TVSS (Transient Voltage Surge Suppression) what is it and why all of a sudden do we need it?

In truth transient voltage surge suppression has been essential ever since the modern electricity distribution system was put in place. For many years the effect of transient voltage surges was not recognised even though equipment damage did occur in many cases. This is especially the case over the last ten years, as mains powered electronic equipment has become much more sophisticated and susceptible to transients. In addition, although the number of power outages is lessening, transient surges have increased, as have the effects of harmonic distortion on the Supply.

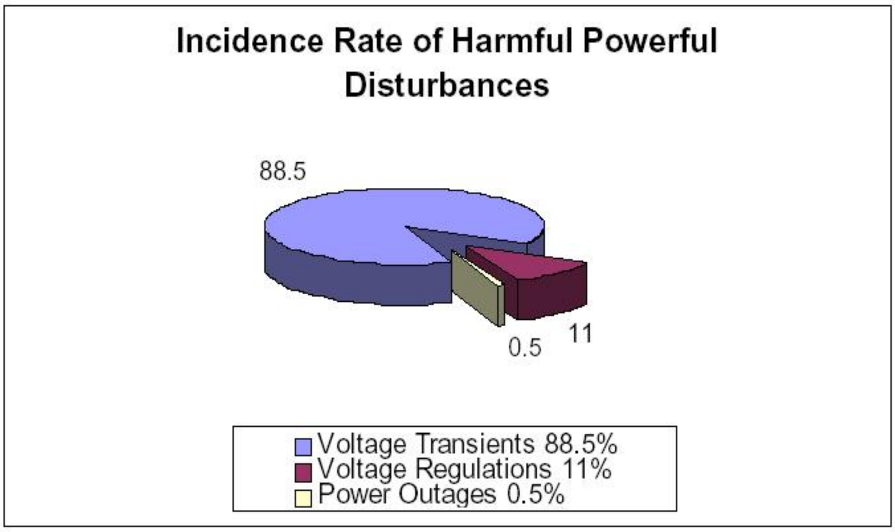


Figure 1. Incidence rate of harmful powerful disturbances

Transient Surge Generation

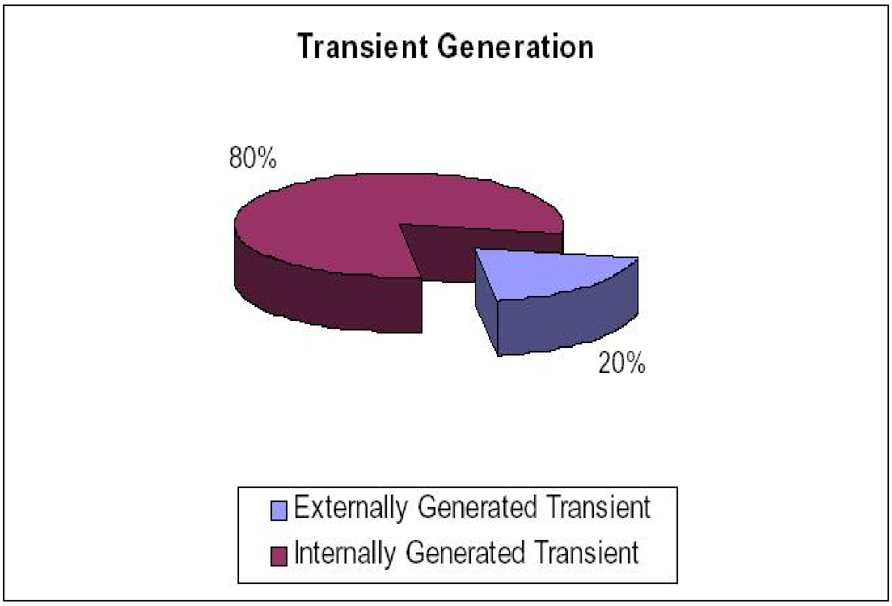


Figure 2.Transient surge generation

Internally Generated Transients	Externally Generated Transients
Up to 80% of transients are generated from internal sources such as inductive load switching and normal equipment operations	At least 20% of transients are generated from external sources such as lightning and power company grid switching.
Possibly causing: Cumulative damage Premature equipment failure Data losses, system resets, and down time.	Catastrophic equipment failure Immediate operation shutdown Long term disruption of business Expensive equipment repair and replacement costs

Transients can be split into two types:

* Impulse, large voltage and current over a short duration i.e. lightning strike.
* Oscillating, lower value voltage and current but over much longer time period (up to 50 times that of lightning strike), e.g. photocopiers, SCR. controlled equipment, inductive load switching.

Up to 80% of transient surges are generated within a company s own site or close by. Two examples serve to illustrate this statistic. Firstly, tests have shown that a twin four-foot fluorescent light fitting can generate 24 x 1200 volt transients when it is switched off. Secondly, just imagine a high tech data storage company geographically close to and on the same power distribution branch as Fred doing some arc welding in his garage. The potential repercussions are obvious, resulting in equipment faults that can range from temporary glitches to the evaporation of components, contacts and PCB track.

Transient surge can infiltrate your equipment by various routes:

*Direct Coupling: caused by lightning strike, or faults on power distribution cables.

* Inductive Coupling: caused by electromagnetic field generated when lightning hits tall objects such as air terminal of a house as shown below.

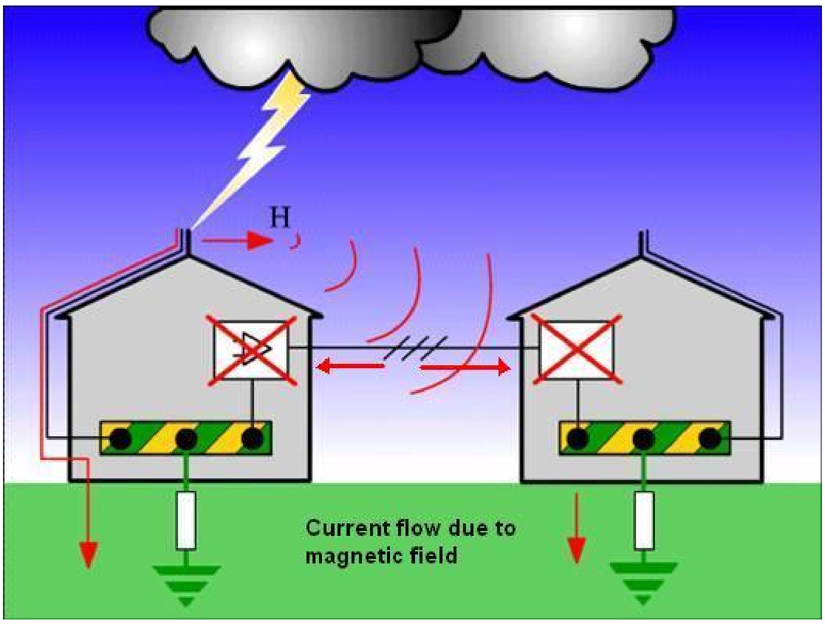


Figure 3.Inductive coupling

Inductive coupling is a magnetic field transformer effect between lightning and cables. A lightning discharge is an enormous current flow and whenever a current flows, an electromagnetic field is created around it. If power or data cabling passes through this magnetic field, then a voltage will be picked-up by, or induced onto it.

* Capacitive Coupling: caused by lightning strikes to building lightning conductors.

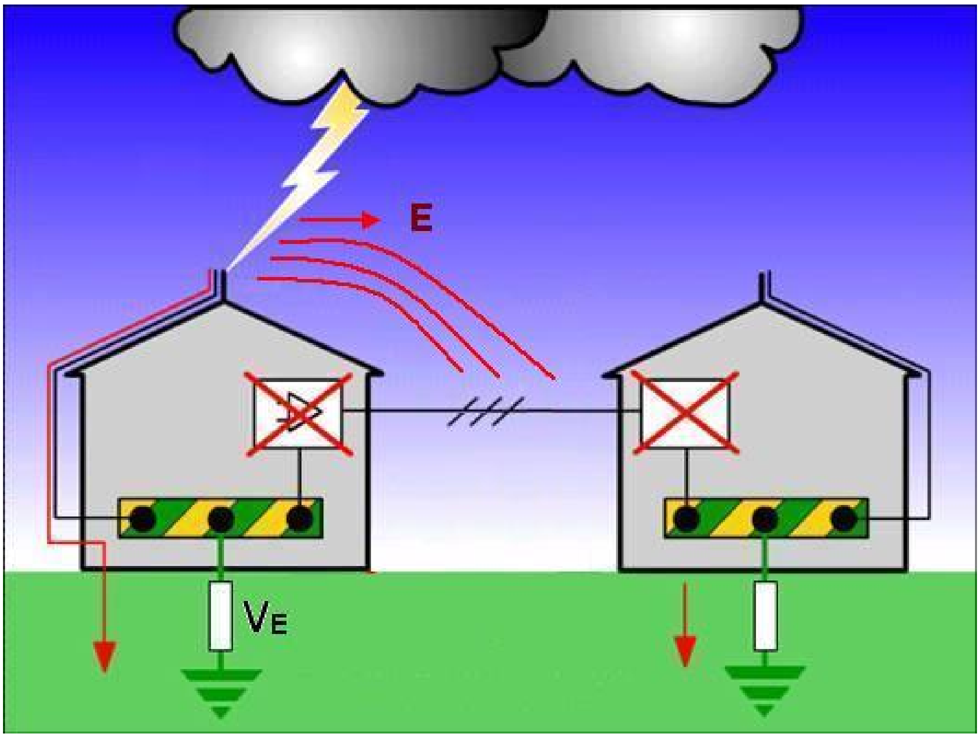


Figure 4.Capacitive coupling

Where long lines are well isolated from earth(eg via transformer or opto-isolators) they can be pulled up to high voltages by capacitance between them and the charged thunder clouds. If the voltage on the lines rises beyond the breakdown strength of the devices at earth end(eg the opto-isolators), they will be damage as shown in figure 4 above.

* Resistive Coupling: caused by direct ground strikes or through the download conductors of a building raising the ground voltage which, in turn, causes large potential differences between earth points as shown in figure 5.

It is the most common cause of transient overvoltages and it will affect both underground and overhead lines. Figure 5 shows two buildings, each contains electronic equipments, which is connected to earth through its mains power supply. A data communication line connects the two pieces of equipment and hence the two separate earths.

A lightning strike to the air terminal of a building will inject a massive current into its ground. The current flows away from its earth electrodes -preferentially through the path of least resistance. The earth electrode, electrical cables and the circuitry of the electronic equipment(once damaged) , are all better conductors than soil. As the current attempts to flow, devastating transient overvoltages can be seen across the sensitive components of the equipment.

Resistively coupled transients can occur when separately earthed structures are only meters apart.

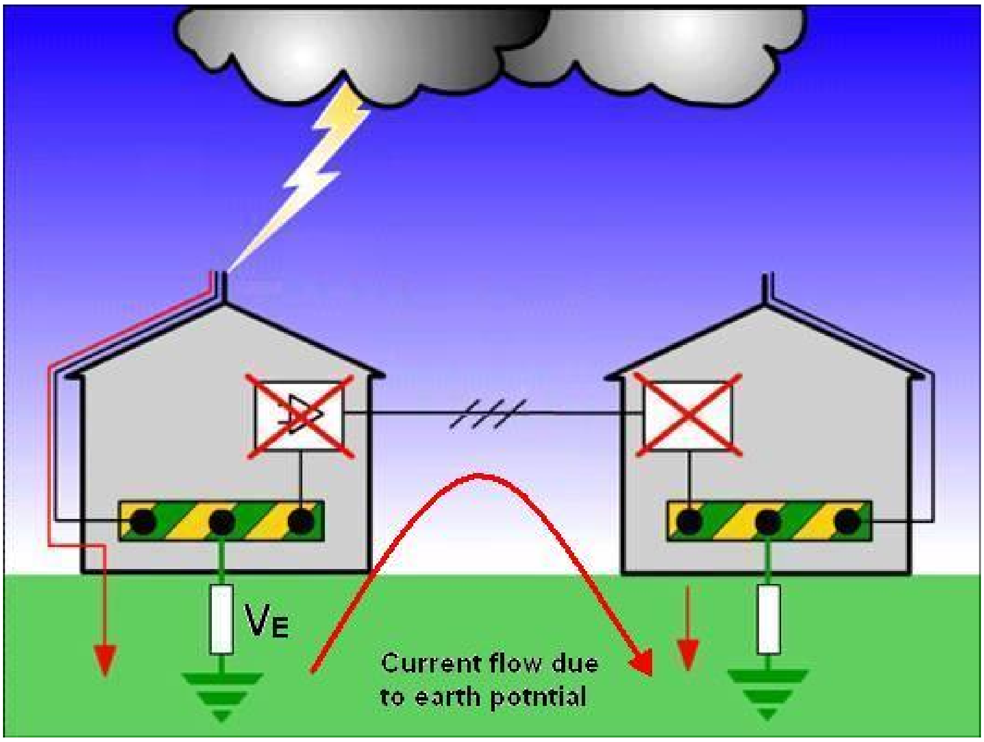


Figure 5.Resisitive coupling

The most commonly discussed transient voltage surge is a lightning strike, although a lightning strike often comprises up to 20 strikes. Both cloud to cloud and nearby ground strikes produce electrical field voltages of hundreds to thousands of volts per metre.

A cloud-to-cloud flash can induce a surge of 7,000 volts per metre in power and/or telephone cables and 70volts per metre a mile away. An incidence of two strikes per square mile per year would seem to be an average figure.

As a result of lightning activity, a power surge of between 10-20,000 volts could reach your building. However the maximum normally considered is 6000V, with currents up to 3,000A appearing at your building main power distribution board.

The impedance of the cabling installed on site limits the amount of current that reaches your equipment. The main low impedance bus bar could carry the full 3000A, but the 30A twin & earth feeding a spur presents a much higher impedance that will limit the current to around 200A for the same transient. Inevitably, insulation breakdown in cabling, mcbs etc. will limit the level of transient surge voltage within the building wiring.

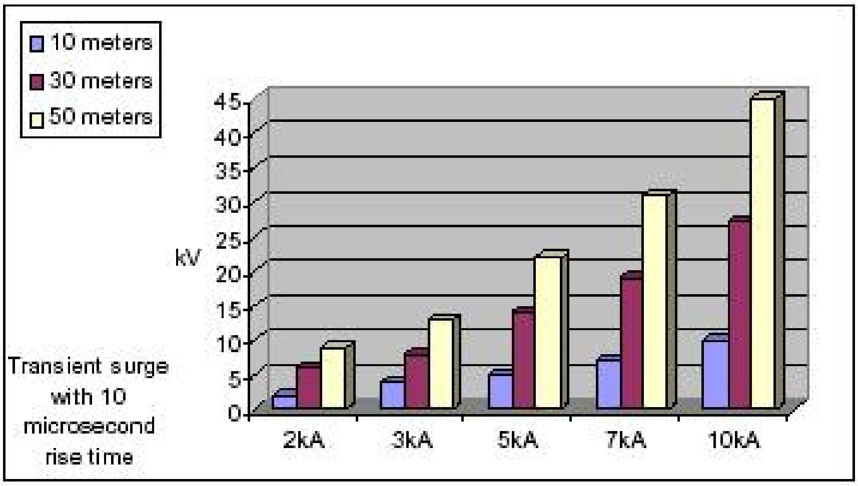


Figure 6. Lightning current on different length of wire

The effect of a transient surge on a circuit is not only dependent on size but also where it hits on the AC cycle. A 200V transient appearing on the sine wave at zero crossover will have little effect but the same transient appearing on the peak of the sine wave will add 200V to the peak value of the sine wave value. In this example, the load will be subjected to a voltage of 525Vac. And remember, transient surges can be positive or negative going.

Calculating the actual effect of a transient over voltage can be done by looking at the way a capacitor or inductor responds to it. In a capacitor any rapid change across the capacitor will produce a large current, which is dependent on the size of capacitor and rate of voltage change. Its effect can be expressed by the following formula.

$$I = C\,dv/dt$$

A rapid change in current in an inductor will cause a large transient voltage to be generated, which can be calculated using the following formula.

$$V = L\,di/dt$$

The shape of a transient surge is normally expressed by two numbers:

Impulse: the first being the rise time and the second being the duration i.e. 8 x 20 microseconds.

Oscillatory: the first being the rise time the second being the frequency .5/100 microseconds/kHz.

In the real world you r equipment, and therefore any TVSS devices, will see far more longer duration transient surges than the short ones caused by lightning. But, of course, we must test for both.

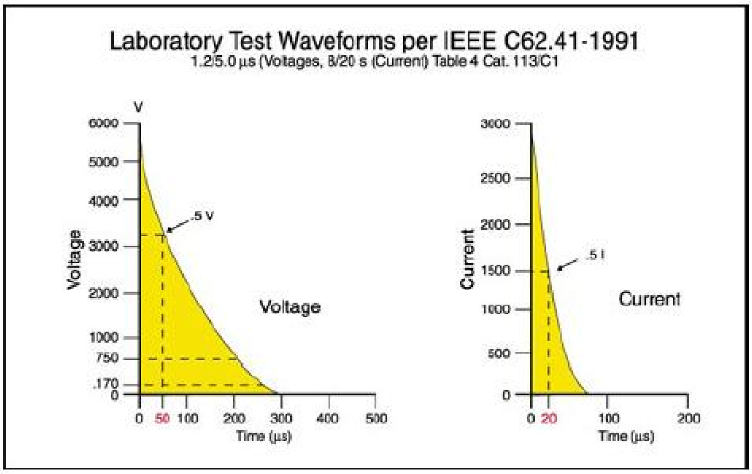


Figure 7. Laboratory test transient waveform(short duration)

For short duration testing we would apply up to a 6kV, 1.2/50 voltage wave form into an open circuit with the TVSS device across it. Here, the voltage reaches 90% of its peak in 1.2μs and then decays to 50% of its value in 50μs.

A 3kA current waveform that reaches peak current after 8 microseconds and decays to 50% of that value in 20μs is applied to a short circuit with TVSS attached.

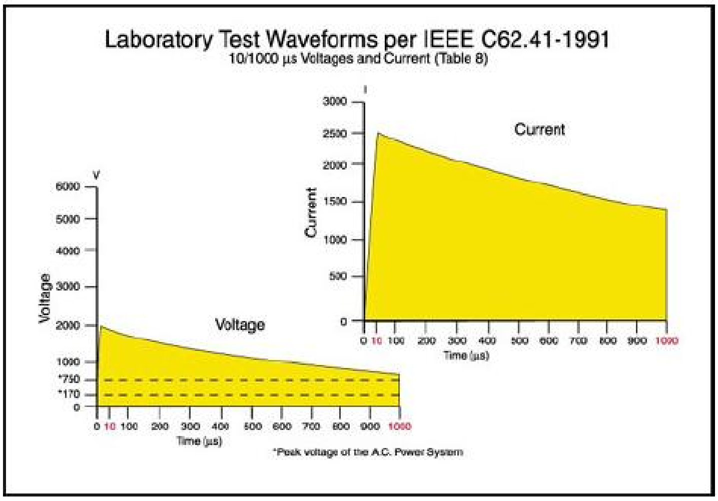


Figure 8. Laboratory test transient waveform(long duration)

For long duration testing, the waveform will have a peak value of 2kV with a rise time of 10μs and a duration 1000μs. The current waveform has a peak of 2.5kA with the same rise and duration times (10/1000μs)

In essence, a TVSS device is a component that limits the amount of energy from a transient and, as a result, protects your equipment from damage.

There are three basic types:

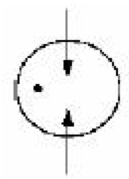
Gas discharge tube (GDT)

Metal oxide varistor (MOV)

Silicon avalanche diode (SAD)

Gas discharge tube

These devices modify an uncontrolled flashover by the use ofspecially designed electrodes in a tube containing one or more gasses under pressure. By altering one or more of the elements that make up the GDT, different breakdown voltages can be achieved, ranging from 100V to several kV. In addition, the slope of the applied voltage has an effect on the breakdown voltage.



Once the GDT fires it becomes a crowbar device that can reduce the applied voltage down to a few tens of volts in nanoseconds, and is able to handle surge currents of 20kA or more for a single x s transient surge.

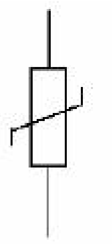
However, there are two points that must be considered when considering using gas discharge tubes:

* Even though the tube may have a low breakdown rating it will still require 600-800V to strike when a confronted with a steep leading edge waveform.

* Once break down has been achieved the arc may not be extinguished once the transient has passed, if the normal line voltage exceeds 10-15volts. This effect can distort the normal signal on the line and, if the circuit can provide enough current, could destroy the tube.

As a result of these considerations, GDT devices are far more effective when used in conjunction with lower clamping devices.

Metal Oxide Varistor (MOV)



Metal Oxide Varistors are made from zinc oxide fragments compressed under very high pressure. Their resistance decreases as the applied voltage increases, which should therefore provide excellent clamping of an applied transient surge. Although their in circuit response time is 35-50 nanoseconds, the resistance characteristic is non linear, and the volt drop across the MOV will increase dramatically as the current increases.

This non linearity means that when the device is subjected to a large transient current surge the clamping voltage will increase and can exceed the level at which damage can occur to equipment. In addition, long duration surge currents will cause the device to destabilise.

On the plus side, MOVs are cheap and can handle large currents. However be careful of claims of very high current capacities that don t also include the voltage protection level.

The life expectancy of an MOV is dependent on both the size and quantity of applied transient surges, because they age as the zinc oxide particles weaken after conducting current.

A 20mm MOV specification may claim 6500Amp peak surge current, but this will only be for a single 8/20μs short circuit transient. As the peak current of the 8/20μs transient surge decreases, the quantity of surges the MOV can take will increase. However a single long duration current

waveform of much lower peak current value can cause the MOV to fail. This could be as low as a 100-200A surge current pulse lasting 1ms.

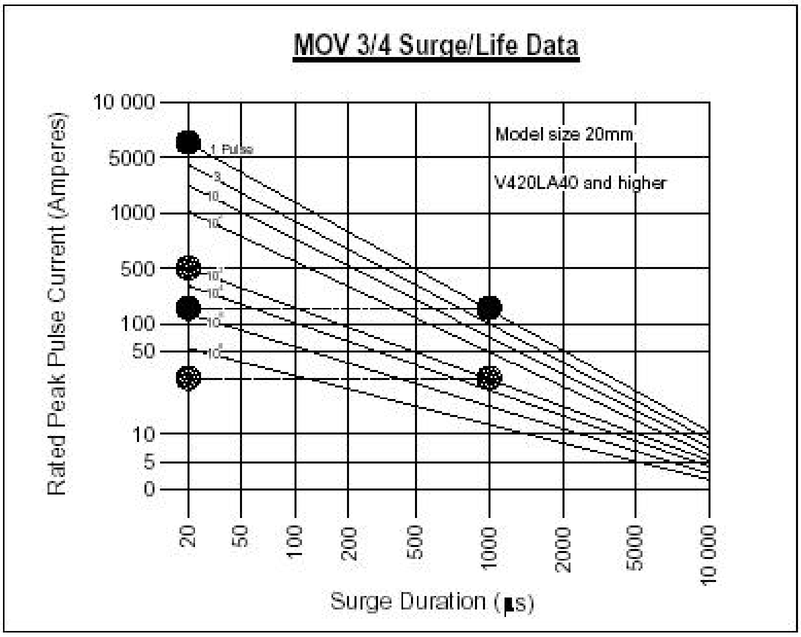
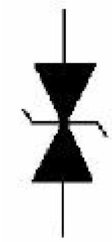


Figure 9. MOV surge life

Silicon Avalanche Diode (SAD)



These semi-conductors are similar to very large junction zener diodes, responding very rapidly to transient surges with an in circuit response time equal to or less than 5 nanoseconds (dependant on circuit inductance) and can therefore handle the rapid rise time of a transient surge much better than an MOV.

Clamping voltages range from a few volts to several hundred volts. However, the clamping voltage selected should be as close to the peak value of the sine wave as possible without continually conducting.

Unfortunately this subjects the device to high levels of transient energy that single diodes cannot dissipate, requiring numerous diodes, so that the energy can be dissipated without the devices sacrificing themselves. Inevitably this means that the suppressor will be larger and more expensive than using MOVs.

Unlike MOVs, silicon avalanche diodes can conduct their maximum current without any increase in clamping voltage. Nor will they degrade in use, as long as their parameters are not exceeded.

TVSS hybrids

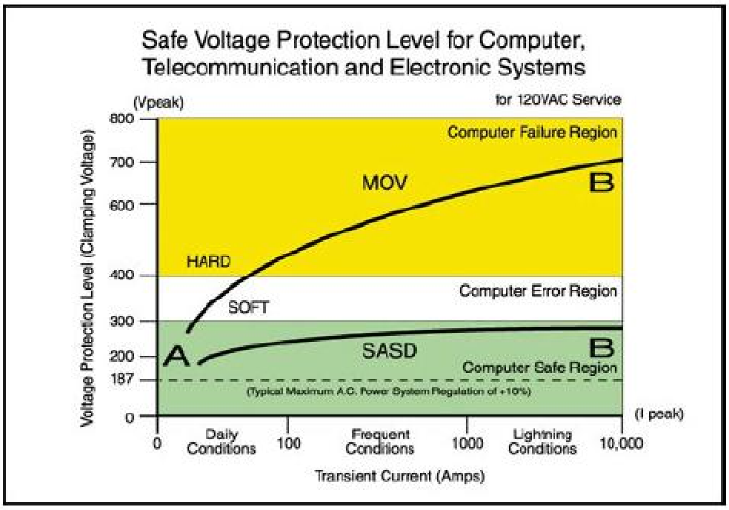


Figure 10. Safe voltage protection level for computer

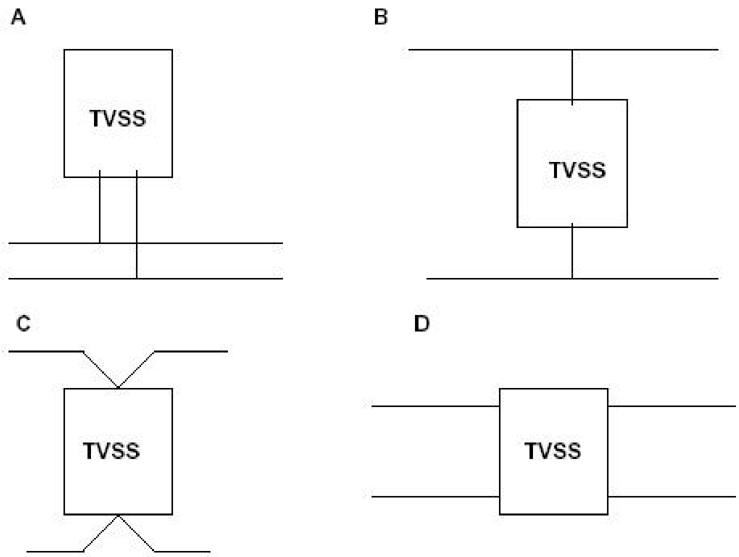
There are many parameters to be considered, when designing an effective suppression unit. We have opted to use a combination of SADs and MOVs, because SADs alone would be far too costly for a unit designed to take the same amount of energy. The silicon avalanche diodes provide a very rapid response while the metal oxide varistors give us the large current capacity. In addition the presence of SADs will prevent the clamping voltage rising as the MOVs take more current. In principle, this sounds an ideal combination, although careful consideration must be given to the response curves of the two devices. Because the SADs react so much quicker, there is a danger that they will be subjected to over current before the MOVs start to conduct. Consequently, it would be inadvisable to use only a few SADs in conjunction with the MOVs, to reduce costs further. Experience dictates that there must be enough SADs to take the current, without damage.

Also, despite what the adverts state, putting a number of MOVs in parallel does not give a total current figure equal to their sum. Typically, these devices have a tolerance of +15%, giving a variation of 30%, plus the fact that their voltage characteristics vary by + 10% when they start to fail. Therefore, the current is not spread equally over all of the devices, an effect that is compounded by the impedance of pcb track, component leads and soldering.

MOVs can be fitted phase to neutral, phase to ground and neutral to ground. Some advertising claims that, when the three variations are used in conjunction, current capacities are equal to the total of the three devices. However, this is not quite true, as the three devices will never all conduct together, and the one between neutral and ground will probably never actually conduct at all.

Ideally, the level of protection provided by the suppression unit should be dependant on where it will be installed within the distribution system. A unit installed on the load side of the main building isolation switch (zone C) will be subjected to much higher voltage and current levels than one protecting individual rings or distribution boxes (zone B) which, in turn, will see more than a unit protecting individual spurs or equipment (zone A). Ideally a staged approach should be adopted with units fitted to all three zones. However, this is not always possible, so the level of the clamping voltage and current rating at each point needs to be calculated to give the best possible protection.

The way in which a TVSS device is installed will also have a dramatic effect on its performance.



In diagrams A & B the devices are far less effective at reducing a transient surges, because of the impedance of the connecting wires. In tests we found a 700V drop in 500mm x 6mm^2 wire for a 6kV x 3.3kA transient, which will be made far worse by the addition of a TVSS isolating mcb.

Connecting as C or D will give far better results although in C some losses will occur due to the connections and pcb track. The TVSS devices are passive, lying between the live and neutral, without posing a threat to the load as, in the event of component failure, the wire and/or thermal fuses will break the cross connection, leaving the supply to load in tact.

Our zone C TVSS unit (TDC209J) uses 28 x 15KP 51V bi-directional SADs and 32 x 20mm 275L40 MOVs.

The SADs are arranged in 4 parallel strings of 7 each with a surge capability of 75kW for a 8x20µs surge and 15kW for a 10/1000µs surge. The breakdown voltage is 396.9V which is close to the maximum peak voltage of the mains, 373V (264Vac), with each string protected by thermal and wire fuses. In the event of a single SAD going short circuit, the breakdown voltage is reduced to 340V which, if accompanied by high mains, means the string will conduct and heat up causing the thermal fuse to blow. Under normal conditions, i.e. nominal mains, one other SAD in the same string would need to fail.

The wire fuses are there in case an excessive surge causes the entire string to fail. The SADs used are capable of withstanding the standard test 6kV surge indefinitely, and will receive a peak of 95kW for 10µs, and an energy pulse of 1.5Joules over the 20µs which is within their rating (75kW for 20µs =1.5Joules). The total rating for the SAD section is 42 Joules. The maximum Joule rating for the SADs is 15J (10/1000µs), giving a maximum theoretical Joule rating of 420J.

The MOV section consists of 32 parallel devices, grouped in fours, with each group protected by a wire fuse. This approach was taken because parallel small diameter devices achieve larger current handling and a lower clamping voltage than an equivalent single large diameter device. In addition much greater redundancy is achieved by the correct fusing of the parallel devices.

Again, using a standard 6kV 2 surge the MOVs will clamp at around 700V, giving a total current of 2650A i.e. 83A/MOV. This should give us a survival time of 100,000 strikes and allowing for the failure of the weakest string, the life expectancy should not be reduced with the remaining devices taking 95A/MOV. In a worse case scenario, if the current was shared by the lowest voltage device in each string, we would have a figure of 330A/MOV giving a life expectancy of a few hundred strikes. The stated maximum Joule rating for the MOVs is 140J (10/1000µs), which will give a maximum theoretical Joule rating of 4,480J.

The total maximum Joule rating for the combination would be 4,900J (10/1000µs). This is a formula that is often adopted in sales literature to enable comparison between competing TVSS devices.

Again, using a standard 6kV 2 surge the MOVs will clamp at around 700V, giving a total current of 2650A i.e. 83A/MOV. This should give us a survival time of 100,000 strikes and allowing for the failure of the weakest string, the life expectancy should not be reduced with the remaining devices taking 95A/MOV. In a worse case scenario, if the current was shared by the lowest voltage device in each string, we would have a figure of 330A/MOV giving a life expectancy of a few hundred strikes. The stated maximum Joule rating for the MOVs is 140J (10/1000µs), which will give a maximum theoretical Joule rating of 4,480J.

The total maximum Joule rating for the combination would be 4,900J (10/1000 s). This is a formula that is often adopted in sales literature to enable comparison between competing TVSS devices.

If any of the fuses in the combined unit fail, an alarm is raised, flagged by two bi-colour LEDs (Green ok/Red fail)-one for the SAD section and one for the MOVs, and a single pole change over relay. Because the alarm circuitry and relay drive are derived straight from the mains, a 8mm creepage and clearance distance is maintained for the alarm contacts, including the relay, a point that some manufacturers appear to overlook.

The PCB layout must provide the largest area of copper allowed by the board size to conduct the transient surge, while keeping the current path as straight as possible. This must be balanced against having enough track-to-track clearance to prevent flash over, even with open circuit fuses.
Flash over can be further reduced by uniformly coating the populated board.

Testing

The equipment used for the following tests was a Schaffner NSG651 (surge generator) and CDN110 (coupling network), plus a Toshiba T1910CS (lap top computer) and Yokogawa DI1540 (oscilloscope).

We first tested the SAD and MOV sections separately before testing the combined unit. After being subjected to 200 x 6kV 1.2x50µs/3.3kA 8x20µs surges at a rate of 3 per minute, we retested the unit and found no degradation in performance.

These units passed a 4kV contact/8kV air ESD test (EN61000-4-2) without difficulty. However, when subjected to16kV, a spark was seen to track around the outside of the LEDs when they were touched with the test probe. The addition of a transparent window in the label to cover the LEDs solved the problem. The test was conducted using a Keytech Minizap MZ-15/EC and test set up as described in EN61000-4-2.

The TDC209J is housed in a din rail mountable case, 6 modules wide, that will fit into a standard consumer unit. For ease of installation, we also produce the TDCE209J and TDCE627M.

For three phase installations, the TDCE627M consists of 3 x TDCE209Js plus an isolation switch housed in a 24 way consumer box. All internal connections are made with solid copper bus bars to reduce losses, and the unit can be wired in series with the supply or, if necessary, in a Tee configuration.

The TDCE209J is similar, but for a single-phase installation, and is housed in a 12 way consumer Box.

For zone B applications we produce the TWBE52J, a wall mounted unit containing 7x15kp SADs and 8x20mm MOVs. It incorporates a green in use led and a red alarm led, plus a single pole change over relay for remote alarm indication. We subjected this device to the same tests as the TDCE209J and then retested after 300 surges, again with no loss in performance. The total joule rating for this unit is 1225Jmax. (10 /1000µs).

Zone A is covered by a range of in line filter/TVSS devices and distribution units. The level of protection required will be dependent on what other TVSS devices are fitted to your supply distribution system, and the quantity of transient surge generating equipment within the building.

Still if a UPS protects your load you don t really need TVSS protection, right? Wrong! Although, most UPS devices now have limited transient surge protection built in, this is usually only through the addition of a few MOVs so, unless information on the level of protection and survivability is given, they can be discounted. Additionally, unless one of the MOVs goes short and blows the input fuse, there is no indication whether the devices are working or not. So, if the load is critical enough to justify the expense of a UPS, surely it must also be worth adding effective protection against transient surges.

Unprotected

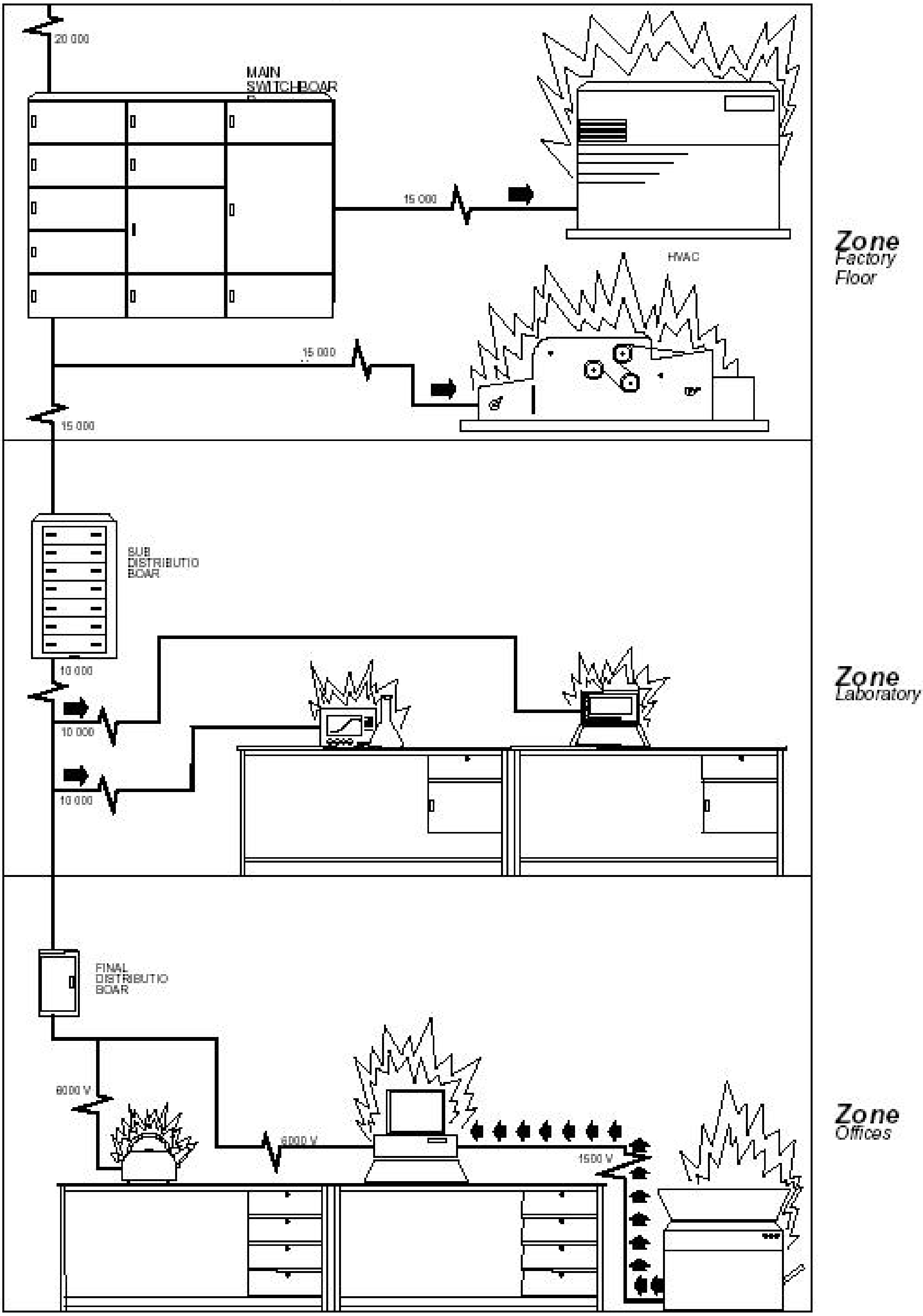


Figure 11.Unprotected equipments are damaged when transient surges coupled onto the wires

Protected Facility

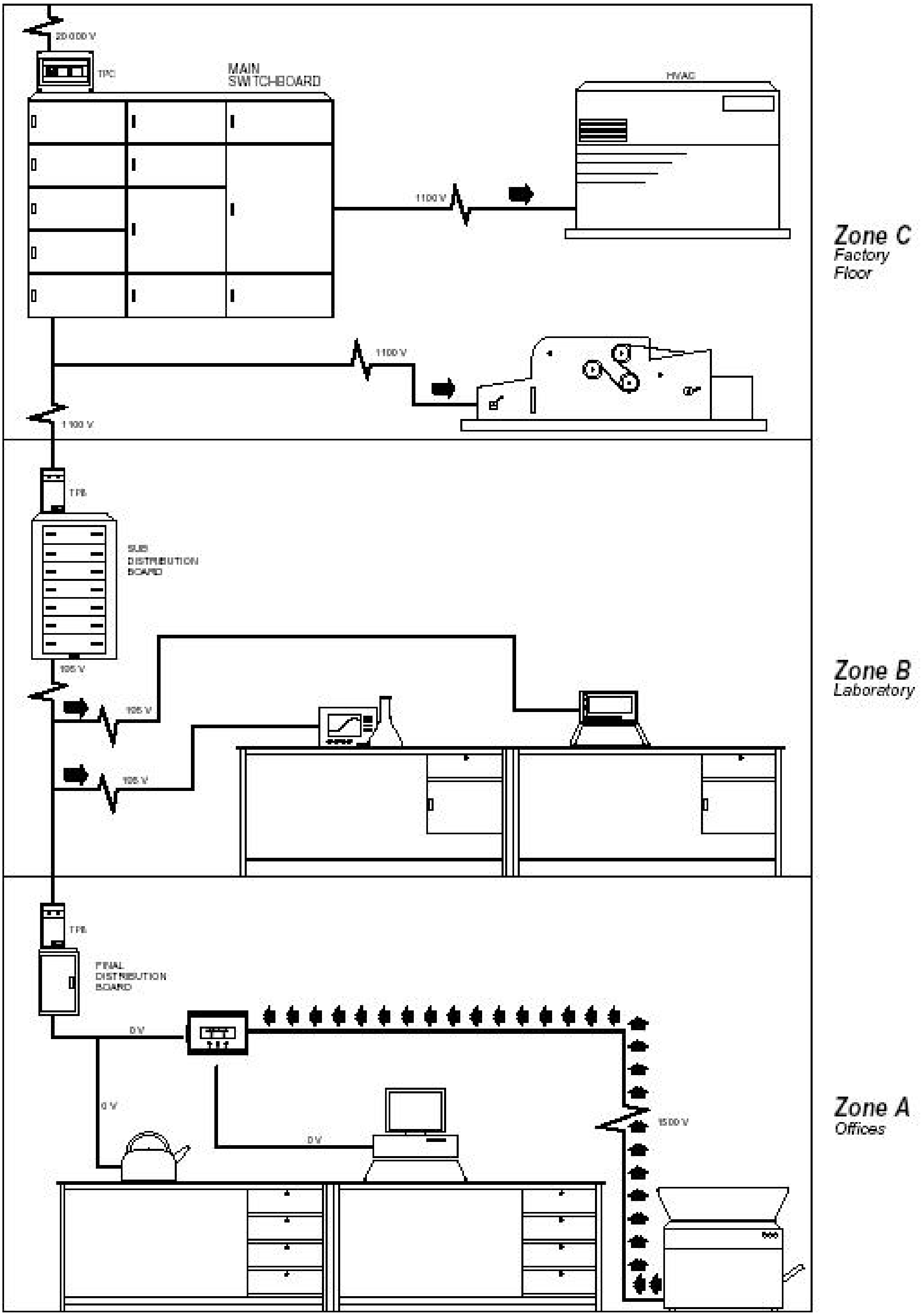


Figure 11.Protected equipments are safe when transient surges coupled onto the wires

For total protection the addition of TVSS devices to the supply line is not enough - signal and communication lines must also be covered.