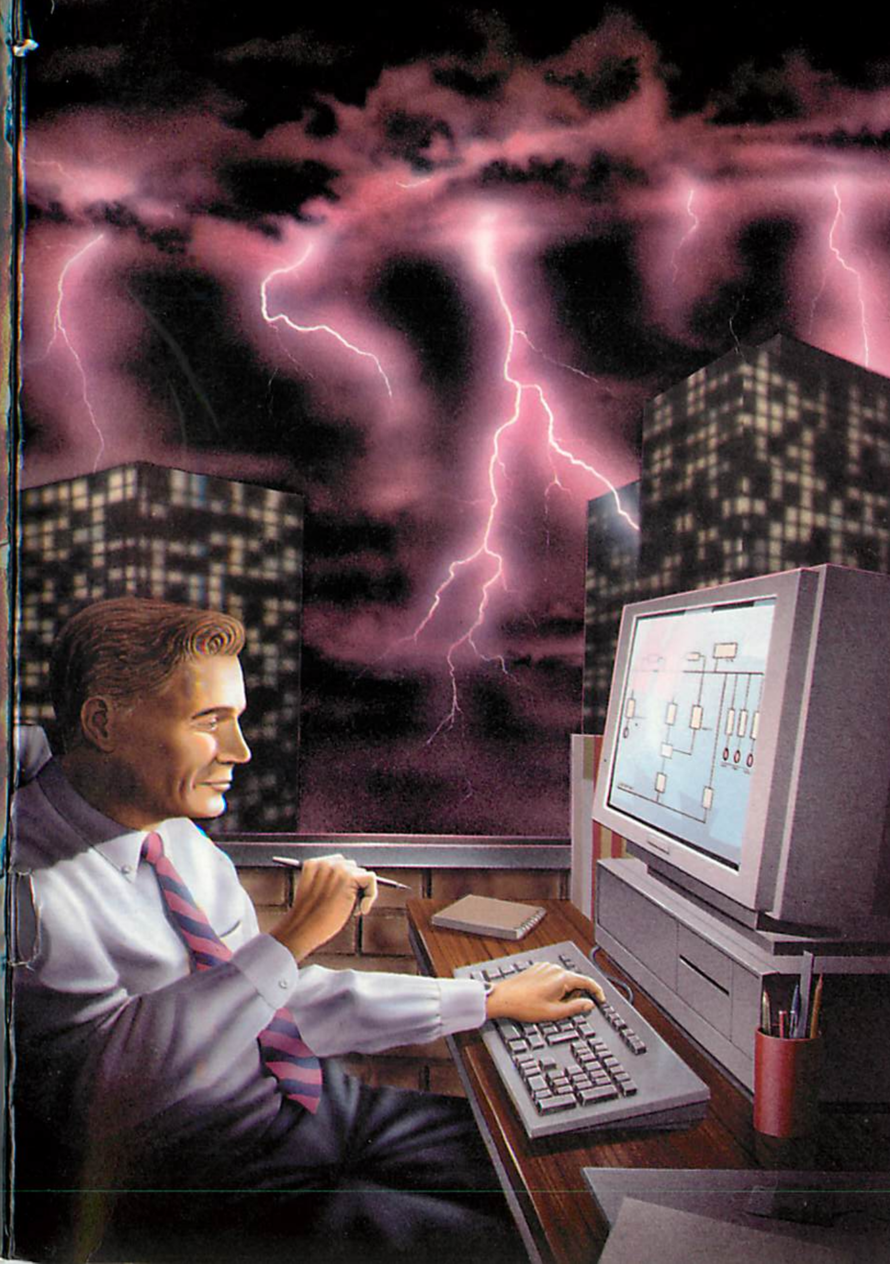
ELECTRONIC SYSTEMS PROTECTION

HANDBOOK

A guide to protecting electronic equipment
from lightning and transient overvoltages



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ELECTRONIC SYSTEMS PROTECTION HANDBOOK

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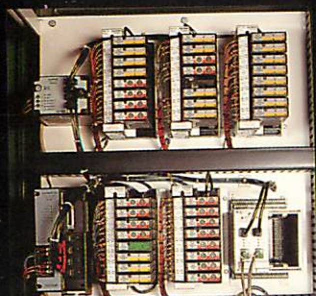
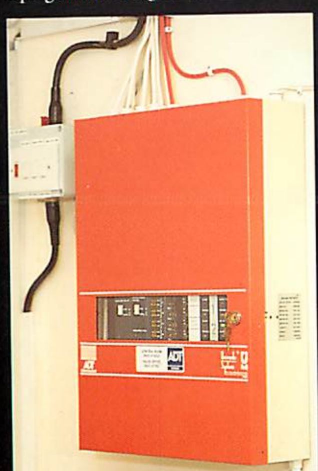
Protect...

...building management systems


...programmable logic controllers


...alarms


...data loggers


...mini computers


...PC CAD systems


...variable speed drives


...CCTV systems

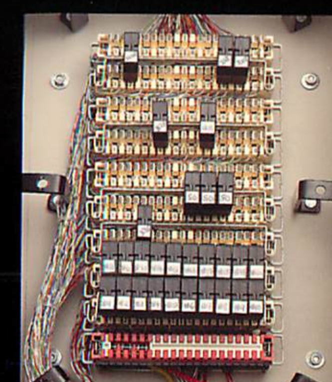

...production control systems


...radio transmitters

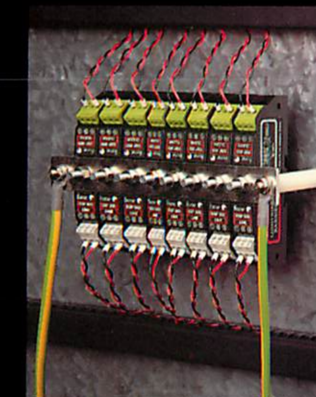

...invertors

Protecting...


...the mains power supply at the main distribution board


...power, CCTV video and two wire control lines to a CCTV system


...a desk top PC based system


...incoming data and signal lines

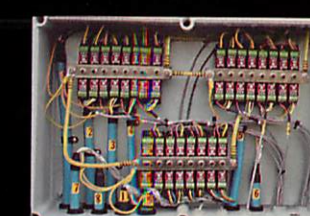

...the mains power supply to a PBX telephone exchange


...the mains power supply from transients fed back into the building on an outgoing feed


...mains power and telephone lines to a telemetry outstation


...telephone lines at a PBX telephone exchange


...a thick Ethernet computer network


...data and signal lines to a control room


...the CCTV video cable to a security system

Notes

SECTION

Introduction

Introduction

The operation of electronic systems can be severely affected by lightning activity or electrical switching events. Both can cause very short duration increases in voltage on mains power and/or data communication/signal/telephone lines, with devastating consequences. All sorts of electronic equipment are at risk: computers, building management systems, PABX telephone exchanges, CCTV equipment, fire and burglar alarms, uninterruptible power supplies, programmable logic controllers, plant sensors, telemetry and data acquisition equipment, and weighbridge installations.

The whole area of 'electronic systems protection' has hitherto been something of a 'black art' with some manufacturers making quite fanciful claims, perpetuating bad installation practices and generally clouding the issue of product performance.

The Electronic Systems Protection Handbook has been produced with the aim of spreading understanding and promoting good practice, by sharing some of our knowledge and expertise. It combines our own extensive experience in this field with knowledge drawn from the papers of other leading authorities and the work of several standards bodies.

It is hoped that the Electronic Systems Protection Handbook will enable you to obtain effective protection for your electronic systems. It is not intended to replace national standards or codes of practice, but to be used in conjunction with them.

We have tried to simplify and demystify the language used. Where this is not practical we have offered explanations and included a glossary of esoteric terms and abbreviations, at the back.

With regard to terminology, there is little general agreement on what to call 'a very short duration increase in voltage'. Indeed, BS 6651:1992 uses three different terms. To avoid ambiguity, we have, until such time as widespread agreement can be reached, elected to use the descriptive term 'transient overvoltage' (sometimes abbreviating it to transient).

W J Furse & Co Ltd's Electronic Systems Protection Division are leading designers and manufacturers of transient overvoltage protectors. Details of Furse ESP transient overvoltage protectors can be obtained by completing and returning the appropriate reply card at the front or rear of this handbook. Should you require assistance or advice in applying transient overvoltage protection, please contact the staff of the ESP Division at the address shown on the rear of this handbook.

Our thanks to the British Standards Institute, the (American) Institute of Electrical and Electronics Engineers, Underwriters Laboratories and Eric Montandon of the Swiss PTT.

Theory of transient overvoltages

What are transient overvoltages?

A ‘transient overvoltage’ is a short duration increase in voltage measured between two or more conductors.

When we say short, we mean anything from microseconds (millionths of a second) to a few milliseconds (thousandths of a second) in duration.

The increase in voltage will vary from a few volts to thousands of volts.

This voltage exists between two or more conductors. For a mains power supply, these conductors would be the live/phase, neutral and earth wires.

‘Transient overvoltage’, is both technically and descriptively the best term. However, transients are also variously referred to as surges, spikes and glitches. The term ‘surge’, though widely used, should be used with caution. In some parts of the world, Britain amongst them, surge is used by the electricity supply industry to refer to a sustained overvoltage of several cycles duration. To avoid confusion, the terms transient overvoltage and transient will be used throughout this publication.

What transient overvoltages are not!

Transient overvoltages are by definition a very specific form of disturbance. It is therefore worth briefly outlining other forms of electrical disturbance in order to understand what transient overvoltages are not!

Most of these disturbances can be represented as an aberration to the normal mains power supply, shown in Figure 1.

FIGURE 1 – Normal mains power supply

UTP Abbrev. for unshielded *twisted pair*. See also *shield*.

V Abbrev. for *volts*.
voltage See *potential*.
voltage standing wave ratio (VSWR) A measurement of the efficiency of line transmission.
VSWR Abbrev. for *voltage standing wave ratio*.
volts Unit of measure of electrical *potential*.

waveform A graphical representation of the periodically varying quantity (eg voltage or current) plotted against time.
waveshape Alternative term for waveform.

μ Greek letter mu used to symbolise *micro* (one millionth).
π Greek letter pi used to denote the ratio of the circumference of a circle to the diameter and approximately equal to 3.14159.
ρ Greek letter rho used to symbolise *resistivity*.
Ω Greek letter omega used as to symbolise *ohms*.

single phase Power supply incorporating one live conductor. See also *phase*.
SPD Abbrev. for *surge protection device*.
spike Alternative term for *transient overvoltage*. See also p5.
stanchion An upright support, often of reinforced steel, used in the construction of buildings.
star supply Three phase power supply incorporating a *neutral* conductor.
structural lightning protection See *lightning protection system*.
suppression level Voltage at which transient overvoltages are controlled or suppressed.
surge Common, but ambiguous alternative for *transient overvoltage* and other terms. See p5.
surge protection device (SPD) Term used to describe transient overvoltage protectors by those who use the word surge to describe transient overvoltages.
swell See p5.
switchfuse Fuse incorporating a switch or isolator, thereby enabling the power supply to devices fed from it, to be turned off.
switching transient Transient overvoltage caused by the operation of large inductive or capacitive loads. See p13.
symmetrical mode See *differential mode*.

TCL Abbrev. for *transient control level*.
telemetry The measurement of events at a distance. Transducers are used to measure physical activities and to convert these to signals that reflect the measurement of the phenomena. The signals are transmitted, often over telephone lines, to a data collection centre for processing. As a result of which, signals may be transmitted back to the distant location to control the processes being monitored.
three phase Power supply incorporating three live conductors. See also *phase*.
transceiver A device used in data communication networks that can transmit and receive information.
transformer A general term describing a component or device that magnetically transforms one alternating voltage to another without change of *frequency*. The usual construction is based upon two or more coils (or windings) of wire placed close to each other. The voltage change is proportional to the difference in the number of turns or windings between each coil.
transient control level (TCL) Term used in BS 6651:1992 to describe the portion of the transient overvoltage reaching equipment. This must be lower than the *equipment transient design level* or susceptibility level. In essence, transient control level means the same as *let-through voltage*.
transient overvoltage An increase in voltage between two or more *conductors*, lasting from *micro*seconds to a few *milli*seconds in duration. Sections 1 and 2 of the handbook discuss transient overvoltages in detail.
transverse mode See *differential mode*.
trunking A square or rectangular surround, with removable cover, for mechanically protecting cables.
twisted pair A cable consisting of a pair of conductors twisted around each other, in order to reduce interference. This is a simple and common communication medium widely used in telephony and other low frequency applications.

UL Abbrev. for the American Underwriters Laboratory, a testing and approvals body. See p96 for reference.
uninterruptible power supply (UPS) See p40-41 and also Example 3, p15-16.
unshielded twisted pair (UTP) See *twisted pair* and *shield*.
unsymmetrical See *non-symmetrical*.
UPS Abbrev. for *uninterruptible power supply*. See p40-41 and also Example 3, p15-16.

'Outage', 'power cut' and 'blackout' are all terms applied to total breaks in the supply lasting from several milliseconds to many hours. Very short breaks, which cause lights to flicker, may be sufficient to crash computers and other sensitive electronic equipment.

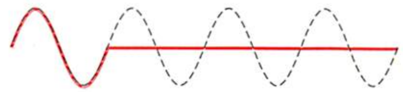


FIGURE 2 – Power cut

'Undervoltages' or 'brownouts' are sustained reductions in the supply voltage, lasting anything from a few seconds.

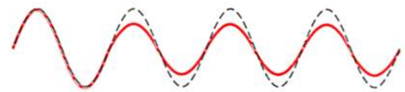


FIGURE 3 – Undervoltage

'Overvoltages' are sustained increases in the supply voltage, lasting anything over a few seconds.

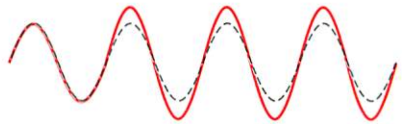


FIGURE 4 – Overvoltage

'Sags' or 'dips' are decreases in the supply voltage, lasting no more than a few seconds.

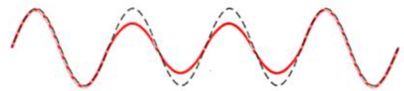


FIGURE 5 – Sag

'Swells' (also called 'surges') are increases in the supply voltage, lasting no more than a few seconds.

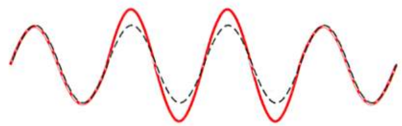


FIGURE 6 – Swell

'Transient overvoltages', 'spikes', (again also referred to as 'surges') or 'glitches' are voltage increases of no more than millisecond duration.

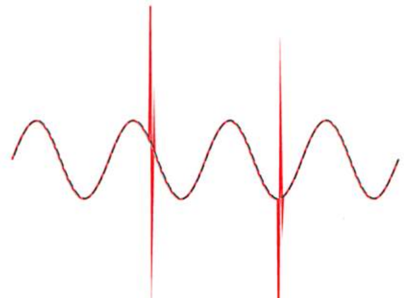


FIGURE 7 – Transient overvoltages

Electrical noise or radio frequency interference (RFI), is a continuous high frequency (5kHz or more) distortion of the normal sine wave.

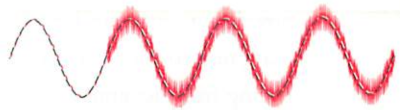


FIGURE 8 – Radio frequency interference

Harmonics are a continuous distortion of the normal sine wave, at frequencies of up to 3kHz.


FIGURE 9 – Harmonics

Nuclear electromagnetic pulse (NEMP), or electromagnetic pulse (EMP), are pulses of energy caused by nuclear explosions and intense solar activity. NEMP or EMP transients are much quicker (a faster rise time) than commonly occurring transients. See page 77.

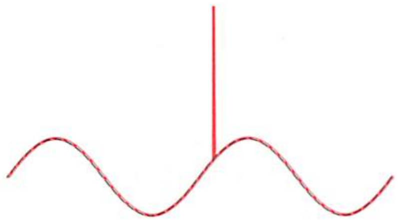


FIGURE 10 – Nuclear electromagnetic pulse

Electrostatic discharge (ESD) is something of a different phenomenon. Unlike the above it does not tend to be transmitted on power or data lines. An electrostatic charge is generated by two insulating objects being rubbed together. A charged object will discharge when it comes into contact with a conducting object. A common example of the charging mechanism could be someone walking over a synthetic carpet. The discharge would occur when the electrically charged person touches a door handle or computer keyboard.


FIGURE 11 – Electrostatic discharge

RCD Abbrev. for *residual current device*.
reactance The result of the presence of *capacitance* and *inductance*.
reflection coefficient Measure of the *impedance* change at a point in a cable. It is the ratio of the signal reflected back from a point to the signal going into that point. High reflection coefficients can, on a data transmission system result in reflections which can be misinterpreted as data or data collisions, disrupting data transmission.
repeaters A form of booster or amplifier used at regular intervals along a transmission channel to regenerate message signals and to overcome impairments such as *impedance*.
residual current device (RCD) Device designed to disconnect a circuit if the *earth leakage current* exceeds a prescribed limit, typically 30 milliamps. Formally, known as an earth leakage circuit breaker.
residual (transient) voltage Alternative term for *let-through voltage*.
resistance The tendency of a material to resist the passage of an electric current and to convert electrical energy into heat energy. Resistance is measured in *ohms*.
resistive coupling See p8-9 for explanation.
resistivity A measure of the amount of resistance due to a material and independent of the dimensions of a sample of the material. Resistivity is symbolised by the greek letter ρ.
resonance The maintenance of oscillation with minimum driving signal.
RF Abbrev. for *radio frequency*.
RFI Abbrev. for *radio frequency interference*.
ring main The way in which wall sockets are supplied in the UK. The power supply is arranged in the form of a ring and is connected to a single point at the power *distribution board*.
RMS Abbrev. for root mean square. It is used to find the DC heat equivalent of an AC voltage or current. For a sine wave the RMS value is equal to its peak value divided by $\sqrt{2}$.
RS 232 An internationally agreed standard for serial data transmission, specifying high and low voltage levels, timing and control.

s Abbrev. for second(s).
sags See p5.
screen To surround or encase a circuit with metal in order to reduce the effect of *electric* or *magnetic fields*. A screened cable is one which incorporates an outer layer of an earthed metal skin. To be effective for transient overvoltage protection purposes, the screen must be a good conductor and earthed at both ends.
self-inductance See *inductance*.
semiconductor Name applied to a group of materials whose ability to conduct electric charge is greater than that of an insulator but less than that of a conductor. Semiconductors are used in a wide variety of solid state components (such as transistors, integrated circuits and diodes) and hence in most electronic systems. Where a semiconductor is connected to a metal or to another semiconductor of different conductivity, a junction is formed. A junction is forward biased when current is flowing through it and reverse biased when it is blocking the flow of current. Bias therefore refers to the direction of the applied voltage.
shield See *screen*.
short circuit A deliberate or (more usually) accidental low *resistance* connection, on an electrical circuit. Its affect is to equal voltages at two points and allow current to flow. If the short circuit is the result of a fault, it will usually cause problems.
shunt Alternative term for *parallel*.
sine wave The natural *waveform* of voltage generated by a coil of wire revolving in a uniform magnetic field. It is therefore the waveform an *AC* mains power supply approximates to. Figure 1 on p4 shows a sine wave.

mains power supply – often connected to *earth* at the substation transformer.
noise Any unwanted, usually *high frequency*, electrical signal.
non-symmetrical voltage The voltage that appears between one conductor and earth in a multiconductor system.
normal mode See *differential mode*.
nuclear electromagnetic pulse (NEMP) See p6.

ohm The unit of *resistance*, *reactance* and *impedance*. It is symbolised by the greek letter Ω.
open circuit A disconnection or break in an electrical circuit (eg by a switch or a component failure) which prevents current flow.
opto-isolator An electronic device which provides isolation between two circuits, through converting electrical signals to light and back again. They are commonly used to block *common mode* interference.
oscilloscope Instrument for measuring and recording electrical *waveforms* and *pulses*.
outage See p5.
overvoltage See p5.

PABX Abbrev. for private automatic branch exchange. See *private branch exchange*.
parallel Refers to a circuit or device that is connected across or between a pair of conductors. Figure 48 on p55 shows a simple parallel connection.
PBX Abbrev. for *private branch exchange*.
PC Abbrev. for personal computer.
PCB Abbrev. for *printed circuit board*.
PDU Abbrev. for power distribution unit. See *distribution board*.
phase Denotes the *live* conductor(s) on electrical systems with two or more alternating supply voltages, displaced in their phasing relative to each other.
pico (p) Prefix to units of measurement equal to 10^{-12}.
potential or **voltage** The measurement in volts (V), of the electric force capable of driving current through a circuit. It is formally defined as the amount of work done, per unit of charge, when a charge is removed from that point to infinity.
potential difference A difference, in *voltage*, between two points.
power cut See outage on p5.
power distribution board See *distribution board*.
printed circuit board Electronic circuit where copper interconnections are produced on board, typically made of glass fibre, by a photographic process.
private automatic branch exchange (PABX) See *private branch exchange*.
private branch exchange (PBX) A telephone exchange, usually serving a single company and located on its premises. It connects the incoming lines of the public telephone network with the private service within the premises.
protector Within this handbook the term has been used as an abbreviation for transient overvoltage protector.
PTO Abbrev. for *public telecommunications operator*.
public telecommunications operator (PTO) The utility or company licensed to operate the fixed (ie not the mobile) public telephone network. In Britain, British Telecom, Mercury Communications, Kingston Communications (in Hull) and a number of cable TV companies are all licensed PTO's.
pulse A single cycle of abrupt voltage or current change. As such, a *transient overvoltage* can be described as a pulse.

radio frequency (RF) A frequency in the accepted practical radio range.
radio frequency interference (RFI) Interference occurring in the *radio frequency* range.

Electromagnetic interference (EMI) is a very broad term referring to system interference.

Electromagnetic compatibility (EMC) is a philosophy referring to attempts to prevent EMI. EMC practice dictates that potential sources of interference are designed so as not to affect equipment, and that potential victim equipment is designed to be immune from potential sources of interference. Lightning cannot be prevented at source, and cannot be fully protected against with simple EMC counter measures.

How transient overvoltages are caused

Transient overvoltages have two main causes – lightning and electrical switching events.

Lightning

Lightning activity can cause transient overvoltages on both mains power supplies and data communication, signal or telephone lines.

Lightning discharges are awesome and are claimed to have currents of up to 530,000 amps, though 200,000 amps is an accepted upper limit. Were lightning to hit a building without a structural lightning protection scheme, this current would seek a path to earth through the building and its fabric – in an erratic and unpredictable manner. The building is likely to be damaged and may even catch fire. Although transient overvoltages will occur, this may be just one aspect of extensive damage to the building and its contents.

If however, lightning strikes a building with structural lightning protection the lightning will travel to earth in a predetermined manner. Transient overvoltages may be caused through resistive, inductive and capacitive coupling (see below).

Lightning can cause transient overvoltages through:

- direct strikes to incoming electrical services
- 'indirect' strikes, which are coupled into electrical services through resistive, inductive and capacitive effects.

Direct strikes to HV power cables. Strikes to high voltage (HV) overhead power lines are quite common. It is often thought that the high voltage to low voltage transformer action eliminates the resultant transient overvoltages. This is not so. Although transformers protect against transient overvoltages between line and earth, line to line transients pass through unattenuated.

> **Line to earth** means between live and earth or between neutral and earth.
> **Line to line** means between live and live or between live and neutral.

When HV lines are struck by lightning they flashover to earth. One line will flashover before the others, converting a line to earth transient into one between line and line – these will easily pass through the transformer.

Also, capacitance between the transformer's windings provides transients between any combination of conductors with a high frequency path through the transformer. This could have the effect of increasing the size of existing line to line transients, as well as providing a path through the transformer for line to earth transients.

Direct strikes to LV power or telephone lines. When lightning hits low voltage (LV) overhead power or telephone lines, most of the current travels to earth as a result of line flashover to ground. A relatively small (but devastating) portion of the lightning current is transmitted along the line to electronic equipment.

Resistive coupling is the most common cause of transient overvoltages and it will affect both underground and overhead lines. Resistively coupled transients occur when a lightning strike raises the electrical potential of one or more of a group of electrically interconnected buildings (or structures).

Common examples of electrical interconnections are:
- power feeds from substation to building
- building to building power feeds
- power supplies from the building to external lighting, CCTV or security equipment
- telephone lines from the exchange to the building

LAN Abbrev. for *local area network*.
LEMP Abbrev. for *lightning electromagnetic pulse*.
Let-through voltage The part of a *transient overvoltage* which is allowed through a protector.
Lightning Barrier Term used to describe Furse ESP transient overvoltage protectors for data communication, signal or telephone lines.
lightning electromagnetic pulse (LEMP) A disturbance produced by the electromagnetic field caused by a lightning discharge and resulting in *transient overvoltages*. See also p7-10 for an explanation of how lightning causes transient overvoltages.
lightning protection system (LPS) The whole system of lightning conductors and earth connections used to protect a building or structure from the effects of a direct lightning strike.
live A conductor or circuit which is not at *earth potential* and is therefore carrying a voltage.
load Equipment or devices drawing power from a power source. Also the output side of a power source.
local area network (LAN) A communication system that links many computers, printers, data storage devices and the like together, within a building or plant (eg *Ethernet*).
longitudinal See *common mode*.
low voltage (LV) Voltage **not** exceeding 1,000 volts *AC* or 1,500 *DC* between conductors, or 600 volts AC or 900 volts DC between conductors and earth.
LPS Abbrev. for *lightning protection system*.
LV Abbrev. for *low voltage*.

m Abbrev. for metre, when used on its own. Also abbrev. for *milli* when used in conjunction with other units.
M Abbrev. for mega (meaning 1,000,000 or 10^6) used as a prefix to units of eg frequency (Hz).
magnetic field The magnetic field of force surrounding a current-carrying conductor.
main incomer The principal incoming power supply to a site or building. See also *distribution board*.
MCB Abbrev. for miniature *circuit breaker*.
MCCB Abbrev. for moulded case *circuit breaker*.
meshed earthing system A system of *earth electrodes* or earth conductors which has been interconnected so as to form a grid or mesh of interconnections.
metal cladding The metal outer layer or skin used in the construction of many industrial buildings.
metallic See *differential mode*.
micro Used as a prefix to units of measurement this means one millionth or 10^{-6}. It is symbolised by the greek letter μ.
milli (m) Prefix to unit of measurement meaning one thousandth (or 10^{-3}), as in mm (one thousandth of a metre) and ms (one thousandth of a second).
mode Synonym for transmission mode. With regard to transient overvoltages the term is used to describe the pair or pairs of *conductors* which *transient overvoltages* exist between.
moisture barrier Outer layer of a, most typically, data communication cable designed to protect its conductors from moisture.
mutual inductance See *inductance*.

n Abbrev. for *nano*.
nano (n) Prefix to unit of measurement meaning 10^{-9}.
NEMP Abbrev. for *nuclear electromagnetic pulse*. See p6.
neutral Having neither positive or negative electric charge. The return line on an *AC*

transmit signals.
FIPS Abbrev. for the American Federal Information Processing Standards body. See also p95 for reference.
flash testing A high voltage test to prove the integrity of electrical insulation.
flashover A temporary breakdown of insulation, allowing a spark or discharge.
frequency The number of times a *waveform* is repeated during a period of time (usually a second), measured in *hertz*.
fuse Protective device which operates to create an *open circuit*, under overcurrent or fault current conditions.

G Abbrev. for giga (meaning 1,000,000,000 or 10^9) used as a prefix to units such as frequency (Hz).
gas discharge tube (GDT) see p91-92.
GDT Abbrev. for *gas discharge tube*, see p91-92.
glitch See transient overvoltages on p5.
ground American term for *earth*.

harmonics See p6.
hertz (hz) Unit of *frequency*.
high voltage (HV) Voltage exceeding 1,000 volts *AC* or 1,500 volts *DC* between conductors, or 600 volts AC or 900 volts DC between conductors and earth.
HV Abbrev. for *high voltage*.
hybrid generator Alternative name for *combination wave generator*.
Hz Abbrev. for *hertz*.

IEC Abbrev. for International Electrotechnical Committee. See p95 for reference.
IEE Abbrev. for The Institution of Electrical Engineers.
IEEE Abbrev. for The (American) Institute of Electrical and Electronics Engineers. Many IEEE publications have been adopted as American National Standards. See p96 for specific references.
IEEE 587 Standard superseded by IEEE C62.41-1991.
impedance A measure of the response of an electric circuit to an *alternating current*. In addition to the *resistance*, the current is also opposed by the *capacitance* and *inductance* of the circuit. Impedance is this combined opposition to current flow.
in-line or **series** Component or device installed within a cable or circuit, such that electric current flows through the in-line device.
inductance The property of an electrical circuit by which a voltage is generated by a change in the current, either in the circuit itself (self-inductance) or in a neighbouring circuit (mutual inductance).
inductive coupling See *coupling* and p9-10.
interwinding capacitance *Capacitance* existing between two wound or coiled wires, such as those found in a *transformer*.
I/O Abbrev. for input/output. The term is used to refer to those operations, devices and data-bearing media that are used to pass information into or out of a computer.
isolation To cut off the power supply to an installation, or a separate part of it, so that it can safely be worked upon.
isolator A mechanical switching device for the purpose of *isolation*.

joule (J) Measure of energy.

k Abbrev. for kilo (meaning thousand) used as a prefix to units of voltage (V), current (A), energy (J) etc.

- between building telephone lines
- between building LANs or data communication lines
- signal or power lines from a building to external or field based sensors.

Figure 12 shows two buildings. Each contains electronic equipment, 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.

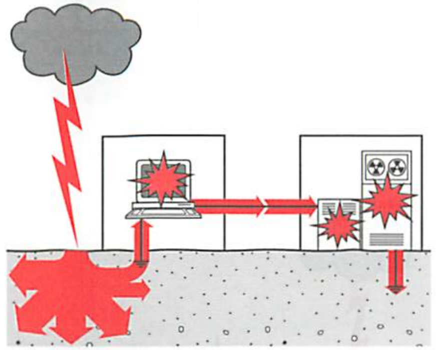


FIGURE 12 – Resistive coupling through a data line

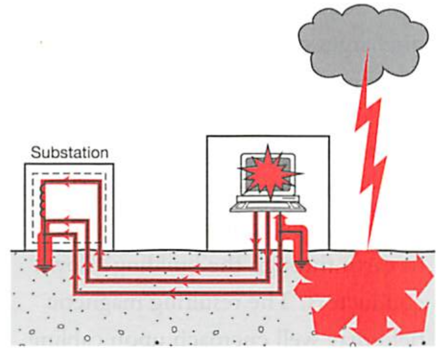


FIGURE 13 – Resistive coupling through the live, neutral and earth conductors of a mains power supply

A nearby lightning strike will inject a massive current into the ground. The current flows away from the strike point – 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.

Figure 13 provides an example of how resistively coupled transient overvoltages can occur on a mains power supply.

Resistively coupled transients can occur when separately earthed structures are only metres apart. Resistive coupling will affect both underground and overhead cables.

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.

This frequently occurs when lightning discharges close to overhead power or telephone lines (Figure 14).

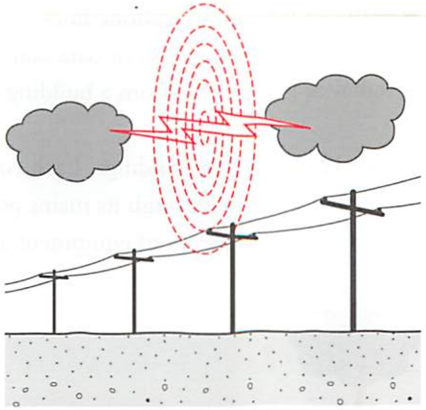


FIGURE 14 – Inductive coupling

Much the same thing happens when a building's lightning protection scheme is struck. The lightning current flows to earth through the building's down conductors. The resulting magnetic field may well encroach upon cabling within the building, inducing transient overvoltages onto it (Figure 15).

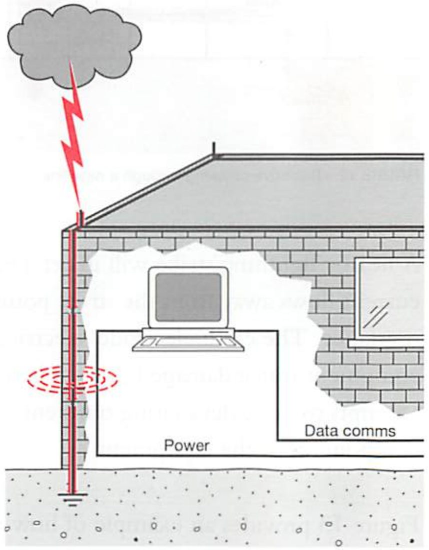


FIGURE 15 – Inductive coupling from a lightning conductor

Capacitive coupling. Where long lines are well isolated from earth (eg via transformers 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 line rises beyond the breakdown strength of the devices at each end (eg the opto–isolators), they will be damaged.

Size of transient overvoltages caused by lightning. The American Institute of Electrical & Electronics Engineers (IEEE) has collated extensive research into transient overvoltages caused by lightning. The American Standard IEEE C62.41 states:

- a typical worst case of 6,000 volts for transient overvoltages within a building's power distribution system – its sparkover clearance ratings will ensure that the transient does not generally exceed 6,000 volts.

conductors. The term main, or main *LV*, distribution board refers to the building's principle distribution board, usually supplied directly from an electricity substation or *HV* to LV *transformer*. A sub distribution board describes a second tier distribution board supplied from the main distribution board and itself supplying either equipment or third tier distribution boards. The term local distribution board, describes the unit which provides the power supply to a particular piece of equipment.

diverter General term for a protective device which diverts current away from a circuit.

draw wire A high tension wire incorporated in many fibre optic and some other data cables, to enable the installer to pull the cable through inaccessible *conduits* or *ducts*.

DTP Abbrev. for desk top publishing. Typically a DTP system is a high powered stand alone computer system incorporating a high definition colour screen, a scanner, colour printer and graphics software.

duct A pipe or *conduit* for mechanically protecting cables.

earth or **ground** Any zero-voltage point. The earth itself is taken as being of zero voltage because its potential is not greatly affected by small currents. *Conductors* which connect equipment or circuits to earth or to an earth network are often referred to as earth.

earth electrode A conductor or group of conductors providing a good electrical connection with the Earth (soil).

earth leakage current A stray current which flows to earth, in a circuit which is electrically sound. For safety reasons, the earth leakage current must be kept within prescribed limits.

earth potential Normally zero *voltage*.

earth reference Connection to *earth*.

ECMA Abbrev. for European Computer Manufacturers Association. See p95 for specific reference.

electric field The field of force surrounding a charged object.

electrical noise See *noise*.

electromagnetic compatibility (EMC) See p7.

electromagnetic field Combined *electric field* and *magnetic field*.

electromagnetic interference (EMI) See p7.

electromagnetic pulse (EMP) See nuclear electromagnetic pulse, p6.

electrostatic discharge (ESD) See p6.

EMC Abbrev. for electromagnetic compatibility. See p7.

EMI Abbrev. for electromagnetic interference. See p7.

EMP Abbrev. for electromagnetic pulse. See nuclear electromagnetic pulse, p6.

equipment transient design level Term used in BS 6651:1992 to refer to the level at which a piece of equipment becomes susceptible to interference from transient overvoltages.

equipotential Of equal *potential*. This term is often used when describing a low resistance connection or bond between equipment and earth, made to ensure that the two points are always at the same voltage.

ESD Abbrev. for *electrostatic discharge*.

ETDL Abbrev. for *equipment transient design level*.

Ethernet This is the product name of a particular form of *local area network*. It is governed by the standard *IEEE* 802.3 and operates over distances of up to around 2.5km. Originally based upon a *coaxial* cable, the system can now also utilise *twisted pair* and *fibre optic* cable.

fibre optic cable A non conducting signalling medium which uses a light beam to transmit messages through a cable of thin filaments of glass or plastic. It is therefore unlike other types of cable which use an electric charge on a conducting cable, to system forms a *capacitor*. An electric field is produced across the system creating a capacitive electrical path between the conductors. See also *coupling* and p10.

CCITT Abbrev. of International Telegraph and Telephone Consultative Committee (from the French, Comité Consultatif International Télégraphique et Téléphonique). This committee of the ITU (International Telecommunications Union), a UN body, was set up to promote standards for the development of telephone, telegraph systems and data networks. See p95 for specific references.

CCTV Abbrev. for *closed-circuit television*.

circuit breaker A resettable alternative to the *fuse*, which creates an *open circuit* under overcurrent or fault current conditions.

clean Cable which is, supposedly, relatively free from interference.

clean earth See p74-75.

closed-circuit television (CCTV) A television system, other than broadcast television, which forms a closed circuit between television camera and receiver. CCTV has many commercial applications, eg security systems.

coaxial cable A type of cable consisting of two concentric conductors separated by insulation, used to transmit high frequency (eg television) signals.

combination wave generator or **hybrid generator** Transient test equipment designed to produce voltage and/or current impulses of defined *waveform*. See also p89 & 90.

common mode The voltage that appears between each of two or more conductors and earth.

conductor Material which electric *current* will easily pass through. Also the set of wires, or conductors, which together form a power or data communication cable or supply. Power supplies typically consist of *live/phase*, *neutral* and *earth* conductors. There is considerable variation in the names applied to the constituent conductors of a data communication, signal or telephone cable. Often there is one or more signal or line conductor together with a *screen* and/or *earth* return conductor.

conduit A channel or pipe for mechanically protecting cables.

coupling The interaction between two circuits which causes energy to be transferred from one to the other. This can be the result of *capacitive*, *inductive* or *resistive* mechanisms.

CP 326 Code of practice (CP) superseded by BS 6651.

cross bond To *bond* together two or more *conductors*.

cross coupling See *coupling*.

current The rate of flow of electric charge, measured in *amps*.

DC Abbrev. for *direct current*.

delta supply A three phase power supply with no *neutral* connection.

differential mode The voltage that appears between two conductors, neither of which is at *earth potential*.

digital signal A signal which operates with a small number, usually only two, voltage levels. Because only two easily distinguishable voltage levels are used, digital systems are free from many of the forms of distortion which affect analogue systems. Both can be affected by transient overvoltages.

dip See sags on p5.

direct current (DC) A steady *current* in one direction. Such as that provided by a battery, a dynamo or the smoothed output of a rectifier circuit.

dirty Cable or supply carrying some form of interference.

discharge current Refers to the transient current flowing through a protection device or component during operation.

distribution board A panel, enclosure or 'board' containing isolators, fuses, air circuit breakers or protective devices, feeding one or more outgoing circuits and supplied by one or more incoming circuits, together with terminals for the neutral and earth

- on mains power supplies within a building, secondary lightning currents are unlikely to be more than 3,000 amps and are certainly no greater than 10,000 amps.

Worst case transient overvoltages for data communication, signal and telephone lines are less easy to quantify with certainty. However, we seem to be dealing with a worst case of 5,000 volts, or so, and hundreds of amps. (Based on the test recommendations of the CCITT.)

Characteristics of lightning. Lightning has a tendency to preferentially strike taller structures and objects. Strikes to ground are, however, quite common where there is a distance between structures of more than twice their individual height.

Figure 16 illustrates how lightning current can enter a building and its associated electronic systems following a lightning strike to buildings, electrical services or surrounding ground.

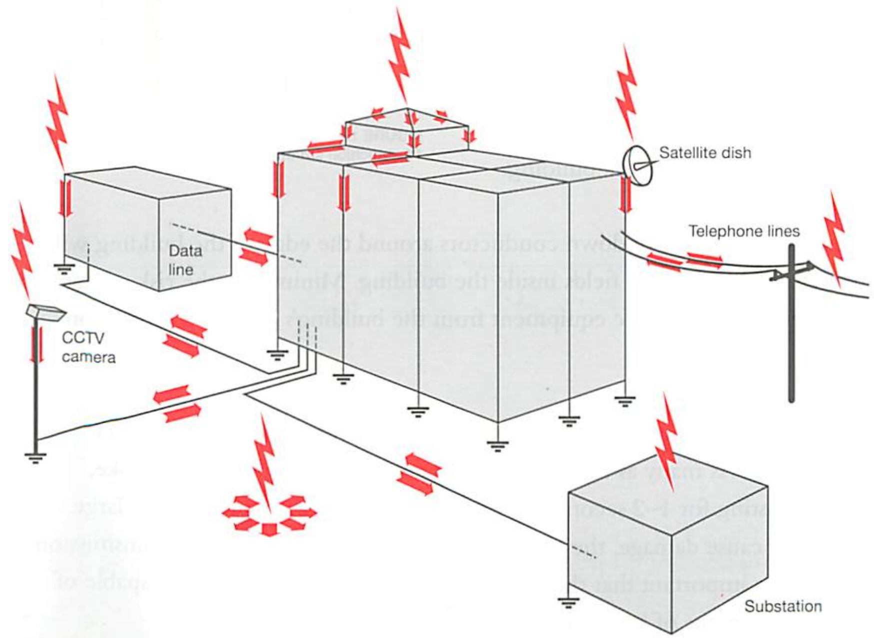


FIGURE 16 – A lightning strike to any part of a site will cause lightning current to flow away from the strike point – the arrows indicate the direction of possible current flow

For lightning protection purposes an all conducting building, with metal cladding and roof is an ideal structure. It effectively provides electronic equipment within it with a 'screened room' environment. Many steel framed or reinforced concrete buildings with metal cladding will approximate to this ideal. If lightning strikes the building, a 'sheet' of current will flow all over the surface and down to earth, provided, that the cladding and roofing is correctly bonded together. Any small differences in resistance will have little effect on current flow – flow paths are dictated by inductance and not resistance, owing to the fast impulsive nature of the lightning return stroke and restrikes.

Current flows in steel framed or reinforced concrete structures show a similar preference towards external conductors. Figure 17 shows that even when lightning strikes the centre of a building's roof, the majority of the current will flow down external conductors rather than the nearer internal conductors. The current flow through the three internal stanchions is relatively small, creating small magnetic fields within the building.

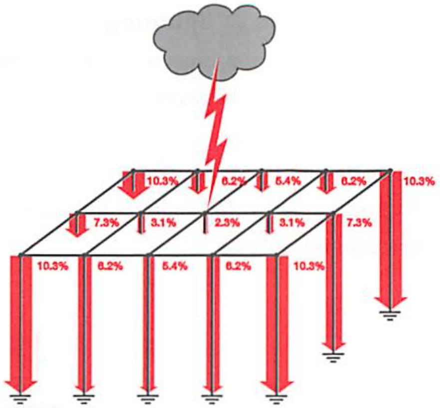


FIGURE 17 – Distribution of lightning current in a 15 stanchion structure Derived from BS 6651:1992

Thus, large numbers of down conductors around the edge of the building will greatly reduce magnetic fields inside the building. Minimising the risk of transient interference to electronic equipment from the building's lightning protection system.

The multiple pulse effect of lightning can cause severe problems with data transmission. As many as twenty restrikes can follow the first return stroke, together lasting for 1–2 seconds. Where the resulting transients are not large enough to cause damage, they will confuse and corrupt data under transmission. Clearly, it is important that the computers error checking facility is capable of rejecting segments of 'nonsense' data lasting up to two seconds.

Glossary

Glossary A list of technical terms, abbreviations and notation. If explanations refer to other terms within the glossary, these *cross references* are shown in italics. Where terms are already adequately defined, even in the technical sense, by a normal English Dictionary, they have been omitted.

A Abbrev. for *amp(s)*.
AC Abbrev. for *alternating current*.
ACB Abbrev. for *air circuit breaker*.
air circuit breaker Large *circuit breaker* typically used for high current, industrial applications.
air termination point Part of a *structural lightning protection* system, intended to intercept potential lightning strikes, to the structure.
alternating current (AC) A *current* that alternately flows in each of two directions. The time between current reversals is usually constant, producing a constant *frequency*. The *waveform* of current plotted against time is assumed to be symmetrical around zero, giving a *sine wave*. The term is normally only used to refer to the mains power supply.
amps, ampere (A) Unit of measure of electric *current*.
analogue signal A signal which represents the size of another quantity, such as temperature or pressure, through the size of its own signal level.
ANSI Abbrev. for American National Standards Institute. ANSI C62.41 is now designated IEEE C62.41. See references.
AS Abbrev. for Australian Standard. See p95 for specific reference.
asymmetrical See *common mode*.
armouring Protective metal covering, commonly incorporated on cables and often also used as an earth conductor on power cables.
arrester Protection device, as in 'Lightning Arrester'. The term arrester is most commonly used to describe basic protectors for high voltage overhead power lines.

bandwidth The band or range of *frequencies* which can be occupied by a signal. Signals outside the nominated bandwidth of a system, may be distorted, loosing or corrupting information.
blackout See outage on p5.
bond To connect metal parts of a system or circuit together, so that they are at a common voltage, usually *earth potential*.
brownout See undervoltage on p5.
BS Abbrev. for British Standard. See p95 for specific references.

CAD Abbrev. for computer aided design.
capacitance The property of isolated *conductors* to store an electrical charge. Capacitance can create limitations in the transmission of signals through circuits.
capacitor A component with significant *capacitance*. It consists of at least two conductors separated by an insulator (which may be solid, liquid or gaseous). The capacitance of a given device depends upon the size and shape of the conductors, the distance between them and the characteristics of the insulator.
capacitive coupling If an isolated conductor (or other electrical charge, such as lightning) is near to a second conductor, but is separated from it by air or some other insulator, the

IEEE C62.33-1982	Standard Test Specifications for Varistor Surge-Protective Devices, July 1983, Reaffirmed March 1988 (The Institute of Electrical and Electronics Engineers, USA).
IEEE C62.41-1991	Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits, February 1991 (The Institute of Electrical and Electronics Engineers, USA).
IEEE 587	Now obsolete predecessor to IEEE C62.41-1991.
IEEE 802.3	Information Processing Systems – Local and Metropolitan Area Networks – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications, 1993 Edition (The Institute of Electrical and Electronics Engineers, USA). Also now available as ISO 8802-3.
IEEE 1100-1992	Recommended Practice for Powering and Grounding Sensitive Electronic Equipment, June 1992 (The Institute of Electrical and Electronics Engineers, USA). Also known as 'The IEEE Emerald Book'.
ISO 8802.3	International Standards Organisation issue of IEEE 802.3, CSMA/CD Access Method and Physical Layer Specifications.
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Acknowledgements

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Figure 34 – Hybrid earthing, reproduced with the kind permission of Eric Montandon of Swiss Telecom. This is contained within report 7.05 of the proceedings of the 21st International Conference on Lightning Protection (Berlin, 1992).

Electrical switching events

Transient overvoltages caused by electrical switching events are very common and can be a source of considerable interference.

Current flowing through a conductor creates a magnetic field in which energy is stored. When the current is interrupted or switched off, the energy in the magnetic field is suddenly released. In an attempt to dissipate itself it becomes a high voltage transient.

The more stored energy, the larger the resulting transient. Higher currents and longer lengths of conductor, both contribute to more energy stored and also released! This is why inductive loads such as motors, transformers and electrical drives are all common causes of switching transients.

The problems transient overvoltages cause

Transient overvoltages, whether caused by lightning or by electrical switching, have similar effects: disruption, degradation, damage and downtime.

Disruption

Although no physical damage is caused, the logic or analogue levels of the systems' are upset, causing: data loss, data and software corruption, unexplained computer crashes, lock-ups, the spurious tripping of residual current devices (RCDs). The system can be reset (often just by switching off and on) and will then function normally. Much of this nuisance may go unreported.

Degradation

This is somewhat more serious. Long term exposure to lower level transient overvoltages will, unknown to the user, degrade electronic components and circuitry reducing the equipment's lifetime and increasing the likelihood of failures.

Damage

Large transient overvoltages can cause damage to components, circuit boards and I/O cards. Severe transient overvoltages can physically manifest themselves through burnt-out circuit boards, however, ordinarily damage is less spectacular. Figure 18 shows a circuit board with both obvious and unapparent damage.

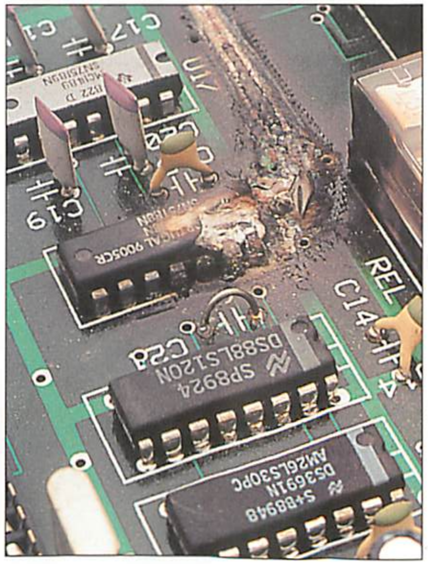

FIGURE 18 – The microchips on this circuit board have all been damaged by transient overvoltages, although only one shows obvious signs of damage

References

AS 1768-1991	Lightning protection, 1991 (Standards Association of Australia). Also designated as NZS/AS 1768-1991 by the Standards Association of New Zealand.
BS 2914:1972	Specification for surge diverters for alternating current power circuits, (British Standards Institute).
BS 6651:1992	Protection of structures against lightning, December 1992 (British Standards Institute).
BS 7671:1992	Requirements for Electrical Installations, 1992 (British Standards Institute). Also known as, and available as, IEE Wiring Regulations, Sixteenth Edition (The Institution of Electrical Engineers).
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Goedbloed JJ	Transients in low-voltage supply networks, IEEE Transactions on Electromagnetic Compatibility, Vol EMC-29, No 2, May 1987 (The Institute of Electrical and Electronics Engineers, USA).
IEC 801-5	Electromagnetic compatibility for industrial process measurement and control equipment – Part Five: surge immunity requirements, DRAFT standard (International Electrotechnical Committee).

The operation of a transient overvoltage protector

Parallel connected protectors for mains power supplies work on the short circuit principle.

A Furse ESP wire-in protector for 240 volt power supplies has a nominal working voltage of 240 volts, and a maximum voltage of 280 volts RMS (ie 396V peak). At 396 volts the current in the unit is negligible, and it behaves as a high resistance. As progressively bigger and bigger transients are applied, the resistance of the unit appears to get smaller (see Figure 103).

The data in Figure 103 can be derived from our published product data and shows the behaviour of the protector. Its resistance gets lower and lower as we pass more current through it and this is the key to how a protector works.

FIGURE 103 – Protector's dynamic resistance

Current	Voltage	Resistance
500A	510	≈1Ω
1000A	530	≈0.53Ω
2000A	570	≈0.29Ω
2500A	590	≈0.24Ω
3000A	600	≈0.20Ω
5000A	690	≈0.14Ω

Simple varistor based protectors also operate on the same principle, but are not as effective at protecting. The largest commercially available varistor (275 VRMS) has a let-through voltage of 820 volts at 5,000 amps, and 780 volts at 3,000 amps. This performance is for the varistor on its own (not a complete protector), and its let-through will increase perhaps by hundreds of volts when failure protection, and terminations are added.

In-line data line protectors are usually constructed in the form of a hybrid circuit. In its simplest form the hybrid circuit consists of gas discharge tubes, resistance, and transient suppressor diodes.

A protector for one wire with respect to earth is shown in Figure 104.

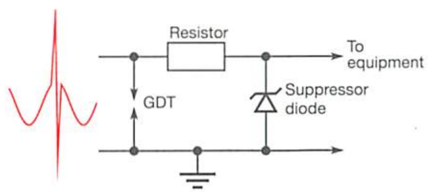


FIGURE 104 – Simple series protector

Initially the transient will cause current to flow into the diode. It will limit the voltage into the equipment to an acceptable level, but can only do so for a short period, after which time it will be destroyed. As current flows into the diode, voltage develops across the resistor until sufficient voltage is available across the GDT to turn it on. At this point the diode is safe.

In practical devices the circuit is reconfigured to provide full protection between all lines and earth. Also the simple circuit, whilst useful as an understanding aid, is usually greatly enhanced to avoid its various drawbacks.

Downtime

Unnecessary disruption, component degradation and damage all result in equipment and systems downtime, which means:

- staff unable to work
- staff overtime
- senior managers and technical specialists unnecessarily tied-up problem solving
- lost productivity
- delays to customers
- lost business.

Example 1 - Switching transients

An engineering company invested heavily in a networked computer aided design (CAD) system. However, the system's many advantages were overshadowed by the all too regular problems it suffered. The system would crash unexpectedly, sometimes hours of work were lost or corrupted and circuit failures seemed to be almost a monthly event. At first, these were assumed to be just 'teething troubles'. But as time went on, and design work slipped further and further behind schedule, relations with the system's supplier became increasingly difficult. Only when one of the engineering team read an article in a professional journal, did they realise that the problem might not be the system, but the environment. They soon observed that the system's failures coincided with the operation of a large drawing copying machine. The operation of this load was injecting switching transients onto the ring main.

Example 2 - Lightning strike to research centre

A lightning strike to a research campus had widespread effects. The PBX telephone exchange was rendered almost totally inoperable, with 80% of the external telephone lines taken out of commission. The pattern of damage clearly indicated induced transient overvoltages on the incoming telephone lines. Elsewhere, there was extensive damage to computer equipment in the admin block, which was closest to the strike point. This equipment was networked to equipment in neighbouring buildings where transceivers, repeaters and some terminals were damaged – indicative of resistively coupled transient overvoltages.

Example 3 - Lightning strike to office block

When lightning struck an office block, its structural lightning protection ensured that the lightning current was carried safely to earth – without damage to the building or its occupants. However, sizeable transient overvoltages were induced on to the mains power supply within the building. Costly damage was suffered to the building management system, its UPS, the door entry system, the telephone exchange, and a large number of computer terminals. Over subsequent months, there were a number of failures to pieces of equipment apparently undamaged during the initial incident – suggesting component degradation had occurred.

How transient overvoltage damage is caused

Nearly all electronic components and circuits suffer transient overvoltage damage in the same way. There are two main physical mechanisms at work, overheating and insulation failure – both are made much worse by the subsequent power follow-on.

Let us consider a simple resistor made from a coil of resistance wire. During transient activity the current flowing through the wire increases, making it hotter. If sufficient heat is generated to melt the wire, degradation will occur. A little more heat and the wire will vaporize – destroying the component. Heat failure, such as this, is common in fuses, printed circuit board tracks, forward biased semiconductor junctions and the like.

In addition to heating, the current flow causes a voltage to be generated across the wire. If the voltage difference becomes high enough to pierce the wire insulation and breakdown the air gap, flashover occurs. This form of failure is common with reverse biased semiconductor junctions, capacitors, transformers, motor windings and such like.

When components connected across power supplies fail, the majority of the physical damage (charring, burning or explosion) is the result of the follow-on current. This occurs when the power current flows down the damage path created by the transient overvoltage.

It should be noted that the silicon chip is a collection of components and inter-connections. Its inter-connections behave like PCB tracks and its components include forward biased or reverse biased junctions, resistors and capacitors.

A third form of failure is not due to a physical mechanism, but the incorrect

Why is this?

If we re-examine how the standard frequency characteristic is measured, we find a signal source and load with 50Ω resistance are used. See Figure 99.

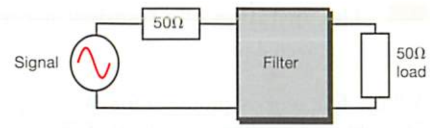


FIGURE 99 – Conventional filter test

The transient on the mains has a much lower resistance than 50Ω, and the load resistance can be any value and indeed often behaves like an open circuit.

Figure 100 shows the frequency characterisation under these new conditions. There now is amplification at the ringing frequency on the previous test. This proves why a filter can make transients worse!

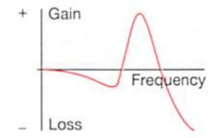


FIGURE 100 – Real world frequency response of a filter

Another problem is that the inductor is wound on a magnetic core. These can become useless at high (transient) currents, due to saturation.

However it is possible, by careful design, to make filters that do work, although most inexpensive devices don't!

For RF applications, where the signal is above the signal range of a lightning transient, it is possible to use high pass and band pass filters as part of a protection strategy.

Principles of protection

In order to explain protection, the 6kV 1.2/50μs, 3kA 8/20μs waveforms and the simple battery analogy (referred to in Appendix C) will be used for illustrative purposes.

If a system suddenly finds a transient imposed upon it there are two methods of protection available.

Protection by open circuit

If an open circuit exists in-line with the victim, no transient currents can flow to it, and voltages are held off by the open circuit (see Figure 101). This is in fact the same protection method as unplugging a piece of equipment during a storm.

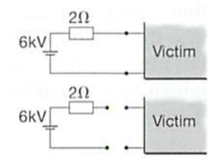


FIGURE 101 – Protection by open circuit

Transformers, line to earth, and opto-couplers, line to earth, behave in this manner, and are able to offer some limited protection. Obviously if their breakdown strength is exceeded, or the transient occurs line to line, they will fail. Fibre optic cable is perhaps the best example of this type of protection.

Protection by short circuit

If a short circuit exists across the victim, no harmful voltages can reach it, and all currents pass through the short (see Figure 102). Most protection devices operate on this principle, however most devices only attempt an imperfect short circuit for reasons covered later.

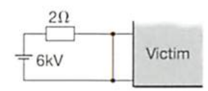


FIGURE 102 – Protection by short circuit

Once on, they tend to remain on as long as power from the system flows into the device. Gas discharge tubes and breakover diodes both operate on this principle.

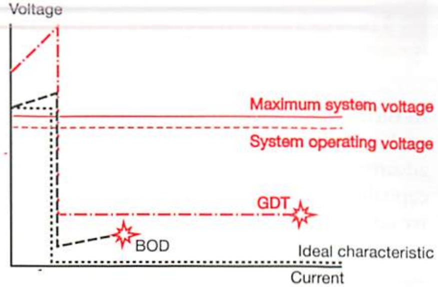


FIGURE 95 – Voltage switching devices

The gas discharge tube (GDT) is an advanced type of spark gap. It usually consists of a pair of electrodes in a glass or ceramic, gas filled package. GDT's can only be obtained for voltages exceeding 90 volts, making them useless on their own for applications much below this level. The turn-on voltage of these devices is characterised by using a slow pulse. As the pulse gets faster (eg a transient) then the characteristic degrades. For example, a GDT rated at say 200 volts, can turn-on at up to 1,000 volts under transient conditions, making it unsuitable for protecting modern electronic equipment, on its own.

Once on, GDT's have 20-30 volts across them, and essentially behave like a short circuit. In this state they are difficult to turn-off, and this precludes their sole use in mains, and power type applications. They can however, handle very high currents.

Breakover diodes (BODs) are thyristor semiconductor devices, which behave much more like the ideal characteristic. They do still have the turn-off problem, and current handling is limited.

Frequency discriminating devices

Filters are an example of frequency discriminating devices. They consist of inductors and capacitors. Inductors behave like an open circuit at high frequency. Capacitors behave like short circuits at high frequency.

The low pass filter is commonly used for RFI mains protection and is sometimes believed to protect against transients. As this device 'gets rid of high frequencies', and transients contain high frequencies, the logic seems reasonable. In fact these devices do not necessarily work.

A standard lightning transient (1.2/50μs) is shown analysed by frequency content in Figure 96. The standard frequency characteristics of a filter are shown in Figure 97. However, Figure 98 shows that if we test the filter with a transient, it actually makes the transient bigger.

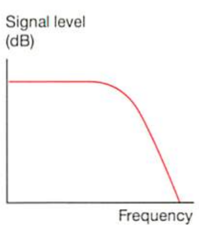


FIGURE 96 – Frequency content of a lightning transient

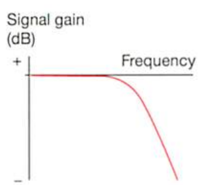


FIGURE 97 – Conventional frequency response of a filter

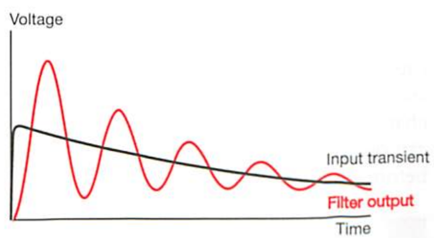


FIGURE 98 – Filter output under transient conditions

operation of systems caused by transients. In power supplies and power conversion equipment, two semiconductor devices are often connected in series across a supply to form the arm of the bridge. The two devices must *never* be on simultaneously. However, transient overvoltages can cause them to trigger at the wrong time, short circuiting the supply, with devastating consequences.

The transient environment

The effects, and the severity of the effects, which transient overvoltages have on electronic systems and their circuitry depends upon:

- the size and frequency of transient overvoltages
- the sensitivity of equipment and its circuitry.

Magnitude and frequency of transient overvoltages

Transient overvoltages (short duration increases in voltage) are surprisingly common. Goedbloed (see References) monitored low voltage mains power supplies for a total of 3,400 hours. He recorded an average of approximately one transient every 8 minutes! A total of nearly 28,000 transient overvoltages.

Fortunately, most of these transients are of a very low level and are unlikely to disturb electronic equipment.

If we look again, but at transients likely to cause disturbance, about 240 were recorded – one disturbance every 14 hours or so!

Most of these will only cause disruption and general nuisance, and unknown degradation of components. In general, the larger the transient overvoltage the worse are its effects (Figure 19).

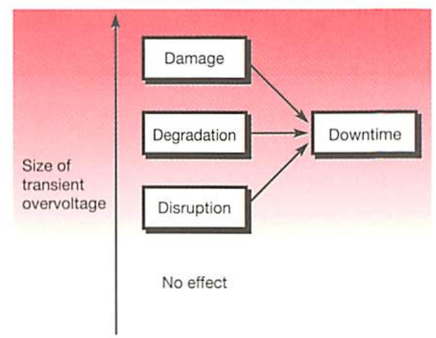


FIGURE 19 – The effects of transient overvoltages

Equipment sensitivity

There is no absolute level of vulnerability which can be applied to all pieces of electronic equipment. Much depends on the sensitivity of differing components and circuit designs. Susceptibility levels will therefore vary with different equipment and manufacturers.

A transient overvoltage sufficient to cause the failure, tripping or lock-up of one piece of equipment, might have no effect on another similar piece of equipment.

The physical damage mechanisms described earlier also depend upon the size of the component or device. As electronics become more advanced and hence smaller, susceptibility grows, increasing sensitivity. Relays have been replaced by transistors, and transistors have been replaced by microchips and microprocessors. Each in turn, less rugged than its predecessor.

Equipment susceptibility levels will become better documented, as EMC standards such as IEC 801-5 are implemented. However, at present the transient susceptibility of particular pieces of equipment can often only be guessed at.

As a general rule **'few solid state devices can tolerate much more than twice their normal rating'** (IEEE 1100-1992, 'The Emerald Book'). A single phase 230 volts power supply has a maximum normal rating of 230V x √2 x 1.1 (10% supply tolerance). This gives us a maximum normal rating of 358 volts and hence susceptibility level of 700 volts or so.

This is of course a rule of thumb only, and should be disregarded where equipment has a known susceptibility level. Ethernet systems, although having a signalling voltage of a few volts, have a susceptibility level of many times this. (ECMA 97 details a minimum susceptibility level of 400 volts for Ethernet communication ports.)

How transient overvoltage protectors work

In order to understand how transient overvoltage protectors work, it is first necessary to understand a little about the components used. All components have their particular advantages and disadvantages, which is why we, at Furse ESP, produce circuits which capitalise upon the strengths of a number of components and eradicate their individual weaknesses.

Protector components

There are three main classes of transient protection components:

- voltage limiting devices
- voltage switching devices
- frequency discriminating devices

Voltage limiting devices

A voltage limiting device will try to hold a transient down to a fixed voltage value. This value is normally chosen to be just above the maximum operating voltage of the system, plus a tolerance.

As more current passes through such devices they lower their resistance in an attempt to keep the voltage constant. The voltage current curve of an ideal device is shown in Figure 94.

Irrespective of what current is applied, the voltage across the device is the same. Two of the commercially available components that exist are the metal oxide varistor (MOV) and the transient voltage suppressor diode.

MOV's are three dimensional structures consisting of many pellets of material that are pressed together. The interface between any two pellets of material forms a semiconductor junction. The number of individual junctions determines what voltage the device is rated for. The overall size of the device determines its current handling capacity.

Although the MOV is able to handle large currents and operates very quickly, its characteristic differs from the ideal. See Figure 94.

The transient voltage suppressor diode is a ruggedised version of the zener diode, with an enlarged semiconductor junction. Its characteristic is close to the ideal, but they can only handle a relatively low current before destruction (Figure 94).

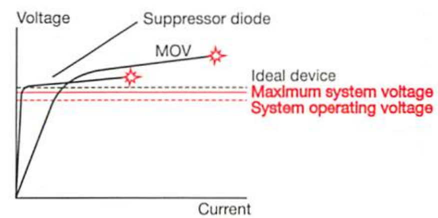


FIGURE 94 – Voltage limiting devices

Voltage switching devices

These devices operate by suddenly switching to a low resistance state at a certain threshold voltage, above the maximum operating voltage of the supply (see Figure 95).

100kHz ± 20kHz, is 'calculated from the first and third zero-crossing after the initial peak'. The ratio between the peak open circuit voltage and the peak short circuit current is 12 for Location Category B environments and 30 for Location Category A environments: that is 6kV, 500A for Location Category B and 6kV, 200A for Location Category A.

Testing equipment

These standardised waveforms can be used either to test protectors for performance or equipment for vulnerability. The test waveform is produced using an impulse (or 'surge') generator.

Figure 92 shows a typical impulse generator. Within the generator there is a high voltage capacitor, which acts as a store of energy. This will be charged up to the required voltage prior to the test. The capacitor is connected to the test sample via a shaping network, in order to produce the standardised waveform.

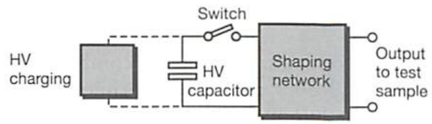


FIGURE 92 – Typical impulse generator

Monitoring equipment, usually a high speed oscilloscope or recorder, is used to observe voltages and currents. The experimental set-up must be carefully designed, in order to avoid noise and interference from the generator.

If testing is to be conducted on a working mains power supply, the generator must be connected to the power supply through a coupling network (see Figure 93). This allows the transient overvoltage onto the mains supply, but not the mains into the generator. Additionally, a back filter should be installed to prevent the transient feeding back into the building housing the test set-up.

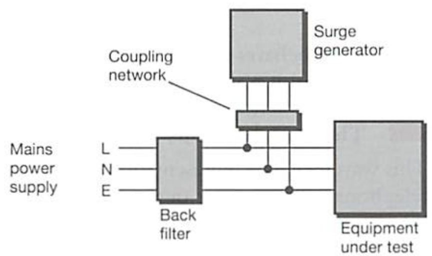


FIGURE 93 – Test set-up for equipment on a working mains power supply

Similar techniques are used to conduct transient testing on working data communication, signal or telephone lines.

Is protection required?

Why protect?

This decision is heavily influenced by the users assessment of the importance of the electronic systems in question. Consider:

- the cost of replacing damaged equipment
- the cost of repair work, especially for remote or unmanned installations
- the cost of lost or destroyed data
- the financial implications of extended stoppages – sales lost to competitors, lost production, deterioration or spoilage of work in progress
- potential health and safety hazards caused by plant instability, after loss of control
- the need to safeguard the operation of fire alarms, security systems, building management systems and other essential services
- the need to minimise fire risks and electric shock hazards.

Thus, the decision whether and what to protect, will be heavily influenced by the associated costs of repair and the criticality of system operation. However, where uncertainty exists a risk assessment may prove helpful. BS 6651:1992 outlines the basis upon which the risk of lightning disruption to electronic equipment can be calculated.

Risk assessment

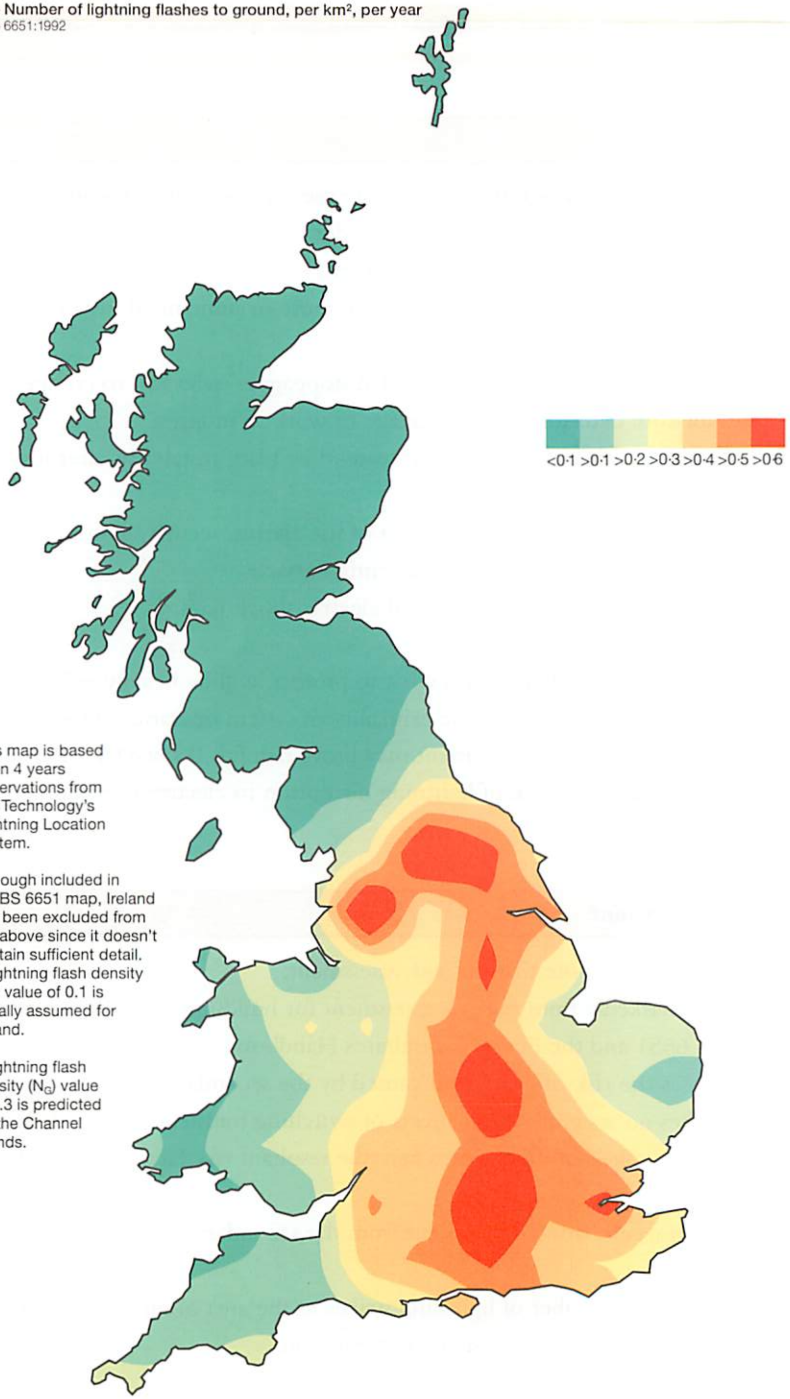
It is important to note that this risk assessment:

- differs markedly from the risk assessment for buildings and structures contained in BS 6651 and the Furse 'Consultants Handbook'
- addresses the risk of disruption caused by the secondary effects of lightning only – it takes no account of the affects of switching transients. Particular note should be taken of this point where the resultant risk factor is borderline.

The threat to electronic equipment from the secondary effects of lightning depends upon:

- the probable number of lightning strikes to the area of influence, and
- the vulnerability of the system configuration.

FIGURE 20 – Number of lightning flashes to ground, per km², per year
Derived from BS 6651:1992



Note 1. This map is based upon 4 years observations from E A Technology's Lightning Location System.

Note 2. Although included in the BS 6651 map, Ireland has been excluded from the above since it doesn't contain sufficient detail. A lightning flash density (N_G) value of 0.1 is usually assumed for Ireland.

Note 3. A lightning flash density (N_G) value of 0.3 is predicted for the Channel Islands.

The 1.2/50μs waveform

This is a voltage waveform used for sparkover testing or for impulse testing devices which are normally non-conducting. Originally it was developed for use in high voltage overhead line work. Its definition is given in Figure 89.

The 8/20μs waveform

This is a current waveform and this also has its origins in high voltage testing, where it was used for devices which did not sparkover, but conducted, (see Figure 89).

The combination or hybrid wave

The difficulty with the above tests is in knowing which one to apply – will the device under test sparkover or not?

To overcome this problem the combination wave generator was developed. This produces both a 1.2/50μs voltage waveform on open circuit and a 8/20μs current waveform on short circuit. It automatically applies the correct stress to the device under test.

BS 6651:1992 proposes the use of a 6kV 1.2/50μs, 3kA 8/20μs generator, as do IEEE C62.41-1991, UL 1449, and AS 1768-1991 amongst others. The draft IEC 801-5 also proposes this type of combination wave, but with peak values of 4kV and 2kA.

As a simplification the 6kV, 3kA combination wave generator can be thought of as a 6,000 volt battery, with a 2 ohms series resistance (see Figure 90). 6kV is seen on open circuit and 3kA on short circuit.

Although it behaves in this manner, the generator, unlike the battery, does not really have 2 ohms resistance.

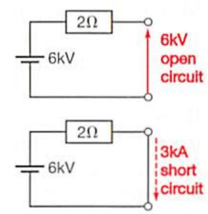


FIGURE 90 – 3kA, 6kV combination wave generator

The 5kV 10/700μs waveform

This waveform is a representation of transient overvoltages on telephone systems and is outlined in CCITT IX K17. It has subsequently been adopted by a number of standards, including BS 6651:1992 and IEC 801-5 (draft). Unlike most other test waves, its shape is not rigorously defined. It is defined by the circuit required to produce the waveform and its short circuit current of 125 amps.

The 0.5μs – 100kHz ring wave

Unlike all of the above waveforms this one is oscillating in nature (see Figure 91). It was originally outlined in IEEE 587 (1987), the predecessor to IEEE C62.41. However, difficulties with the definition resulted in erratic test results.

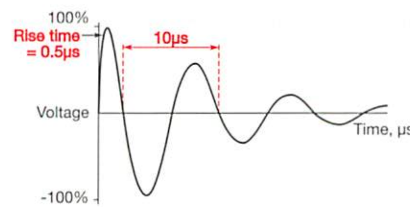


FIGURE 91 – The 0.5μs – 100kHz ring wave
Reproduced from IEEE C62.41

IEEE C62.41-1991 has clarified the definition of the ring wave. The rise time of 0.5μs ± 0.15μs, is defined as 'the time difference between the 10% and 90% amplitude points on the leading edge of the waveform'. Its decay is defined not by time but by the reduction in size of subsequent peaks, such that the second peak is between 40% and 110% of the first peak and all other peaks are 60% of the preceding peak. The frequency of

Transient overvoltage simulation and testing

To enable reliable and repeatable testing, a number of standardised transient overvoltage waveforms are used. Although these may differ from actual transient overvoltages, the standardised forms are based upon years of observation and measurement, and generally provide a fair approximation of the real world transient.

The transient waveform

Transient waveforms have a fast rising edge and a longer tail. They are described through their peak value (or magnitude), rise time, and their duration (or fall time). Its duration is measured as the time taken for the test transient to decay to half its peak value. Figure 88 shows this – for simplicity this has been drawn with straight lines. Both the voltage and the current of the test waveform are described in this way.

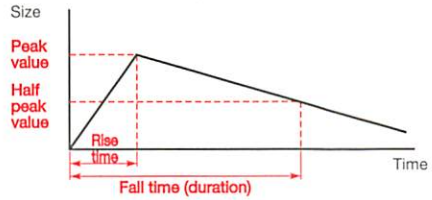
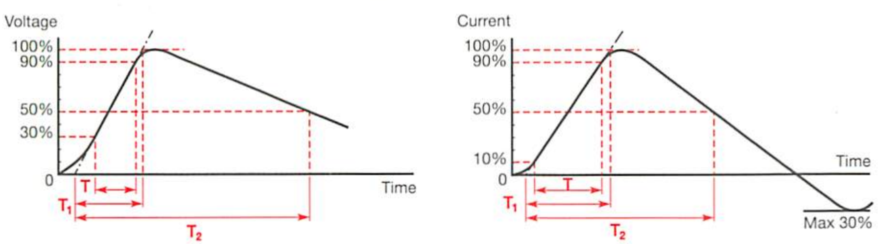


FIGURE 88 – The transient waveform

A test transient overvoltage which is described as 6kV 1.2/50µs, therefore has a peak voltage of 6,000 volts. This peak value is reached in 1.2 microseconds and it lasts for (ie decays to half its peak value in) 50 microseconds.

In practice there are a number of commonly used transient overvoltage test waveforms.

FIGURE 89 – Definition of 1.2/50µs voltage and 8/20µs current waveforms



Definitions of the waveform parameters	In accordance with BS 923:Part 2		In accordance with BS 5698:Part 1	
	Front time	Time to half value	Rise time (10% to 90%)	Duration (50% to 50%)
Open circuit voltage	1.2µs	50µs	1µs	50µs
Short circuit current	8µs	20µs	6.4µs	16µs

Note. The BS 923 definition is the more commonly used, although both are valid for BS 6651:1992. Reproduced from BS 6651:1992.

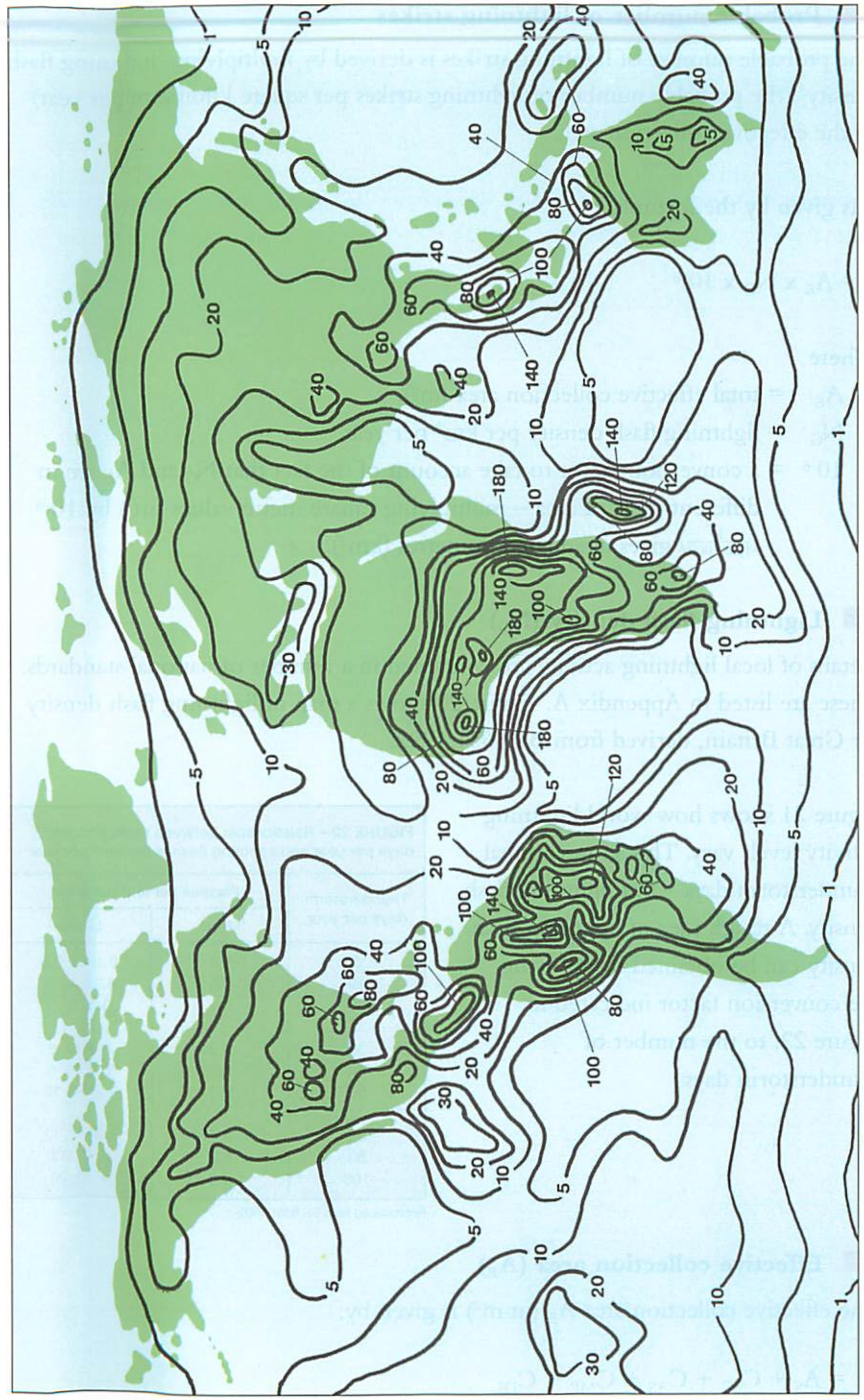


FIGURE 21 – Map showing thunderstorm days per year throughout the world (based on World Meteorological records for 1955)

Probable number of lightning strikes

The probable number of lightning strikes is derived by multiplying 'lightning flash density' (the probable number of lightning strikes per square kilometre per year) by the effective collection area.

It is given by the formula:

$P = A_E \times N_G \times 10^{-6}$

Where

A_E = total effective collection area (m^2).

N_G = lightning flash density per km^2 per year.

10^{-6} = a conversion factor to take account of the fact that N_G and A_E are in different units of area – multiplying square metre values (m^2) by 10^{-6} ($\frac{1}{1,000,000}$) gives us square kilometres (km^2).

Lightning flash density (N_G)

Details of local lightning activity are contained in a number of national standards. These are listed in Appendix A. Figure 20 shows a map of lightning flash density for Great Britain, derived from BS 6651:1992.

Figure 21 shows how world lightning activity levels vary. This shows annual thunderstorm days – not lightning flash density. A rough idea of lightning flash density can be obtained by applying the conversion factor indicated in Figure 22, to the number of thunderstorm days.

FIGURE 22 – Relationship between thunderstorm days per year and lightning flashes per km² per year

Thunderstorm days per year	Flashes per km² per year	
	Mean	Limits
5	0.2	0.1 to 0.5
10	0.5	0.15 to 1
20	1.1	0.3 to 3
30	1.9	0.6 to 5
40	2.8	0.8 to 8
50	3.7	1.2 to 10
60	4.7	1.8 to 12
80	6.9	3 to 17
100	9.2	4 to 20

Reproduced from BS 6651:1992

Effective collection area (A_E)

The effective collection area A_E (in m^2) is given by:

$A_E = A_S + C_{SG} + C_{AS} + C_{MP} + C_{DL}$

2 x D x L and L has very conservatively been assumed to be 250m. Giving:
$C_{DL} = (2 \times D \times L_1) + (2 \times D \times L_2)$
$C_{DL} = (2 \times 100m \times 1,000m) + (2 \times 100m \times 250m)$
$C_{DL} = 200,000m^2 + 50,000m^2$
$C_{DL} = 250,000m^2$

The total collection area (A_E) is thus:
$A_E = (A_S + C_{SG} + C_{AS}) + C_{MP} + C_{DL}$
$= 114,800m^2 + 70,000m^2 + 250,000m^2$
$= 434,800m^2$

Probable lightning strikes

The probable number of lightning strikes (P) is given by:
$P = A_E \times N_G \times 10^{-6}$
$P = 434,800m^2 \times 0.3 \times 10^{-6}$
$P = 0.130$

Weighting factors

This is combined with weighting factors for the type of structure (F), its degree of isolation (G) and the type of terrain (H), to arrive at the overall risk. These can be derived from Figures 26, 27 and 28. The buildings have structural lightning protection to BS 6651, giving F=1. The plant is isolated from surrounding structures, giving G=2 and is on flat ground giving H=0.3.

Overall risk

The overall risk is obtained from:
$R = P \times F \times G \times H$
$R = 0.130 \times 1 \times 2 \times 0.3$
$R = 0.078$

1÷R (=12.8) tells us that there will be an average of 13 years between transient overvoltages caused by lightning.

Exposure level

The risk value R can also be used to indicate the classification of exposure level, or type of protector required. The plants critical processes and the possible environmental consequences of a loss of plant control indicate a consequential loss rating of 4. See Figure 29.

By looking at Figure 30 we can see that a high exposure level protector is required.

The telephone service is provided by a single incoming cable to an office building, from where it is routed around the site. Also, the site is criss-crossed by a plethora of signal lines to instrumentation and process control systems.

All the buildings and structures have structural lightning protection to BS 6651. The plant is located on a flat estuary site in Teesside and is situated away from trees and other structures.

The risk assessment which follows, considers the plant as a whole. However, if required, one could alternatively calculate a separate risk for each building or structure.

We begin by calculating P, the probable number of lightning strikes (lightning flash density multiplied by the effective collection area).

Lightning flash density

From the Figure 20 map, we can see that the lightning flash density (N_G) for the site is 0.3.

Effective collection area

The collection area of the main buildings', their surrounding ground and that of the associated structures ($A_S + C_{SG} + C_{AS}$) can be calculated together, using a simple approximation. The overall collection area extends D metres around the structures, where D is equal to the soil resistivity value. Since this is not known, a soil resistivity value of 100Ωm is assumed, giving D=100m. This can be seen on Figure 87. Interestingly, this collection area approximates to a rectangle of 280m by 410m, giving:

$A_S + C_{SG} + C_{AS}$ = 280m x 410m

$A_S + C_{SG} + C_{AS}$ = 114,800m²

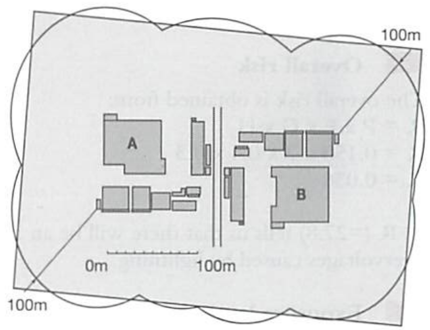


FIGURE 87 – The plant's collection area approximates to that of a 280m x 410m rectangle

The collection area of mains power supplies. The collection area of each of the two incoming mains power supplies (high voltage underground cable to an on-site transformer) is given in Figure 24, as 0.1 x D x L. Since L, the length of the cable is not known, 1,000m must be used. The power supply to other buildings is distributed through a low voltage underground power duct – one from building A and one from building B. Again the collection area of each of these is given in Figure 24, as 2 x D x L. We have conservatively assumed each of these to have a total length of 125m. This gives:

$C_{MP} = (0.1 \times D \times L_1) + (0.1 \times D \times L_1) + (2 \times D \times L_2) + (2 \times D \times L_2)$

C_{MP} = (0.1 x 100m x 1,000m) + (0.1 x 100m x 1,000m) + (2 x 100m x 125m) + (2 x 100m x 125m)

C_{MP} = 10,000m² + 10,000m² + 25,000m² + 25,000m²

C_{MP} = 70,000m²

The collection area of data lines. The collection area of the incoming underground telephone service is given by Figure 25 as 2 x D x L. Since its length, L, is not known, a maximum value of 1,000m should be used. Within the site, telephone and signal lines are assumed to be routed through an underground duct. Its collection area is also given by

where

A_S = the plan area of the structure (m²).

C_{SG} = the collection area of the surrounding ground (m²).

C_{AS} = the collection area of adjacent associated structures and their surrounding ground (m²).

C_{MP} = the collection area of incoming/outgoing mains power supplies (m²).

C_{DL} = the collection area of data lines leaving the earth reference of the building (m²).

Thus the overall collection area has a number of constituent elements, which we will consider separately.

Plan area of the structure (A_S). This is often a simple length by width calculation, requiring little further explanation. In practice this is often calculated together with the collection area of the surrounding ground (C_{SG}) – as in the sample calculations given in Appendix B.

Collection area of the surrounding ground (C_{SG}). Section 1 described how lightning strikes to earth or structures cause large local increases in earth potential. The affect of a nearby ground strike on a building's earth potential will diminish the further this strike is from the building. Thus, beyond a certain distance a ground strike will not significantly increase the building's earth potential. This is the collection distance D, measured in metres.

The distance D should be taken to be numerically equal to the soil resistivity value – up to a maximum value of D = 500m for a soil resistivity of 500Ωm or more. Where the soil resistivity is not known, a typical 100Ωm resistivity soil should be assumed giving D = 100m.

The collection area of the surrounding ground is an area extending D metres all around the building. Figure 23 shows this area for a rectangular building.

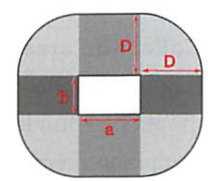


FIGURE 23 – The collection area of the surrounding ground for a rectangular building

This area is therefore calculated as follows:

$$C_{SG} = 2\,(a \times D) + 2\,(b \times D) + \pi D^2$$

Note, the four quarter circle areas have been combined to give a circular area which can be calculated using πr^2 where the radius, r, is equal to D.

If the structures height (h) exceeds D, the collection distance is assumed to be h.

Where a complex shaped building is being assessed, approximations and rough graphical methods will allow the area to be calculated with sufficient accuracy.

Collection area of adjacent associated structures and their surrounding ground (C_{AS}). Where there is a direct or indirect electrical connection to an adjacent structure, the collection area of this structure should be taken into account. Typical examples are lighting towers (supplied from the main building), radio transmission towers and other buildings with computer control and instrumentation equipment.

Structures within a distance of 2D from the main building are considered to be adjacent. As before, the collection area is calculated as the area of the structure plus the area extending D metres all around the building. Once again if the height of the structure h, exceeds D, the collection distance is assumed to be h. Any part of this area which falls within the collection area of the main structure (C_{SG}) should be disregarded.

Collection area of incoming/outgoing mains power supplies (C_{MP}). The effective collection areas of all incoming and outgoing power supplies should be considered. This includes outgoing supplies to neighbouring buildings, CCTV equipment, lighting towers, remote equipment and the like.

The effective collection areas of different types of mains power supplies are shown in Figure 24.

Collection area of data lines leaving the earth reference of the building (C_{DL}). The effective collection areas of all incoming and outgoing data lines should be considered. This includes data lines to other buildings, security equipment, remote data logging equipment etc.

The effective collection areas of different types of data lines are shown in Figure 25.

The total collection area (A_E) is hence:
$A_E = (A_S + C_{SG}) + C_{MP} + C_{DL}$
$= 70{,}686m^2 + 30{,}000m^2 + 200{,}000m^2$
$= 300{,}686m^2$

Probable lightning strikes

The probable number of lightning strikes (P) is given by:
$P = A_E \times N_G \times 10^{-6}$
$P = 300{,}686m^2 \times 0.5 \times 10^{-6}$
$P = 0.150$

Weighting factors

This is combined with weighting factors for the type of structure (F), its degree of isolation (G) and the type of terrain (H), to arrive at the overall risk. These can be derived from Figures 26, 27 and 28. Although the building has structural lightning protection to BS 6651, at over 100m in height equipotential bonding may be difficult to achieve, giving F=2. The building is located amongst others of a similar height and so G=0.4. The area is flat, giving H=0.3.

Overall risk

The overall risk is obtained from:
$R = P \times F \times G \times H$
$R = 0.150 \times 2 \times 0.4 \times 0.3$
$R = 0.036$

$1 \div R$ (=27.8) tells us that there will be an average of 28 years between transient overvoltages caused by lightning.

Exposure level

The risk value R can also be used to indicate the classification of exposure level, or type of protector required (Figure 29). The activities carried out within the building are vital to the company and a major loss of computing systems would cripple its operations. The company propose a consequential loss rating of 4. By looking at Figure 30 we can see that a high exposure level protector is required.

Example 4 – A process plant

A process plant consists of two main manufacturing buildings (A&B), each with many smaller associated buildings and storage structures. The exact dimensions of the buildings' and structures' are not known, however none are more than 15m high. See Figure 86. Pipework (not shown) connects many of the buildings. Buildings A and B each contain an on-site transformer, which is supplied by an 11kV underground power supply. From here, power is distributed within the building and outside to its associated structures.

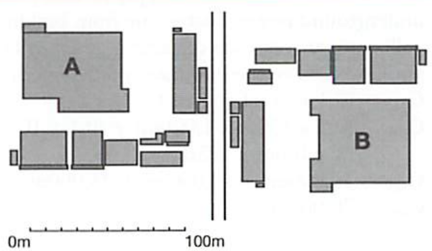


FIGURE 86 – Plan view of process plant

We must first calculate P, the probable number of lightning strikes (lightning flash density multiplied by the effective collection area).

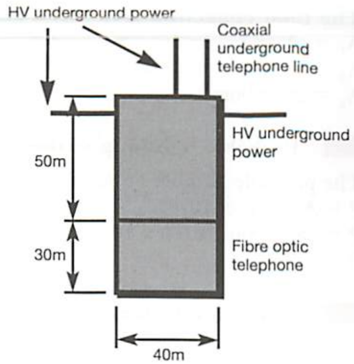


FIGURE 83 – Plan view of office block

Lightning flash density

From the Figure 20 map, we can see that the lightning flash density (N_G) for this part of London is 0.5.

Effective collection area

The collection area of the building and its surrounding ground $A_S + C_{SG}$ (NB there are no electrically connected associated structures), can be calculated using a very simple method. The area of the building is known. The collection area of the surrounding ground extends D metres around the structure, where D is equal to the soil resistivity value. Since this is not known, a soil resistivity value of 100Ωm is assumed, giving D = 100m. However, we also know that where the height (h) of the building exceeds D, that this value should be substituted for D. Thus, for the tower block part of the building the collection area extends 120m around and for the rest of the building the collection area extends 100m around. Figure 84 shows this. Interestingly, this collection area approximates to a circle of 150m radius (see Figure 85). The area of a circle is given by πr^2 (where r = radius), giving

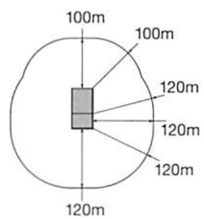


FIGURE 84 – Collection area of office block

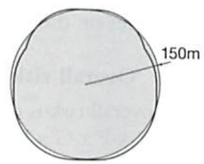


FIGURE 85 – The collection area is approximately equal to that of a circle of 150m radius

$A_S + C_{SG} = \pi\ 150^2$
$A_S + C_{SG} = 70{,}686\text{m}^2$

The collection area of each of the three incoming mains power supplies (high voltage underground cable to an on-site transformer) is given in Figure 24, as 0.1 x D x L. Since L, the length of the cable is not known, a value of 1,000m must be assumed. This gives:

C_{MP} = (0.1 x D x L) + (0.1 x D x L) + (0.1 x D x L)
= (0.1 x 100m x 1,000m) + (0.1 x 100m + 1,000m) + (0.1 x 100m x 1,000m)
= 10,000m² + 10,000m² + 10,000m²
= 30,000m²

The collection area of data lines. The collection area of the fibre optic cable is given by Figure 25 as 0. The collection area for the underground coaxial cable is given as 2 x D x L, by Figure 25. Since its length is not known, 1,000m should be used. This gives a collection area for data lines (C_{DL}) of:

C_{DL} = (2 x D x L) + 0
= 2 x 100m x 1,000m
= 200,000m²

FIGURE 24 – Effective collection area of incoming/outgoing power supplies	
Type of mains service	Effective collection area (m²)
Low voltage overhead cable	10 x D x L
High voltage overhead cable (to on-site transformer)	4 x D x L
Low voltage underground cable	2 x D x L
High voltage underground cable (to on-site transformer)	0.1 x D x L

Reproduced from BS 6651:1992

Note 1. D is the collection distance in metres. Under no circumstances should h be used in place of D.

Note 2. L is the length, in metres, of the power cable up to a maximum value of 1,000m. If the value of L is unknown 1,000m should be used.

Note 3. Where there is more than one power line/cable, they should be considered separately and the collection areas summated. Multicore cables are treated as a single cable and not as individual circuits.

FIGURE 25 – Effective collection area of incoming/outgoing data lines	
Type of data line	Effective collection area (m²)
Overhead signal line	10 x D x L
Underground signal line	2 x D x L
Fibre optic cable without a conductive metallic shield or core	0

Reproduced from BS 6651:1992

Note 1. D is the collection distance in metres. Under no circumstances should h be used in place of D.

Note 2. L is the length, in metres, of the data line up to a maximum value of 1,000m. If the value of L is unknown 1,000m should be used.

Note 3. Fibre optic is a non conductive means of data transmission. It therefore has a collection area of zero.

Note 4. Where there is more than one data line/cable, they should be considered separately and the collection areas summated. Multicore cables are treated as a single cable and not as individual circuits.

Vulnerability of system configuration

The overall risk to electronic equipment from the secondary effects of lightning will therefore depend upon P (the probability of a strike) and:

- the type of structure (F)
- the degree of isolation (G)
- the type of terrain (H).

Weighting factors based upon the relative degrees of risk are assigned for F, G and H in Figures 26, 27 & 28 respectively.

FIGURE 26 – Type of structure (Factor F)	
Structure classification	Value of F
Buildings with lightning protection and equipotential bonding to BS 6651	1
Buildings with lightning protection and equipotential bonding to CP 326	1.2
Buildings where equipotential bonding for electrical or electronic equipment may be difficult (eg buildings over 100m long)	2.0

Reproduced from BS 6651:1992

FIGURE 27 – Degree of isolation (Factor G)	
Degree of isolation	Value of G
Structure located in a large area of structures or trees of the same or greater height (eg in a large town or forest)	0.4
Structure located in an area with few other structures or trees of similar height	1.0
Structure completely isolated or exceeding at least twice the height of surrounding structures of trees	2.0

Reproduced from BS 6651:1992

FIGURE 28 – Type of terrain (Factor H)

Type of country (or terrain)	Value of H
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300m and 900m	1.3
Mountain country above 900m	1.7

Reproduced from BS 6651:1992

Calculation of overall risk

We described earlier how the threat to electronic equipment from the secondary effects of lightning depends upon:

- the probable number of lightning strikes to the area of influence, and
- the vulnerability of the system configuration.

We have now seen how the former can be calculated from $P = A_E \times N_G \times 10^{-6}$ and how the latter is given by the weighting factors F, G, and H.

Thus, the risk (R) of a lightning strike coupling into electrical or electronic systems through incoming/outgoing mains power supplies or data lines is:

$R = P \times F \times G \times H$

The average number of years between transient overvoltages caused by lightning is given by 1÷R.

It should be noted that average values such as these are based on periods of many years.

This risk assessment (R) is intended only to guide the users protection decision. Both the commercial impact of systems damage and downtime and the health and safety implications should be considered. These factors are outlined in detail at the beginning of Section 3. Often the decision to protect will be based upon a simple comparison of:

- the cost of damage and downtime to computers and plant systems, with
- the cost of protection and prevention.

Protector exposure levels

This risk assessment can also be used to indicate the type of protector required at different types of installation.

BS 6651 provides a four tier classification of installations, based upon the

The total collection area (A_E) is thus:
$A_E = (A_S + C_{SG} + C_{AS}) + C_{MP} + C_{AB+SH} + C_{DL}$
$A_E = 57{,}600m^2 + 21{,}200m^2 + 5{,}000m^2 + 200{,}000m^2$
$A_E = 283{,}800m^2$

Probable lightning strikes

The probable number of lightning strikes (P) is given by:
$P = A_E \times N_G \times 10^{-6}$
$P = 283{,}800m^2 \times 0.6 \times 10^{-6}$
$P = 0.170$

Weighting factors

This is combined with weighting factors for the type of structure (F), its degree of isolation (G) and the type of terrain (H) to arrive at the overall risk. These can be derived from Figures 26, 27 and 28. The warehouse and the administration building have structural lightning protection to BS 6651, giving F=1. The warehouse is bigger than neighbouring structures on the industrial estate, giving G = 1. The terrain is flat, giving H=0.3.

Overall risk

The overall risk is obtained from
$R = P \times F \times G \times H$
$R = 0.170 \times 1 \times 1 \times 0.3$
$R = 0.051$

1÷R (= 19.6) tells us that there will be an average of 19½ years between transient overvoltages caused by lightning.

Exposure level

The risk value R can also be used to indicate the classification of exposure level, or type of protector required. The warehouse operation would be significantly disrupted through the loss of its computer systems. This suggests a consequential loss rating of 2 or 3 (see Figure 29), depending on the severity of the financial loss associated with the downtime.

By looking at Figure 30 we can see that medium or high exposure level protectors are required, depending on the financial implications and risks associated with computer and security system downtime. As the site is in an industrial area, switching transients may well occur. It would therefore be prudent to use mains power protectors rated for a high exposure level.

Example 3 – City centre offices

Corporate offices in London are in a building with a maximum height of 120m and a 40m x 80m area (see Figure 82). It has three incoming power supplies, all from 11kV underground cables. The telephone service is provided by a fibre optic cable and also by an underground coaxial cable. The building has structural lightning protection, is on flattish ground and amongst other tall buildings. Figure 83 shows a plan view of the building.

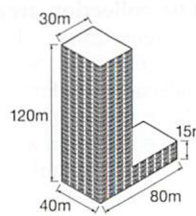


FIGURE 82 – City offices

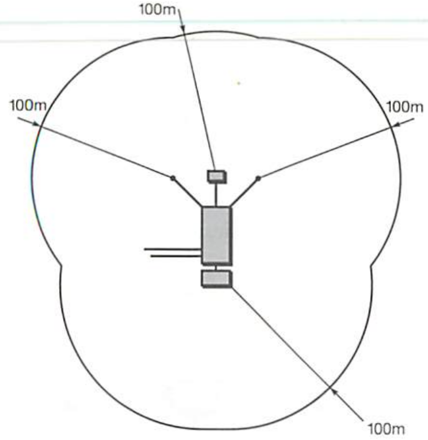


FIGURE 80 – Collection area of warehouse site

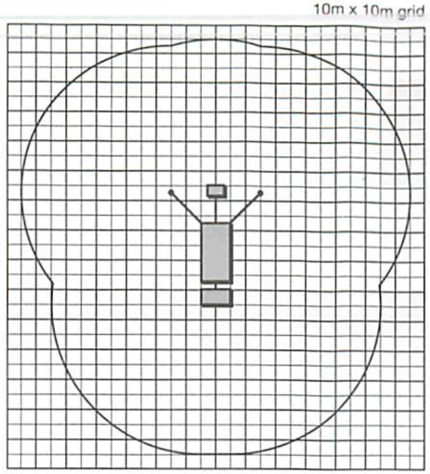


FIGURE 81 – Area can be calculated by counting the squares

The collection area of separate mains power supplies. The collection area of the incoming mains supply (a high voltage underground cable to an on-site transformer) is given in Figure 25 as 0.1 x D x L. Since L, the length of the cable, is not known, a value of 1,000m must be assumed. The collection area of the outgoing supplies to the lighting masts, must also be calculated. These low voltage underground cables, each have a collection area of 2 x D x L, from Figure 24 (the collection areas of the supplies to the administration building and the security hut are considered below). This gives:

$C_{MP} = (0.1 \times D \times L_1) + (2 \times D \times L_2) + (2 \times D \times L_2)$
$= (0.1 \times 100m \times 1,000m) + (2 \times 100m \times 28m) + (2 \times 100m \times 28m)$
$= 10,000m^2 + 5,600m^2 + 5,600m^2$
$= 21,200m^2$

The collection area of between-building services. The power supplies to the administration building and to the security hut, share the same ducting as the telephone and data communication lines to these buildings. Thus, each duct will behave like a single cable. It can be seen from Figures 24 & 25 that underground low voltage power cables have the same collection area, as underground data or signal lines. This is given by 2 x D x L. The collection area of the cabling to the administration building (AB) and the security hut (SH) is:

$C_{AB+SH} = (2 \times D \times L_1) + (2 \times D \times L_2)$
$= (2 \times 100m \times 5) + (2 \times 100m \times 20m)$
$= 1,000m^2 + 4,000m^2$
$= 5,000m^2$

The collection area for the incoming underground telephone service (C_{DL}) is given by Figure 25. Since, its length is not known, 1,000m should be used.

$C_{DL} = 2 \times D \times L$
$= 2 \times 100m \times 1,000m$
$= 200,000m^2$

consequential effects of damage to the installation's contents. This is shown in Figure 29.

It is interesting to note that this consequential loss rating is almost entirely based upon financial losses (unlike the assessment for structures, which is based upon the risk to life). Transient overvoltages pose less of a threat to life, than direct lightning strikes. However, there are circumstances in which damage to electronic equipment can pose a threat to life:

- damage to control systems at nuclear or chemical plants could allow the escape of toxic material
- disruption or damage of essential hospital equipment (eg life support systems)
- loss of communication systems can delay fire and ambulance services
- the failure or erratic operation of certain industrial systems (eg robots) can endanger operator safety.

FIGURE 29 – Classification of structures and contents

Structure usage and consequential effects of damage to contents	Consequential loss rating
Domestic dwellings and structures with electronic equipment of low value and small cost penalty due to loss of operation	1
Commercial or industrial buildings with essential computer data processing, where equipment damage and downtime could cause significant disruption	2
Commercial or industrial applications where loss of data or computer process control could have severe financial costs	3
Highly critical processes where loss of plant control or computer operation may lead to severe environmental or human cost (eg nuclear plant, chemical works, etc)	4

Reproduced from BS 6651:1992

Note. The examples of structure usage are only intended to give greater meaning to the descriptions of consequential effect, they should not be seen as binding.

Threats to life such as these would all necessitate a maximum consequential loss rating.

In most cases however, the loss is a financial one; the cost of repairing damaged electronic hardware plus the knock-on, consequential costs. These costs may already have been detailed as part of the company's overall disaster recovery plan. If not they can be roughly calculated. The replacement cost of susceptible equipment will be known and for most businesses the cost of lost production or business revenue, can be estimated.

These costs, particularly the consequential ones, can be frighteningly high. This can cause companies to apply a higher consequential loss rating to their business than that indicated in BS 6651's consequential loss framework (Figure 29).

Combining together the risk (R) with the consequential loss rating we can determine the exposure level for which transient overvoltage protectors should be designed (see Figure 30).

FIGURE 30 – Classification of exposure level

Consequential loss rating	Exposure level : R =			
	< 0.005	0.005 – 0.0499	0.05 – 0.499	> 0.5
1	Negligible	Negligible	Low	Medium
2	Negligible	Low	Medium	High
3	Low	Medium	High	High
4	Medium	High	High	High

Reproduced from BS 6651:1992

Note. Where the exposure level is negligible protection is not normally necessary.

These exposure level categories are based on a lightning risk assessment only. Where transients of other cause are likely to be present, you should consider upgrading protectors. Mains power supplies are also susceptible to switching transients. Where the presence of switching transients is anticipated, a protector from the next highest exposure level should be used (unless a high exposure level protector is already required). Protector exposure levels are explained in greater detail in Section 6.

Sample risk calculations

Sample risk assessments for a range of different types of site can be found in Appendix B.

1÷R (=17.9) tells us that there will be an average of 18 years between transient overvoltages caused by lightning.

Exposure level

The risk value R can also be used to indicate the classification of exposure level, or type of protector required. The farm is essentially domestic in nature and its electronic equipment is low in value, suggesting a consequential loss rating of 1 (see Figure 29).

From Figure 30 we can see that a low exposure level protector is indicated.

Example 2 – Small industrial site

A warehousing operation on a Manchester industrial estate consists of the warehouse (12m high with a 20m x 40m area), an administration building (6m high, 20m x 10m area) and a security hut (3m high, 10m x 5m area). The incoming power supply is from an 11kV underground cable to a transformer in the warehouse. Two underground, 240V supplies leave the warehouse to 12m high lighting masts, each 28m away. Power, telephone and security cables are routed in an underground duct to the security hut, 20m away. Similarly, power, telephone and computer cabling is routed in an underground duct to the neighbouring administration building, 5m away. A single 60 core, underground cable provides the incoming telephone service. The soil resistivity of the site is unknown but assumed to be 100Ωm. Figure 79 shows a plan view of the site.

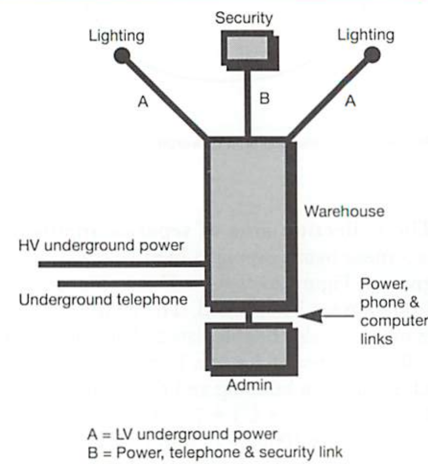


FIGURE 79 – Plan view of warehouse

We begin by calculating P, the probable number of lightning strikes (lightning flash density multiplied by the effective collection area).

Lightning flash density

From the Figure 20 map, we can see that the lightning flash density (N_G) for the site = 0.6.

Effective collection area

The collection areas of the buildings' and their surrounding ground ($A_S + C_{SG} + C_{AS}$) can be calculated together, using a simplified method. The layout of the site and the areas of the buildings' are known. The collection area of the surrounding ground extends D metres around each structure, and this includes the two lighting masts. D is equal to the soil resistivity value, which is known to be 100Ωm (D=100m). Figure 80 shows this collection area. This area can easily be calculated using a 'counting the squares' method (see Figure 81). This gives us $A_S + C_{SG} + C_{AS}$ = 57,600m^2.

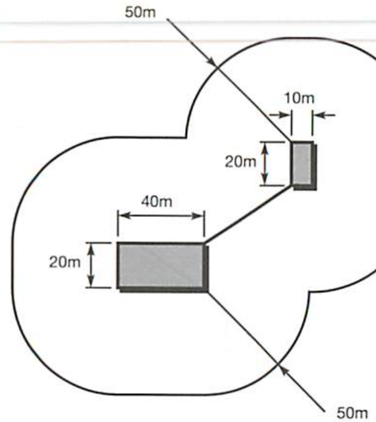


FIGURE 77 – Collection area of farm site

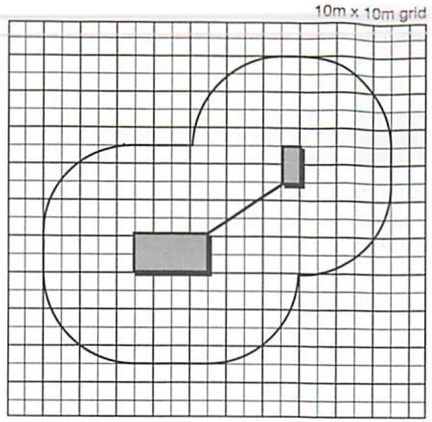


FIGURE 78 – Area can be calculated by counting the squares

The collection area for data lines (or in this case telephone lines) leaving the building's earth reference (C_{DL}), is given in Figure 25. The telephone service is supplied by overhead line, giving it a value of 10 x D x L. Where, as in this case, its length (L) is not known, 1,000m must be assumed.

$C_{DL} = 10 \times D \times L$
$C_{DL} = 10 \times 50m \times 1{,}000m$
$C_{DL} = 500{,}000m^2$

The total collection area (A_E) is therefore:

$A_E = (A_S + C_{SG} + C_{AS}) + C_{MP} + C_{DL}$
$A_E = 22{,}600m^2 + 105{,}000m^2 + 500{,}000m^2$
$A_E = 627{,}600m^2$

Probable lightning strikes

The probable number of lightning strikes (P) is given by:

$P = A_E \times N_G \times 10^{-6}$
$P = 627{,}600m^2 \times 0.3 \times 10^{-6}$
$P = 0.188$

Weighting factors

This is combined with weighting factors for the type of structure (F), its degree of isolation (G) and the type of terrain (H), to arrive at the overall risk. These can be derived from Figures 26, 27 and 28. The buildings have structural lightning protection to BS 6651, giving F=1. Although isolated from other buildings, the farm has a few trees of similar height close to it, giving G=1. The flat terrain gives H=0.3.

Overall risk

The overall risk is obtained from

$R = P \times F \times G \times H$
$R = 0.188 \times 1 \times 1 \times 0.3$
$R = 0.056$

Protection techniques and basic considerations

There are several techniques which can be used to minimise the lightning threat to electronic systems. Like all security measures, they should wherever possible, be viewed as cumulative and not as a list of alternatives.

The use of transient overvoltage protectors is covered in detail in Section 5. Although best incorporated at the project design stage, transient overvoltage protectors can also be readily installed at existing installations.

BS 6651:1992 describes a number of other measures to minimise the severity of transient overvoltages caused by lightning. These tend to be of greatest practical relevance for new installations. These measures are:

- extensions to the structural lightning protection system
- earthing and bonding
- equipment location
- cable routeing and screening
- use of fibre optic cables.

Extending structural lightning protection

It may be necessary, and certainly beneficial, to enhance the building's structural lightning protection, in order to take account of the requirements of electronic equipment. (Detailed recommendations on the theory and practice of structural lightning protection can be found in the Furse 'Consultants Handbook'.)

Minimising induced voltages

In Section 1 we saw how lightning currents preferentially flow down external conductors. Thus, a building's lightning protection is enhanced by having many down conductors around the edge of the building. The greater the number of down conductors around the sides of the building, the smaller the magnetic fields inside the building, and the lower the likelihood of transient interference into electronic equipment.

It follows from this that extra down conductors should be installed on buildings containing important installations of electronic equipment.

Protecting exposed systems

Many systems incorporate elements installed outside or on the building. Common examples of external system components include:

- aerials or antennae
- measurement sensors
- parts of the air conditioning system
- CCTV equipment
- roof mounted clocks.

Exposed equipment, such as this, is not only at risk from transient overvoltages caused by the secondary effects of lightning, but also from direct strikes!

A direct lightning strike must be prevented, if at all possible. This can be done by ensuring that external equipment is within a zone of protection and where necessary bonded to the structural lightning protection. Figure 31 shows CCTV cameras safely positioned within the 45° zone of protection provided by the building's lightning protection.

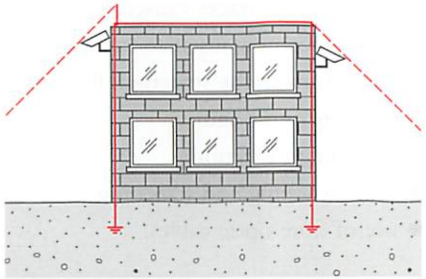


FIGURE 31 – CCTV cameras located within the 45° zone of protection provided by an air termination point (left) or flat roof-top conductor (right)

It may be necessary to include additional air termination points in the building's lightning protection scheme, in order to ensure that all exposed equipment is protected.

For exposed parts of the air conditioning system, it is possible just to bond its metal casing on to the roof-top lightning conductor grid.

Where air termination points cannot be used, for example with whip aerials, the object should be designed to withstand a direct lightning strike or be expendable.

Exposed wiring should be installed in bonded metallic conduit or routed such that suitable screening is provided by the structure itself. For steel lattice towers the internal corners of the L-shaped support girders should be used.

Sample risk assessment calculations

Example 1 – Farm buildings

A farm building in rural Lincolnshire is 6m high with a 10m x 20m area. It has an incoming telephone line and a low voltage overhead power supply (fed from a transformer 200m away). An underground power supply leaves the building to provide lights for a barn 50m away (20m high, 20m x 40m area). The farm buildings are amongst mature trees, but are isolated from other buildings, in flat country. They have structural lightning protection to BS 6651. The soil resistivity at the site is known to be 50Ωm. Figure 76 shows a plan view of the Farm.

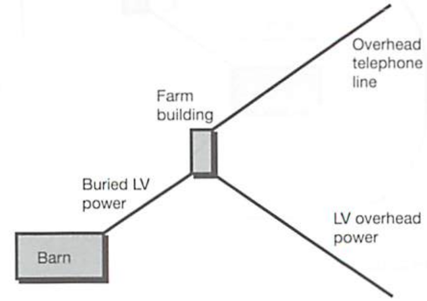


FIGURE 76 – Plan view of farm

Following the procedure outlined in Section 3, we must first calculate P, the probable number of lightning strikes (lightning flash density multiplied by the effective collection area).

Lightning flash density

From the Figure 20 map we can see that the lightning flash density (N_G) for this part of Lincolnshire = 0.3.

Effective collection area

The collection areas of the buildings' and their surrounding ground ($A_S + C_{SG} + C_{AS}$) can be calculated together, using a simplified method. The areas of the two buildings' are known. The collection area of the surrounding ground extends D metres around each building (where D = soil resistivity = 50m). Figure 77 shows this. The area can easily be calculated using a 'counting the squares' approach (Figure 78). This gives us $A_S + C_{SG} + C_{AS}$ = 22,600m².

The collection area of mains power supplies. The collection area of the incoming mains power supply (a low voltage overhead cable) is given in Figure 24 as 10 x D x L (where L is the length of the cable). The collection area of the outgoing supply, to the barn must also be calculated. This low voltage underground cable has a collection area of 2 x D x L (from Figure 24).

This gives

C_{MP} = (10 x D x L_1) + (2 x D x L_2)
= (10 x 50m x 200m) + (2 x 50m x 50m)
= 100,000m² + 5,000m²
= 105,000m²

National standards detailing lightning activity

Country	Source document	Information shown
Australia	AS 1768-1991	Thunderstorm days
Britain	BS 6651:1992	Lightning flash density
Canada	ANSI/NFPA 780 (1992)	Thunderstorm days
Finland	SFS-handbook 33	Average annual lightning strikes
France	UTE C15-531 (1986)	Thunderstorm days by Département
Germany	DIN 57185/VDE 0185 (1983)	Thunderstorm days
Italy	CEI 81-1 (1990)	Lightning flash density
Kenya	KS 04-503;Part 1:1990	Thunderstorm days
Netherlands	NEN 1014 (1991)	Thunderstorm days
New Zealand	NZS/AS 1768-1991	Thunderstorm days
Poland	PN-55/E-05003	Thunderstorm days
Singapore	CP33:1985	Thunderstorm days
South Africa	SABS 03:1985	Lightning flash density
Sweden	SS 487 01 10 (1978)	Thunderstorm days
USA	IEEE C62.41-1991	Thunderstorm days
USA	ANSI/NFPA 780 (1992)	Thunderstorm days

The following countries either don't have a lightning protection standard (marked*), or have one which doesn't contain details of lightning activity.

Belgium
Cyprus*
Greece
Hungary
Ireland*
Malaysia*
Romania*
Saudi Arabia*
Taiwan
Thailand*
Trinidad + Tobago
Venezuela

If you are aware of other national standards which contain details of lightning activity, please fax or write to the Marketing Manager of the ESP Division at the address on the rear of this handbook.

Cables attached to masts should be routed within the mast (as opposed to on the outside) to prevent direct current injection.

The protection of radio towers is discussed in Section 8 – Questions and answers. Reference is made to earthing and bonding (below) and the use of transient overvoltage protectors (Section 5).

Earthing and bonding

The basic rules of earthing are given in the Furse 'Consultants Handbook' and clauses 16 and 17 of BS 6651. Additional and complementary guidance is given here to: improve earthing, and to achieve an area of equal potential, ensuring that electronic equipment is not exposed to differing earth potentials and hence resistive transients.

All incoming services (water and gas pipes, power and data cables) should be bonded to a single earth reference point. This equipotential bonding bar may be the power earth, a metal plate, or an internal ring conductor/partial ring conductor inside the outer walls. Whatever form it takes, this equipotential bonding bar should be connected to the electrode(s) of the earthing system.

All metal pipes, power and data cables should, where possible, enter or leave the building at the same point, so that it or its armouring can be bonded to the main earth terminal at this single point (see Figure 32). This will minimise lightning currents within the building.

If power or data cables pass between adjacent buildings, the earthing systems should be interconnected, creating a single earth reference for all equipment. A large number of parallel connections, between the two buildings' earths, are desirable – reducing the currents in each individual connection cable. This can be achieved with the use of a meshed earthing system.

Power and data cables between adjacent buildings should also be enclosed in metal conduits, trunking, ducts or similar. This should be bonded to both the meshed earthing system and also to the common cable entry and exit point, at both ends.

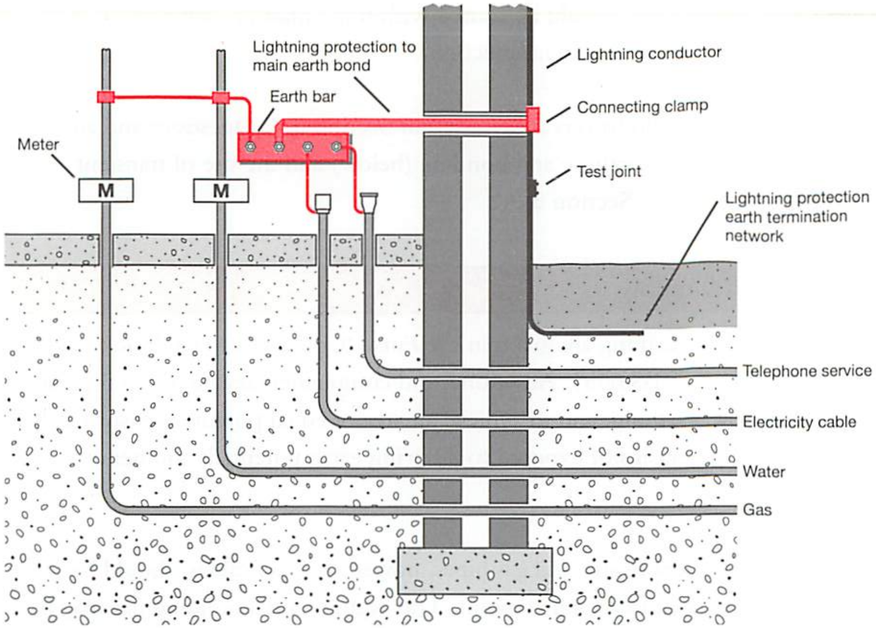


FIGURE 32 – Bonding of incoming services

Equipment location

Electronic equipment should not be located where it will be close to large current flows and the threat of induced transient overvoltages.

- Equipment should not be located on the top floor of the building where it is adjacent to the roof-top air terminations and conductor mesh of the building's lightning protection system.
- Similarly, equipment should not be located near to outside walls and especially corners of the building, where (as we saw in Figure 17) lightning currents will preferentially flow.
- Equipment should not be located in buildings close to tall, lightning attractive, structures, such as masts, towers or chimneys. These tend to have a single route to ground, causing very large current flows and hence very large magnetic fields.

The issue of equipment location can only be ignored if the building corresponds to the screened room ideal (bonded metal clad roof and walls), described on page 12.

Can I use a lightning and transient overvoltage protector to protect against NEMP (nuclear electromagnetic pulse)?

A protector designed for lightning protection purposes is unlikely to be suitable for NEMP protection. Very fast sources of interference such as NEMP, contain an element of radiated interference (as they contain frequencies >30MHz), as well as conducted interference. Whilst a lightning protector may be able to stop the conducted interference (although it is difficult to know without testing with a nuclear pulse!), the radiated interference will always bypass the protector.

Furthermore, NEMP requirements impose the need for extensive screening and bulkhead mounts on the protector, and so specialist devices are used.

protection is often relatively high when compared with the cost of the equipment. Also, although inconvenient, the loss of domestic TV does not have a downtime financial loss associated with it.

If one were to fully protect the installation it would be necessary to prevent a direct lightning strike to exposed parts of the system and to protect power and signal line inputs to the equipment. Thus, TV aerials and satellite receiver dishes should be within a protected zone of the structural LPS. The incoming coaxial cable should be protected with a suitable Lightning Barrier. (Some cable TV systems carry fibre optic cable right up to the subscribers home, negating the need for a Lightning Barrier.) The mains power supply to TV, video and satellite/cable decoding box should also be protected.

There are some crude, low cost protectors available, which though giving peace of mind are unlikely to actually protect.

Can weighbridge installations be protected from lightning?

Weighbridges are often in exposed locations where they are very susceptible to lightning – destroying load cells, amplifiers and display equipment.

Most cases of weighbridge damage are caused by resistively or inductively coupled transient overvoltages. This sort of lightning damage can be eliminated. Lightning and transient overvoltage protectors should be installed on power, signal and telephone lines into the indication unit building and on signal lines local to the weighbridge's load cells. Furse manufacture a signal line protector specifically designed for load cell installations. In addition to the installation of transient protectors, it may be necessary to enhance the earthing and cross bonding of the weighbridge platform.

Direct lightning strikes to the weighbridge are relatively rare and complete protection cannot be guaranteed. However, the correct installation of appropriate lightning and transient overvoltage protectors, together with adherence to good earthing and bonding practices, will greatly reduce the incidence of damage.

A detailed Application Note entitled 'Protecting weighbridge load cell installations against lightning' is available from the ESP Division of Furse.

Cable routeing and screening

Power, data communication, signal and telephone cabling may also be at risk from induced transient overvoltages within the building.

Equipment cabling should avoid possible lightning carrying conductors such as those on the roof and within, or on, the building (see equipment location above).

Large area loops between mains power and data communication cabling are, as a result of inductive coupling, effective at capturing lightning energy, and should therefore be avoided. Figure 33 shows a large loop area created between power and data communication cabling.

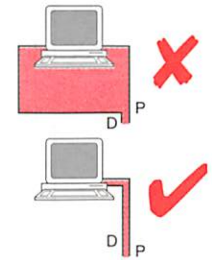


FIGURE 33 – Loop areas between mains power (P) and data communication (D) cabling

To minimise loop areas, mains power supply cables and data communication, signal, or telephone wiring should be run side by side, though segregated. The cables can be installed either in adjacent ducts or separated from each other by a metal partition inside the same duct.

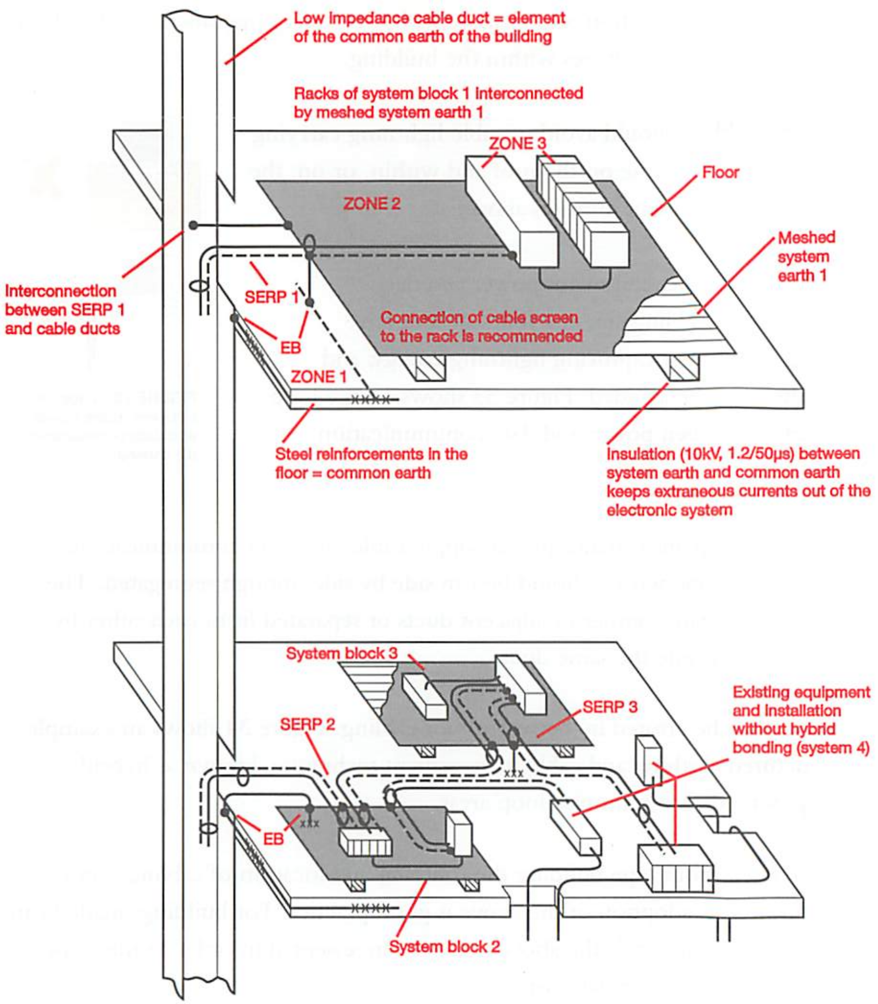
Loops can also be created by between floor cabling. Figure 34 shows an example of a structured earthing and cable management technique, known as hybrid earthing, intended to minimise loop areas.

For a screened room type building the routeing and location of cabling is not as critical, however, adoption of the above is good practice. For buildings made from non-conducting materials the above practices are essential in order to minimise damage to equipment or data corruption.

Cable screening or shielding is another useful technique which helps to minimise the pick-up and emission of electromagnetic radiation. Power cables can be shielded by metallic conduit or cable trays, whilst data cables often incorporate a screening outer braid.

The screen acts as a barrier to electric and magnetic fields. Its effectiveness is determined by its material and construction as well as by the frequency of the impinging electromagnetic wave.

FIGURE 34 – Hybrid earthing (after Eric Montandon)



Note. The new system blocks (1,2 & 3) are hybrid-bonded and may be connected to the existing system 4.

KEY

Zone 1	=	Not directly exposed to lightning
Zone 2	=	No partial lightning currents
Zone 3	=	Made up of equipment shielding
EB	=	Equipotential bonding
XXXX	=	Steel reinforcements in concrete
SERP	=	System earth reference point. This is the only metallic interface between the system and common earth. It must be directly connected to the structures steel reinforcement where cables leading to the system enter. All conductors that are bonded to the system earth within the system zone must be earthed at the SERP.

Regulations). Detailed guidance on above ground earthing can be found in FIPS 94 and IEEE 1100-1992 (The Emerald Book).

What measures should I take to safeguard a radio transmitter against lightning?

Radio sites consist of a mast and building(s) housing equipment. These can be protected by following the recommendations of BS 6651:1992, CCITT (Ch 6, 7 & 8) and a useful publication by Jackman and Palmer of South Western Electricity entitled 'Recommendations for Lightning Protection, Electrical Supplies, and Earthing Systems at Radio Sites and Telecommunication Terminals'. Figure 75 shows how an installation should be protected.

The mast should be bonded and earthed (1). Where possible aerials should be located within the 45° or rolling sphere zone of protection created by the metallic mast (2). The building should be cross-bonded to the mast and its earth (3). Coaxial feeders should be bonded at the top and bottom of the mast (4 & 5) and also on entry to the building (6). Cables between the mast and the building, routed in a metal cable tray, duct or conduit, should be bonded to the mast and the building's main electrical earth. Additionally, Furse ESP protectors should be installed in the building on all incoming mains power supplies, data communication and telephone lines (7, 8 & 9).

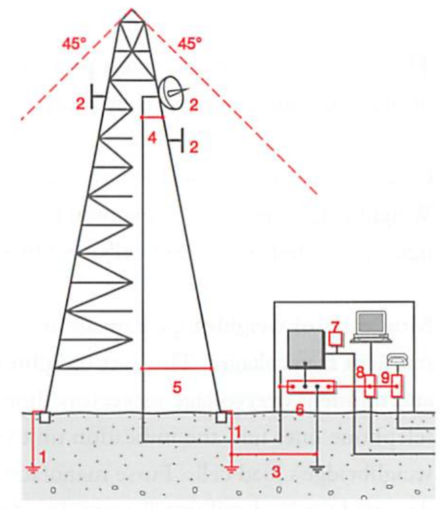


FIGURE 75 – Protection of a radio transmitter

These bonding techniques will be more than adequate to protect high power transmitters and valve based equipment. Lower power semiconductor based equipment may need additional protection on the RF outputs and inputs.

How can I protect television and satellite receiving equipment against lightning?

Although it is possible to protect TV and satellite equipment from lightning it is generally considered uneconomical to protect domestic installations. The cost of

Is it possible to prevent transient overvoltages by not bonding the building's lightning protection system (LPS) to the main earth?

No. Not only will this not prevent transients, it will often make the problem much worse. When carrying a lightning strike to earth, an unbonded LPS may side flash into the building and on to the electrical system. This could occur anywhere in the building and is likely to occur **after** the transient protectors on the incoming electrical services – allowing the complete destruction of electronic equipment.

It should also be recalled that failure to bond the building's LPS to the main earth contravenes the practices detailed in BS 7671:1992 (IEE Wiring Regulations) and BS 6651:1992 (lightning protection) amongst others.

Is there any danger of a transient overvoltage caused by lightning melting a Lightning Barrier's earth lead, since this has a much smaller cross sectional area than a lightning conductor?

Certainly not! Lightning conductors, for structural lightning protection purposes, usually have a minimum cross sectional area of $50mm^2$, whereas the earth connection for a Furse ESP Lightning Barrier is typically a $10mm^2$ cable. The cross sectional area of the lightning conductor needs to be large to compensate for corrosion and also to withstand the massive mechanical forces of a direct lightning strike. However, the earth cable of a Lightning Barrier is subjected to a much smaller, secondary effect current and is not exposed to corrosion.

What is a 'clean earth'?

The term 'clean earth' is used to describe many things! A separate earth wire routed back to:

- the main earth bar
- a totally independent earth electrode
- an independent earth electrode, bonded to the main earth bar.

In reality there is no such thing as a clean earth, merely a variety of earthing practices with differing benefits. The first and last of these are practices which conform to wiring regulations, whilst the second does not and is dangerous.

Earthing practices should not violate safety requirements, such as those of BS 7671:1992 'Requirements for Electrical Installations' (IEE Wiring

For transient protection purposes the screen should be bonded to earth at both ends, although there are instances, particularly in instrumentation, where single-end earthing is preferred to help minimise earth loops.

Use of fibre optic cable on building to building data links

Special care should be taken with the protection of data lines which:

- pass between separate buildings, or
- which travel between separate parts of the same building (ie not structurally integral) and which are not bonded across. Examples include parts of a building which are separated by settlement gaps or new wings which are linked by brick corridors.

Fibre optic cable is the optimum method of protection for building to building data links. This will completely isolate the electronic circuits of one building from the other, preventing all sorts of EMC problems including transient overvoltages.

The use of fibre optic cable for data transmission does not diminish the need for the protection of the mains power supply to equipment.

Many fibre optic cables incorporate metal draw wires or moisture barriers and steel armouring. This can establish a conductive link between buildings, defeating the object of using a fibre optic link! If this cannot be avoided the conductive draw wire, moisture barrier or armouring, should be bonded to the main cable entry bonding bar as it enters each building, or stripped well back. No further bonding should be made to the fibre optic cable's 'metal'. Lightning protection for fibre optic cable is considered in greater detail by CCITT IX K25.

The cost of fibre optic cable may make it unattractive for low traffic data links and single data lines.

Where conductive data lines, such as unshielded twisted pairs or coaxial cables are required, precautions should be taken to prevent transients from flowing along the line, threatening equipment at each end:

- install transient overvoltage protectors/Lightning Barriers (see Section 5 on deployment of protectors and Section 6 on the selection of protectors)
- interconnect the earthing systems of the buildings'.

The earthing systems of the buildings' can be interconnected via cable armouring, metal trunking, raceways or conduits. These should be bonded, at each end, to each building's earth system, thus providing an electrically continuous link. If many parallel data links exist between buildings a good interconnection of earths will be achieved, producing very low induced voltages. Also, it is beneficial to install earth cables linking each structures earth.

Certain types of coaxial and screened cable should only be bonded to earth once (ECMA 97 details types of LAN for which this is the case). The use of transient overvoltage protectors (see Section 5) will provide additional bonding, whilst retaining the integrity of the system's screening.

can still provide transients with a high frequency path through the transformer.

Where line to line transients exist, transformers are of little protective value. Line to line refers to transients which exist live to live and neutral to live. When high voltage power lines are struck by lightning they flashover to earth. One line will flashover to earth before the others, converting a transient between lines and earth to one between line(s) and line. These will pass easily through transformers.

Additionally, where transformers at one earth reference feed power distribution boards in another building, or site lighting etc at another earth reference, resistively coupled transients can occur.

One company we've encountered had installed an isolation transformer for the sole purpose of transient protection. In spite of its claimed protection properties, nearby lightning activity damaged several pieces of equipment on their site. During line to line transient tests, transient overvoltages passed straight through the transformer. Indeed, as a result of resonant ringing they were larger on the output than on the input side!

Live to earth transient tests showed surprisingly large transient overvoltages let-through the transformer. Transients recorded on the output side were as much as half of those input, as a result of interwinding capacitance.

So whilst transformers have some protective benefit, they can hardly be called effective transient overvoltage protection.

Why are specialised protectors required for network systems, such as Ethernet?

Protectors for data communication, signal and telephone lines ('Lightning Barriers') are fitted into the line (ie in series). This introduces a small impedance into the line and a capacitance across the line. For twisted pair signalling below 1MHz, this generally causes no problems. However, at higher frequencies this impedance and capacitance would cause problems. Protectors for these systems need to be specially designed to have lower line capacitance and impedance. For impedance matched systems (eg coaxially wired computer networks such as Ethernet) it is essential that the protector is impedance matched, in order to avoid reflections.

Do transient overvoltages on power cables only happen on *mains* power supplies or can they also occur on other power supplies?

Although transient overvoltages are associated with mains supplies they can also occur on generator supplies, battery supplies and UPS outputs. If the generator, battery or UPS is located in a separate building then the supply can be susceptible to resistive, inductive and capacitive transients in just the same way as a mains power supply.

Also generator, battery and UPS supplies have a lower current capability than the mains and hence a higher source impedance. This means that it is easier for switching events to cause transients.

Do I really need transient overvoltage protection on a power supply that incorporates a tap-switching line conditioner or other form of voltage regulator?

Yes. Dr Standler, a leading American authority in transient protection, has applied transient overvoltages of up to 6kV to the input side of tap-switching line conditioners from two well-known manufacturers. Their electronic control circuits were destroyed and one of the line conditioners had an output RMS voltage 20% higher than it should be. This sort of sustained increase in RMS voltage is capable of destroying many pieces of electronic equipment. The installation of effective transient overvoltage protection, before the conditioner, will prevent its damage and hence protect the equipment it supplies.

My power supply is already protected by a filter ..... isn't it?

Filters, although providing excellent protection against radio frequency interference, can actually make transient overvoltages worse! This is explained on page 92-93 and shown in Figure 98.

I've been told that 11kV to 415V distribution transformers provide transient overvoltage protection – is this true?

The short answer is, yes and no! Whilst distribution transformers certainly provide a degree of protection they also contain 'sneak paths', which allow transients through to the LV power distribution system.

High voltage to low voltage transformer action theoretically eliminates transient overvoltages with respect to earth (ie live to earth and neutral to earth). However, stray capacitance between the primary and secondary windings of the transformer

Deployment of transient overvoltage protectors

Transient overvoltage protectors should be used to supplement and support the protection techniques outlined in Section 4.

When deploying transient overvoltage protectors, our objective is always to install the transient protection between the source of the threat and the equipment we are trying to protect (Figure 35).

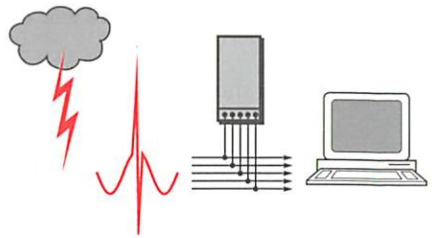


FIGURE 35 – Transient protectors should always be installed between the source of the threat and the equipment we are trying to protect

We saw earlier that transient overvoltages can be conducted into electronic equipment via,

- mains power supplies
- data communication, signal and telephone lines.

We must therefore look at protecting both power and data communication/ signal/telephone inputs.

On mains power supplies, transient overvoltages can be caused by the secondary effects of lightning, supply faults originating outside the building, or by switching transients caused by the operation of other pieces of equipment within the building.

Transient overvoltages on data communication, signal and telephone lines are mainly the result of lightning activity.

Suitable lightning and transient overvoltage protectors are produced by the ESP Division of W J Furse & Co Ltd.

Protecting mains power supplies against lightning

Lightning can inject transients into the building's power distribution system via:

- the incoming power supply
- outgoing supplies to on-site equipment

- power supplies travelling between buildings
- induction from lightning conductors carrying lightning currents to earth.

Both overhead and underground cables can be affected by lightning. Underground cables which provide a link between two different earth references, are subject to resistively coupled transients. Overground or overhead cables are susceptible to resistive, inductive and capacitive transients.

Thus protection should be applied as outlined below.

Protect the incoming power supply

Mains power supplies entering the building should be protected, to control large externally generated transients before they enter the building's power distribution system.

A suitable protector should be installed on the main LV incomer or at the main LV distribution board. (See Section 7 for details of installation technique.)

Some buildings have more than one main incomer or main distribution board – all should be protected.

Protect outgoing power supplies to on-site equipment

Mains power supplies leaving the building may also need to be protected.

- Protection as the supply leaves the building will prevent transients from outside being injected back into the building's power distribution system – often there will be a local distribution board or auxiliary services board feeding this external equipment, at which protection can be installed.
- Sensitive external or on-site equipment, such as CCTV cameras, should also be protected locally – although the equipment will share the same power earth as the main building, it is likely to be inadvertently connected to a local earth (pole mounted cameras and site lighting may be earthed locally via its support mast) and hence vulnerable to resistive transients.

Power supplies travelling between buildings

Mains power supplies between buildings should be protected at each end. Supplies between buildings should be considered as above: an outgoing supply (from one building) and an incoming supply (to the other building).

Does a large joule or energy rating indicate a good protector?

Sometimes yes, and sometimes no! In fact energy is a very misleading measure of a transient overvoltage protectors performance, as the following example shows.

Consider two transient protectors each with the same maximum discharge current, but with different energy ratings. See Figure 74.

FIGURE 74 – Energy comparison

Protector characteristics	Protector 1	Protector 2
Energy rating	540 joules	140 joules
Max discharge current (8/20μs waveshape)	10,000 amps	10,000 amps

At first glance Protector 1 appears to be the best, as it has a higher energy rating. On closer inspection this is seen not to be the case.

We know from first principles that: Energy = voltage x current x time

Current and energy values are explicitly stated in Figure 74, whilst time is given by the pulse width of 20μs (20 x 10^{-6} seconds). If we assume the waveform is square in shape we can roughly calculate the voltage present across the protectors. This is the voltage which will be let-through the protector.

$$\text{Protector 1, voltage} = \frac{\text{energy}}{(\text{current x time})} = \frac{540}{(10{,}000 \times 20 \times 10^{-6})} = 2{,}700 \text{ volts}$$

$$\text{Protector 2, voltage} = \frac{\text{energy}}{(\text{current x time})} = \frac{140}{(10{,}000 \times 20 \times 10^{-6})} = 700 \text{ volts}$$

A let-through voltage of 2,700 volts will destroy most pieces of electronic equipment, whilst a let-through voltage of 700 volts will provide most pieces of electronic equipment with effective protection. Thus, where energy is concerned, first impressions can be misleading.

This is why BS 6651:1992 and IEEE C62.33-1982 discourage the use of energy ratings as a comparative indicator of protector merit.

Why are some protectors rated for maximum transient currents greatly in excess of the 10kA indicated in BS 6651 and IEEE C62.41?
Since there aren't any worthwhile technical reasons for greatly over-rating protectors, one can only speculate as to the real reason.

Very often, the protectors maximum transient current is unattainable. Consider, for example, a protector rated for a maximum transient current of 100kA. If the protector is installed on a mains power supply, normal practice is to use an in-line fuse for cable protection. A fuse rated at 500 amps or so would be required to allow 100kA to pass. Manufacturers own installation instructions typically recommend 100 amp fuses – effectively de-rating the 'protectors' maximum transient current to 20kA!! Also most protectors have internal disconnect mechanisms. Few, if any, of these are capable of handling 100kA.

It is also worth noting that even if the 'protector' really could handle 100kA, the inductive voltage drop on just 10 cm of connecting lead would be 1,250 volts – giving the 'protector' an unacceptably high let-through voltage. So even if the 'protector' survives, the equipment won't!

Finally, many protectors which claim to handle such large currents are physically large. The difficulty of installing a physically large protector often results in longer connecting leads, causing additional inductive voltage drops and even higher let-through voltages.

Is it important to choose a protector with a fast response time?
Although the response time of a protector is important, it is not an important characteristic in its own right (and no standard outlines response time tests). In fact nearly all transient protection components (except gas discharge tubes) respond quickly. If a protector responds too slowly this will be shown through a high let-through voltage.

Some manufacturers abuse response time, quoting sub pico-second response times. Although unpackaged semiconductor material can respond this quickly, the packaged component cannot since it incorporates wires. The time taken for electricity to travel along these wires causes a much longer response time. In fact, a sub pico-second response time would require the packaged component to be a ridiculous 0.3mm in size!!

Power supplies within the building

In Section 1 we saw how transient overvoltages can be induced on to power lines from the electromagnetic field caused by a large current, such as lightning. In a similar fashion, when the building's lightning protection system carries a current to earth, it creates a magnetic field. If electronic equipment or its power supply is located near to these current carrying conductors, then an induced transient will result.

In new buildings it may be possible to ensure that this risk is eradicated. However, for most existing installations this particular transient source is a very real threat. It is therefore advisable to install protection locally to important pieces of equipment, to control lightning induced transients inside the building.

This is explained in greater detail below.

Protecting mains power supplies against switching transients

Switching transients can be caused both outside the building (eg by high voltage switching) or inside the building.

Transients which originate outside, on the supply to the building, can be large and hence very destructive. The main incoming LV power supply or supplies should therefore be protected, preventing these transients from entering the building's power distribution system. Often a suitable protector will already have been installed on lightning protection grounds. As with lightning, a suitable protector should be installed on the main LV incomer/distribution board.

Within the building's power distribution system, switching transients are caused by the operation of other pieces of electrical or electronic equipment. In particular, the operation of large inductive loads can cause sizeable transients. These loads include air conditioning systems, lifts, and all motorised industrial equipment.

It should be recalled that our protective objective is to install the protection between the source of the problem and the equipment we are trying to protect. We therefore have two options:

- install protection local to the offending piece(s) of equipment, or
- install protection local to the equipment we are trying to protect.

Installing protection local to the offending piece of equipment, although technically desirable, is only recommended if the transient problems experienced can be clearly attributed to the operation of that piece of equipment. Often switching transients are caused by a number of different pieces of equipment.

Installing protection local to the equipment we are trying to protect has a couple of advantages:

- local protection may already be required on lightning protection grounds
- it ensures protection against both present and future sources of switching transients.

The installation of protection local to the equipment we are trying to protect is thus, the approach generally favoured by Furse.

All pieces of sensitive equipment, whose smooth operation is important, should be protected locally against switching transients. Examples of sensitive equipment include: the mainframe or mini computer, stand alone computers such as CAD and DTP systems, UPS, the PBX telephone exchange, telemetry equipment, data logging and acquisition equipment, and programmable logic controllers.

Local protection can be achieved with either wire-in protectors at local power distribution boards or plug-in protection.

If protection is required for a number of computer terminals it may be more cost effective to install a wire-in protector at the LV distribution board supplying the ring main, rather than individually protecting each terminal with a plug-in protector.

Protecting uninterruptible power supplies (UPS)

An uninterruptible power supply or UPS, is essentially a large battery providing several minutes back-up power.

Many UPSs incorporate a small filter, and on this basis many UPS manufacturers have loosely claimed that their devices provide transient overvoltage protection. Some manufacturers have gone as far as to suggest that their UPSs protect against transient overvoltages caused by lightning. However, the type of filters used only provide protection against quite low level transients, and not against the larger

How do transient overvoltage protectors work?

Transient overvoltages can be eliminated in two ways.

Protectors can behave like an open circuit during a transient overvoltage, keeping the transient voltage on the other side of the protector and stopping the flow of transient current (Figure 71). Opto-isolators in common mode, transformers in common mode and, to an extent, in-line inductors all behave in this manner.

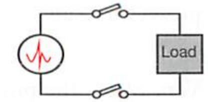


FIGURE 71 – Protection by open circuit

Alternatively, protectors can behave like a short circuit during a transient overvoltage, shorting out the transient voltage and allowing the transient current to flow through it (Figure 72). Many transient overvoltage protectors and, to an extent, shunt capacitors, follow this principle.

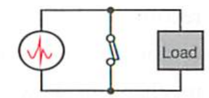


FIGURE 72 – Protection by short circuit

Furse ESP protectors are based on the 'short circuit' principle, although in reality they do **not** cause a short circuit. The oscilloscope trace in Figure 73 shows how an ESP unit suppresses a transient overvoltage on a mains power supply, **without** disrupting the power supply.

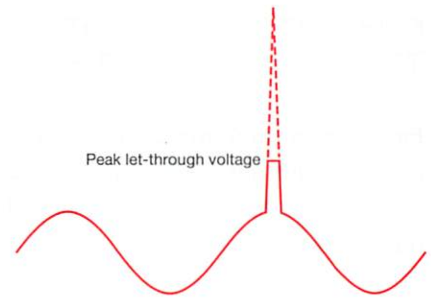


FIGURE 73 – Protected mains power supply

Appendix D describes the workings of transient overvoltage protectors in greater detail.

Do transient overvoltage protectors save data?

Protectors on a mains power supply can save data by avoiding a crash or power problem during which corruption could occur.

Protectors on data communication, signal and telephone lines cannot save data, only the system. This is because the let-through voltage can appear as an invalid signal, distorting a sequence of data. However, since the protector has prevented damage, the system's error checking facility will request retransmission of the data sequence.

transformer would be able to continue operation after the event. The next transient would find it much easier to flashover the now degraded insulation. The process could then continue until a catastrophic short circuit failure occurs. Similar degradation can occur to the silicon dioxide insulation in integrated circuits (or microchips). In severe cases the first transient will be terminal!

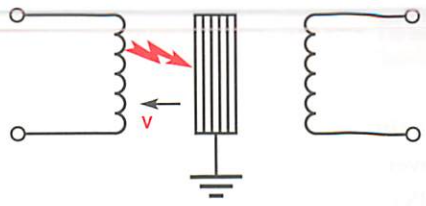


FIGURE 70 – Flashover in a transformer

How do transients cause energy damage?

Energy damage is the result of overheating. Many components, such as resistors and forward biased semiconductors, normally have a current flowing through them. The current flowing through the component will be increased by a transient overvoltage, causing heating. If sufficient heat is generated, material in the component will melt, changing its characteristics. Once this occurs a component may fail short circuit or open circuit. If the transient overvoltage is still present, then secondary failures may occur, eg a component that has already failed open circuit may then suffer flashover. Fuses, resistors and printed circuit board tracks are all damaged in this way.

Is component damage always visible?

Most cases of damage are not obvious. It is common to find circuit boards that look as good as new, but with every semiconductor internally damaged. Only in most severe cases do we see ruptured cases, charring and fire. In fact much of this more spectacular damage is caused by power follow-on and not by the transient.

What is power follow-on?

When a transient overvoltage causes a short circuit failure, this can create a path for the power supply. Consider a component connected to live and neutral on a mains power supply, failing short circuit as a result of a transient. At this point no outward signs of damage exist. Mains current flows into the short circuit and continues until a fuse blows or the component spectacularly blows itself apart. This also explains why it is often difficult to tell how big a transient overvoltage was by looking at the damage it caused.

transients which cause the disruption, degradation, damage and downtime we are trying to avoid!

Where equipment is connected to a UPS, good lightning and transient protection should still be used.

- Most UPS systems have a bypass connection which operates during faults, overload, UPS failure or routine maintenance. At this time the UPS is literally bypassed. Providing that good transient protection units are fitted the critical load will, during bypass, be connected not to a raw supply but to a panel at which transient overvoltages are controlled to a low and harmless level.
- The modern electronic UPS, itself a sophisticated piece of electronic equipment, may be prone to the effects of transient overvoltages. More traditional motor-generator (or rotary) designs are less prone to this problem.
- Some UPSs have their neutral connected straight through from input to output, potentially allowing the unhindered passage of neutral to earth transients.
- Where the UPS is in an external building separate from its load, its output, its input and the load will require protection.

The protector should be installed at the local power distribution panel, feeding the UPS. On large UPSs the protector can be installed within the UPS cabinet, on the power incomer.

Some larger UPSs are supplied with Furse ESP protectors built-in and therefore provide effective protection against transient overvoltages caused by lightning.

Protecting data communication, signal and telephone lines

Transient overvoltages on data communication, signal and telephone lines are primarily caused by the secondary effects of lightning.

Inside the building, screened cables can offer protection against voltages induced from current carrying lightning conductors. Most data cables incorporate a metallic screen.

Outside the building, data lines are susceptible to transient overvoltages. Underground cabling, between separate earth references, will be susceptible to resistively coupled transients. Overground or overhead cables may be susceptible to resistive, capacitive and inductive transients.

Thus, as a general rule transient protectors should be installed on all incoming and outgoing data communication, signal and telephone lines. See Figures 36 & 37. Furse ESP produce a range of Lightning Barriers for this purpose.

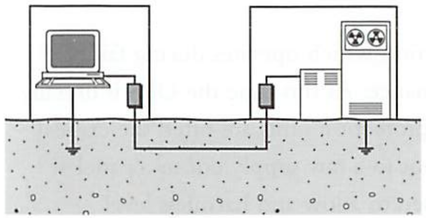


FIGURE 36 – Transient protectors installed on underground incoming/outgoing data lines

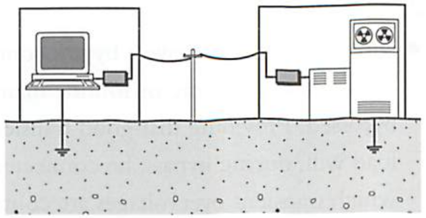


FIGURE 37 – Transient protectors installed on overhead incoming/outgoing data lines

Spare cores and unutilised cables should be connected to an electrical earth, at each end.

Fibre optic cable

It is not necessary to install transient protectors on fibre optic data lines. As a non-conductive method of communication, fibre optic cable cannot transmit transient overvoltages. However, many fibre optic cables have metallic elements, which can create conductive between-building links. This metallic armouring, moisture barrier or draw wire, should be stripped well back, or bonded to earth at each end (see page 35).

Unprotected data lines

Where one end of a data line is connected to an unimportant piece of equipment, a conscious decision not to protect the equipment can be taken. This is only recommended if the equipment in question:

- is of low monetary value
- is easy and inexpensive to repair
- is not performing a critical operation (ie consider the health, safety and financial implications of downtime).

WARNING An important piece of equipment must have all of its inputs protected, even ones considered functionally unimportant. Otherwise transients may enter the equipment via an 'unimportant' input, causing damage to important circuitry.

Questions and answers

Is there any difference between a 'surge' and a 'transient' or 'transient overvoltage'?

BS 6651:1992 uses the terms 'surge', 'transient voltage' and 'lightning transient' to describe the very short duration increases in voltage caused by lightning. In this context 'surge' means the same as 'transient overvoltage', or in its shortened form 'transient'. However 'surge' is a vague term also used to describe overvoltages of up to a few seconds ('swells') in duration. It is for this reason that the terms 'transient overvoltage' and 'transient' have been used throughout this handbook.

How are transient overvoltages caused?

Transient overvoltages can be generated by lightning, (through resistive, inductive or capacitive coupling) or by electrical switching events. A more detailed explanation of 'How transient overvoltages are caused' can be found in Section 1.

What are the modes transient overvoltages occur in?

'Modes' refers to the combinations of conductors which transient overvoltages occur in, and can be measured between. Lightning transients generally start as disturbances with respect to earth, whilst switching transients start as disturbances between live/phase and neutral. During propagation, mode conversion can occur (eg as a result of flashover). Hence transients can exist between any pair of conductors, in any polarity, simultaneously.

How do transient overvoltages degrade and damage electronic equipment?

Degradation and damage differ in their degree of severity – both are caused by flashover and heating.

How do transient overvoltages cause flashover?

Consider a transformer winding and an earthed lamination. If a small transient voltage is present between the winding and earth, no current flows and no heating occurs. However, if a larger transient voltage is present, flashover or insulation breakdown occurs, and a transient current flows through the transformer, causing heating, burning and arcing (Figure 70). In a minor case the are connected to the same earth bar. The voltage drop in the soil does not appear in the system and causes little problem.

If 'absolute' earthing is attempted (Figure 69) the Lightning Barrier will be by-passed.

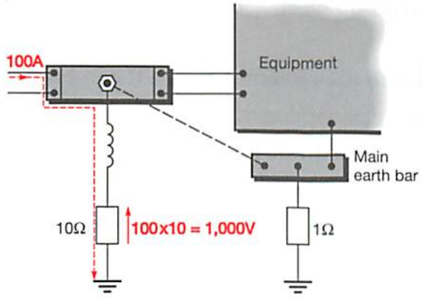


FIGURE 69 – 'Absolute' earthing

The resistance of the earth network connected to the Lightning Barrier is unlikely to be lower than 10 ohms. If a 100 amps current flows into a 10 ohms earth, a voltage of 1,000 volts will appear. This will add to the inductive volt drop on the earth lead and the let-through voltage of the Barrier. Since the equipment is referenced to the main earth electrode (which is at zero volts since no current is flowing) the equipment will see in excess of the 1,000 volts and be destroyed.

A bond between the Lightning Barrier and main earth bar will improve the situation, providing the length limitations discussed on page 59 are met. However, this results in an arrangement little different from that described as 'relative' earthing.

When to install additional earthing

Most industrial and commercial buildings have an electrical earth and perhaps a structural lightning protection earth bonded to it. The earthing arrangement at the site should have a resistance to earth of 10 ohms or less. Where this is so, additional earth electrodes, although generally improving the electrical earth, will probably have little benefit. (Note, some electricity companies recommend lightning protection earths to be less than 1 ohm.) Where there is no electrical earth network (eg at outstations, domestic or small commercial properties), or where the network is suspect, it should be improved using additional earthing materials, until an overall resistance not exceeding 10 ohms is achieved. At certain sites, buried pipes and metallic borehole linings may form a good earthing electrode without the need for additional earthing.

Further information on earthing is available in the Furse 'Consultants Handbook'. A comprehensive range of earthing materials are available from the Earthing and Lightning Protection Division of W J Furse & Co Ltd.

PBX telephone exchanges

Most sizeable businesses and organisations have their own telephone exchange or private branch exchange (PBX). This is the link between the telephone company's incoming lines and the customer's own internal extension lines.

Just like other communication lines, telephone lines which travel into the building or between buildings should be protected. PBXs can be protected against transient overvoltages with two tier (gas discharge tube plus semiconductor) protection. This typically consists of semiconductor protection installed at board level and gas discharge tubes installed on the main distribution frame. In practice, this is hardly ever done in the UK nor, we think, in most other parts of the world. However, if lines are correctly protected with both gas tubes and semiconductors, this tends to be true of the incoming (PTO) telephone lines only and not extension lines. These often travel from building to building and are therefore very much at risk from lightning.

The use of gas discharge tubes alone does not provide adequate protection.

The PBX should be properly protected by devices with a suitably low let-through voltage. Devices specifically intended for this purpose are available from Furse ESP. The PBX is an excellent place to install protection since all incoming and outgoing lines meet at this point. (The selection and specification of transient overvoltage protection is discussed in detail in the next section.)

Application guide

A pictorial application guide which combines examples of a number of common applications can be found inside the back cover of this handbook.

Choosing and specifying protectors

In selecting a transient overvoltage protector it is important that the device selected fulfils the following requirements.

- **Survivability**. It is vital that the protector chosen is capable of surviving the worst case transients expected at its intended installation point. Also, since lightning is a multiple pulse event, the protector should not fail after exposure to the first transient.
- **Transient control**. The protector should be able to control transients to a level below the susceptibility and vulnerability of the equipment we are protecting. For example, if a computer's operation is unhindered by transients of up to 700 volts, then the let-through voltage or transient control level of the protector should be less than 700 volts. Allowing a suitable safety margin, the worst case let-through voltage of the protector should be 600 volts, or less. (NB The connecting leads of a correctly installed protector will cause an increase in the let-through voltage – see Section 7.)
- **System compatibility**. The protector should not impair or interfere with the protected system's normal operation. Communication systems and intrinsically safe circuits are particularly susceptible to this type of problem.

Location categories

The protectors ability to survive and to achieve a suitable let-through voltage clearly depends upon the size of transient it will be subjected to. This in turn may depend upon the protector's location. The American standard IEEE C62.41, and subsequently BS 6651 outline three location categories. See Figure 38.

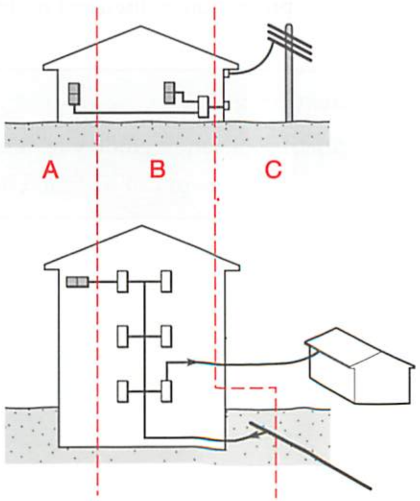


FIGURE 38 – Protector location categories

Mains power supplies

As a mains borne transient travels through a building, the amount of current it can source grows smaller (due to the impedance of mains cables

Earthing

Contrary to popular belief, earth is not a sponge which soaks up electricity with no effect on voltage!

Earth is a reference point. It can be seen in Figure 67 how the electrical earth bar in a building is connected to the earth electrode arrangement by a conductor. This will have a small (virtually negligible) resistance, and an inductance. The earthing electrode arrangement itself also has inductance and resistance. The resistance of a typical network can lie anywhere between 0.1 ohm and 100 ohms.

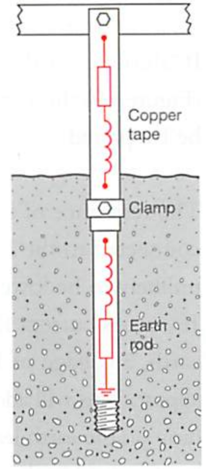


FIGURE 67 – Typical earth arrangement

The earthing network is connected to 'true earth' which is itself a concept, rather like infinity and just like infinity, can never be reached.

When a current flows from the main earth bar to earth, the potential of the bar will rise. A far cry from the 'earth is a sponge' misconception.

For this reason, when earthing protectors we employ a concept of 'relative' earthing, rather than 'absolute' earthing.

'Relative' versus 'absolute' earthing

Let us consider a data line protector in use and see what affect differing earthing practices will have. We shall assume that the earth impedance of the building earth is 1 ohm.

Figure 68 shows how a 'relative' earthing installation might be. If just 100 amps flows to earth, then the main earth bar will rise to more than 100 volts as a result of resistive and inductive voltage drops.

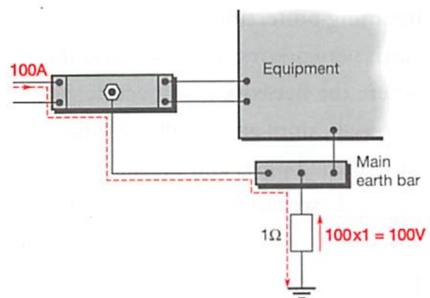


FIGURE 68 – 'Relative' earthing

Although this may appear to be a problem, it is not, since both the Lightning Barrier and the equipment

Routeing of clean cables to prevent cross coupling

Transient overvoltages are a form of conducted interference, which means that they flow along wires to get from source to victim. The protector forms a barrier between the transient source and the equipment to be protected. It is therefore particularly important that neither the 'dirty' incoming line or the 'dirty' earth cable are routed too close to the outgoing 'clean' line. Otherwise transients can be re-introduced onto the line after the protector! Figure 65 shows examples of good and bad practice.

When protectors are installed in groups, the orientation of adjacent rows should be rotated in order to keep clean lines away from dirty incoming lines (see Figure 66). As a general rule a minimum distance of 15cm should be maintained between clean and dirty lines.

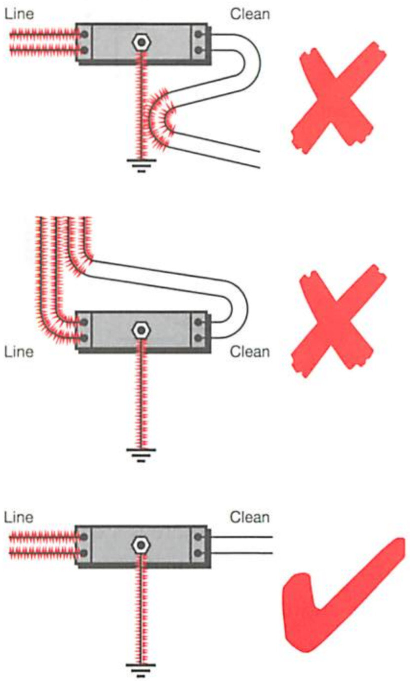


FIGURE 65 – Cable routeing

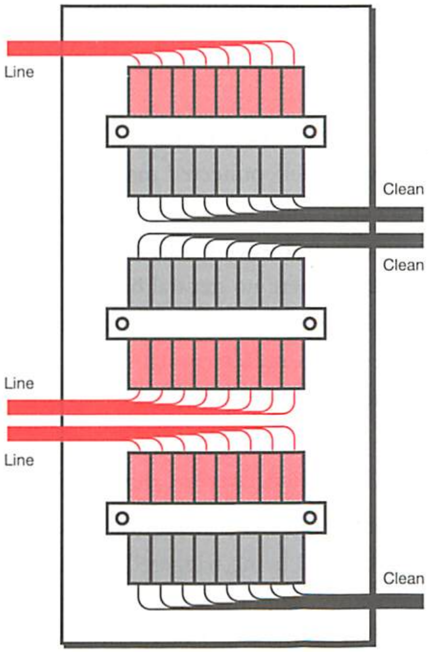


FIGURE 66 – Positioning of adjacent rows of Lightning Barriers

and current division). This is based upon the assumption that a typical mains transient caused by lightning has a 1.2/50μs waveform. (Appendix C discusses transient overvoltage simulation and testing in greater detail.)

Location Category C is defined as either:

- outside the building, or
- the supply side of the main, incoming, LV distribution board; ie the board bringing the power supply into the building from the electricity supply authority, LV transformer or from another building, or
- the load side of distribution boards providing an outgoing power supply to other buildings or to on-site equipment.

Location Category B is defined as either:

- on the power distribution system, between the load side of the incoming distribution board and the supply side of a socket outlet or fused spur, or
- within apparatus which is not fed from a wall socket, or
- sub-distribution boards located within a 20m cable run of Category C, or
- plug-in equipment or a fused spur located within a 20m cable run of Category C.

Location Category A is defined as either:

- plug-in equipment or a fused spur located more than a 20m cable run from Category C.

Data communication, signal & telephone lines

Transient overvoltages on data lines are not significantly attenuated by the cable and so protectors should always be rated for Location Category C. Regardless of where they are installed in the building, the worst case will be similar. This is based upon a 10/700μs waveform transient (see also Appendix C).

Exposure levels

Transient overvoltage protectors are designed to protect against the probable worst case transient overvoltage. In high transient exposure level areas, very large transients (perhaps only occurring once in every x thousand events) can be anticipated over much shorter timescales than in a low transient exposure level area. Thus, the probable worst case transient will be much smaller in a low transient exposure level area, than in a high exposure area.

The transient exposure level can be derived from the risk assessment – see Section 3, earlier. However, if a risk assessment has not been done, it is probably wise to assume a risk, R = 0.6. This can be combined with the consequential loss rating (in Figure 29) in order to derive the protector exposure level from Figure 30.

Probable worst case mains transients for high, medium and low exposure levels are tabulated in Figures 39, 40 and 41, for all location categories.

All data line protectors fall within Category C and probable worst case data line transients are tabulated in Figure 42.

FIGURE 39 – Mains power supply – Category C

System exposure level	Peak voltage	Peak current
High	20 kV	10 kA
Medium	10 kV	5 kA
Low	6 kV	3 kA

Derived from original work in IEEE C62.41-1991 and reproduced from BS 6651:1992

FIGURE 40 – Mains power supply – Category B

System exposure level	Peak voltage	Peak current
High	6 kV	3 kA
Medium	4 kV	2 kA
Low	2 kV	1 kA

Derived from original work in IEEE C62.41-1991 and UL 1449 and reproduced from BS 6651:1992

FIGURE 41 – Mains power supply – Category A

System exposure level	Peak voltage	Peak current
High	6 kV	500 A
Medium	4 kV	333 A
Low	2 kV	167 A

Derived from original work in UL 1449 and reproduced from BS 6651:1992

FIGURE 42 – Data lines – Category C

System exposure level	Peak voltage	Peak current
High	5 kV	125 A
Medium	3 kV	75 A
Low	1.5 kV	37.5 A

Derived from original work in CCITT IX K17 and reproduced from BS 6651:1992

Protector performance

These location categories and their probable worst case transients, provide us with a yardstick with which to evaluate protectors.

Subjecting the protector to an appropriate transient test enables us to determine whether it will survive. The protectors let-through voltage for this test tells us its transient control level. Let-through voltage is a measure of the amount of the transient overvoltage which gets past, or is let-through, the protector.

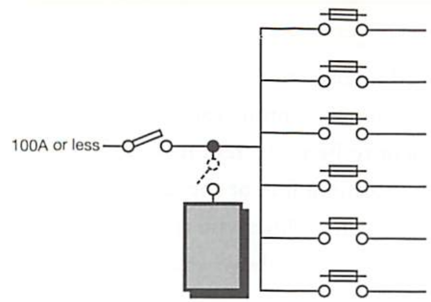


FIGURE 62 – Protector connected, via an optional isolator, to the incoming side of a supply rated at 100 amps or less

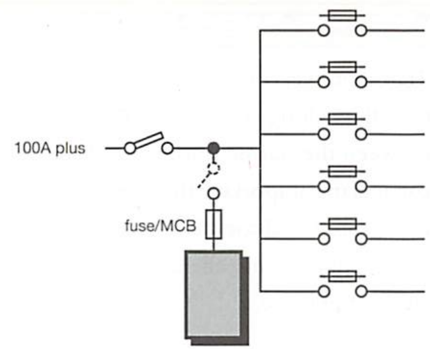


FIGURE 63 – Protector connected, via a 63 or 100 amps HRC fuse or 63 amps MCB and an optional isolator, on the incoming side of a supply rated at more than 100 amps

When transients are expected from the load, then a protector should also be installed on the outgoing way feeding that load (see Figure 64).

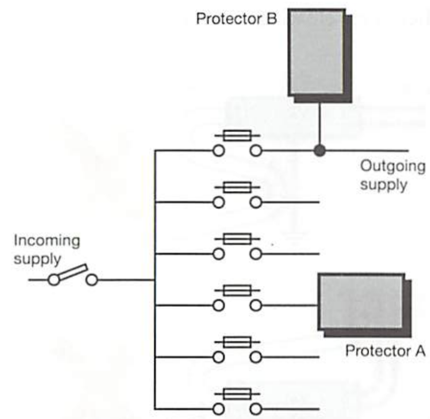


FIGURE 64 – Protector (B) connected to prevent transients from the load. As before, a protector (A) is connected to prevent transients on the incoming supply

Neutral connection

Many parallel connected mains protectors must have a neutral connection. If such a unit is to be installed where no neutral bar is available (eg delta supplies) then the protectors neutral terminal should be connected to the earth bar.

Residual current devices (RCD)

Where the power distribution system incorporates RCD units, there is a danger of the RCD being triggered by transient activity. RCDs installed before protectors could therefore open circuit the supply causing power loss. RCDs installed on the load side of protectors will be less susceptible to tripping caused by transients. (To prevent this problem special transient immune RCDs should be used.) Protectors should only be installed on the load side of RCDs if the load in question represents a transient source.

A 63 or 100 amps fuse will stand approximately 20kA of transient current. Furse ESP mains wire-in protectors are typically rated for a maximum transient current of 20kA. Thus, fusing the connecting lead(s) will not significantly impair the protectors performance (unless fuses of less than 63 amps are used).

Isolation

Use of a switchfuse rather than a fuse, or if no fuse is necessary, an isolator, enables the protector to be isolated for maintenance or insulation/flash testing. To fully isolate the system, a switched neutral is desirable.

Connection point

Protectors installed on power distribution systems are typically connected either on the incoming supply to the distribution board or on an outgoing way.

When the expected transient is coming from the supply side (as in most cases), the protector can be installed on the first outgoing way of the distribution board (as an alternative to the incomer). See Figures 59, 60, 61, 62 & 63.

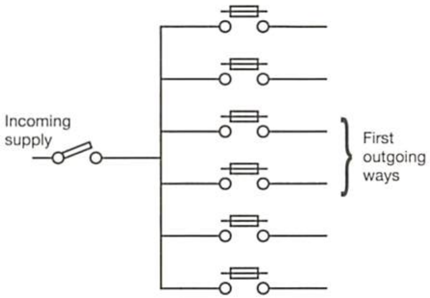


FIGURE 59 – Schematic drawing of a power distribution board, with six outgoing fuse, MCB or MCCB ways

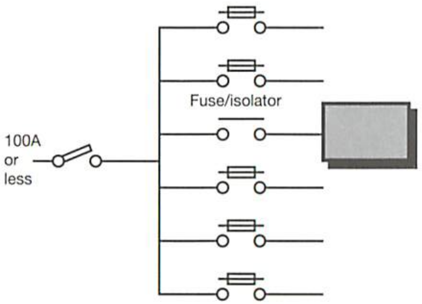


FIGURE 60 – Protector connected, via isolator or 63 amps HRC fuse, to the first outgoing way of a supply rated at 100 amps or less

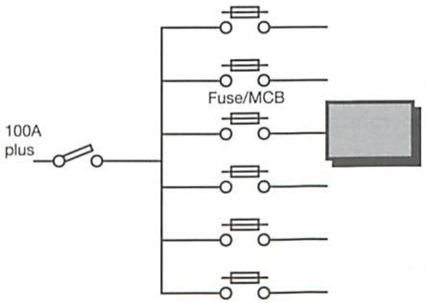


FIGURE 61 – Protector connected, via 63 or 100 amps HRC fuse or 63 amps MCB, to the first outgoing way of a supply rated at more than 100 amps

Thus, if a protector is required for a mains power distribution board (Category B) in a high exposure level, it should be able to repeatedly survive a transient of 6kV and 3kA. Its let-through voltage when injected with this 6kV, 3kA transient, should be no greater than the desired transient control level.

The let-through voltage of a protector also takes into account its response time. Protectors with slow response times will have consequently higher let-through voltages. Response times are only of significant importance when dealing with very fast transients such as NEMP.

BS 6651:1992 Appendix C, suggests that manufacturers of transient protectors should provide the following information about their products.

Let-through voltage

The protectors let-through voltage should be quoted against a given test, eg 600V (live-neutral, neutral-earth, live-earth), 6kV 1.2/50μs, 3kA 8/20μs, BS 6651:1992 Category B-High.

Let-through values should be the result of tests conducted on the complete protective circuit – it should not be a theoretical value derived from the performance of one or more components.

For mains power protectors, testing should be conducted on the following basis:

Category C and B – a combination wave generator should be used capable of producing 1.2/50μs voltage and 8/20μs current waveforms, in accordance with Figures 39 & 40. IEEE C62.41-1991, UL 1449 and AS 1768-1991 all contain similar tests.

Category A – a combination wave generator should be used, incorporating a non-inductive output resistor. The generator will be capable of producing a 1.2/50μs voltage waveform and current waveform which will deviate from the normal 8/20μs, in accordance with Figure 41. This test is also detailed in UL 1449. (IEEE C62.41 and AS 1768 both use a different, ring wave, test for Category A tests.)

For data line protectors, a generator capable of producing 10/700µs waveshapes in accordance with Figure 42, is used. This is described in Figure 1 of CCITT IX K17.

Transient overvoltage testing is discussed further in Appendix C.

Modes of protection

Transients can occur between any combination of conductors. Manufacturers should therefore make quite clear, which modes of transient propagation let-through performances relate to, eg:

- live/phase(s) to earth, live/phase(s) to neutral and neutral to earth for mains power supplies
- line to line and line(s) to earth for data lines.

Maximum surge current

This is the maximum transient current the protector can withstand, eg 20,000 amps, 8/20µs. Again this is a test value for the whole protector and not a theoretical value.

The maximum surge current of the protector also takes account of its energy handling capability. Energy ratings, as a sole indicator of protective performance are misleading, since the energy deposited in a protector by a transient current source depends upon the suppression level (ie let-through voltage). Thus, lower energy ratings don't necessarily mean that the protector is less likely to survive.

High impulse current – data lines only

The international telecommunication standard also calls for high impulse current testing of data line protectors for telephone lines. This test (within CCITT IX K12) is intended to test the capability of the gas discharge tube(s) present in most data line protectors. Test levels are shown in Figure 43.

FIGURE 43 – High impulse current tests

System exposure level	High impulse current
High	10 kA
Medium	5 kA
Low	2.5 kA

Derived from original work in CCITT IX K17 and reproduced from BS 6651:1992

A combination wave generator capable of producing 1.2/50µs voltage and 8/20µs current waveforms, should be used to apply this test.

Many text books state that the inductance of a cable is 1.2 or 1.0µH/metre, and the table shows these rules of thumb to be valid for practical cable sizes.

It should be noted, that the very large cable (100mm^2) gives some improvement. However, in practice use of such a large cable would increase cable length due to the physical difficulty of terminating and routeing such a large conductor. This will in many cases nullify any advantages gained.

So, provided that a reasonable cable size is used (ie larger than 2.5mm^2) then voltage drops due to transient overvoltages will be inductive in nature and not resistive.

Other minor effects, such as a skin effect also occur, but are of little significance at these frequencies.

Although the preceding example relates to a parallel protector, the same fundamental principles apply to the earth lead of a series protector.

Other aspects of the installation of parallel protectors for mains power

Protective fuses

Parallel connected protectors for mains power supplies generally contain internal protection. However, as a matter of general electrical safety the parallel connecting leads may also require protection.

Protectors can be connected without fusing, to supplies of 63 amps or less when using 4mm^2 conductor and to supplies of 100 amps or less with 10mm^2 conductor. Since a parallel connected mains protector draws a negligible current, these cable ratings are based on fault clearance values and not on continuous operating values.

On larger supplies than these, live/phase connecting leads must be protected with a suitable fuse (or MCB or MCCB). This is to protect the connecting leads (not the protector) in the event of a short circuit.

A 4mm^2, or greater, cable can be used on the load side of a 63 amps fuse, whilst 10mm^2 cable can be used on the load side of a 100 amps fuse. The cable between the supply and the fuse should be rated in accordance with normal wiring regulation practice.

Where even 4 metres of connecting lead is not sufficient, the data line should be re-routed to bring it within 4 metres of the earth. If this is not possible, the protector can be connected to the electrical earth local to the equipment being protected (eg the earth bar of the local power distribution board).

Can the voltage drop in the connecting leads be eliminated by increasing the lead's cross sectional area?

Increasing conductor size to reduce voltage drop is an attractive idea. However, in practice, it makes little difference.

Consider, for example, a protector connected in parallel to a mains power supply, with two 50cm connecting leads and diverting 3,000 amps (8/20µs) current. The resistive voltage drop on 1 metre of cable is tabulated in Figure 57, for a range of cable sizes.

FIGURE 57 – Resistive voltage drop

Cable size (mm²)	Resistive voltage drop (volts)
1	51.6
2.5	20.6
4	12.9
6	8.6
10	5.16
100	0.516

If these resistive voltage drop (or V_L) values are applied to a protector with a let-through of 600 volts, even the use of 1mm² connecting leads will not cause an unacceptable voltage to reach equipment. In reality, such small cable is unlikely to be used and would in any case contravene good practice. Whilst increasing conductor size will reduce resistive voltage drop the use of large conductors is not beneficial, since the problem is not one of a resistive voltage drop.

The real problem is inductive voltage drop. Figure 58 shows inductive voltage drop for a range of conductor sizes. (It should be noted that the calculation is an approximate one based upon a 8/20µs waveform but assuming a straight rising edge.) It can clearly be seen that the inductive voltage drop is disproportional to cable size. A dramatic (ten fold) increase in cross sectional area is required for a relatively small decrease in voltage.

FIGURE 58 – Inductive voltage drop

Cable size (mm²)	Inductance (µH)	Inductive voltage drop (volts)
1	1.2	450
2.5	1.1	376
4	1.1	376
6	1.0	342
10	1.0	342
100	0.7	239

The subject of transient overvoltage simulation and testing is discussed in greater detail in Appendix C.

System impairments and compatibility – performance in the passive state

Any factor that may interfere with the system during normal operation should be quoted. These may include the following:

- nominal operating voltage
- maximum operating voltage
- leakage current
- nominal current rating
- maximum continuous current rating
- in-line impedance (or resistance)
- shunt capacitance
- bandwidth
- voltage standing wave ratio (VSWR) or reflection coefficient

FIGURE 44 – General indication of potential system impairments which manufacturers of transient overvoltage protectors should provide details of

	Protectors for mains supplies		Protectors for data lines		
	Parallel protectors	In-line protectors	Low frequency protectors	Network protectors	Radio frequency protectors
Nominal operating voltage	✓	✓	✓	✓	✓
Maximum operating voltage	✓	✓	✓	✓	✓
Leakage current	✓	✓	✓	✓	✓
Nominal current rating	✗	✓	✓	✓	✓
Max continuous current rating	✗	✓	✓	✓	✓
In-line impedance	✗	✗	✓	✓	✓
Shunt capacitance	✗	✗	✗	✓	✓
Bandwidth	✗	✗	✓	✓	✓
Voltage standing wave ratio	✗	✗	✗	✓	✓

Figure 44 summarises potential causes of incompatibility or system impairment for different types of power and data line protectors. Protector manufacturers should therefore document values for their protector for all the characteristics indicated.

The question of the protector being incompatible with the system it is trying to protect, most commonly arises with data communication, signal and telephone systems.

However, when a mains power protector is based on a gas discharge tube connected across the supply, operation of the gas discharge tube can short circuit the supply. The large mains current flowing through the tube is likely to destroy the tube and disrupt the power supply.

Specification for lightning & transient overvoltage protection

A number of products are available which claim to protect electronic equipment against lightning and transient overvoltages. However, testing shows many of these to have an unacceptably high let-through voltage. This can prove disruptive and harmful to electronic equipment.

The only way to be sure of getting truly effective protection is to explicitly specify Furse ESP, by name. Where company/organisation policy forbids this, use of the specification which follows will reduce the likelihood of you ending up with ineffective protection.

Explanation of key requirements

In order to provide effective protection, a transient overvoltage protector should:

- be compatible with the system it is protecting
- survive
- have a low let-through voltage, for all combinations of conductors
- not leave the user unprotected, as a result of failure, and
- be properly installed.

Compatibility. It is important that the protector does not interfere with or restrict the system's normal operation.

- It is undesirable for mains power supply protectors to disrupt or corrupt the continuity of power supply and for them to introduce high earth leakage currents.

Minimising voltage drops in series connected protectors

Keep the barrier earth bond as short as possible

It is imperative that the connecting lead from the protector to earth (the 'barrier earth bond') is kept as short as possible for the reasons previously outlined. (Figure 50 on page 56 shows the typical connection of a series protector on a data communication line.)

Standards give us worst case transient overvoltages of 5kV 10/700µs with a 125A current, on data lines. This makes the requirement for short connecting leads a little less onerous than on mains power supplies. We recommend a maximum of 1 metre for the barrier earth bond on a Furse ESP Lightning Barrier for twisted pair lines. Although a shorter lead should be used if at all possible.

BS 6651 recommends that all services enter the building in general proximity. Thus, incoming data lines should be in the same area as the incoming power supply, the main distribution board and hence the main earth bar, facilitating short barrier earth bonds.

Accommodating barrier earth bonds of more than 1 metre

If a 1 metre barrier earth bond cannot be achieved, lengths of 2, 3 or 4 metres can be accommodated by using 2, 3 or 4 parallel, segregated, barrier earth bonds.

This can be done because inductance and hence inductive voltage drop is related to the magnetic field around a conductor, which relates to the current flowing through it. As the number of conductors increases, the current and hence the inductive voltage drop decreases. For this principle to apply, the magnetic fields must be separate, which is why the barrier earth bonds must be segregated. (A minimum distance of 5cm between parallel conductors, is suggested.) Note, there is a diminishing return in the improvement obtained for each additional conductor and lengths of more than 4 metres are not recommended.

Occasionally, both the data line protectors and the main earth bar are located on a large metal sheet. Where this is so, the protectors should be bonded to the sheet (which in turn should be bonded to the earth bar), to take advantage of the sheet's inherently low inductance.

and cancel. Since inductance relates to magnetic field it too tends to be cancelled. In this way, binding leads closely together reduces the voltage drop in cables.

Accommodating connecting leads exceeding 25cm

It is not always possible to keep connecting leads less than 25cm long. In this case, the technique of using two parallel sets of bound conductor allows use of cable lengths of up to 50cm.

We know from the previous discussion that a well bound 25cm length of conductor has an acceptable voltage drop. It follows that a length of cable twice as long will have approximately twice the voltage drop. However, by introducing a second parallel, segregated bundle of conductors, we can bring the voltage drop back down to acceptable levels. This is because inductive voltage drop relates to magnetic field strength, which in turn relates to current. With two bundles of cable (Figure 56) each will only carry half the overall current.

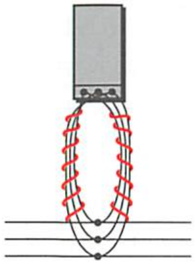


FIGURE 56 – Two tightly bound, parallel sets of segregated conductors

In practice protectors for mains power supplies are usually mounted on or in, power distribution boards. One problem which can occur is that the earth lead needs to be significantly longer than the phase and neutral connections and longer than 25cm. Once again, this can be achieved through the use of two connecting leads. This can be done in one of two ways.

For metal cabinets or distribution boards one conductor should be closely bonded to the metal of the panel, whilst the other should be connected directly to the earth bar. This, in turn, should be bonded directly to the metal of the panel. Transient current can now flow through the metal back of the distribution board. Since this is a plate and not a wire, it has the inherently useful property of having a low inductance, which helps to keep the let-through voltage low.

If this is not possible, two connections can be made to the earth bar. One of these should be within the set of bound conductors, whilst the other should be separate.

- Protectors for data communication, signal and telephone lines should not impair or restrict the systems data or signal transmission. (See also Figure 44 and 'Systems impairments and compatibility', earlier.)

Survival. Although lightning discharges can have currents of 200kA, transient overvoltages caused by the secondary effects of lightning are unlikely to have currents exceeding 10kA. The protector should therefore be rated for a peak discharge current not less than 10kA.

Let-through voltage. The larger the transient overvoltage reaching the electronic equipment, the greater the risk of interference, physical damage and hence system downtime. Thus, the transient overvoltage let-through the protector should be lower than the level at which interference or component degradation may occur.

Modes of protection. A transient overvoltage can exist between any pair of conductors; phase and neutral, phase and earth, neutral and earth on mains power supplies; line to line, line to screen/earth on data communication, signal and telephone lines. Thus, the transient overvoltage protector should have a low let-through voltage for all combinations of conductors. (These are shown in Figures 45, 46 & 47.)

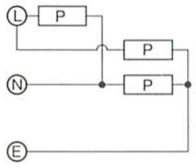


FIGURE 45 – Modes of protection (P) for single phase mains power supply

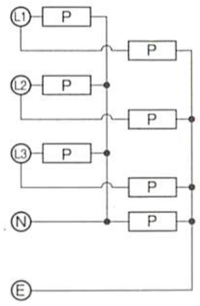


FIGURE 46 – Modes of protection (P) for three phase mains power supply

Protection failure. When in-line protectors (such as those for data communciation, signal and telephone lines) fail, they take the line out of commission, thereby preventing damage to the system. However, it is unacceptable for protectors on mains power distribution systems to fail short circuit. If these protectors suddenly fail they will leave the system unprotected. It is therefore important that protectors for mains power distribution systems have a properly indicated pre-failure warning, whilst protection is still present.

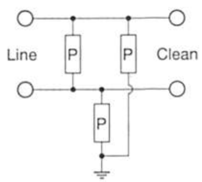


FIGURE 47 – Modes of protection (P) for data communication, signal or telephone lines

Note. Data line protectors usually include some line resistance or impedance, which is omitted from the above for clarity.

Installation. The performance of transient overvoltage protectors is heavily dependent upon their correct installation (eg the length and configuration of connecting cables). Thus, the transient overvoltage protector must be supplied with documentation detailing the installation practice. The installer is required to conform with these installation instructions.

Specifying protection for mains power distribution systems

1 Transient overvoltage protectors should be installed on all power cables entering or leaving the building, in order to protect equipment connected to the power distribution system against transient overvoltages coming into the building from outside.

2 Protectors should also be installed at local power distribution boards feeding vulnerable equipment, in order to protect these against transients generated downstream of the protectors in 1, above. (These transients may be the result of inductive coupling or electrical switching.)

3 Protectors shall be tested in accordance with the requirements of:
BS 6651:1992 'Protection of structures against lightning' (Appendix C),
BS 2914:1972 'Specification for surge diverters for alternating current power circuits',
IEEE C62.41 - 1991 'Recommended practice on surge voltages in low voltage AC power circuits'.

4 Protectors for a given Location Category shall be rated for a High Exposure Level (as defined by BS 6651:1992), unless contrary information is available.

5 The protector must not interfere with or restrict the system's normal operation. It should not:
- corrupt the normal mains power supply
- break or shutdown the power supply during operation
- have an excessive earth leakage current.

6 The protector shall be rated for a peak discharge current of no less than 10kA (8/20 microsecond waveform).

7 The protector shall limit the transient voltage to below equipment susceptibility levels. Unless otherwise stated, the peak transient let-through

Minimising voltage drops in parallel connected protectors

Keep the connecting leads as short as possible

Inductance and hence inductive voltage drop is directly related to cable length. The shorter the cable length the lower the voltage drop. Thus connecting leads should be kept as short as possible. As a guide we state a maximum length of 25cm for any one connecting lead to the Furse ESP 240/415.

> **WARNING** If a protector is installed with excessively long connecting leads, then it will impair the protectors performance to the extent that the protector becomes ineffective.

Bind cables tightly together

In addition to keeping cables short, they should be tightly bound together over as much of their length as possible, using cable ties, adhesive tape or spiral wrap. This is very effective at cancelling inductance.

Inductance is associated with the magnetic field around a wire. The size of this field is determined by the current flowing through the wire (Figure 53). A wire with the current flowing in the opposite direction will have a magnetic field in the opposite direction (Figure 54).

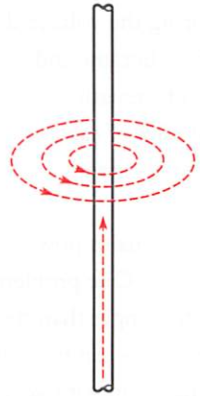


FIGURE 53 – Magnetic field caused by a current flow

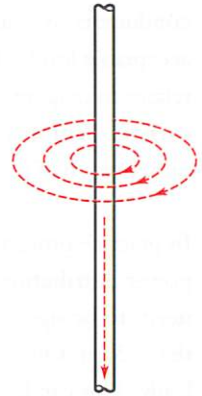


FIGURE 54 – Magnetic field caused by an opposite current flow

A parallel connected protector will, during operation, have currents going in and out of it in opposing directions and thus connecting leads with opposing magnetic fields (Figure 55). If the wires are brought close together, the opposing magnetic fields interact

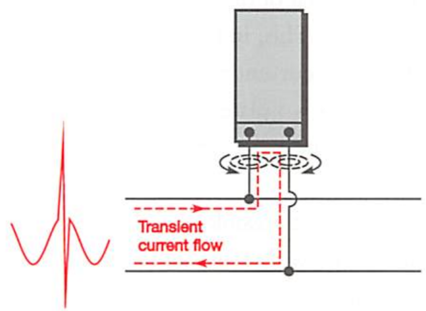


FIGURE 55 – The connecting leads of a parallel protector have opposing current flows and hence magnetic fields

To demonstrate the effects of long and unbound connecting leads we applied a 6kV, 3kA test to a wire-in Furse ESP protector for 230-240 volts mains power supplies. The protector has got a let-through voltage of 600 volts when measured across its terminals, of 630 volts with recommended lengths of bound connecting lead and of 1,200 volts with unacceptably long, 2 metre, bound connecting leads. If these connecting leads are left unbound, then the let-through voltage rises to 810 volts with recommended connecting leads, and to 2,300 volts with 2m leads. See Figure 49.

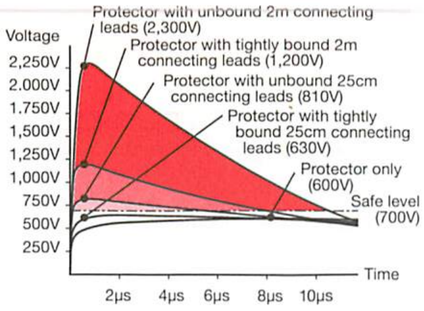


FIGURE 49 – Effect of poor installation on let-through voltage

Lightning Barriers for data communication, signal and telephone lines are usually installed in the line they are protecting. Figure 50 shows this type of 'series' installation. This type of protector behaves differently with line to line transients than with line to earth transients.

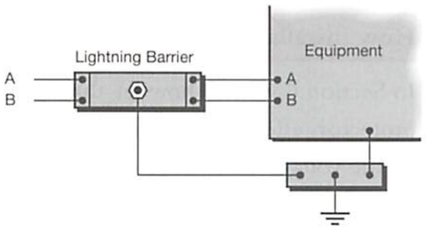


FIGURE 50 – Series installation of a Lightning Barrier for data communication, signal or telephone lines

A line to line transient between A & B (see Figure 51) is reduced to a let-through voltage of V_P. In this case there is no voltage related to the earth lead.

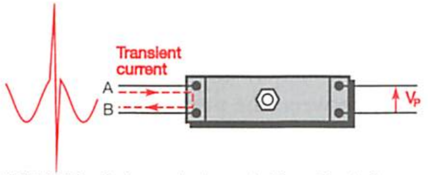


FIGURE 51 – Series protector controlling a line to line transient

However, for line to earth transients there will also be a voltage (V_L) between the protector and earth (see Figure 52). In this case the voltage reaching the equipment will be the let-through voltage of the protector (V_P), plus the voltage associated with the connecting lead (V_L).

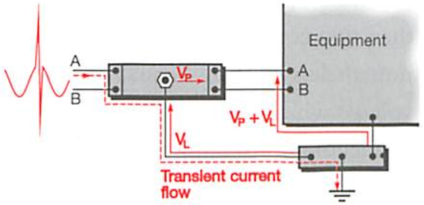


FIGURE 52 – Series protector controlling a line to earth transient

voltage shall not exceed 600 volts, for protectors with a nominal working voltage of 230 or 240 volts, when tested in accordance with BS 6651:1992 Category B – High (6kV 1.2/50 microsecond open circuit voltage, 3kA 8/20 microsecond short circuit current).

8 This peak transient let-through voltage shall not be exceeded for all combinations of conductors:
- phase to neutral
- phase to earth
- neutral to earth.

9 The protector should have continuous indication of its protection status. Status indication should clearly show:
- full protection present
- reduced protection – replacement required
- no protection – failure of protector.

10 Remote indication of status should also be possible via a volt free contact.

11 The status indication should warn of protection failure between all combinations of conductors, including neutral to earth. (Otherwise a potentially dangerous short circuit between neutral and earth could go undetected for some time.)

12 The protector shall be supplied with detailed installation instructions. The installer must comply with the installation practice detailed by the protector manufacturer.

Specifying protection for data communication, signal and telephone lines

1 Transient overvoltage protectors shall be installed on all data communication/signal/telephone lines entering or leaving the building, in order to protect equipment connected to the line, against transient overvoltages. (Where data lines link equipment in separate buildings, transient overvoltage protectors should be installed at both ends of the line in order to protect both pieces of equipment.)

2 Protectors shall be tested in accordance with the requirements of:
BS 6651:1992 'Protection of structures against lightning' (Appendix C),
CCITT IX K17 'Tests on power fed repeaters using solid-state devices in order to check the arrangements for protection from external interference'.

3 Protectors shall be rated for Location Category C - High Exposure Level (as defined by BS 6651:1992), unless contrary information dictates a lower Exposure Level.

4 The protector must not impair the system's normal operation. It should not:
- suppress the system's normal signal voltage
- restrict the system's bandwidth or signal frequency
- introduce excessive in-line resistance
- cause signal reflections or impedance mismatches (high frequency systems only).

5 The protector will have a low transient let-through voltage for tests conducted in accordance with BS 6651:1992 Category C – High (5kV 10/700 microsecond test).

6 This let-through performance will be provided for all combinations of conductors:
- signal line to signal line
- signal line to screen/earth.

7 The protector shall be rated for a peak discharge current of 10kA.

8 The protector shall be supplied with detailed installation instructions. The installer must comply with the installation practice detailed by the protector manufacturer.

9 The protector manufacturer should allow for the facility to mount and earth large numbers of protectors through an accessory combined mounting and earthing kit.

Effective installation technique

Detailed installation instructions are supplied with all Furse ESP units and are available separately upon request. This section is intended as a general discussion of installation technique and it should not be seen as a substitute for the relevant product installation instructions.

Is installation technique important?

Correct installation is vital. Not just for the obvious reasons of electrical safety but also because poor installation technique can significantly reduce the effectiveness of a protector.

How installation affects performance

In Section 6 we saw how let-through voltage is the primary measure of a protectors effectiveness. An installed protector has its let-through voltage increased by the voltage drop on its connecting leads.

If we consider a simple parallel connection, two lines are bridged with a protector (see Figure 48). The protector has a let-through voltage of V_P. There is also an additional voltage (V_L) between the protector and the lines. We can assume that V_L is shared equally between the two connecting leads. (Although in reality parallel connected protectors often have more than two connecting leads, V_L will nonetheless be shared equally between the conducting connecting leads.) The voltage which will reach equipment is therefore V_P plus V_L. Long, and unbound, connecting leads both contribute to larger V_L values. Thus, it is important that this variable V_L is kept as small as possible, through correct installation.

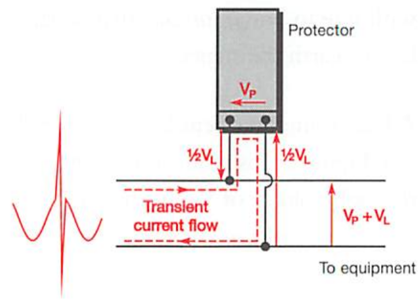


FIGURE 48 – Let-through voltage of a simple parallel protector