A thunder-storm can produce a magnificent display of light and noise. It can be an exhilarating experience to watch a storm in progress, especially out in the country, where it is sometimes possible to see the hill tops being struck by lightning. In the cities, buildings are sometimes struck, particularly if they are tall.

by Ian Poole

WHEN LIGHTNING STRIKES!

THE Empire State Building in New York is struck over a thousand times a year, and tall buildings in the UK also suffer. The British Telecom Tower in London also receives many direct strikes. Fortunately, tall buildings like these are designed to withstand direct strikes and they suffer little or no damage.

In some areas of the world, thunderstorms are far more frequent than they are here in Britain. In fact, over the whole of the globe, there are several thousand storms taking place at any one time, and about a hundred lightning-strikes every second. Some figures seem to suggest that the greenhouse effect may be causing storms to occur more often.

When storms occur, enormous amounts of energy are unleashed. Houses, trees, and any other structures which are hit can be severely damaged if they are not properly protected. Despite the fact that storms occur on about ten days in each year in Britain and there are many discharges in each storm, comparatively few houses are struck. However, even without a direct strike, these electric storms can still cause considerable amounts of damage and inconvenience, especially to sensitive electronic equipment.

Possibly the most obvious possibility for damage is seen by television and radio equipment. Even without a direct strike, considerable voltages can be induced in aerials. For

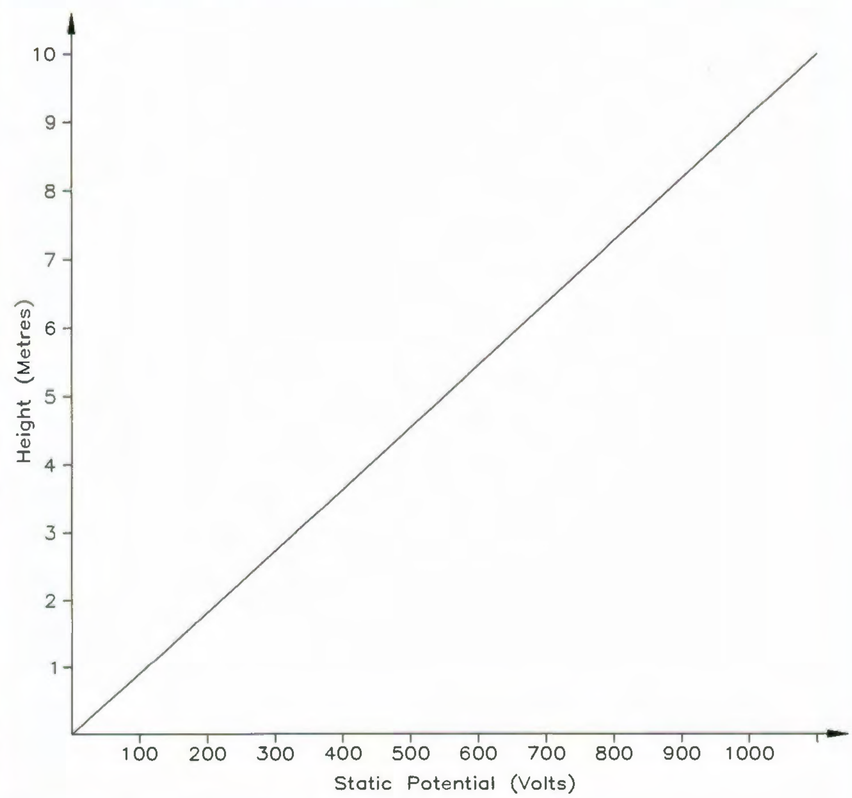


Figure 1. Voltage gradient on a normal day

short wave aerials, the voltages induced can reach several hundred volts, even when the discharge is a mile or more away.

Another way in which lightning can cause problems, is when power lines are struck. This energy can travel along the supply system, resulting in large voltage spikes appearing at the input to sensitive equipment. Near strikes can also induce large voltages into wiring, which can be equally damaging. These aspects are becoming increasingly important where computers are concerned. Spikes and surges of this nature can cause damage to equipment or possibly more importantly, it can cause data to become lost or corrupted, losing many hours of valuable work.

However, before looking at ways of protecting against the effects of lightning, it is interesting to look at how the storms arise, and how a lightning strike occurs.

A Normal Day

During an electric storm, some enormous voltages are generated. However, even on a normal day, there is a large electrostatic voltage gradient. It is normally around 100V/m, as shown in Figure 1. It is caused by the charged particles entering the atmosphere from the sun, and it means that the ionosphere is held at a colossal voltage above the earth.

The Storm

Thunder-storms can occur in a number of ways. Generally, they are associated with hot summer days, but they can also appear at other times of the year and even in winter, when it is colder. There are two main types of storm. The most familiar occurs on a hot summer's day, and it gives plenty of warning of its arrival. It needs hot, still air, which rises in small or local thermals, carrying with it huge quantities of water. Because the air is still, these thermals remain well-defined, and rise to considerable heights. As the air rises, it cools and the water condenses, forming a type of cloud known as cumulo nimbus. These clouds can be seen in the distance as great dark storm clouds, rising very high into the air. In fact, the top of these clouds can be many miles high. Inside them, it can be very violent, as some small aircraft have found to their peril. As the air is still, these storms move very slowly, and can last for a number of hours.

The second type of storm can occur at any time of the year, and it is associated with a frontal system of air. The approach of the cool air causes the warmer air to be pushed out of the way rapidly. In turn, this causes much of the warmer air to rise very quickly, and the turbulence this causes can result in thunder-storms. As these fronts have to be fast-moving to cause thunder, the storms that they generate do not stay in any place for long and appear to be short-lived. Even so, they still produce quite a lot of electrical activity.

Storm Voltages

Thunder-storms drastically alter the normal voltage gradient which exists in the atmosphere on a normal day. The steadily increasing positive voltage is totally disrupted. The bottom of a thunder-cloud is negatively charged with respect to the earth, but the top of the cloud is positively charged. The cloud grows as the thermals bring in all the new water vapour. As a result of the condensation of these colossal amounts of water, heat is released high up in the cloud, which increases the thermals and further water is carried up even higher. Eventually, the top of the cloud freezes. This point may be several miles high and the potential many millions of volts above the Earth, see Figure 2. The matter is complicated still further by the fact that positively charged hailstones from the top of the cloud start to fall and meet the warm rising air. This results in a cold, positively charged centre to the storm, surrounded by a negatively charged area.

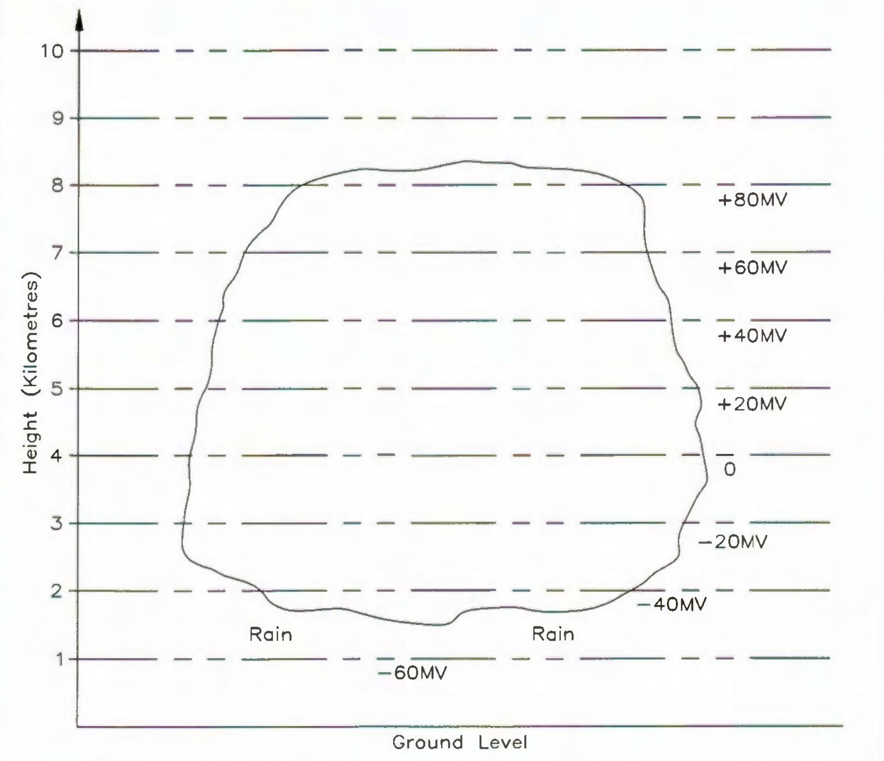


Figure 2. Charge associated with a thunder-cloud

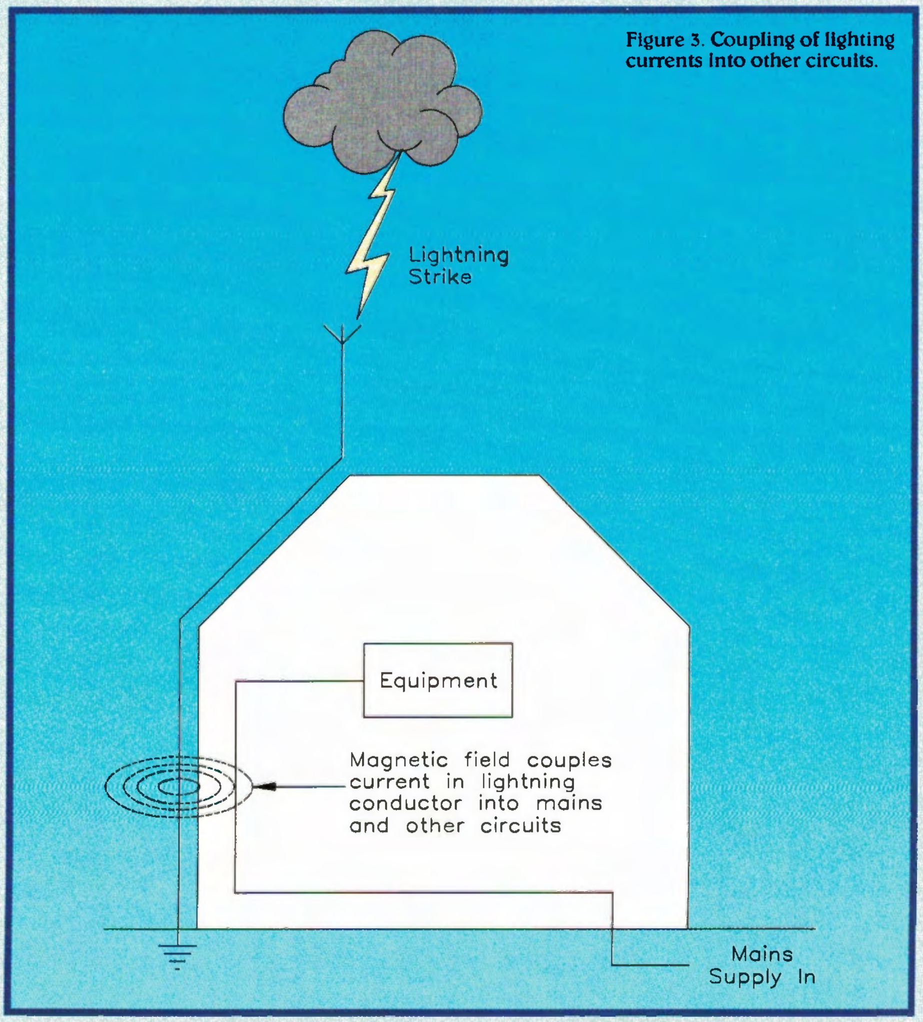


Figure 3. Coupling of lighting currents into other circuits.

These potential changes can be detected quite easily by an electrometer, which can be used to monitor the onset of a storm. Whilst the storm is still some distance away, the normal voltage gradient will exist and the electrometer will register a positive reading. Then, as the storm clouds are still some way off, the reading will start to fall. In fact, these variations can be detected up to 15 miles away on the most sensitive instruments.

As the storm-clouds approach, the readings will fall still further, and actually change from positive to negative. With the onset of rain, there is a very sharp transition from negative back to positive. This can happen in a matter of seconds, and the actual potential reached can be quite large, often reaching several thousand volts per metre.

Lightning Formation

Lightning is formed because the voltage gradient becomes so high that the air actually breaks down, and current flows. However, the way in which this happens is not as straightforward as might be expected. The lightning consists of two main parts. The first is known as a leader. Under the cloud, there is a lot of turbulence, and this causes areas of high charge to occur. This results in the areas where the voltage gradient becomes so steep that the air actually breaks down, and a path of about 50m becomes ionized. This in turn, brings the electrical bottom of the cloud down by this amount. The process is repeated many times and each time, the stroke progresses towards the ground. Not all leaders continue to the ground, and many split into several tracks. This is why photographs of lightning usually show one main track of ionization, with several leaders which end without reaching the earth.

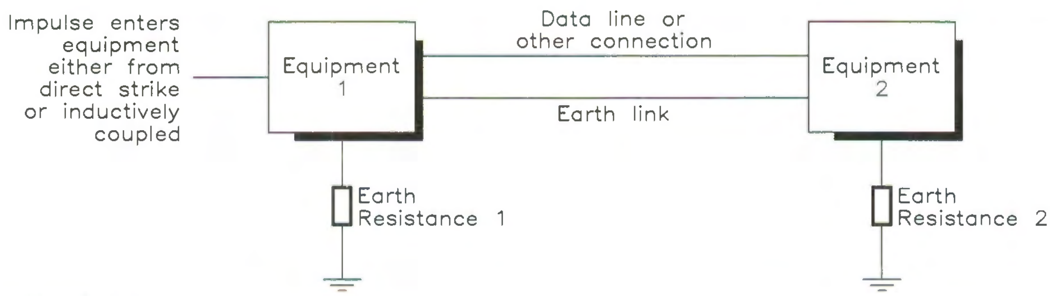


Figure 4. Earth current sharing.

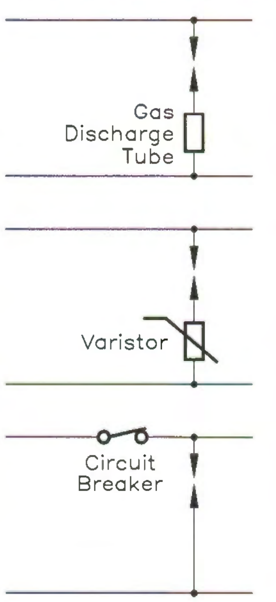


Figure 5. Methods of overcoming the follow current.

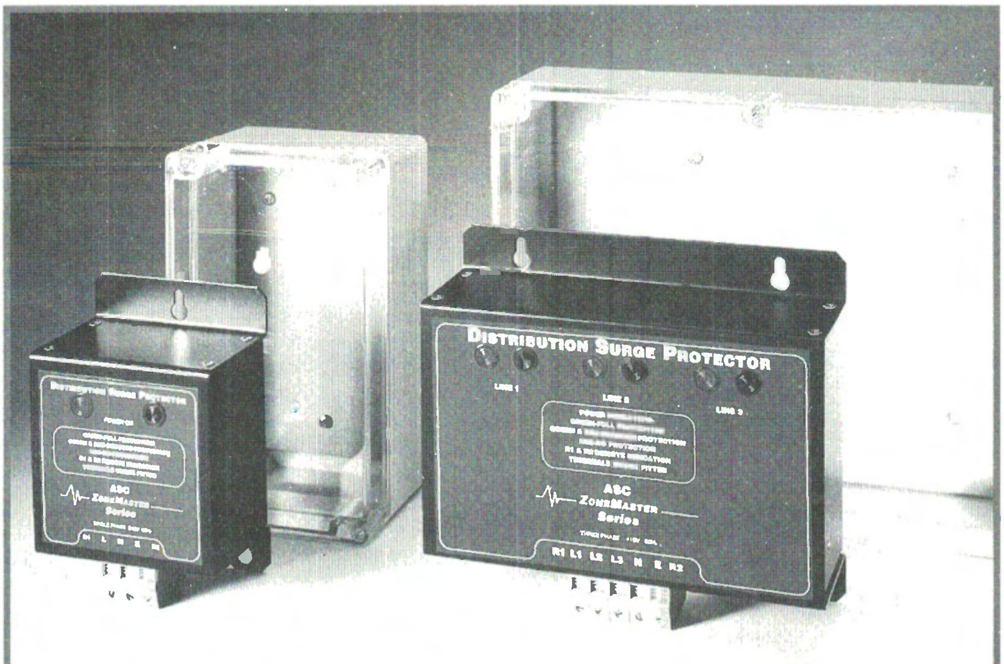


Photo 1. Distribution surge protector units.

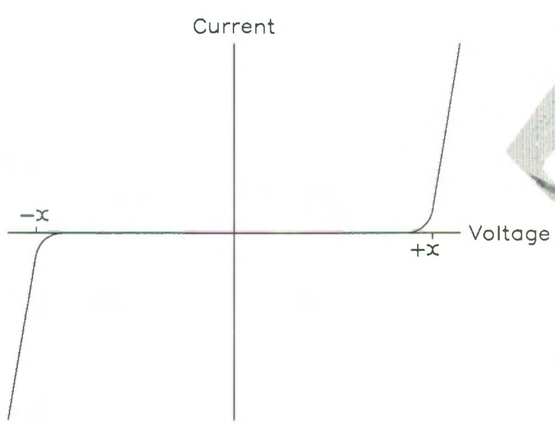


Figure 6. Response curve of a metal oxide varistor.

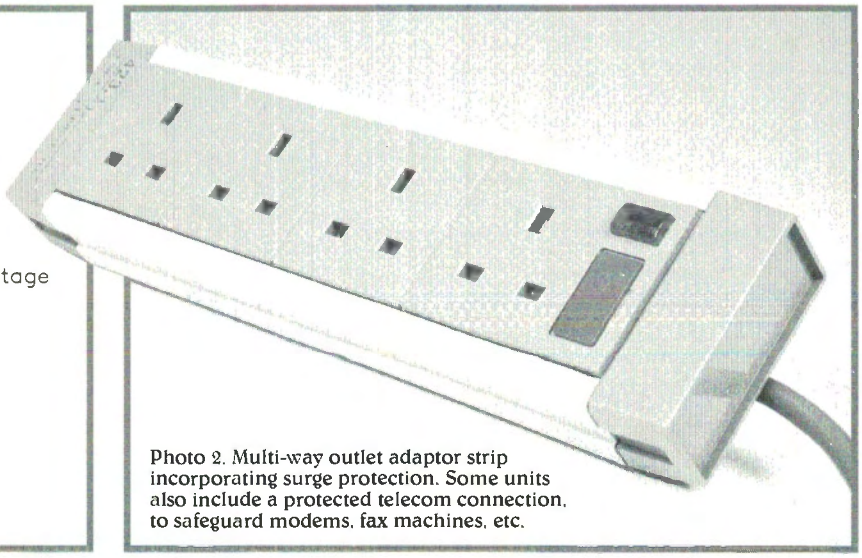


Photo 2. Multi-way outlet adaptor strip incorporating surge protection. Some units also include a protected telecom connection, to safeguard modems, fax machines, etc.

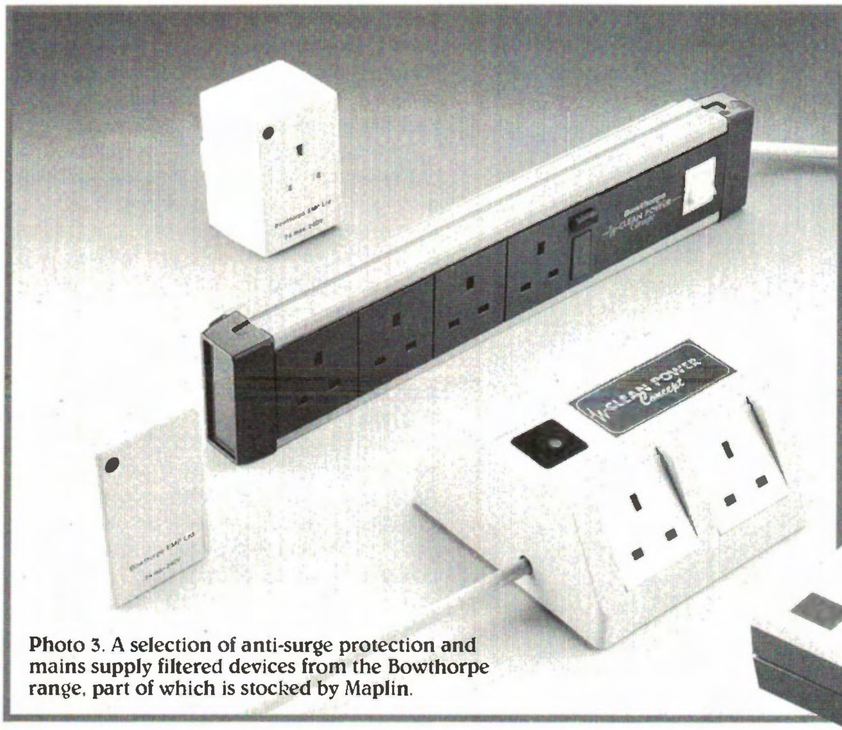


Photo 3. A selection of anti-surge protection and mains supply filtered devices from the Bowthorpe range, part of which is stocked by Maplin.

Below: Photo 4. Bowthorpe type 023 4-way outlet adaptor strip, with built-in surge protection.

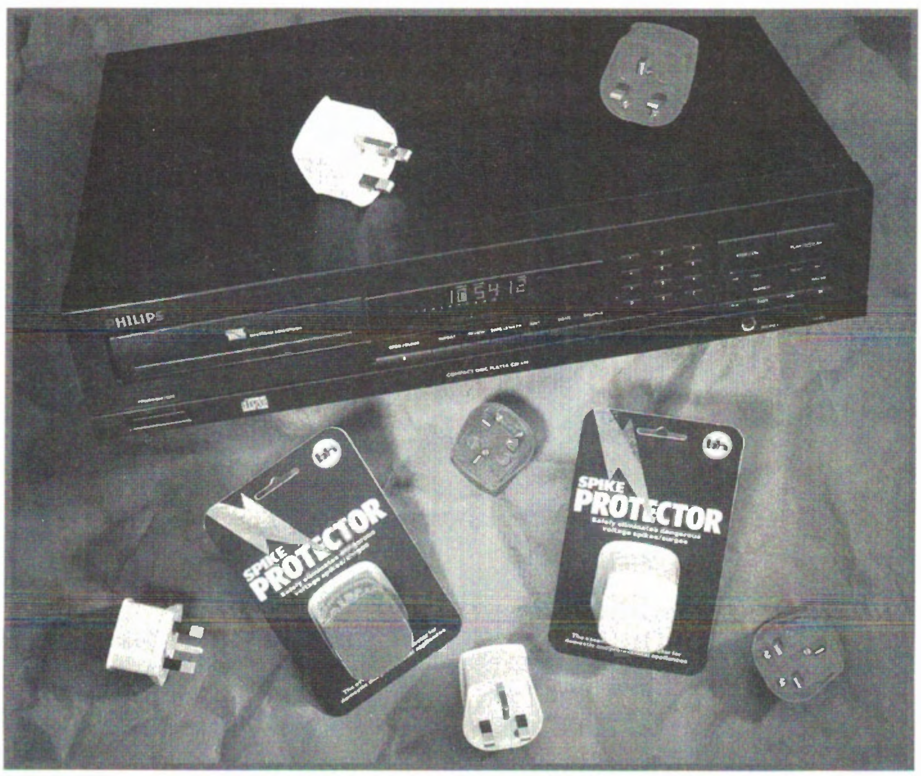
Bottom left: Photo 5. Spike/surge protector plugs are a convenient way of protecting sensitive mains-powered electronic equipment, wherever they may happen to be in use.

When the leader nears the ground, it induces an opposite charge generating upward-moving leaders from the ground. These travel upwards from the tallest points in the vicinity, to meet the leader from the cloud. The two strokes meet at a point which is usually about 50-60m above the ground, often the one from the tallest object reaching the downward leader first. When this occurs, there is a short-circuit path between the cloud and the ground. It is at this point that the main discharge occurs, with a current flowing upwards from the ground to the cloud. Potential differences in excess of several hundred million volts are involved, and peak currents between about 10,000 to 100,000 can flow.

The colossal current flowing gives rise to the dissipation of massive amounts of heat. This causes the air in the immediate vicinity of the conduction channel to rise to temperatures in excess of 20,000°C. This enormous rise in temperature causes the air to expand along the whole length of the stroke. This occurs very rapidly and sets up a shock wave, which moves outwards to give the characteristic sounds of thunder.

The lightning stroke is completed very quickly. The leader is the slowest, travelling at a speed of around three hundred miles a second. The main discharge is much faster. This travels at a speed of about 37,500 miles a second. The stroke is also over very quickly. It only takes about 10μs for the current to rise to its peak value, with current densities of over 1,000A/cm^2.

After the main stroke has been completed, there is a possibility that a large amount of charge still remains. In this case, a second discharge may take place. This can occur a few milliseconds after the first discharge is completed. A leader propagates down the original path, completing the circuit to ground, whereupon the second stroke occurs.



Effects of Lightning

Electronic equipment can easily suffer damage in an electric storm. This can happen in a number of ways. The most obvious occurs when the equipment of a cable leading to it suffers a direct strike. Fortunately, this occurs comparatively infrequently, as the effects are disastrous.

The secondary effects of a lightning-strike are far more common. For example, lightning may strike a high voltage power line. When this occurs, a large surge will be sent down the power line. Although there are lightning arresters installed in the power system, some of the surge can still get through to the normal 230V distributed mains supply. Spikes of several kV appearing at the mains outlet can arise on occasions. Fortunately, much of the distribution wiring in the UK is below ground (apart from the grid distribution system itself), and the effects of strikes are often dissipated by the time they reach the consumer.

Surges can also be created in other ways. Near strikes, or those which hit lightning-arresters, can generate surge voltages in power cables and data lines either capacitively or inductively. Also, imperfect earthing can cause currents to flow along data lines connecting two pieces of equipment.

If there is any coupling between different circuits, this can also cause surges to be induced. If a lightning strike is safely conducted to earth as shown in Figure 3, then large magnetic fields will be created in the vicinity of the conductor. By Faraday's laws of induction, changes in the magnetic field will cause a voltage to be induced in any nearby conductors. As the currents from a lightning-strike are very large and rise very rapidly, very large voltages can be induced in nearby wiring. This wiring can be any cabling, including mains wiring or data cables. When this happens, it is not uncommon to see voltages in excess of several thousand volts generated.

The other way in which voltages can be

generated occurs when two pieces of equipment are connected together, as shown in Figure 4. Here, a large voltage is generated and passes to earth near the first piece of equipment. However, as the earth is not perfect and a small resistance exists, some current will flow through the wire connecting the two pieces of equipment and then to earth of the second piece of equipment. This can result in voltages appearing on data lines for computers, which are very much higher than would normally be expected.

It is interesting to note that it is not just lightning that causes surge voltages to be induced in wiring. Often, pieces of electrical machinery being turned on and off can send a large back emf along the mains wiring. This can be seen by the power input to other pieces of equipment. The spikes can also be inductively coupled into other cabling as well, making any cables liable to pick-up.

Protecting Against Lightning

Often, when lightning causes damage, the true cause is not known. When a piece of equipment fails, it is usually attributed to a random failure and little investigation into its cause is undertaken. As a result, many of the failures caused by lightning go unnoticed, and no steps are taken to prevent any further occurrences.

Fortunately, this is beginning to change. Failures in computer systems can be very costly. Even though hardware can be insured against lightning damage, the software and lost data cannot be recovered. Sometimes, when a company relies on its computer for the day-to-day running, lost data and downtime can cost much more than the hardware repairs. It is for this reason that many companies are beginning to take the risk far more seriously, and seek ways of reducing the possibility of damage and data corruption.

Protective Devices

There are three main devices which are used in protection against surges and spikes. The largest of these is a gas-filled discharge tube. This has the highest surge current handling capacity, many being able to discharge transient currents of up to 10kA. This makes this type of device ideal for arresting any surges on the incoming mains line.

These tubes are based on a spark gap, which is one of the oldest types of arresting device. In its most basic form, it simply consists of two electrodes often made from carbon and spaced between 60 and 150μm apart. The spark then occurs in the air gap between these two electrodes. The disadvantage of this type of device is that electrodes erode after a large or sustained discharge.

To overcome this problem, the electrodes can be made of metal and the whole device enclosed in a tube filled with an inert gas such as argon. This sealed tube is the gas discharge tube used today. Under normal operation, it has little effect on the line. However, when a surge appears, the breakdown voltage of the tube is exceeded and it starts to conduct. This provides a low resistance path for the surge current, which can be safely dissipated to ground.

One of the problems with a discharge tube is that when the arc is struck between the two electrodes, it can easily be maintained,

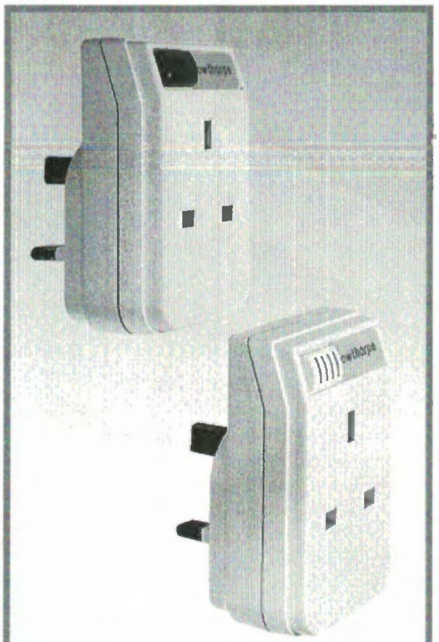


Photo 6. Bowthorpe pulse protector/mains supply monitoring units, with either visual or audible indication of supply irregularities.

even after the transient is completed. The current which flows is known as the 'follow current', and it can be maintained almost indefinitely. There are a number of ways of overcoming this problem. One is to add a resistor in series with the tube as shown in Figure 5, but this reduces the efficiency of the tube. Alternatively, a varistor can be used instead. Finally, a circuit breaker can be employed, which will be triggered when the discharge tube conducts. However, by the time the breaker has acted, the transient will have passed and been dissipated by the tube.

A second type of device is called a metal oxide varistor. The term varistor can be applied to almost any resistor whose resistance is voltage dependent. However, the term is normally used in conjunction with devices which actually dissipate energy. Varistors can be made from a variety of materials. Most modern ones are manufactured from mixtures of metal oxides of which, zinc oxide is generally the main ingredient. Older types of varistors were made from silicon carbide. These were initially introduced in 1930, and although they do not have a very non-linear curve, they are more robust than many of the modern metal oxide versions. This factor alone has meant that they are still used in some areas today.

A varistor generally has a smaller surge current handling capacity than the discharge tube, but it is much faster acting. The reaction time can often be less than 50ns. However, they can have a relatively high capacitance, and this makes them unsuitable for any data transmission or high-frequency applications. Under normal operating conditions, a varistor has a relatively high resistance, but as the voltage rises, its resistance falls, so that the surge can be safely conducted away to earth. The varistor is bipolar as shown in Figure 6, and it acts the same way for surges of either polarity.

Whilst varistors are very useful, they do have the disadvantage that their efficiency falls after a number of discharges have passed through them. Despite this, they are very effective and are often used in conjunction with discharge tubes for primary protection. Zener diodes are often used for protection. Whilst their surge current handling capability is smaller than discharge tubes or varistors, their operation is very fast, often reacting within pico-seconds. Each type of protection device has its own advantages and disadvantages. To exploit the advantages of the individual components, many protection units will include two or more types of device.

Where to Protect

To obtain the optimum protection, different types of safeguard equipment should be installed in different places. In this way, any harmful spikes can be dissipated as early as possible. Normally, the primary protection will be fitted across the incoming supply at the first point where access can be gained. If the supply is a three-phase one, then individual diverters are generally connected from each supply to earth. The neutral line should also have its own diverter as well, otherwise this could carry a harmful spike. At this point, it is worth limiting the voltage to about 600V. However, it is found that ringing within the installation can bring the voltage back up to levels as high as 2kV. Further pro-

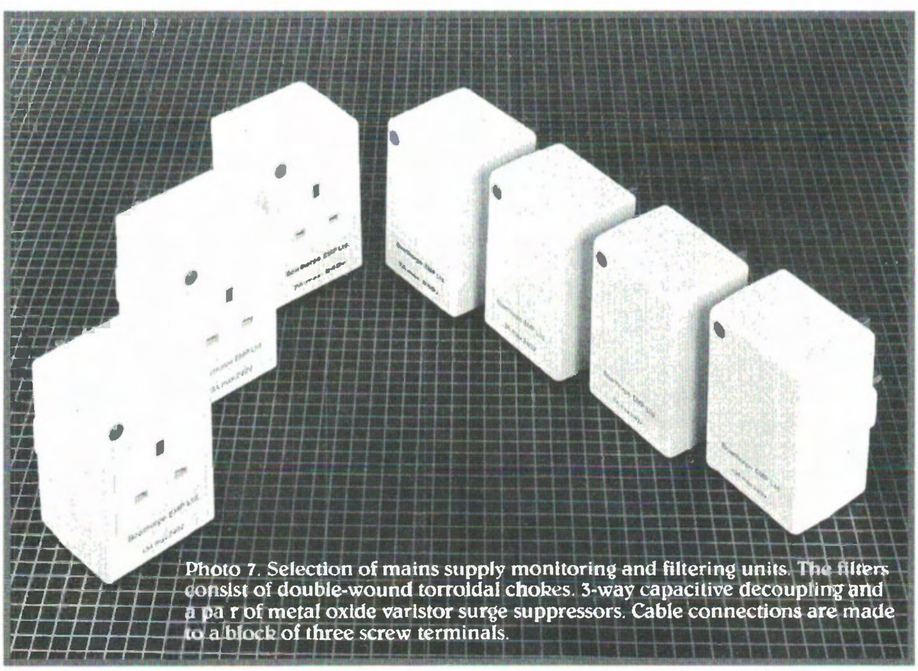


Photo 7. Selection of mains supply monitoring and filtering units. The filters consist of double-wound torroidal chokes, 3-way capacitive decoupling and a pair of metal oxide varistor surge suppressors. Cable connections are made to a block of three screw terminals.

tection is needed to overcome these effects, as well as those caused by electrical equipment within the building. In a large building, this protection may well be provided for individual floors or other defined areas, by means of distribution surge protectors, as shown in Photo 1. This method of protection may often be similar to that provided at the supply point.

The final protection should be provided where equipment is connected to the supply. Here, multi-way outlet adaptor strips (see Photos 2 to 4) or surge protection plugs and sockets like those illustrated in Photos 5 to 7 may be used. These have a lower current dissipation capability and a higher breakdown voltage than the primary protection devices. In this way, the primary protection devices take the full force of the surge, and leave the secondary devices to take care of local surges and the effects of ringing. If they had a lower breakdown voltage than the primary devices, they would tend to take the full force of the surge and draw the surges towards the equipment being protected.

Whilst it is very important to protect the mains input to equipment, computer systems are also likely to have a large number of interconnecting cables to enable the data to be transferred. In a computer network, it is likely that the network cables may be many tens or hundreds of metres long. These cables are naturally very susceptible to the pick up of transients. To protect them, special protection units are available, which are specially manufactured, often with connectors on either end, so that they can be conveniently inserted into the line with the minimum of disruption.

Summary

Whilst lightning is the most drastic form of voltage surge likely to be seen by most equipment, there are many other sources of electrical surges. Motors and many other forms of electrical equipment, including fluorescent lights, can generate large spikes when they are switched. These spikes travel down the power lines, or may sometimes be induced into data cables, causing problems with sensitive systems.

With an ever-increasing dependence on computers and other electronic equipment, it is important that the correct surge and spike protection is incorporated. Whilst it may seem an unwanted outlay during the installation phases of a project, it could save its cost many times over when the system is in operation. E

Acknowledgment

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Surge Protection Devices

Surge protection devices stocked by Maplin:
Surge Protecting Mains Plug, Order Code KU20W.
Surge Clock (Counts the number of damaging spikes on the mains supply), Order Code KR42V.
13A Pulse Protector, Order Codes CX64U and CX65V.