage but less than the voltage which will cause damage.

   For example a 4-20mA loop circuit, generally operating at 24V DC would be protected with a 36V clamping device.

   For AC operation, the choice of clamping voltage must be greater than the peak voltage. So for a 24V AC system with a peak voltage of 34V, 36V clamping would still just be satisfactory.

b) *Operating current*. Multistage transient protectors have series impedance to segregate each stage. These may be resistor or inductors. Check that the voltage drop across the protector will not be excessive at normal operating current.

c) *Operating frequency*. The frequency response of transient protectors is limited by the capacitance of both the MOV's and transzorb diodes. In addition series inductors combine to form a low pass filter. With digital signalling in particular, square wave distortion can result in the transient protection degrading the actual signal.

   At radio frequencies, the only device that can successfully be utilised for transient protection is the gas arrester. It has inter-element capacitances of around 1pF and can be used into the GHz range. Such devices are available in machined enclosures with the appropriate coaxial cable connector fitted.

APPLICATION

A general representation of a signal line between two buildings is shown in figure 12. There are two ways in which lightning may damage equipment connected at either end of this cable.

a) *A direct strike* to either of the buildings will raise the earth potential of one building with respect to the other. A voltage stress will then be placed on equipment connected at both ends of the cable.

b) *Induction*. The electric field collapse associated with a nearby lightning strike will induce voltages into the cable. The end result is the same - voltage stress on both pieces of equipment.

Regardless of whether the equipment is correctly bonded to a single earth and the building has a properly installed lightning protection system, the fact that a cable leaves the building places the installation at risk.

Figure 12 demonstrates the principles to be applied. Connect transient protection at both ends of the cable referenced to the local earth at each end. Then the equipment is electrically clamped to each local earth.

The rise in earth potential bypasses the equipment via the protection and creates a circulating current in the connecting cable. The cable is generally self protecting due to its inherent impedance and the system will be protected.

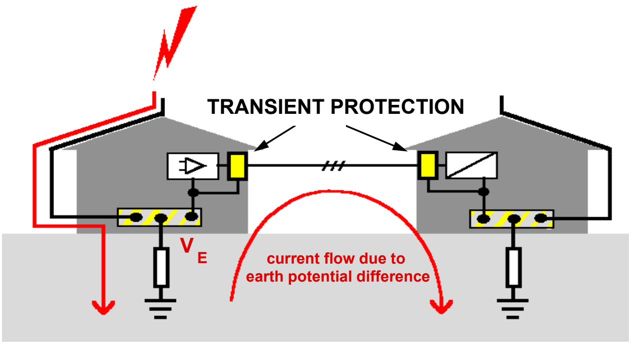

Fig 12. Signal line protection

SCADA SYSTEM PROTECTION

Communications sites used to relay information from RTU's to the master control station are generally placed on mountain tops and other elevated sites. As a result they are prone to lightning damage.

Figure 13 shows the layout of a typical communications site. To provide protection at this site, the following should be implemented:

a) *Direct Strike Protection*. Provide a finial at the top of the tower so that direct strikes do not directly strike antennas. The tower legs are the best downconductors available. They provide four parallel paths to ground and have a low impedance.

b) *Earthing*. Provide an earth bar in the building. Connect all earths to this bar. Connect the earth bar to the site and tower earth by one connection. Therefore create a single point earth, an equipotentinal plane.

c) *Bonding*. Bond the sheath of the antenna cable to earth at the top (antenna), at the point where the cable leaves the tower for the cable runway and at the point of entry into the building.

d) *Surge Protection*. Provide surge protection at the power service entry referenced to the station earth. This is generally necessary regardless of any surge protection that may be present on the distribution transformer. Only if the two earths are adjacent and bonded together can the building surge protection be omitted.

Protect the coaxial antenna feed by surge protection inserted in the coaxial feeder at the point of entry into the building.

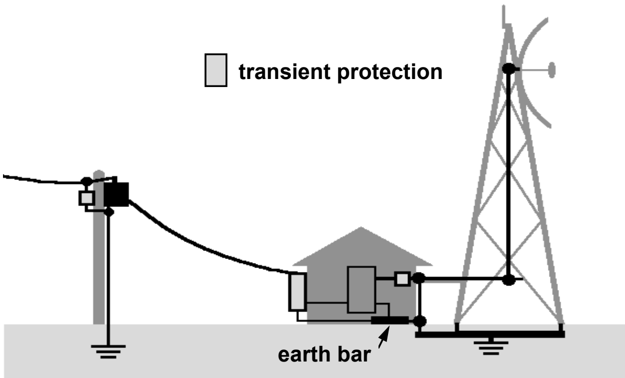

Fig 13. Communications site protection

Figure 14 represents a typical metering and telemetry station on a gas pipeline. By way of example there is a transducer mounted on the pipe sending analogue information to the RTU in the building.

The pipeline is insulated, and isolated from the metering skid by insulating joints. The skid is itself earthed.

Lightning may enter by either a direct strike to the building, induction due to a nearby lightning strike or by a strike in the vicinity of the pipeline. This strike may be many kilometres from the metering station. Because the pipe is insulated, large voltages may be induced into the pipe and travel along the pipe to exit at the earth of the skid.

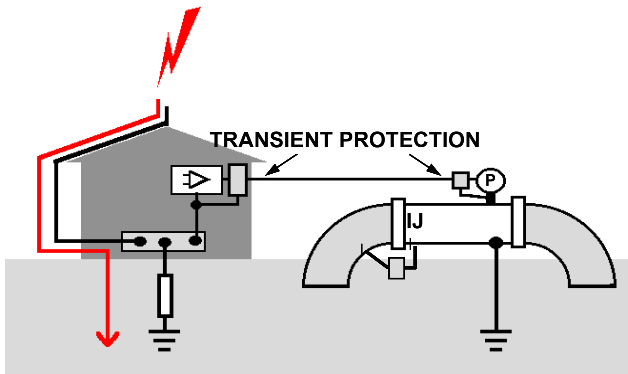

Fig 14. Instrumentation system protection

To provide protection at this site, the following should be implemented:

a) *Direct Strike Protection*. Provide a lightning protection system for the building. In the case of all metal construction it can be argued that the building already acts as a Faraday cage and

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no protection, other than earthing of the structure is required.

b) *Earthing*. Provide an earth bar in the building. Connect all earths to this bar and so create a single point earth, an equipotential plane. If the skid is mounted some distance from the building, the skid earth and the building earth must be treated as separate and so transient protection is required on signaling cables between the pipe and the building.

c) *Surge Protection*. Although not shown in figure 14, surge protection at the power service entry is necessary. The signal cables also require transient protection at both the transducer and RTU ends.

The transducer will then be clamped to the potential of the pipe and the RTU to the building.

d) *Insulated Joints*. A pipe induced surge can cause the insulated joints to arc over so creating a path to ground. To prevent this fit a protection unit consisting of a large capacity gas arrester across each flange. The arrester will safely conduct the surge to ground and open circuit after.

e) *Cathodic Protection*. If the pipe is cathodically protected, lightning protection will be required for the cathodic protection power supply. The aim is to clamp all electrodes to the same point. Generally pipe earth is convenient. The design of such protection depends upon the cathodic protection power supply, its configuration and construction.

CONCLUSION

SCADA systems may be successfully protected from lightning damage once an understanding of the mechanisms is gained.

Cables and services entering buildings must be protected, despite the presence of area building protection and proper earthing systems. A systems approach is required where due consideration to all aspects of lightning protection is essential. When only part of the required solution is implemented our equipment will still be vulnerable.

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Phillip R Tompson *graduated from the University of Queensland with an honours degree in Electrical Engineering in 1972. His early experience was gained as a communications engineer with Telecom Australia, then with power utilities specialising in communications and control systems design and management. His work now involves consultancy in the field of lightning protection, power quality as well as product design work for surge and overvoltage protection products. He is a chartered member of IE(Aust), IEE, and IEEE as well as a member of the Australian Standards Committee on lightning protection..*