Foundation Fieldbus End Users Council Australia Inc.

9 Corcoran St Duncraig, WA 6023

P.O. Box Z5546 Perth, WA 6831

SURGE PROTECTION FOR FIELDBUS SYSTEMS

Chris Ground
MTL Surge Technologies

Abstract
The current trend gathering momentum in the Process industry is that of "Fieldbus" systems. These systems offer significant benefits to the user and integrator and are most likely to become the future standard for control. Whilst much thought has gone into the development of standards relating to physical layers, reliability and safety, one area which could impact, and is not addressed thoroughly in standards, is that of surge protection. The consequences of not understanding and failing to comprehend the risk could be as small as system unreliability or as severe as a potential life-endangering situation. The talk will address cause and effect, risk analysis and technical considerations when considering "Fieldbus" systems.

Keywords

Fieldbus, Lightning, Surges, Risk, Reliability

1. Introduction

Fieldbus systems are being promoted as having many advantages over conventional point to point wiring such as a substantial cost saving in field wiring (10:1 appears a well publicised number). Decrease in installation costs and lower overall maintenance also figure highly in the advantages of a fieldbus installation.

All of the advantages present a compelling argument for the migration to this type of technology however, as with all new technologies, the reliability of operation in harsh environments such as lightning prone geographical areas is not yet well understood. This is reasonable since the probability of a major lightning related problem on Fieldbus could be as high as once in ten years. So, while it is true to say that there are a number of installations already running which are proving quite robust this does not mean that there is room for complacency.

In determining the reliability of any system from both a safety and operational viewpoint, the possibility of damage to electrical equipment by surges derived from lightning or other electrical equipment must be considered. Where the consequences of a system failure are significant, then the prevention of damage by surges becomes even more important. Recently designed electronic equipment is usually provided with some degree of protection against transient over-voltages [1-2 kV] but is not adequately protected against the higher transients [10-20 kV] induced by lightning. It is not easy to predict what damage these transients will cause and frequently the damage is only evident after some time has elapsed. It is important to recognise that if a surge enters a complex process control system, the damage caused may not be directly related to the point of entry and subsequent diagnosis of the cause of the fault may be difficult. That significant damage to instrument systems can occur, even in countries not subject to a high incidence of lightning storms, is illustrated by recent well-publicised incidents in the United Kingdom using conventional (presumably more robust) technology.

1.2 Probability of a lightning strike

The principal factor in determining the probability of a lightning strike is the geographical location. For example, the Amazon Basin has 200 thunderstorm days per year, the Mexican
Gulf 100 and the North Pole less than one. Detailed, (but sometimes conflicting) data on the probability of lightning strikes on a particular location is readily available in most parts of the world. The measurement most widely used is flash density, that is flashes to ground per km^2per year. In the US most areas have more than 5 flashes to ground per km^2per year, with specific areas, such as Florida, having in excess of 50. Flash density in Australia is estimated between 2 to 50 from available data and dependant upon geographic area. (NASA OTD). These statistics are very useful, for example a plant (covering an area of 0.2 km^2) in an area with a flash density of 5, can expect to be struck once every year.

The size and shape of a structure also influences the probability of a lightning strike. Almost all-industrial plants have tall chimneys or pieces of equipment, which are particularly effective in attracting lightning. Usually plants are located on flat areas, and are frequently the highest point for some distance. There are some other factors, which increase the probability of a lightning strike, although the mechanisms are not always understood. For example the proximity of power lines, railway tracks and pipelines all appear to be factors that increase the probability of a lightning strike, and are all likely to be present in, or adjacent to a plant. Another example, where the risk is significantly enhanced is an offshore production rig, which may protrude some 50m from a flat sea.

1.3 Failure mechanisms

Lightning current flowing through a structure and creating significant differential voltages across the instrumentation loop is the principal cause of instrument damage. These voltages then cause an insulation failure, usually between the instrument circuitry and the instrument case, allowing part of the lightning current to flow through the circuit causing damage. The damage caused is sometimes spectacular, particularly if the circuit has a large power source, which can follow through on the initial insulation failure. The type of damage, which causes the greater problem, is when semiconductors are partially damaged and fail at inconvenient times several months after the initial incident. The majority of modern electronic equipment is designed to withstand the level of voltage and energy associated with an electrostatically charged human being; [a typical test is 4kV from 150 pF through 330 ohms]. But the voltages generated by the lightning currents are considerably higher than this and invariably will damage almost all electronic circuitry.

It is important to recognise that a well-bonded structure NOT eliminate the risk of damage. Even a well-bonded structure will have some residual inductance [0,1µH/m]. It is this inductance combined with the fast rise time of the lightning surge [10 µs], which creates the damaging voltage difference. The probability of where a lightning strike will hit a plant and the flow of the current through the structure can be influenced by a conventional lightning protection system. However whatever the lightning protection system utilised, the lightning current must flow through the structure and transient voltage differences caused by the inductance of the structure will always occur.

There are other mechanisms, which cause damage, but the voltage difference generated and the consequent insulation breakdown is the predominant cause.

A convenient rule of thumb is that where a structure may be subjected to a lightning current surge, and the instrument circuit includes a vertical displacement greater than 10m and/or an horizontal displacement greater than 100m then surge protection is necessary. This is a very approximate guide and is further explained in Appendix 1 of this paper. As with many derived rules the parameters should be set out for plant personnel to follow. This paper supports the logic that the threat from lightning should never be ignored and, to that end, decisions of whether or not to fit surge protection should be documented through the design and operations process. Whilst the mathematical model, in appendix 1, gives a compelling argument to fit surge protection as physical separation increase over 100m horizontal and 10m vertical it would be remise not to give guidance on what to do under this distance. Irrespective of the topography a view should be taken on the consequential loss of a segment with respect to functionality. If the function is critical for any individual instrument on a segment then surge protection should be fitted to that segment.

Under 50m physical separation horizontal and 5m separation vertical the risk of surge invasion is at its lowest however other factors should be considered regarding the location of the facility, the consequence of losing operations and above all safety. If after all these factors are taken into consideration and the decision is made to omit surge protection a person in authority should sign this decision off.

Between 50m and 100m physical separation horizontal and between 5m and 10m vertical of equipment the question should be “why should surge protection not be fitted” and then compelling arguments written up and signed off by a person in authority. Above 100m is the highest vulnerability and a more intensive risk assessment carried out and then signed off.

The author, in the later examples, has assumed that any physical separation over 50m horizontal and 5m vertical presents a tangible risk and therefore has used this distance as a basis for the application of surge protection.

Another technique that is useful in helping to decide whether surge protection is necessary is to consider each point of invasion of the system (the comparison between single loop integrity and Fieldbus will be shown later in this document). As well as invasion from the immediately adjacent structure as discussed, the possibility of invasion from other sources such as sources of power, and data highways from other systems should always be considered. In practice these sources are frequently a significant risk, because they involve considerable distances and frequently have different reference potentials [earths, grounds or structures]. This risk can be removed at a low cost and is probably the minimum level of protection required, and should be applied in almost all circumstances. The basic requirement is to consider each point of invasion and make a positive decision as to whether surge protection is necessary or not. Sometimes in areas of low risk it is decided to protect only the devices where damage could cause significant economic or operational damage, such as the input ports of a process control system and accept the smaller consequences of damage to the field device. This decision may be justified, but a consequence of protecting or bonding one point in a circuit is to increase the potential differences to which the remainder of the circuit is exposed.

1.4 Risk analysis

The steps to be taken in a risk analysis are to establish the probability of damage due to a lightning induced surge and then decide whether the cost of protecting against the damage is justified.
It is not possible to accurately quantify the probability of lightning induced damage, but it is possible to arrive at acceptable estimate for this purpose. The information required is:

- The location of the installation
- Any features which affect the probability of a lightning strike, such as a prominent tall structure, or the presence of high-voltage power distribution system, and interconnected pipelines.
- The lay out and physical separation of the Fieldbus system.
- The source of power to the system.
- The interconnection to other systems

For example suppose the plant is located in Queensland, inland. It comprises a series of storage tanks 15m high, 30m in diameter and the Fieldbus system interconnects three tanks 30m apart with the Fieldbus host and power supply 100m away. The mains power to the system is derived from a remote source. The host control system has inputs from other similar Fieldbus systems and sends processed data to a management system some 500m away.

The ‘analysis’ is then as follows:

Inland Queensland has a ground flash density of 6/ km^2/year generating possibly 42 surges. (Up to 16 surges can be contained in a single ground flash, the Author has used a conservative 7 surges in the calculation)

The tanks are tall but not conspicuous; hence probably have a multiplying factor of two giving 84 surges/km^2. The three tanks have an aggregate area of approximately 4000m^2 giving a surge rate of one surge every 3 years. There is a comparable risk of the potential of the location of the host being elevated which is more difficult to estimate, but assuming it is similar then the total probability of a surge becomes higher, at least once per year and maybe several times each year.

Any such surge is likely to cause damage because the majority of the instruments are more than 10m above ground and the trunk is 100m long.
The estimated risk is therefore that the system would be damaged every year. The reliability of the system is further decreased by the possibility that the host could be damaged by invasion from the data highway or the other Fieldbus systems.

A rate of failure of once every year is operationally undesirable, and could possibly have safety implications. The cost of installing comprehensive surge protection would not be small but when weighed against the cost of repair and the possible loss of production can be readily justified. On the basis of this analysis surge protection should be fitted to the Fieldbus system itself, the other Fieldbus systems feeding the host, the data highway and the mains power supply to the host. The resultant system would then be very similar to that illustrated in Figure 5, but could be modified if a brief analysis of the points of invasion justified the change. This type of estimate can be criticised as not being sufficiently accurate, but it does give a measure of the order of the risk. Frequently the estimate can be supplemented by the experience gained from nearby plants, although it is not always easy to find a relevant comparison and the evidence is not likely to be statistically justified.

The failure rate caused by the usual component failure rates of devices for a Fieldbus system varies considerably with the complexity of the system and the devices used. However if a simplistic, but justifiable, view is taken that a typical Fieldbus system has ten devices with an individual failure rate of once every 50years, then the expected failure rate would be once every five years. In most circumstances this type of failure would occur at a single point, be detected by the diagnostics available in the system and be quickly rectified. Whereas damage caused by a lightning surge is likely to be spread throughout the system. This analysis suggests that in a significant proportion of the world surge protection of Fieldbus circuits is necessary to prevent the failure rate of the circuit being very high. Where specific precautions to increase the reliability of the circuit, such as duplicating power supplies and fitting current limiting devices to spurs have been taken then the need to fit surge suppression is increased.

It is difficult to generalise about the cost of lightning surge damage since every application is different. The common factors are:

- The cost of replacing the damaged equipment, and detecting subsequent failures due to partial damage.
- The cost of possible loss of production.
- The possible effect on safety for example undetected damage to intrinsically safe equipment and preventing high voltages entering Zone 0 locations.
- The possible effect on indirectly related systems such as control system computers.

In general if there is a significant risk of lightning induced damage, the cost of the protection devices and their installation can be readily justified.

2. Single loop integrity vs fieldbus

When considering surge protection and how it may affect any system the first question is how the surge is likely to enter the system. On a point-to-point system the surge would enter at either end of the loop (field or control) dependant upon where the lightning strike or raise in potential took place Figure 1.

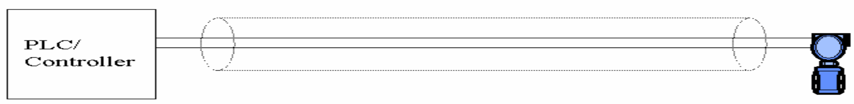

Figure 1 Single loop integrity

In one aspect the fieldbus segment is similar; the surge will enter the system from either the field end or host end however, since the number of field points on the segment is increased for example by 10:1 then there are ten times as many points where the surge can enter at the field end Figure 2. System design will play a key role in determining how great the risk is and how many points of entry are susceptible. The distance between any two points on the system is going to effect the susceptibility and any distance greater than 50m horizontally and 5m vertically would be sufficient to raise concern in a well bonded structure with distances considerably below this in a structure with relatively little bonding or facilities located in an area of high lightning probability.

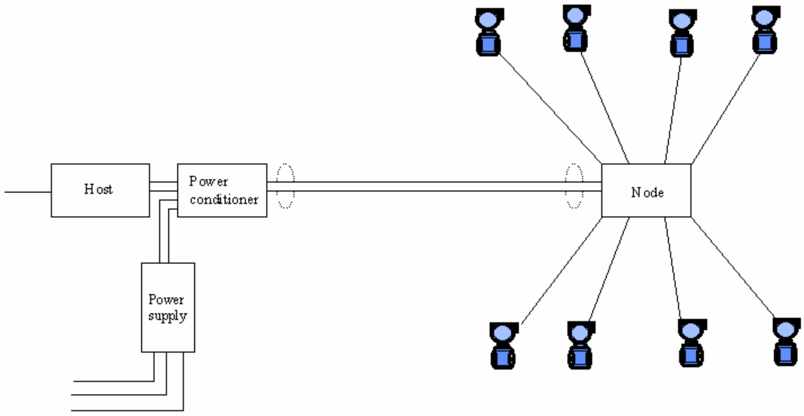

Figure 2 Simple Fieldbus scheme

When considering the system design the effective distance between any two potential entry points has to be established. From Figure 3 it can be seen that there are eight potential loops to consider in the first instance e.g. between A_1 – L_1…….L_8. Additionally the distance between any of the instruments must be considered i.e. the instruments on L_1 & L_2. This distance is not the length of the wiring but the physical separation between the two instruments. The physical distance separating the two devices will directly determine whether the potential difference between them during lightning activity will be sufficient to allow a surge to enter the system.

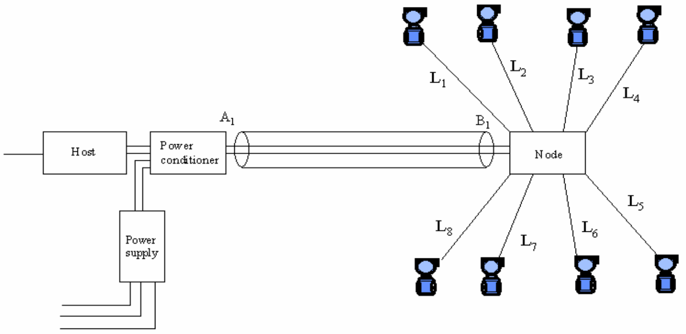

Figure 3 Effective physical separation in a simple Fieldbus scheme

Figure 4 demonstrates that in this layout the distance between the instrument on L_1 and that on L_4 may be sufficient to allow enough potential difference for a surge to enter the system since they are connected at separate blocks on the trunk wiring. The junction blocks on the trunk wiring can be separated by several 100's of metres.

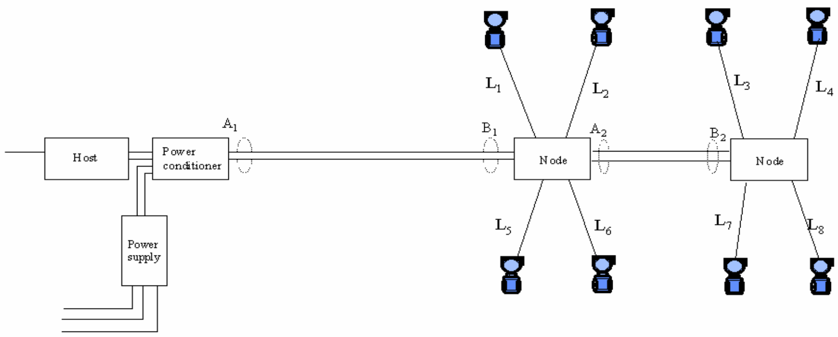

Figure 4 Effective physical separation in a more complex Fieldbus scheme

Figure 5 shows a system where surge protection has been applied. In this example it has been assumed that all of the instruments are within 50m of each other in the lower part of the structure and will, during storm activity, not be at sufficient differences in potential which will cause a surge to enter the system. Surge protection devices have been placed at either end of the trunk as this has, in this example, exceeded 50m. Protection has been applied also to protect the power supply and any LAN connection.

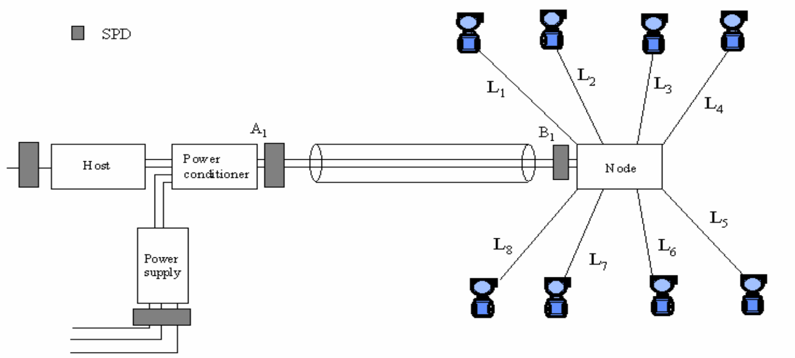

Figure 5 Surge protection applied to a simple scheme

Where the junction blocks supporting the instrument spurs are placed along the length of the trunk each block is considered separately. In Figure 6 the instruments around each junction block are in the lower part of the plant and the instruments are all within 50m of each other. The junction blocks may be separated by several 100 metres. The surge protection shown will act locally to protect each cluster of instruments.

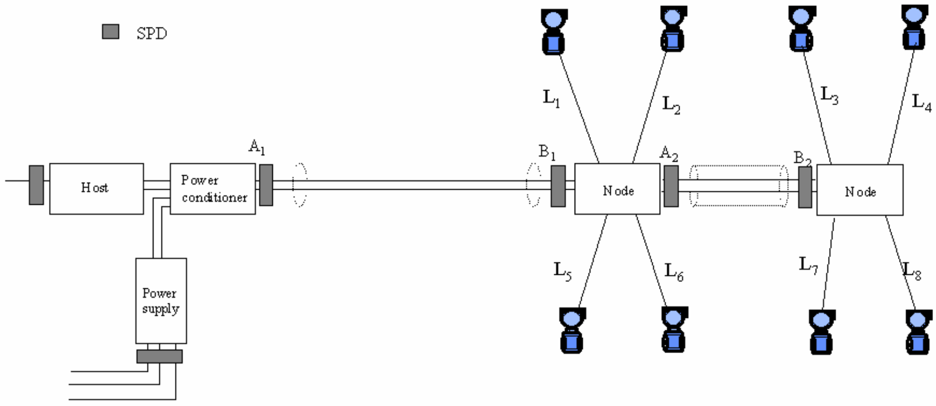

Figure 6 Surge protection applied to a more complex scheme

Figure 7 posses an example where in one of the instruments one is separated vertically by a distance of more than 10 metres from the other instruments. The remaining instruments remain at a low level, have no vertical separation and are within 50 metres of each other horizontally. Surge protection has been applied to that spur (L_8) as well as to each end of the trunk. The surge protectors will act to prevent the surge from mitigating through the other instruments connected to the junction block

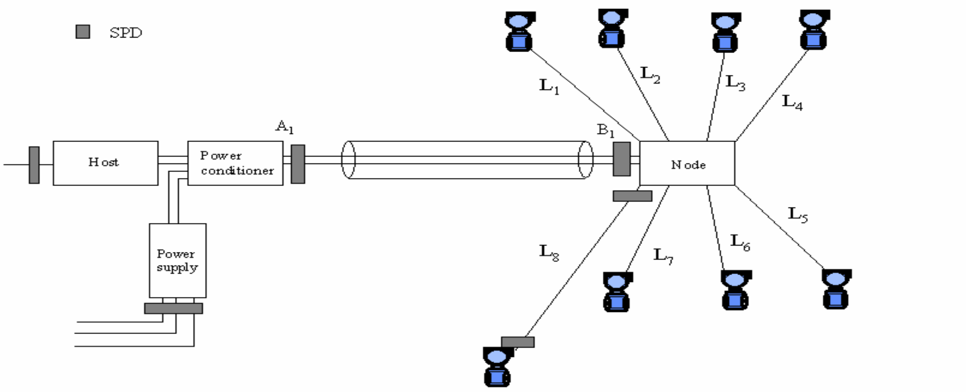

Figure 7 Surge protection applied to spurs

.

It can be seen that from just a few examples the possible permutations regarding the location of instruments is vast and can significantly affect the way a system performs with respect to surge withstand. Also evident are the steps required to mitigate the risk from surges that should be applied to all system designs.

3. Summary

In summary the options open to the engineer designing a fieldbus system are enormous and, as the technology advances, the Engineer will have many topics which they will have to study and understand. The subject of surge protection is a fairly well understood topic with respect to conventional control technologies and most users will be in a position to implement a reasonable scheme by which to mitigate the risk. On fieldbus, however, the topic is less well understood and the effects far more critical to a reliable operation. The author hopes paper has gone some way to explaining the basics of how surges will affect fieldbus systems and how the risk can be reduced.

Appendix 1

Voltage differences across a structure

It is usual to consider that surge protection should be applied to all systems where interconnected devices are separated by more than 10m vertically or 100m horizontally. This appendix explains how this rule of thumb is derived.

Figure 8 shows diagrammatically a simple well-bonded plant with one prominent vertical vessel

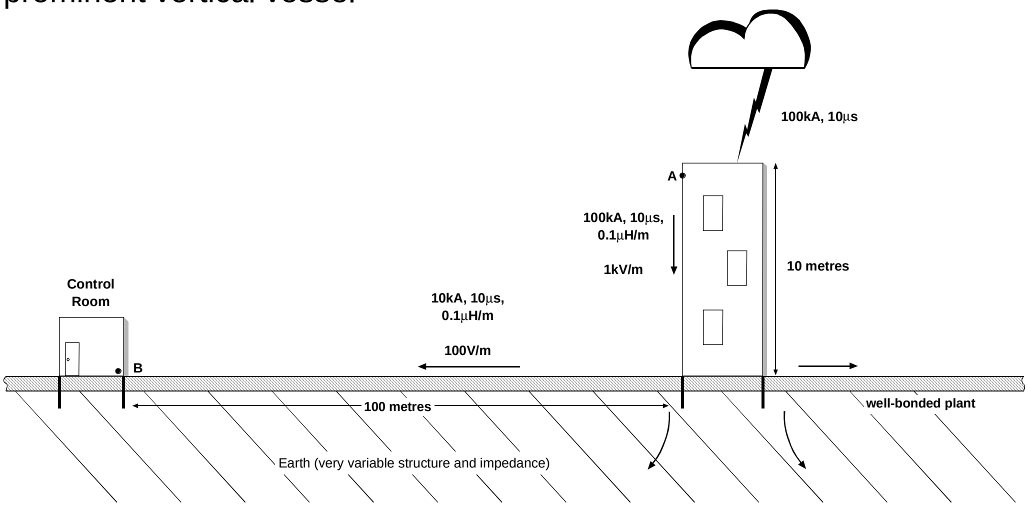

Figure 8 Lightning strike on ‘simple’ plant

The analysis assumes that a lightning pulse of current of 100 kA, with a rise time of 10µS strikes the top of the vertical vessel, flows down the vessel and then disperses in a combination of the ground and the well-bonded structure of the plant. The portion of the current, which flows in the structure between the vessel and the control room, is one tenth of the whole, 10kA. The inductance of the tower and plant is considered to be 0,1µH. Using the normal equation of V=Ldi/dt the voltage generated across the vertical vessel is 1kV/m and that horizontally across the plant is 100V/m. If it is considered desirable to limit the maximum voltage across the insulation of interconnected instruments at A and B to 1kV, then the maximum vertical distance is 10m and the maximum horizontal distance 100m. Where both horizontal [Xm] and vertical [Ym] distances are involved the voltage becomes (10X+Y) kV.

The 'rule of thumb' is an oversimplification but used within its limitations is a useful guide.

References

1. NASA OTD – Lightning detection network. Information on website http://thunder.msfc.nasa.gov/

Abbreviations

1. SPD – Surge Protective Device
2. PLC – Programmable Logic Controller