On the selection and installation of surge protection devices in a TT wiring system for equipment and human safety

ARTICLE in SAFETY SCIENCE · JULY 2011
Impact Factor: 1.83 · DOI: 10.1016/j.ssci.2011.02.002

1 AUTHOR:

Chandima Gomes
Universiti Putra Malaysia
198 PUBLICATIONS 875 CITATIONS

All in-text references underlined in blue are linked to publications on ResearchGate, letting you access and read them immediately.

Available from: Chandima Gomes
Retrieved on: 30 March 2016
On the selection and installation of surge protection devices in a TT wiring system for equipment and human safety

Chandima Gomes *

Centre of Excellence on Lightning Protection, Department of Electrical and Electronics Engineering, Universiti Putra Malaysia, Serdang, 43400 Selangor, Malaysia

Abstract

This paper provides a comprehensive guidance for the selection and installation of transient protection devices, especially in a TT wiring system with the aim of safeguarding both the equipment concerned and the operators and users of equipment. A number of core and fringe issues with respect to surge protection have been discussed in details with the view of developing high level of electrical safety practices among engineers. The information presented can also be used as educational material that guides electrical engineers in addressing lightning protection issues of LV power systems and ELV signal systems. A number of real life examples and survey outcomes that reflect misinterpretation of standards and scientific practices, gathered in the South Asian region have also been discussed.

1. Introduction

The annual property damage due to lightning and switching transients in a small developing country such as Sri Lanka, exceeds 2.5 million USD. Out of these losses, 75% is due to the damaged electrical and electronic systems (unpublished data of a survey done in Sri Lanka). In the other extreme, in USA, during the period 2002–2004 lightning caused a loss of 213 million USD (Ahrens, 2008) and lightning is responsible for 1.065 billion USD total insurance industry losses in 2008 alone, according to Insurance Information Institute Report (2009).

The indirect effects of lightning such as out-of-operation time in the industrial, banking and other service sectors due to damaged equipment and data losses will be much higher than the above mentioned figure. A majority of the lightning and switching transients do not give rise to catastrophic outcome; instead they cause degradation in the electronic circuitry. Repeated, exposure to such transients will finally cause the permanent equipment failure. Most often such failure occurs in a totally unsuspecting atmosphere, thus the cause of failure is hardly attributed to the correct source. Due to these reasons, the industrial, commercial and public sectors should pay extra attention on transient protection to avoid unforeseen losses.

Transient caused electrical failure in equipment may lead not only to electronic damage but also human fatalities. Arcing due to a transient, between earth and line inside an equipment, may lead to permanent short circuiting (due to fusing of conductors) which will electrocute the operator or user. However, the transients may cause even worse threats to the human life due to unexpected power failures, data losses and signal distortion in the fields of medical, petrochemical, defence, etc. For an example, an undesired signal modification in a medical equipment due to a lightning generated transient may take the life of a patient whose life rely on the equipment. Hence it is of prime importance for the maintenance engineering sector that the low voltage and signal systems are firmly protected against lightning and switching transients.

In this paper we present a comprehensive guidance for non-specialized electrical engineers in designing, selection, installation and maintenance of surge protective devices, to safeguard the electrical and electronic devices and consequently the operators and users. The tutorial also addresses important issues and concerns in the pre-design and post-installation stages. The term “earthing” is used in this paper for the process referred as “grounding” in some countries.

2. Planning of protection

2.1. Pre-requirements

The loss due to both lightning and switching transients can be minimized by installing Surge Protective Devices (SPDs) in the power systems and communication/data line systems. However before planning the installation of SPDs one has to ensure that:

- the wiring system, starting from the main panel, is according to the codes of practice in a given country,
electrical safety devices such as earth fault tripping devices (referred as RCDs, RCCBs or ELCBs), over current tripping devices (MCBs, MCCBs or thermal fuses) and voltage stabilizing devices are properly installed and they are in good condition,

- the electrical system has a single earthing point (close to the main panel) with DC earth resistance less than about 5 Ω at the earth pit,
- load distribution is balanced and optimized,
- power feeds to outdoor systems are confined into dedicated distribution boards,
- CPUs are in good condition (CPUs themselves do not generate harmonics and transients).

If the infrastructure of the building is at pre-design stage then one should plan the locations of equipment in a zonal lay-out. i.e. Robust and unsophisticated electrical items (large motors, machines, power tools, etc.) should be placed closer to the main panel and more sophisticated equipment (computers, medical equipment, communication equipment, etc.) should be located at inner rooms where power is provided from more inward power distribution boards.

For a productive and cost effective surge protection scheme the following steps should be taken:

- System analysis and risk assessment.
- Strategic location selection for protective devices.
- Selection of appropriately coordinated protective devices.
- Proper installation and commissioning.
- Regular maintenance and replacement of faulty devices.

2.2. The threat

The lightning may affect our system when there is a

- direct strike or side flash to a building,
- direct strike or side flash to a service line, or
- strike to a location near to a service line.

Lightning may cause equipment or system damage in several ways. In each of the above case the lightning energy may enter the systems by one or more of the three coupling mechanisms; resistive, inductive and capacitive coupling.

When lightning strikes a building, the current may enter the power lines by insulation breakdown of air and the wires (arching) or by back-routing via earthing systems. This is basically a resistive coupling. As the current flows through steel reinforcement, down conductors, etc., a part of the energy is injected into the power lines through inductive coupling (via electromagnetic induction).

A lightning strike to a LV power line is a resistive coupling. A strike to an MV line may transfer part of the energy through both inductive and capacitive coupling at the transformer (between the primary and secondary coils). There can also be a resistive coupling if there is an insulation breakdown between the coils.

A nearby strike basically induces voltage impulses in service lines through inductive coupling while strikes near to the utility may cause a potential rise in the earthing system which leads to resistive coupling. The coupling methods due to various lightning strike locations are depicted in Fig. 1.

2.3. Protection scenario

The low voltage power line SPDs are most often connected in shunt. In a TT wiring system (Fig. 2), the most practiced in the South Asian region; the SPDs are recommended to be connected in one of the two arrangements as shown in Fig. 3 (IEC 62305-1, 2006; IEC 62305-4, 2006). Out of the two arrangements the connection type-2 has a wider usage among many engineers in the region.

The role of surge protective devices (SPDs) is twofold. As a transient propagates in a line, the SPDs should switch itself from high impedance mode to low impedance mode for a short duration allowing the transient to pass into earth. After that it should be
Fig. 3. Two types of SPD connections in a TT wiring system.

switched back to the high impedance mode. In the event of a ground potential rise (e.g., a nearby lightning strike) the SPDs should be switched into low impedance (ideally short circuit) mode equalizing the earth, neutral, and line potentials.

Let us discuss the operation of connection type-2 in the event of a voltage impulse propagating in Line-1. Let the SPDs from each line to neutral be $S_1$, $S_2$, and $S_3$ respectively and the one from neutral to earth be $S_4$. The presence of voltage impulse at Line-1 generates a potential difference across $S_1$ thus after a certain time period (response time, say $T_1$), $S_1$ switches to low impedance (let’s assume $S_1$ has zero impedance in the low impedance mode) bringing the Line-1 voltage to neutral. Hence, a potential difference develops between the neutral and Line-2. Line-3 and earth causing $S_2$, $S_3$, and $S_4$ to switch to zero impedance mode after periods $T_2$, $T_3$, and $T_4$ respectively. Hence Line-2 and 3 and earth reaches the same potential with Line-1 in time periods $T_1 + T_2$, $T_1 + T_3$, and $T_1 + T_4$ respectively. These time intervals should be short enough to prevent insulation breakdown between respective lines/neutral/earth or driving dangerous currents through the loads connected between them.

Note that while the SPDs $S_1$ and $S_4$ are in the low impedance mode, currents will flow into both the utility earth via local earth bar and the substation earth via the neutral line in a TT wiring system. The component of current that flows into the substation earth depends on the earth resistance of both the utility earth and the substation earth and the wire length to the substation from the utility. In the event that the earth resistance of the utility earth is high and the substation is located close to the utility, a considerable current may flow into the utility earth. In the event of such a current flow the neighbouring buildings, which are supplied power by the same substation, will unavoidably experience a potential rise in their power neutral (with respect to their own utility earth). Hence, in the absence of SPDs, the equipment of the neighbouring buildings may be damaged depending on the level of potential rise.

In the event of an earth potential rise (e.g., due to a nearby lightning strike) $S_1$ switches to low impedance mode taking earth potential to the neutral and subsequently the SPDs $S_1$, $S_2$, and $S_3$ operate equalizing the line potentials with earth and neutral potentials. Note that in this case, a current may flow from local earth, which is at raised potential to the substation earth via the neutral line.

Due to several reasons SPDs are needed to be connected to the LV system at several stages in a given building. This scenario of connecting SPDs in several stages is known as the “Zonal Concept”. The most exposed zone; closer to the power entry point (usually the main power panel) and power outreaching points; is termed Zone-1. The Zone-2 is usually the sub panels to which only partial lightning currents or reduced voltage impulses reach and Zone-3 is the power socket level which experiences even lower lightning energy.

There are three prominent factors that lead to the zonal concept.

a. Finite impedance of SPDs: Although we assumed zero resistance for SPDs under low impedance mode, in reality they have finite impedance (non-zero). Therefore, as the current flows through the SPD at low impedance mode, a potential difference builds up across each SPD which will be felt by the downstream equipment (which are to be protected). A large current results a large potential difference, hence we need SPDs in several stages to have a low output voltage to appear across the protected equipment ($V_3$ in Fig. 4). This phenomenon will be described in detail under the Section 3.2.

b. Backdoor intrusion of lightning transients: In most of the building complexes one may find power panels from which electricity is fed into external devices such as CCTVs, security systems, garden lamps, gate controllers, etc. Lightning current may enter the building via these electrical paths and affect the equipment connected to the power system even if the main panel is installed with SPDs.

c. Transients generated within the building: Many switching operations, involved with large inductive and capacitive loads, generate fast transients that carry sufficiently high energy to affect sophisticated electronics. Only a properly coordinated network of SPDs will be able to prevent such transients from damaging the equipment.

SPDs used to protect communication and data line systems most often have both shunt and series components thus they both divert and attenuate the transients. The protection of equipment...
from transients coming through data lines will be discussed in a separate section.

3. Selection of devices

3.1. Impulse current

The surge protective devices are usually referred by their impulse current handling capacity, although, the more logical way is to refer them by the zone at which they should be connected. The IEC 62305-1, 2006; IEC 62305-4, 2006 specify two current impulse waveforms for the testing of surge protective devices. The waveforms are specified by their rise time and half peak width. The two specified waveforms are referred as 10/350 $\mu$s and 8/20 $\mu$s waveforms; where the first number refers to the rise time (approximately) in micro seconds and the second to the half peak width in micro seconds. The 10/350 $\mu$s and 8/20 $\mu$s waveforms are depicted in Fig. 5.

In the selection of SPDs, the most exposed zone or Zone-1 needs SPDs with higher rating of impulse current handling. The Zones-2 and 3 need sequentially reducing values of current handling capacity. The values of the current rating should be determined by following an appropriate standard and also taking into account the geographical location, thunderstorm density, equipment to be protected, etc.

As per the IEC 62305-4, 2006, the SPDs connected at Zone-1 (known as Class I protectors), should be tested for the 10/350 $\mu$s impulse while the SPDs of other classes should be tested for the 8/20 $\mu$s current impulse. At Zone-1, SPDs may encounter direct lightning currents entering the system from outside the premises, hence they should be able to withstand large amount of charge and energy, specifically due to the so called “continuing currents”. In real lightning, most of the return stroke current waveforms show an almost steady component of few hundred Amperes, following the initial peak. These components, which are called as continuing currents, may exist for several hundred milliseconds. The duration and magnitude of continuing currents of positive lightning may be several times greater than the above mentioned values which are typical for the negative lightning. The 10/350 $\mu$s waveform takes into account the energy and charge of such continuing currents thus testing of SPDs that encounter direct lightning, against the 10/350 $\mu$s test impulse is well justified. However, at present the USA based Standards (IEEE/ANSI C62.41, 1991) or its latter modifications do not specify the 10/350 $\mu$s impulse for testing of any class of SPDs. These Standards are now under revision to improve the recommendations (ANSI/IEEE 1100, 2005).

As per the diagram in Fig. 4, the current pulse which passes through the SPD at Zone-1 gives rise to the voltage $V_1$ which is predominately determined by the inductance of the current path. Hence, the contribution of the mostly uniform continuing current to the voltage $V_1$ is insignificant compared to that of the impulse component. SPDs in Zones-2 and 3 are subjected to voltage $V_1$, $V_2$ or a part of the voltages induced in the wire lengths between SPDs which does not contain long duration components. Thus, the SPDs in the inner panels are subjected to currents with less duration and smaller energy. Therefore, their testing against 8/20 $\mu$s current impulse is justified.

In most of the technical specifications published by the manufacturers the 10/350 $\mu$s waveform is referred as $I_{\text{imp}}$ and 8/20 $\mu$s impulse by $I_{\text{max}}$.

It is noteworthy to state that in natural lightning, the rise time of the return stroke current waveform may be as small as a fraction of a microsecond. Hence even after propagating a short length of transmission lines the lightning current waveform will maintain a much smaller rise time than that is specified by the 10/350 $\mu$s test waveform. A fast rising edge of the current may result (a) dangerous voltages appearing across the protected equipment before the SPDs switch to low impedance mode or (b) large voltages ($V_1$) appear across the SPD at Zone-1. However, taking an action against such drawback is beyond the capacity of a practicing engineer.

Another problem encountered by the field engineer in selecting SPDs is the different notations used for the SPDs connected at different zones (e.g. Classes I–III; Classes/Categories C, B A; Classes B, C, D, etc.). Although most of the previous Standards in Europe are now suppressed and the successors are integrated with IEC 62305, 2006, several manufacturers still refer in their literature to the previously used national standards.

With over 10 years experience in the South Asian region in recommending SPDs for various types of buildings we have developed the following table of specifications for the current handling capacity of SPDs which provides reasonably good outcome (Table 1). The specifications have been refined by taking into account the performance of SPDs over 200 installations in the region. Note that the success of a network of surge protection depends on several factors; the current handling capacity is one of the important parameters. Also note that the values in the Table 1 are the current handling capacity of each SPD connected between a line and the neutral. The SPD between the neutral and earth should have a current handling capacity of above 75% of three times the value of one SPD between line and neutral. For an example at the main panel of a high risk location in an area of low lightning density (3 Phase system); $I_{\text{imp}}$ of each SPD from line to neutral = 40 kA $I_{\text{imp}}$ of SPD from neutral to earth = $(40 \times 3) \times 75/100 = 90$ kA.

Note that these are minimum values for the above installation. It has been found that several leading manufacturers indicate the current handling capacity of their SPDs as three times the

![Fig. 5](image-url)
The response time of a SPD depends basically on its constituent components. SPDs are primarily made by one or more of the following components:

- Spark gaps or gas discharge tubes (GDT).
- Metal Oxide Varistors (MOV).
- Zener Diodes or Silicon Avalanche Diodes (SAD).

In addition some other linear and non-linear devices such as, capacitors, inductors and positive temperature coefficient resistors (PTCR) are also included in the circuits to improve the performance.

The three basic components have their own advantages and drawbacks. For examples; the current handling capacity and the response time increase in the order of SAD, MOV and GDT. The
increment of the former characteristic is an advantage while that of the latter is a disadvantage. Hence, in most of the products the components are combined to improve the overall performance. Thus, the end-product response time may be different from the response time of any of the individual components.

As far as the end user is concerned it is the overall response time of the SPD is of importance. This value may vary from several to several tens of nanoseconds depending on the technology used.

3.4. Maximum continuous operating voltage

Under no-impulse conditions, the SPD remains almost open-circuited (except for a leakage current in the order of micro amperes in MOV/SAD based SPDs). However, if the operating voltage (e.g. 230 V rms) is increased to a higher value for few cycles (due to some fault) there is a chance that the SPD may switch into low impedance mode (note that the SPD goes through this transition at few kilo Volts under impulse conditions but at much lower voltage at 50 Hz). If such transition takes place, a large current under nearly operating voltage will flow through the SPD which is not made to withstand such high energy. As a result the SPD may be totally damaged.

The maximum of such operating voltage, only under which the SPD is safe, is termed the maximum continuous operating voltage (MCOV). As per the standards (IEC 62305-4, 2006) the MCOV should be above 110% of the operating voltage. In most of the European countries an MCOV of 270 V is recommended for MOV based SPDs. However, in countries where the power quality is not very reliable (significantly fluctuating voltage) a value of 300 V or 320 V is more appropriate. It can be shown that the larger the value of MCOV, the greater the let-through voltage of the SPD (LittleFuse, 2009; He et al., 2008). Therefore, it is always advisable to select an SPD with the least MCOV that can withstand a power quality of a given region.

3.5. Other parameters

There are few other parameters that should also be considered in selecting SPDs:

- **SPD failure mode**: SPDs may fail either in open circuit mode or short circuit mode depending on the internal arrangement and the type of components. If they fail in open circuit mode there will be no interruption to the power supply. However, in such an event, which will be most probably be unnoticed for considerable time (until a technical person detects the failure) the down stream equipment will be exposed to the transient threat. If the SPD fails in short circuit mode the MCCBs (in series with power lines) will be tripped which will give the technical staff an indication of SPD failure. However, in the presence of MCCBs in series with SPDs as well, the rating of the two tripping devices will decide whether the power is interrupted or not. It is always a tricky decision to compromise protection with convenience (of not having power interruption). Hence, the best solution is to select SPDs that fail in the open circuit mode, which are integrated with a remote fault indication device. The fault indication display (better to have a beeping system) can be placed at a location where technical persons frequently visit. Alternatively, SPDs (with remote fault indicators) that fail in short circuit mode can be used with properly coordinated MCCBs to ensure that there will be no power interruption due to SPD failure.

- **Atmospheric conditions**: The range of temperature, humidity and pressure under which the device can be used, is also an important parameter, especially for outdoor-installed systems in regions that undergo extreme weather conditions.

4. Installation

4.1. Earthing of SPDs

The installation of SPDs plays a vital role in the surge protection of equipment. It is highly recommended to have a single earthing point that runs out of the building (at the main panel) of which the earth resistance should be kept below 10 Ω (IEC 62305-4, 2006). In more specific cases (military, petrochemical/explosive industries and communication and broadcasting) the required resistance may be lower than this value (even below 1 Ω in some cases). The main panel should be connected to the earth pit by conductors of cross-section not less than 35 mm². The earth bars of all sub panels should be connected to the main earth bar (at the main panel) by 16 mm² cables. One has to make sure that the SPDs at a given distribution panel are connected to the earth bar of that panel itself. All the equipment empowered by that panel should be provided with earth connection from that same earth bar. In building complexes, when the power is extended from one building to another, it is highly recommended to install a main earth bar at the power entrance of each building. This main earth bar should be connected to the mother earth as specified above. A schematic diagram of this scenario is given Fig. 6.

4.2. Concerns of connection

4.2.1. Length restriction of connecting wires

In the installation of the SPDs, it should be strictly adhered to the practice of using the shortest possible lengths of conductors...
in connecting the power lines to the SPDs and SPDs to the main earth bar. As per the Standards (IEC 62305-4, 2006), the length of wire in each of the above cases should not be greater than 50 cm. Otherwise even if one selects SPDs with lower voltage protection level, the actual let-through voltage will be much higher than what is expected.

To check the reality of the above recommendation for the wire lengths let us refer the diagram of single phase SPD system in Fig. 7. As a current impulse passes through the SPDs potential differences build up across the terminals, which will be felt by the downstream equipment. The voltage between line and neutral (differential mode voltage), \( V_D \), and that between line and earth (common mode voltage), \( V_C \) are given by the following equations.

\[
V_D = V_{LS} + V_{S2} \\
V_C = V_{LS} + V_{S2} + V_{S1} + V_{SE}
\]

The inductance of the copper wire is in the order of 1 \( \mu \)H/m. Therefore, the potential drop across a 0.5 m length for a lightning current having a maximum current derivative of 5 kA/\( \mu \)s is

\[
V = L \frac{di}{dt} = 2.5 \text{ kV}
\]

(Note that we have not taken in to account the voltage drop due to the resistance, \( iR \), as it is negligibly small compared to the component due to induction.)

Hence, for SPDs having a voltage protection level of 1.8 kV the actual let-through voltages appear across the protected equipment are

\[
V_D = 2.5 \text{ kV} + 1.8 \text{ kV} = 4.3 \text{ kV} \\
V_C = 2.5 \text{ kV} + 1.8 \text{ kV} + 1.8 \text{ kV} + 2.5 \text{ kV} = 8.6 \text{ kV}
\]

Therefore, even with SPDs having zero voltage protection level, a sizable potential difference will appear across the equipment under transient condition.

Most often it will be somewhat difficult to achieve 50 cm limitation due to the space restrictions. Hence, it is recommended to connect the lines in “V” connection (Fig. 8) instead of “T” connection (as shown in Fig. 7). In practice, such connection (as in Fig. 8) is very difficult to be implemented after the installation and commissioning of the wiring system. Therefore, the lightning protection system designer should plan the installation of SPDs at the construction stage of the building. Fig. 9 shows a set of SPDs installed in a 3 Phase system with “V” connection from line to SPD and proper length between SPD and earth point.

The author has noticed that at many installations in South Asia, Middle East Asia and Far East Asia, the engineers have overlooked the maximum length recommended in the Standards (IEC 62305-4, 2006). The Fig. 10 shows such an erroneous installation came across at a site in in South Asia. Note that the wire length of “T” connection from line to SPD is about 1.2 m and that from SPD to earth bar is about 2.3 m. The MCCBs (of which the purpose is discussed in the next paragraph), SPDs and the earth bar could have been conveniently located at spaces A–C shown in the diagram.

Fig. 7. The let-through voltage felt by the downstream equipment as the transient current flows through the SPDs. Note that the wire length between the two SPDs is assumed to be zero.

Fig. 8. The V connection of SPDs to the line and using a earth point at which the earth reference is connected to the SPD. The arrangement leads to almost zero potential difference between the line and SPD (VLS) and very small voltage between SPD and Earth (VSE). The arrangement is very useful at locations with space restriction.

Fig. 9. SPDs (in a 3 Phase system) connected properly. Note that in the V connection, the dirty “IN” lines and clean “OUT” lines are installed perpendicular to each other to minimize re-induction of transient energy. Similarly the earth lines that carry the transients to mother earth have kept far separated from the clean lines. Background picture was adapted from the literature of OBO Bettermann Ltd.
The recommendations in (IEC 62305-4, 2006) allows connection of SPDs before (source side) or after (load side) the earth fault tripping device (RCD, ELCB, RCB, RCCB, etc.). However, when the SPDs are installed after the earth fault tripping device (say RCD), the following situation may arise: consider a lightning transient (specifically one that contains continuing current) passes through the RCD along the line. The RCD detects such transient as an inward current. As the SPD diverts the transient to earth, there will be no return current; hence the RCD misidentify the situation as an earth fault. This leads to nuisance tripping of the RCD at regular intervals, especially during the lightning seasons. At number of cases of buildings in areas of high lightning density and those very close to tall communication/broadcasting towers, experience this problem due to the prevalence of lightning currents entering their systems. Therefore we strongly recommend the installation of SPDs on the source side of the earth fault current tripping device to avoid such nuisance tripping.

5. Special concerns

5.1. Protection of signal systems

Lightning surges may also enter the equipment through data and communication lines. In most of the instances the lightning energy couples with these data lines in the form of induced voltages. The normal operating voltage of such lines is in the range of few to few tens of Volts and the operating current is from milli-Amperes to few Amperes. These systems are also called as extremely low voltage (ELV) systems. Therefore, even voltage or current pulses which are not that significant in LV power systems may damage or cause data losses/memory upsets in ELV systems.

Most of the SPDs that protect data and communication lines have a series component that attenuates the energy and a shunt component that diverts the energy. Therefore in such cases one has to pay extra attention on several additional specifications.
which are not significant in power system protection. These parameters are listed below

- **Insertion loss and bandwidth**: Signal communication systems transfer information at much higher frequencies than the transmission of power which takes place at frequencies up to about 60 Hz. Therefore, the inductive component connected in series and the parasitic capacitance of the shut components limit the applications of an SPD in signal systems. MOVs, which are widely used in power protection system, are almost unusable in signal protection systems due to its large stray capacitance. Most often, SPDs for signal systems comprised only of Gas Discharge Tubes (GDT) or GDT and SAD with series inductor. Even with such, the SPD has a certain insertion loss and bandwidth restriction. Therefore, the protection system designer should pay extra attention on the requirements of the system to be protected. Failure to do so may result non-functioning, malfunctioning or limited functioning of the protected system. For an example in a South Asian country, a vendor of lightning protection systems, encountered heavy losses after importing and installing a large number of SPDs to data lines that feed auto teller machines of a bank having country-wide branches. It has been found that the data lines feeding the machines are CAT-6 type while the SPDs that have been imported can be applied only for lines up to CAT-5. Hence, since the installation of the SPDs the machines went into either non-functioning or malfunctioning states leading to a chaotic situation among customers of the bank. Consequently the bank ordered the vendor to remove the SPDs with immediate effect and refund the advanced payment. Such incidents may cost even the reputation of the protection system designer as well. As of today, CAT-5e are the most commonly used type of Ethernet cables, hence the protection system designer is cautioned to check the actual bandwidth of the cable and select a suitable SPD for the purpose.

### 5.2. Integration of earthing systems

It is well understood that to prevent dangerous potential differences all metal parts of a given installation should be interconnected. In case that they cannot be integrated, they should be separated by a certain minimum distance. There is no clear specification of this minimum distance for earthing systems in any of the major standards. As it is reported in (Gomes, 2004) there are observations of over few meter arcs between different earthing systems in the event of lightning strikes to the external lightning protection system (LPS). However, it should be emphasized that unless the LPS earth is a distributed mesh-like grid with earth resistance less than about 1 Ω, integration of the power earth into that without properly coordinated SPD system will be hazardous.

To demonstrate this situation, consider the potential of the LPS earth rising to 10 kV (due to both inductance and resistance of the earthing system) in the event of a lightning strike to the LPS. As the power earth is integrated to the LPS earth the 10 kV potential appears at the equipment earth points which may be separated by few centimeters (or even few millimeters) from the line and neutral which are at a much smaller potential. Therefore, nearly 10 kV potential difference will build up across the earth and line/neutral causing an arc between them. Hence, we emphasize that both integration of earthing systems and the installation of SPDs should be done together.

Most often the manufacturers of digital equipment demand a dedicated or clean earth (isolated from other earths) for such equipment. These systems need a fixed earth reference; however the power earth potential frequently fluctuates by small voltages due to earth faults, loop currents, etc. under normal operation. Under such requirement the two earthing systems can still be integrated for safety purposes though a spark gap which is termed a transient coupler. The transient coupler keeps the two earthing systems separate under normal conditions but connects them under transient condition. A transient coupler connecting two earthing systems at a site in Sri Lanka is depicted in Fig. 11.

The transient couplers will also be very useful in interconnecting conducting parts made of different metals which need to be equipotentialized under transient conditions to prevent dangerous sparking. Earthing of petroleum pipes and chemical containers is an example of the application of transient couplers.

### 5.3. Sites very close to towers

If the site is situated close to a tall communication or broadcasting tower one should take extra measures to protect the equipment from lightning transients. A tall tower is more probable to intercept with lightning stepped leader that reaches earth within a large area. Therefore, when there is a nearby tower the chances of lightning current flowing in the close proximity to the site are high. Such lightning currents may induce considerably large voltages in the nearby wiring systems both due to the proximity and the propagation of current through a conducting path. Hence, at such sites the SPD network should very comprehensive as the

---

**Table 2**

<table>
<thead>
<tr>
<th>Category</th>
<th>Upper cutoff frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT-3</td>
<td>16</td>
</tr>
<tr>
<td>CAT-4</td>
<td>20</td>
</tr>
<tr>
<td>CAT-5</td>
<td>100</td>
</tr>
<tr>
<td>CAT-5e</td>
<td>250, 350, 400, 550</td>
</tr>
<tr>
<td>CAT-6</td>
<td>250</td>
</tr>
<tr>
<td>CAT-6a</td>
<td>500</td>
</tr>
<tr>
<td>CAT-7</td>
<td>600</td>
</tr>
<tr>
<td>CAT-7a</td>
<td>1000</td>
</tr>
</tbody>
</table>

Note that different manufacturers produce CAT-5e cables of several upper cut off frequency as they claim. As of today, CAT-5e are the most commonly used type of Ethernet cables, hence the protection system designer is cautioned to check the actual bandwidth of the cable and select a suitable SPD for the purpose.

---

**Fig. 11.** A transient coupler which interconnects the two earthing systems.
chances of induction in internal wiring system are high. In ordinary buildings it has been recommended to have extra SPDs if the wire length between two protected points is larger than 30 m (IEC 62305-4, 2006). This length needs to be significantly reduced if there is a tower in the site.

If a neighbouring building is provided power from the same transformer that feeds power to the tower related equipment, the situation can be worse. The action of SPDs at the tower site raises the lines/neutral to the elevated potential at the site earth. Hence at the neighbouring building, a transient potential difference develops between the line/neutral and its earth which is most probably at zero potential. Unless the building power system is installed with proper network of SPDs such potential difference may result insulation breakdown within equipment. Furthermore, if the tower is not implemented with a distributed earthing system that has a sufficiently low earth resistance a considerably high ground potential rise may occur causing the “back flashing” in the power system of the neighbourhood in the absence of SPDs.

6. Conclusions

A comprehensive guidance has been given in this paper for field engineers who are involved with designing and implementation of surge protection systems for LV and ELV networks, especially in regions where TT wiring system is practiced. A number of issues encountered by the ground level engineers are discussed pointing out the inadequacies of standards and also the non-adherence (or limited adherence) of field engineers to the recommendations of the standards. We make the following conclusions with regard to our observations and analysis.

a. It is less costly, less disturbing the other systems and more effective to design the surge protection system together with the wiring system of the building.

b. A zonal approach to the protection scenario has many advantages. There are three major reasons why one has to adapt a zonal protection approach.

c. While the current handling capacities of SPDs are important parameters in selecting the appropriate SPD system for a given installation, the highest priority should be given to the let-through voltage felt by the downstream equipment.

d. Both voltage protection level of SPDs and the wire lengths of installation are equally important in reducing the final let-through voltage.

e. In regions where power quality is not very high, the MCOV of the SPDs should be selected appropriately; not so low that the SPD will be damaged under sustained over voltages and not so high as to increase the voltage protection level significantly.

f. In the protection of signal systems one has to pay extra attention on bandwidth of the SPD so that it is well above the upper cutoff frequency of the signal cables in the system.

g. Integration of earthing systems is very necessary; however such integration should accompany the installation of proper SPDs.

h. Sites close to large metal towers need higher level of concern in the planning of surge protection system.

i. The abnormalities and irregularities of electrical network of the building should be rectified before the installation of the SPDs to have the optimum gain of installing such.

Acknowledgements

The authors would like to acknowledge the Department of Electrical and Electronics Engineering, Universiti Putra Malaysia and Department of Physics, University of Colombo, Sri Lanka, for placing excellent research facilities to complete the work.

References


