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SERIES K: PROTECTION AGAINST INTERFERENCE

ITU-T K.44 – Causes of telecommunication system overvoltage and overcurrent conditions and their expected levels

ITU-T K-series Recommendations – Supplement 18

ITU-T

International Telecommunication Union

Supplement 18 to ITU-T K-series Recommendations

ITU-T K.44 – Causes of telecommunication system overvoltage and overcurrent conditions and their expected levels

Summary

Supplement 18 to ITU-T K-series Recommendations discusses how surge and power fault overvoltages and overcurrents are coupled into telecommunication systems, the likely disturbance levels and mitigation measures.

History

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ITU-T K.44 – Causes of telecommunication system overvoltage and overcurrent conditions and their expected levels

1 Scope

This supplement provides information on:

– the coordination of primary and equipment port protection;
– MDF residual impulse voltage at the equipment ports;
– current impulse testing of equipment AC mains ports;
– earth and neutral potential rise;
– power fault testing sequence used to avoid possible ITU-T K.21 equipment fires;
– Ethernet port testing.

2 Reference

[ITU-T K.44] Recommendation ITU-T K.44 (2019), *Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the terms defined in [ITU-T K.44].

4 Abbreviations and acronyms

This Supplement uses the abbreviations and acronyms defined in [ITU-T K.44].

5 Conventions

None.

6 Surge and power fault conditions

6.1 Introduction

Surge and power fault conditions is a subject currently under study by ITU-T. The most up-to-date information is provided in this Supplement for the benefit of manufacturers and operators, and to promote discussion on these topics.

6.2 Primary protection coordination

The effects of the operation of primary protection are described in [b-ITU-T K.11].

To ensure the coordination of the protection components with the equipment, it is necessary to check that:

1) the equipment will not be damaged by worst-case voltages that may appear between the input terminals and between an input terminal and the equipment earth reference;
2) the equipment will not be damaged or interfered with by the operation of the primary protection over the complete range of surge voltages.

The operation of primary protection with a switching characteristic has two effects:

– It limits the maximum voltage applied to the equipment and hence, depending on the internal impedance of the equipment, the maximum current that the equipment must withstand.

– It produces a very rapid change of voltage and current, which by inductive or capacitive effects can reach sensitive parts of the equipment not apparently exposed to line voltages.

6.2.1 Cases where the primary protection does not operate

For surge voltages where the primary protection is not activated, attention should be paid to the value of the currents that can flow in the internal cabling network. Large currents in the internal cabling network may disturb other equipment. [b-ITU-T K.27] describes earthing and bonding inside a telecommunication building and [b-ITU-T K.11] treats coordination with electrical protection devices.

6.2.2 Cases where the primary protection does operate

Lightning surge simulation requires special attention to be paid to:

– a change in the operating voltage of gas discharge tubes (GDTs) with voltage rate rise;

– potential differences developed across the protection frame and any associated earth wiring due to high current flow;

– the fast dU/dt, caused by the operation of the GDT, which may damage sensitive components or cause incorrect operation (equipment lock-up or corruption of data in memories).

To check coordination with primary protection, attention must be paid to the operating principles of the GDT. First, the 10/700 µs firing voltage of GDT(see Figure I.1-4 of [ITU-T K.44]) is generally higher than the direct current (d.c.) firing voltage but generally less than the 1 kV/µs firing voltage. Secondly, the d.c. firing voltage, and hence the 10/700 µs firing voltage, can vary considerably for the same protector type. For example, the d.c. firing voltage of a 230 V GDT is allowed to vary from 180 V to 300 V [b-ITU-T K.12].

For these reasons, primary protection coordination is checked by replacing the agreed primary protector with a special test protector. The d.c. firing voltage of the special test protector is to be equal to 1.15 times the specified maximum d.c. firing voltage of the agreed primary protector. The tolerance on the firing voltage is ±5%. For a 230 V primary protector, the firing voltage of the special test protector is 345 V ±17 V. This test protector is used for both the lightning, power induction and power contact tests. The special test protector should have a similar characteristic to the agreed primary protector.

6.2.3 Principles of coordination

[b-ITU-T K.11] states that:

– No device exists which has the characteristics for suppressing ideally all voltages or currents connected with disturbances.

– It is sometimes necessary to use more than one protective device.

Some protectors have a higher let through voltage at fast rates of rise. In this case it may be necessary to use a multistage protection circuit to reduce the surge stress step by step to the level that is harmless to the equipment.

Figure 6.2-1a shows the principle of protection by a ladder circuit.

A primary protector is applied at the location of the border, such as a main distribution frame (MDF) external to the equipment under test (EUT). Most of the surge current is bypassed to earth at this point. An inherent protector is inside the EUT, and it diverts the let through current of the primary protector. There may also be a third protector inside the EUT that is part of the black-box.

It is important that there be resistance between the protectors so that these do not connect to each other directly. This makes the circuit look like a ladder. Considering the coordination between primary and inherent protection, there should be resistance R_{in}. This R_{in} is virtually the same as the input resistance of the EUT when the inherent protector, such as a thyristor device or a diode, turns on and connects R_{in} to earth. Figure 6.2-1b shows the equivalent circuit when the inherent protector turns on. If there is no resistance between the primary and inherent protector, only the protector which has the lower turn-on voltage will operate. In this case, only the inherent protector operates and it prevents the operation of the primary protector, so coordination is not achieved. R_{in} is necessary to increase the voltage across the primary protector high enough to cause the primary protector to operate.

The point is that the inherent protector usually turns on at a lower voltage than the primary protector at the MDF. At first, the current flows into the black-box and generates voltage across the inherent protector and it turns on. Then the current that flows through R_{in} and the inherent protector generates the voltage across the primary protector.

Therefore, the inherent protector is not a subsidiary but an essential device because it usually operates earlier than the primary protector and protects the following components. The voltage drop across the coordination resistance, due to the current flowing in the inherent protector, operates the primary protector which bypasses the majority of the surge current to earth.

In a traditional circuit using a bulky transformer or coil inside the EUT, it is possible that there is no inherent protector. The sum of the resistance, R_{in} plus R_e, is high enough that the primary protector turns on without much current flowing into the EUT. Figure 6.2-1c shows such an equivalent circuit.

If there is an inherent protector, such as a semiconductor surge protective device (SPD) in the EUT, it usually operates faster than the primary protector at the MDF. If there is no resistance between the primary and the inherent protector, the operation of the inherent protector disturbs the operation of the primary protector. Coordination is achieved when there is sufficient resistance between the protectors, and the voltage drop across the resistance allows the primary protection to operate correctly. When coordination is designed correctly, the EUT is not damaged up to the maximum test level. Above the maximum test level, the primary protector must operate for lightning surges.

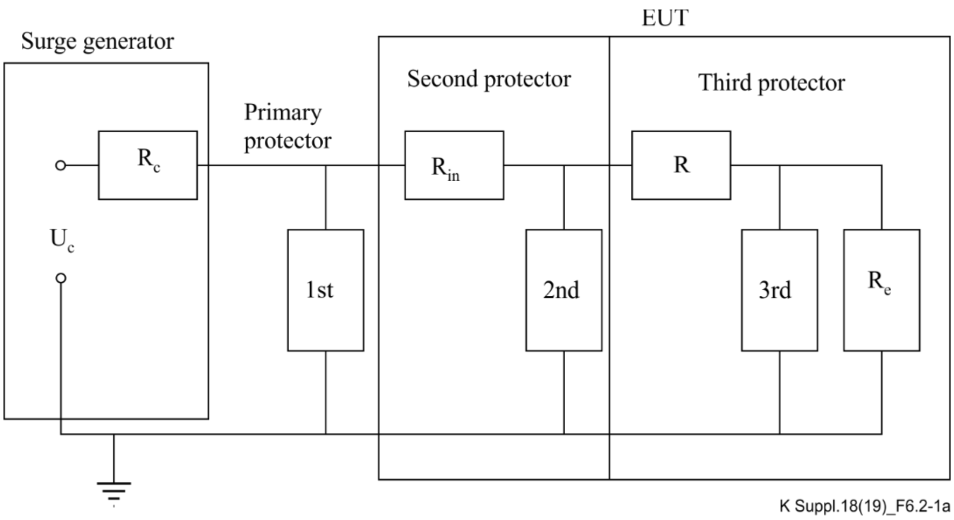

Figure 6.2-1a – Principle of protection by ladder circuits

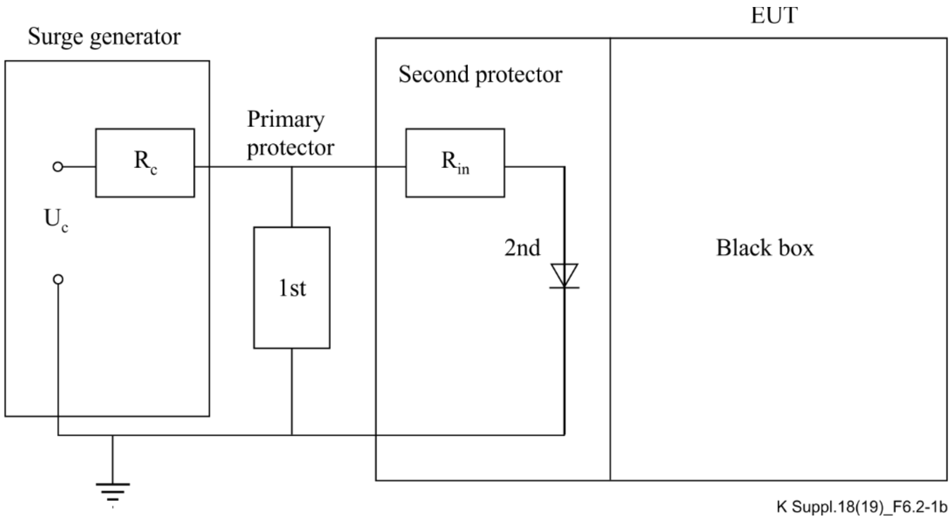

Figure 6.2-1b – Equivalent circuit when the second protector turns on

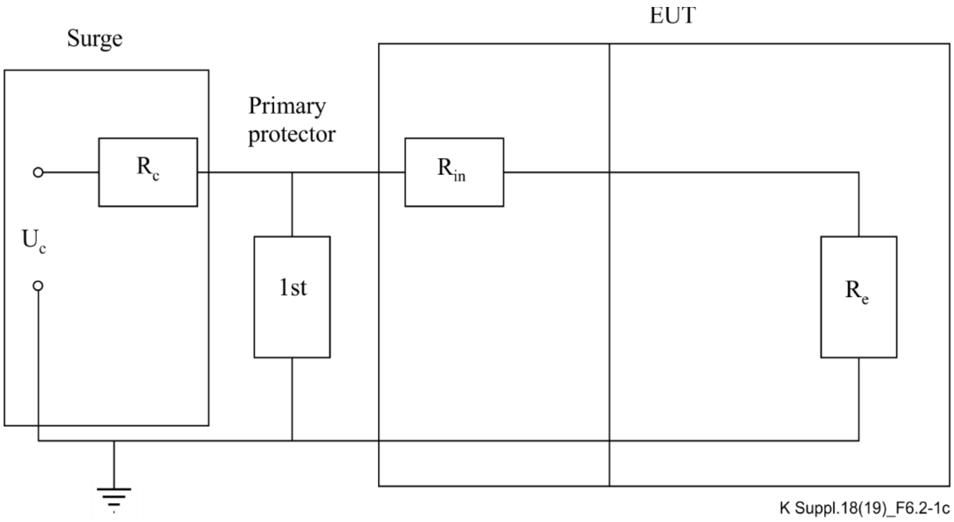

Figure 6.2-1c – Robust circuits with no second protector

6.2.4 Coordination testing of switching and clamping SPDs

[b-IEC 62305-4] contains information on the theory of coordination. The specific tests that need to be performed to confirm coordination are outlined below.

There are four combinations of surge protective devices (SPDs) and these are shown in Figure 6.2-2.

Figure 6.2-2a: To perform coordination testing of the SPDs in Figure 6.2-2a, it is necessary to perform the following tests:

1) U_c set to produce a waveform just under the firing voltage of the primary protection (maximum surge stress for the inherent protector);
2) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

Figure 6.2-2b: To perform coordination testing of the SPDs in Figure 6.2-2b, it is necessary to perform the following tests:

1) U_c set to produce a waveform just under the firing voltage of the inherent protection (maximum surge stress enters the circuit components downstream of the inherent protection);
2) U_c set to produce a waveform just under the firing voltage of the primary protection (maximum surge stress for the inherent protector);
3) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

Figure 6.2-2c: To perform coordination testing of the SPDs in Figure 6.2-2c, it is necessary to perform the following test:

1) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

Figure 6.2-2d: To perform coordination testing of the SPDs in Figure 6.2-2d, it is necessary to perform the following test:

1) U_c set to produce a waveform just under the firing voltage of the inherent protection (maximum surge stress enters the circuit components downstream of the inherent protection);

2) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

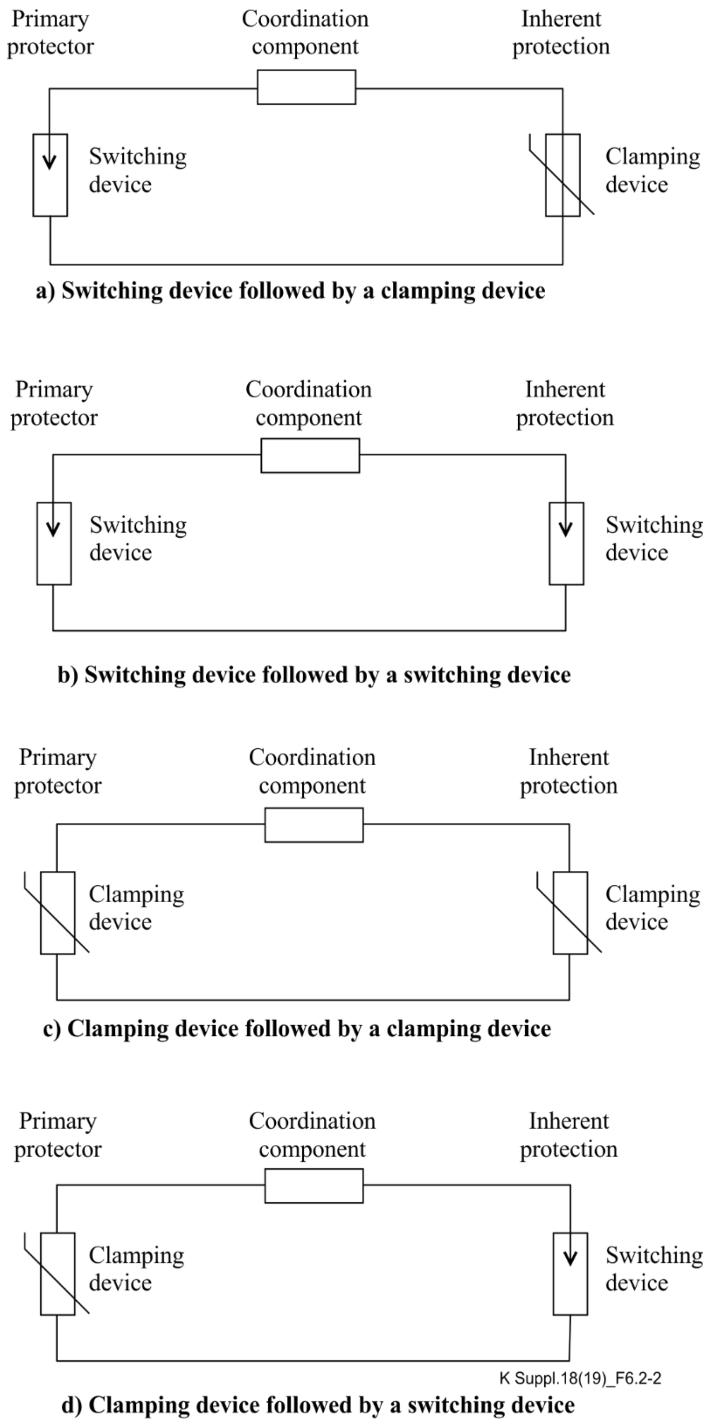

Figure 6.2-2 – Combinations of SPDs

6.3 MDF voltage at the input of equipment

6.3.1 General

The firing voltage of a GDT depends on dU/dt. If R_p is known, the dU/dt of U_{si} can be calculated by simulation program with integrated circuit emphasis (SPICE) transient simulation (see Figure 6.3-1). Using the firing voltage versus dU/dt information in the GDT data sheet, the actual firing voltage for each condition can be simulated. Figure 6.3-2 depicts the model used to calculate the reduced voltage at the equipment input due to the impedance of the MDF cable. Figure 6.3-3 shows the simulation results for a 1 m MDF cable between the GDT and the equipment and a 1 m MDF earth cable. It shows that the GDT operates at a higher voltage in a shorter period of time when U_c is high. If U_c is low, the GDT operates at a lower voltage in a longer period of time.

Figure 6.3-4 shows the same simulation but with a 10 m MDF cable between the GDT and the equipment and a 10 m MDF earth cable. The inductance of the 10 m MDF cable and the 10 m earth cable is almost 10 μH, respectively. The total inductance of 20 μH can be an effective low pass filter for the high speed residual voltage caused by GDT operation. The MDF cable suppresses the high dU/dt surge caused by operation of the GDT. This simulation shows that the test lead between the surge generator and the EUT has to be short, e.g., less than 2 m.

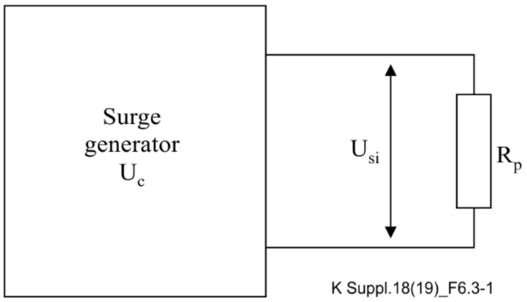

Figure 6.3-1 – A model to calculate the dU/dt of U_{si}

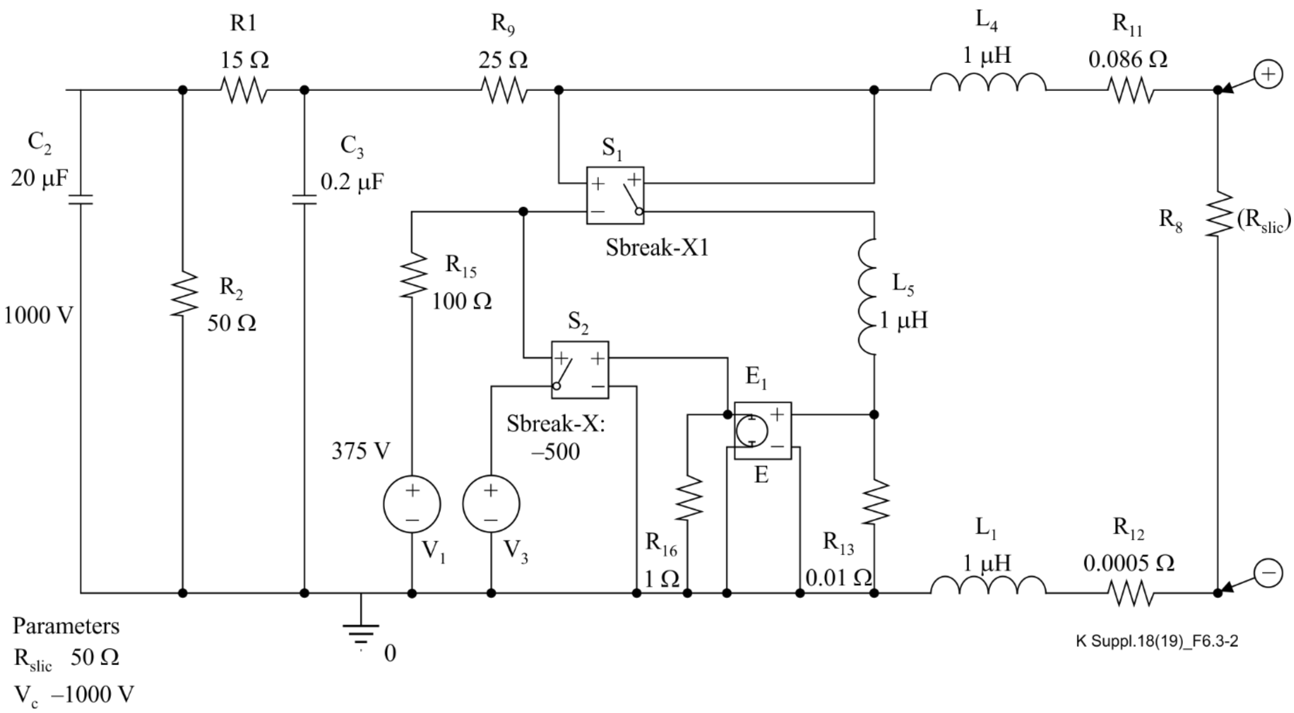

Figure 6.3-2 – The SPICE model used to calculate the reduced voltage at the equipment input due to the impedance of the MDF cable

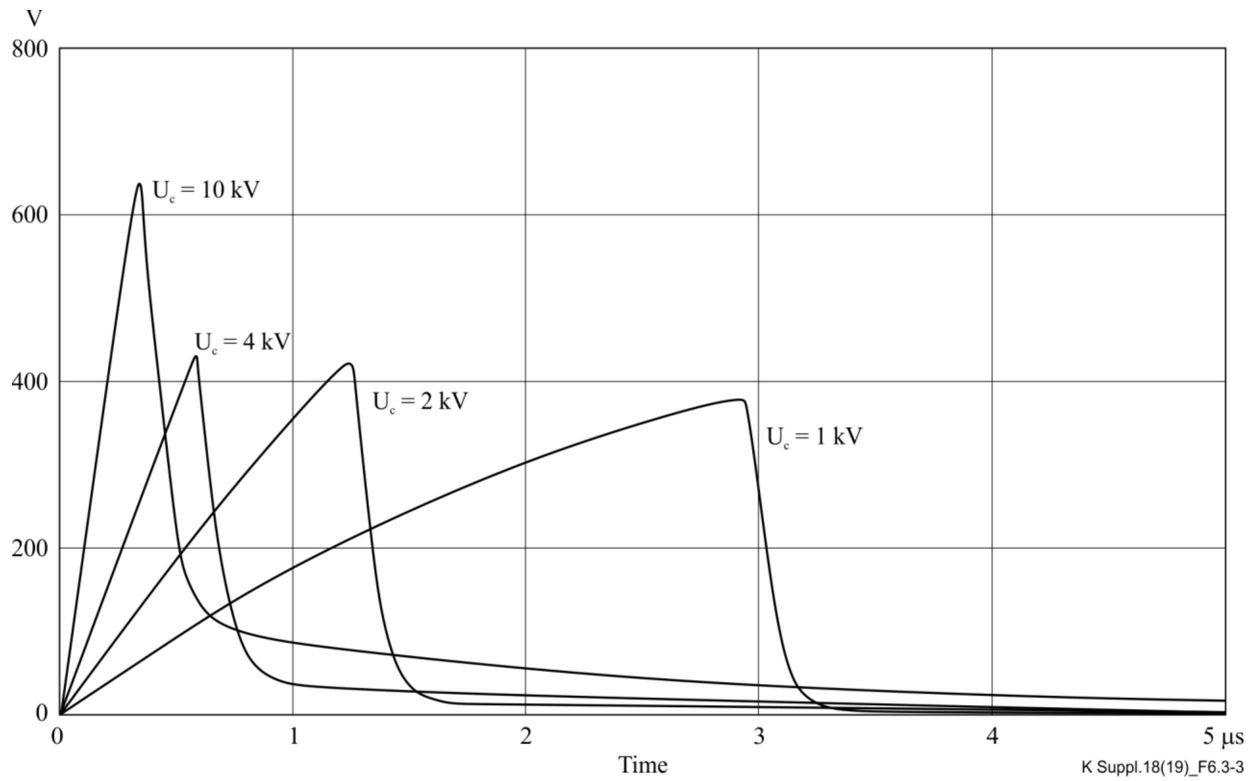

Figure 6.3-3 – Simulation results for a 1 m MDF cable

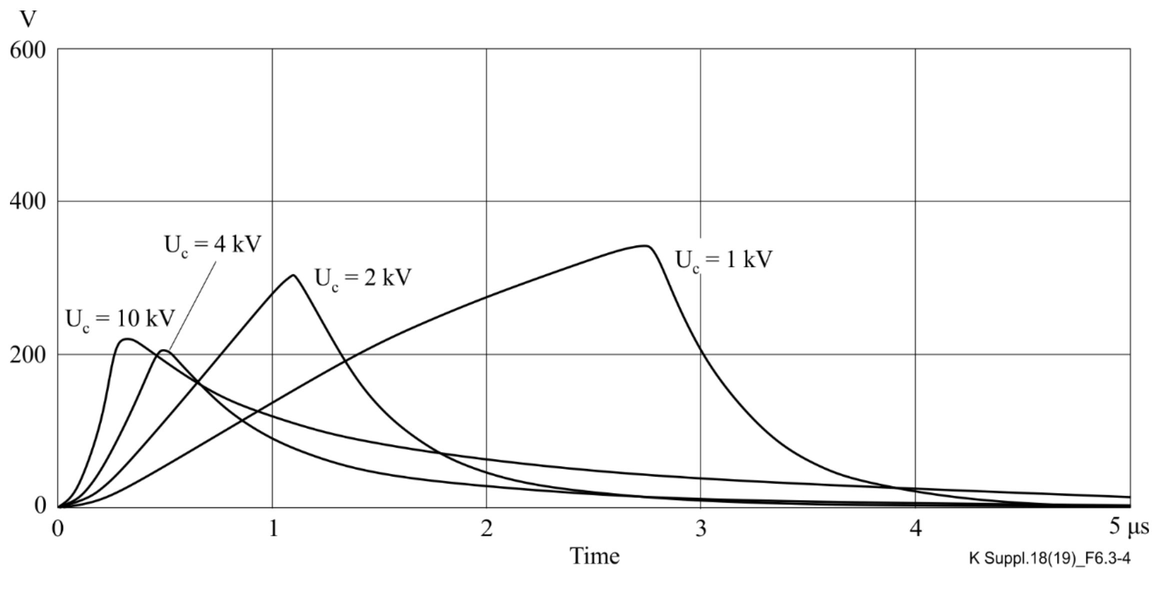

Figure 6.3-4 – Simulation results for a 10 m MDF cable

6.3.2 MDF earth wire voltage drop

The inductance of the MDF cable between the primary protector and the EUT has a good effect for high dU/dt surges, but the inductance of the MDF earth cable has the opposite effect. This is particularly so when it is considered that the current from all GDTs, which have operated, flows in the MDF earth cable. Inductance is a function of the length of the cable and does not change much if the diameter of the cable is changed. The length of MDF earth cable cannot be zero, so there is always inductance. The voltage drop caused by the MDF earth cable is due to the surge current which flows after the GDT operates. The voltage drop of the MDF earth cable appears at the input of the equipment, so it is necessary to have a bonding configuration which will have the minimum possible inductance and resistance. Figure 6.3-5 shows where inductance of the MDF earth cable exists.

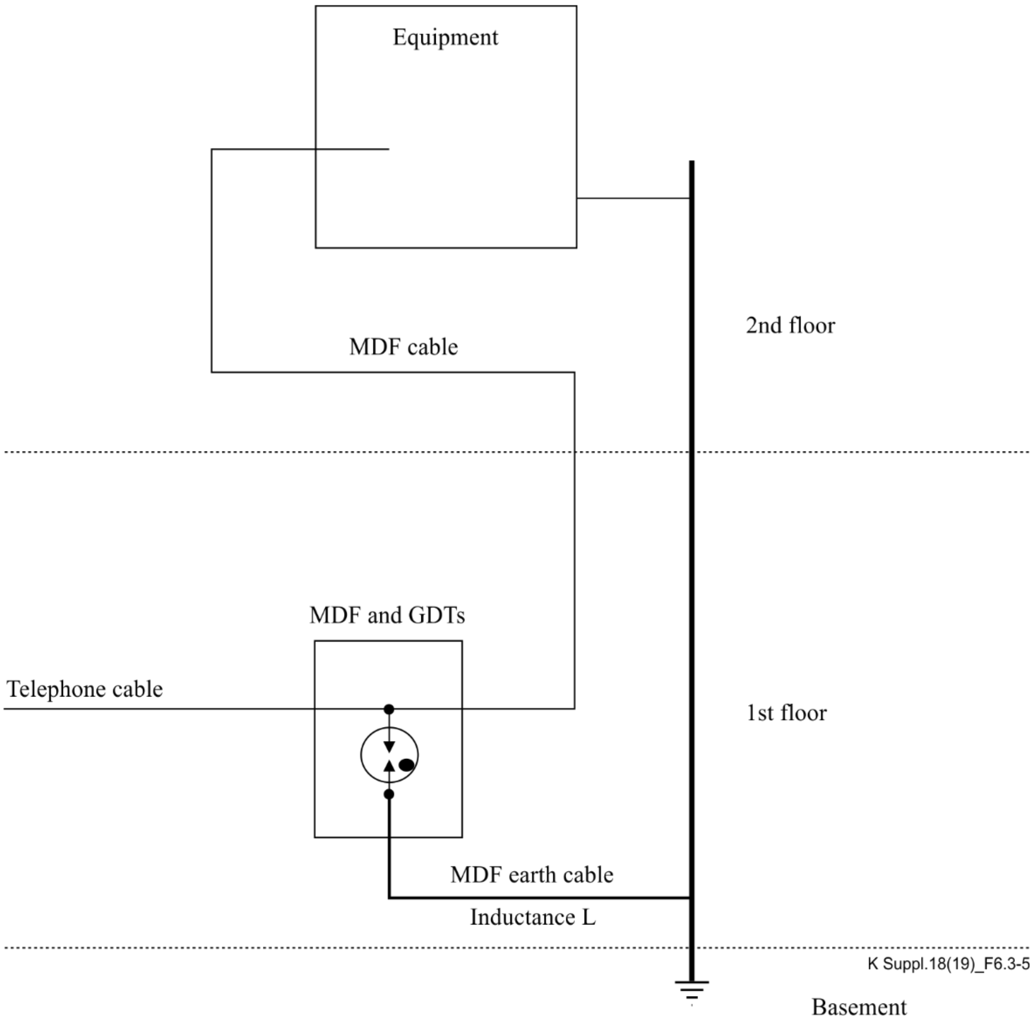

Figure 6.3-5 – Inductance of MDF earth cable

When there is significant length of MDF earth cable, as shown in Figure 6.3-5, a multiple cable or mesh configuration is desirable.

Multiple cables which are not tied together but separately connected will reduce the inductance nearly 1/N, where N is the number of cables (see Figure 6.3-6).

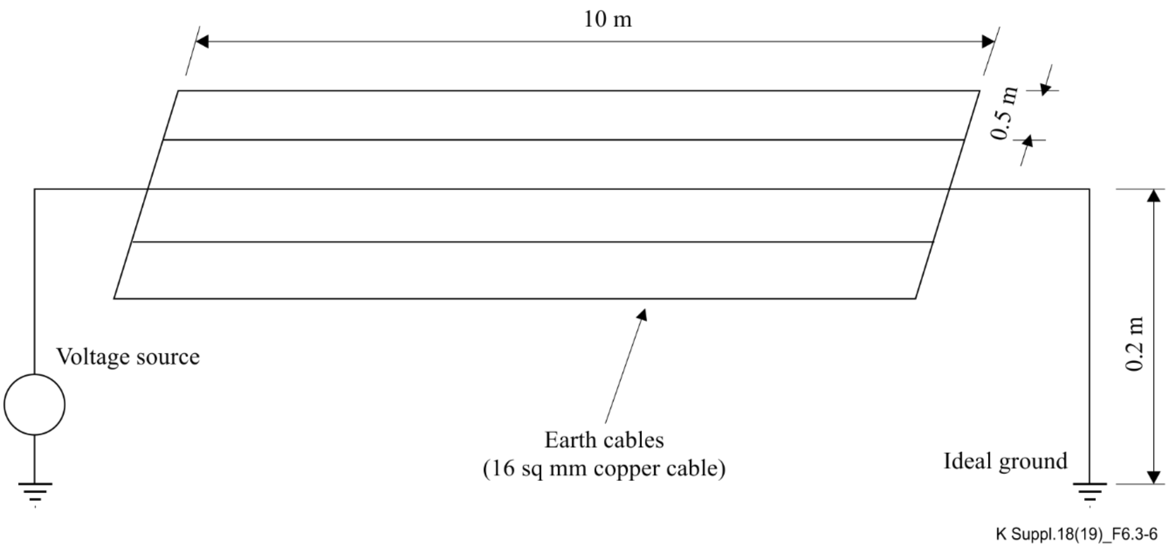

Figure 6.3-6 – Use of multiple earth wires to reduce inductance

The inductance calculated using ACCUFIELD simulation is shown in Table 6.3-1.

Table 6.3-1 – Inductance versus number of conductors

N (number of conductors)	Total inductance
1	10.89 µH
2	6.16 µH
3	4.39 µH
5	3.05 µH

6.3.3 Earth voltage drop test

Where there is an external protection frame and/or an earth wire connecting it to the earth bar, high currents flowing in the protection frame or the earth wire will cause a voltage drop at the input of the equipment (see Figure 6.3-7).

Damage due to an earth voltage drop has been observed in the United Kingdom and Australia.

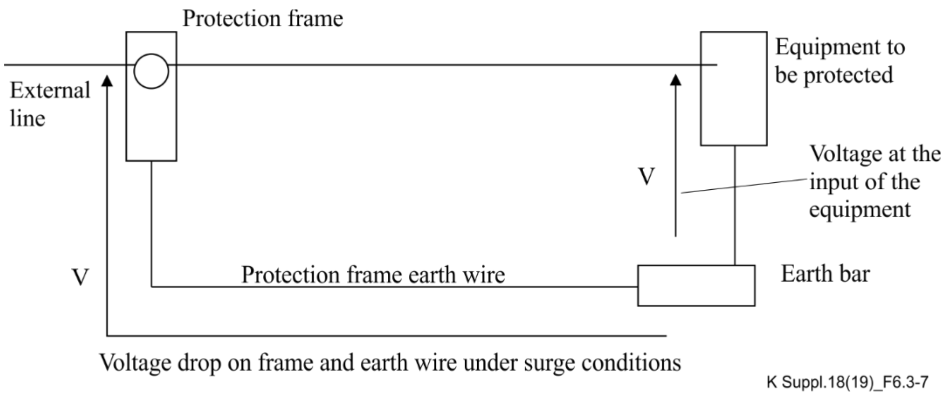

Figure 6.3-7 – Voltage drop in earth wires

6.3.3.1 United Kingdom's example of earth voltage drop problem

Some small switching systems installed at customer premises have suffered damage due to the potential difference created by the earth bonding wires of the protection and switching equipment. The bonding for the protection was typically routed over an indirect route to the main earth terminal. The equipment protective earth was connected to the power system wiring earth, and hence the main earth terminal. Due to differences in impedance, a large potential difference was developed between the equipment line terminals and the protective earth of the equipment. This resulted in a small flash-over from the circuitry to the equipment chassis, damaging the equipment. The solution was to bond the protection as close to the equipment as possible using the correct d.c. sparkover voltage protectors, such that mains could not get on the line in the event of a power fault on the equipment earth. A further problem has been experienced where the equipment was very well earthed, with what appeared to be short bonds to the common earth point, i.e., no different to many thousands of other installations, and a very low d.c. earth resistance from the MDF to the main earthing terminal (MET). Lightning was causing damage to the equipment even though protectors had been fitted. Deeper investigation showed that the bond from the MDF blocks to the earth riser was a short 'pig-tail' of earth wire, creating a high impedance to surge current, and hence high volt drop in the earth. When the earth connection is corrected, the problem is solved. Anything greater than approximately a 20-Ω impedance can cause this problem, so even a small inductance can cause a problem.

6.3.3.2 Australian example of an earth voltage drop problem at customer premises

Australia has suffered a lot of lightning damage to small customer switching systems as a result of potential differences occurring in the telecommunication line and the mains power supply due to the length of the bond wire between the protection frame and the main earth terminal. Where it was not possible to reduce the bond wire length to less than a few metres, a combined telecommunication and mains port protection unit has had to be installed at the equipment. These protection units are very expensive, costing in the order of US$ 150 for a 10-pair (telecommunication line) unit. Single pair units can cost as little as US$ 15. Note that it is essential that this protection unit has a fully bonded earth between the telecommunication port protection and the power line protection. Not all units have this equipotential bond.

6.3.3.3 Australian example of an earth voltage drop problem at a telecommunication centre

Telstra has experienced damage to equipment installed in a telecommunication centre that was protected by primary protection. Investigation of the problem showed that a breakdown was occurring between the wiring from the MDF and the chassis of the equipment. The breakdown voltage between the wire and the chassis was approximately 1.5 kV for a 10/700 µs waveform. This proves conclusively that earth voltage drops of 1.5 kV and greater can occur in practice. Rather than change the earth wiring in the exchange, different equipment was used to perform the function. These exchanges are earthed in accordance with [b-ITU-T K.27] and the equipment is in an isolated bonding network (IBN). There needs to be a balanced approach between installation practices, resistibility of equipment and the addition of external protection.

6.3.3.4 Possible test for resistibility to earth voltage drop

As shown in clause 6.3.2, the most significant voltage occurs when a single earth wire is used to connect the protection frame to the earth bar. Earth voltage drop is less of a problem across the protection frame due to the parallel down conductors in the frame, and is also less of a problem when multiple earth wires are used to connect the frame to the earth bar.

This test is not applicable if one or more of the following occurs:

– The equipment earth reference conductor is connected to the base of the protection frame.

– Shielded cables are used between the protection frame and the equipment.

– A mesh bonding network (BN) earthing system is used.

– The protection frame is directly connected to the CBN by short conductors (<1 m).

Table 6.3-2 and the generator in Figure 6.3-9 are based on the test surge 4, specified in Table 4-2 and clause 4.6.6 of [b-GR-1089]. The Telcordia test, which is widely used in North America, has a maximum peak open circuit amplitude of 2.5 kV.

Table 6.3-2 – Test voltage

Description	Uc(max)
Large external frame with a small number of down conductors or long earth wire (<10 m) in a building or large shelter.	2.5 kV
External frame in a cabinet with a medium length single earth wire (<3 m).	1.5 kV
Small external frame with a short earth wire (<0.5 m).	Test not required. The voltage at the input of the equipment is assumed to be less than that which occurs for tests 2.1 and 2.2 in Table 2a of the applicable resistibility Recommendation (e.g., [b-ITU-T K.20], [b-ITU-T K.21] or [b-ITU-T K.45]).

The approximate surge voltage generated by a surge current being conducted in a bond wire is shown in Figure 6.3-8.

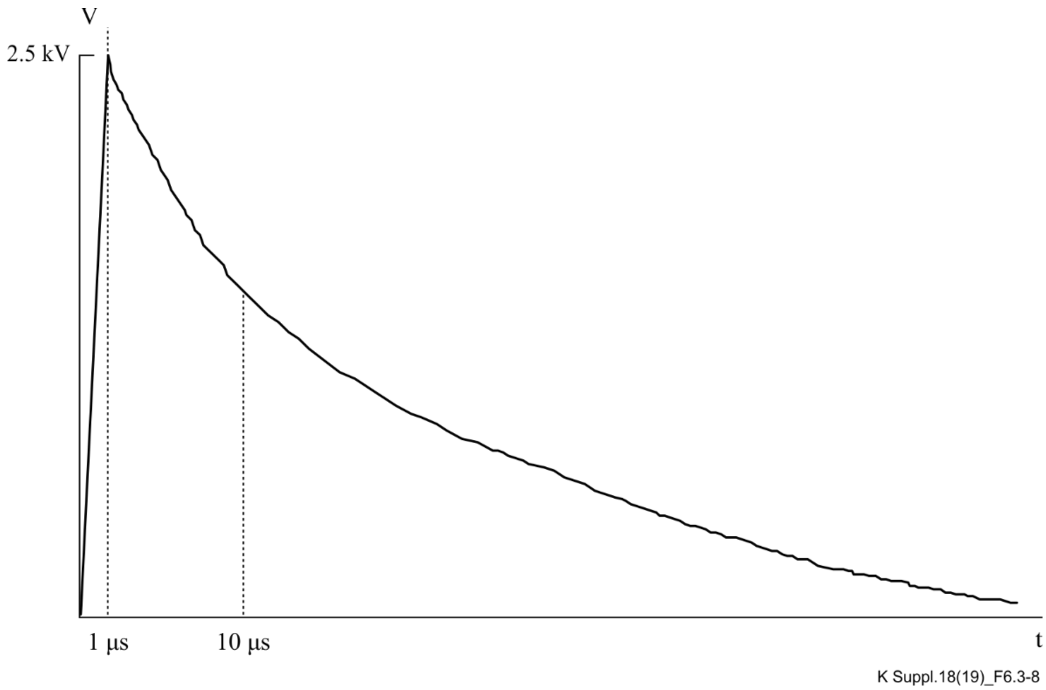

Figure 6.3-8 – Earth voltage drop

The circuit in Figure 6.3-9 produces a 2/10 µs waveform and may be used to reproduce this effect.

An approximate magnitude of the voltage which may occur is given in Table 6.3-3.

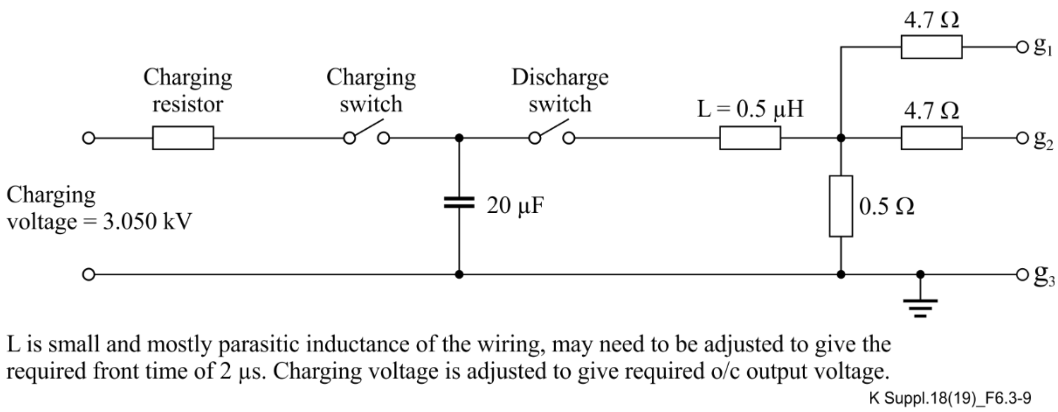

Figure 6.3-9 – 2/10 µs current surge generator

Table 6.3-3 – Earth voltage drop test

Test no.	Test description	Test circuit	Test level	Number of tests	Agreed primary protection	Acceptance criteria	Comments
1.1	Earth wire voltage drop	Figures 6.3-9 and A.5-1 of [ITU-T K.44]	See Table 6.3-2	5	5 of each polarity	A	Applies only to equipment where there is a large protection frame and/or a single earth wire between the primary protection and the common earth point.

6.4 Current test on mains ports

When lightning strikes a building or shelter housing telecommunication equipment, the current waveform is considerably longer than the 8/20 μs waveform traditionally used to test mains ports. Studies in Germany have shown that the current waveform involved in a direct strike can have a 1/2 value of up to 350 μs. An example in [b-ITU-T Handbook] shows that mains power line surges can have long tails. Tests on switch-mode power supplies have shown that a 350 μs tail can cause damage, whereas a 20 μs tail does not. There is no paper documenting this damage. It was therefore proposed that a value of 10/350 μs be used to check coordination of primary protection with the equipment being tested. While this has been discussed in ITU-T, agreement for this test could not be obtained. This test remains under study. The coordination test in the product Recommendations requires an 8/20 μs waveform.

The proposed test is shown in Table 6.4-1.

Table 6.4-1 – Coordination test for mains ports to simulate a direct strike to the building or shelter

Test no.	Test description	Test circuit	Test level	Number of tests	Agreed primary protector	Acceptance criteria
1.x.a	Direct lightning mains port coordination L-N	Figures 6.4-1 and A.6.4-1 of [ITU-T K.44]	I(max) = 10 kA R = 0 Ω	5 of each polarity	Agreed primary protector (mains)	A Note – A switching protector must operate at I(max)
1.x.b	Direct lightning mains port coordination L+N-E	Figures 6.4-1 and A.6.4-2 of [ITU-T K.44]	I(max (L+N)) = 10 kA R = 0 Ω	5 of each polarity	Agreed primary protector (mains)	A Note – A switching protector must operate at I(max)

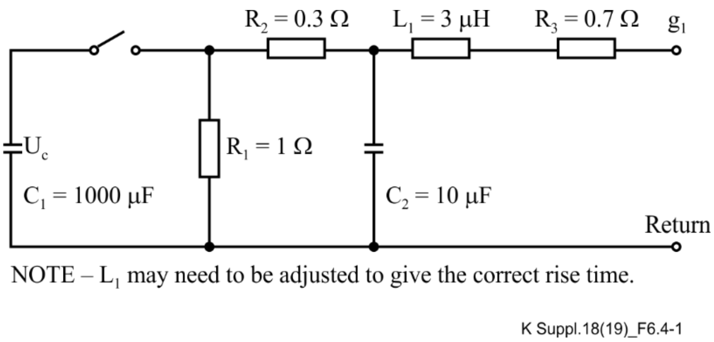

Figure 6.4-1 – 10/350 µs current surge generator

6.5 Earth and neutral potential rise

6.5.1 Background

Depending on low voltage public distribution network design, some risks such as neutral potential rise and lightning surge transfer may occur on low voltage power plant.

6.5.2 Explanation

Earth and neutral potential rise happens mainly when the medium voltage/low voltage (MV/LV) transformer insulation is broken, or spark gaps operate to prevent transformer destruction by a lightning induction or direct strike to the line. An important 50 Hz current flows and the earth potential rises.

6.5.2.1 Earth potential rise

The first point is to understand the way to limit earth potential rise (EPR) when a fault occurs on the power plant. See Figure 6.5-1.

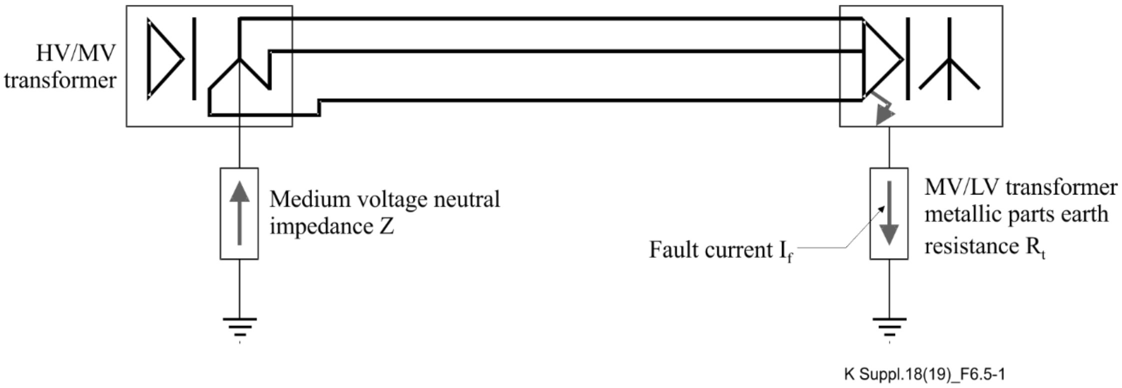

Figure 6.5-1 – Factors affecting the fault current

The worst-case fault current I_f is obtained when neglecting high voltage (HV) line impedance and coupling between the transformer's metallic parts earth and other earthing systems as neutral earth.

$$I_f = U / \sqrt{3 \cdot (Z + R_t)}$$

where U is the voltage between medium voltage active conductors.

The rise of earth potential at the MV/LV transformer is EPR = $R_t \cdot I_f$ (LV = low voltage).

In France, this EPR value is limited to 6 kV.

6.5.2.2 Neutral potential rise

6.5.2.2.1 Coupling between transformer and neutral earth systems

As a result of the design of neutral earthing, neutral potential rises by conductive coupling when medium voltage is connected accidentally to earth.

National regulations may fix limits for this rise of neutral potential (for example, 1500 V in France). See Figures 6.5-2 and 6.5-3.

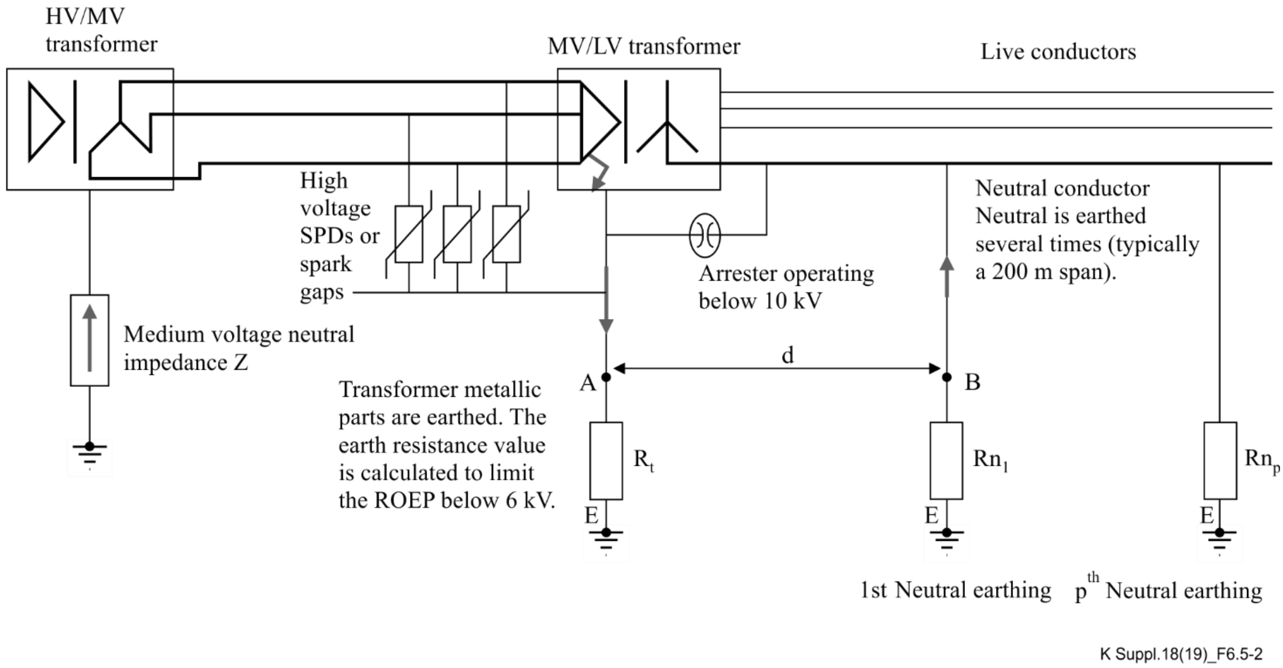

Figure 6.5-2 – Coupling into LV neutral

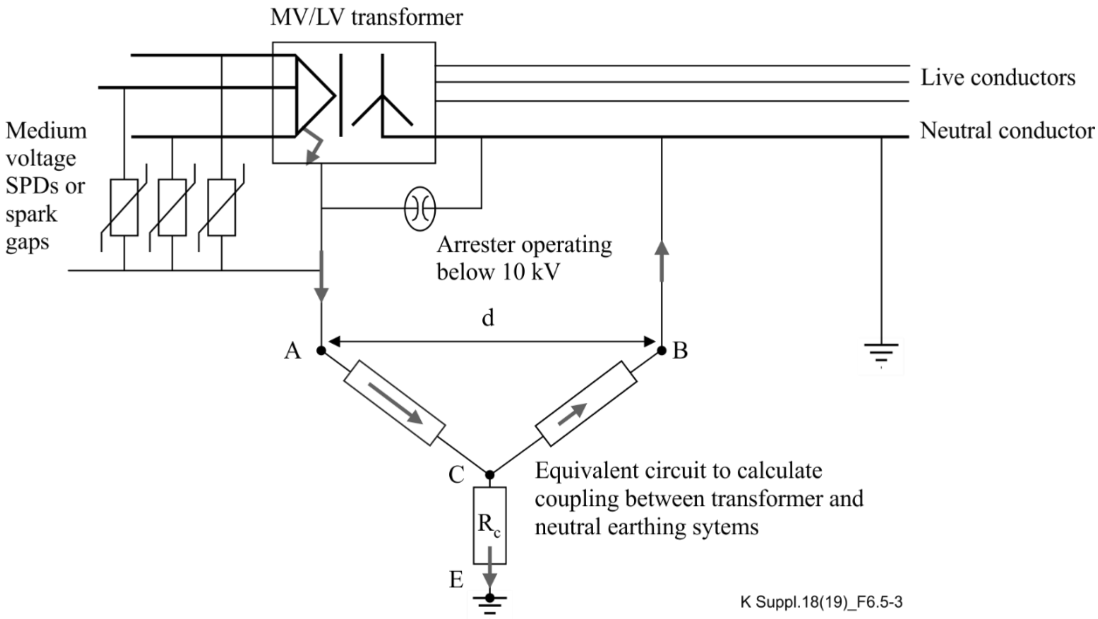

Figure 6.5-3 – Limiting EPR by earthing design

The coupling resistance $R_c = \rho \cdot I / 2 \cdot \pi \cdot d$ is adjusted by varying d to obtain a rise of neutral potential below 1500 V or a coupling ratio (V_{AE}/V_{BE}) below 15% when a fault occurs.

When the soil has a high resistivity, the calculated resistance values may sometimes not be achieved and the rise of earth potential may be higher than 1500 V.

6.5.2.3 Currents that may flow through equipment

Figure 6.5-4 gives an illustration of the mechanism of current flow through equipment.

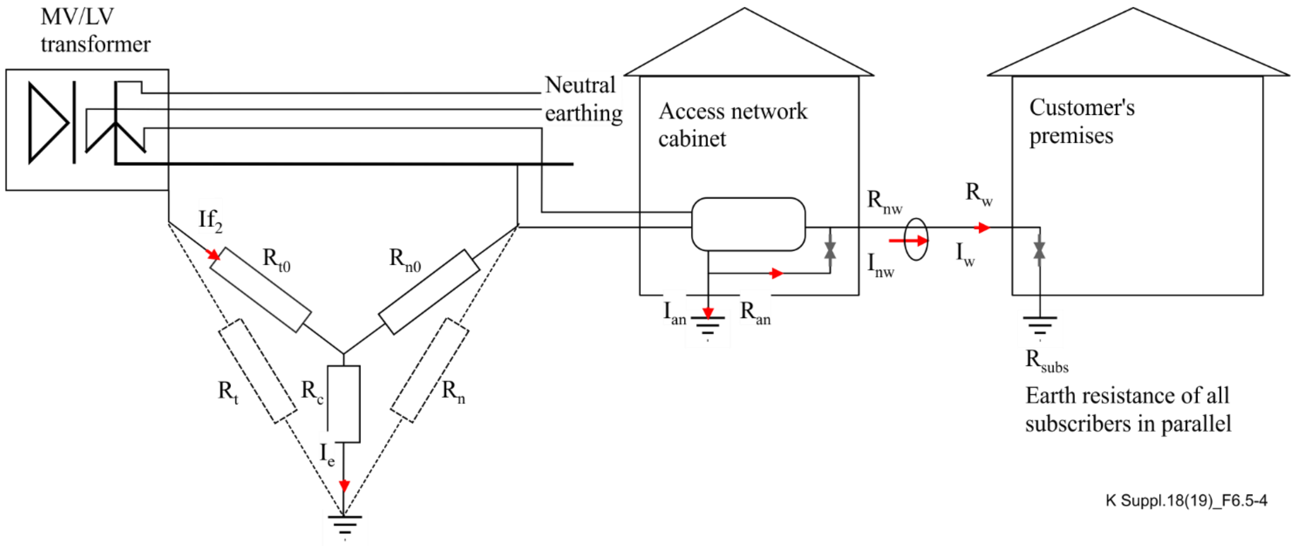

Figure 6.5-4 – Mechanism of current flow through equipment

The results of the calculation when it is assumed that:

– 28 customers are connected with the same symmetric pairs (length 5 km, wire diameter 0.4 mm);

– the equivalent resistance of all their earthing systems in parallel is 2 Ω;

– the access network cabinet earth resistance is 50 Ω;

– the power system characteristics are Z = j40 Ω, R_t = 30 Ω, R_n = 15 Ω, d = 8 m;

– the soil resistivity is 300 Ω.m;

show that tens of amps may flow through the equipment (disruptive discharge between mains port and equipment earth) to the access network cabinet earthing system.

Current may also flow either directly by telecommunication line SPDs (if they are installed, and in case of disruptive discharge between mains port and equipment earth) or through the equipment (disruptive discharge between the mains and telecommunication external ports) to the customer premises (I_w is approximately 1 A).

Note that the calculation is based on the same principle when replacing in Figure 6.5-4 the customer premises by a telecommunication centre, or the access network cabinet by the customer premises.

6.5.2.4 Surge transfer

The lightning induced or direct surges transfer from medium voltage to low voltage may occur mainly if:

1) the transformer insulation breakdown is prevented by bypassing it with an arrester;

2) the transformer insulation between medium and low voltage windings is broken.

Figure 6.5-5 gives an illustration of overvoltage to neutral.

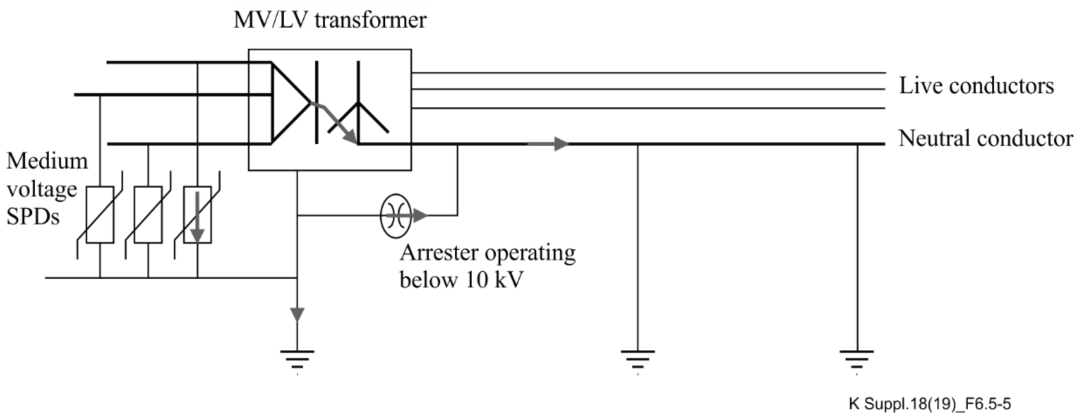

Figure 6.5-5 – Transfer of overvoltage to neutral

The surge will be followed by a significant 50 Hz current in case 1 when spark gaps are used, and always in case 2.

6.6 Equipment fire in equipment complying with Recommendation [b-ITU-T K.21]

A network operator has experienced a problem with a fire occurring in equipment which complies with [b-ITU-T K.21]. The problem was able to be reproduced by performing the power contact test on a sample which had been subjected to the power induction test. It was subsequently found that the power induction test was damaging the positive temperature coefficient thermistor (PTC) but not sufficiently to show up in the functional tests.

To test for this effect, it is suggested that test 2.3.1a (4.3.1a) of [b-ITU-T K.21], using the 20 Ω test resistor, be applied to a port which has previously undergone the power induction inherent test.

6.7 Ethernet

6.7.1 Insulation

Many pieces of equipment are protected by making their insulation voltage withstand higher than the expected system transient. A non-telecommunications example is the withstand voltage of a motor winding to its metal rotor or stator. Insulation provides separation between two conductive parts at different electrical potentials. Insulation is made up of three components:

– Insulation: The insulating material interposed between two conductive parts.
– Creepage distance: The shortest distance along the surface of an insulating material between two conductive parts.
– Clearance: The shortest distance in air between two conductive parts.

Clearance distances are set so that the maximum expected voltage difference does not break down the clearance. Creepage distances are set so that the maximum expected voltage difference and pollution degree do not cause flashover or breakdown (tracking) of insulation surface.

Solid insulation thickness is set so that the maximum expected voltage difference does not cause breakdown. In transformers, solid insulation separates two or more windings. Transformers can be used in port interface circuits to provide isolation or impedance matching or both. The most common transformer isolated signal port is the Ethernet port.

Insulation coordination is the design procedure of making the insulation voltage higher than the expected voltage difference between the separated circuits. For transformers, the rated insulation voltage is normally expressed as an alternating current (a.c.) root mean square (RMS) voltage. For equipment ports subjected to lightning surges it is more appropriate to use the rated impulse voltage.

The standard impulse used for testing has a 1.2/50 μs waveform. The 1.2/50-8/20 combination wave generator can be used for insulation testing.

After testing, the port insulation resistance is measured according to [b-IEC 60950-1] and [b-IEEE 802.3]. The standard requirement is for the 500 V d.c. insulation resistance to be > 2 MΩ. Different values of test voltage may be agreed between the manufacturer and purchaser.

6.7.2 Ethernet ports

The IEEE standard for Ethernet ports [b-IEEE 802.3] uses insulation voltages of 1.5 kV RMS, 2.25 kV d.c. and a 2.4 kV 1.2/50 μs impulse. These voltage levels are for the IEEE Standard [b-IEEE 802.3] Environment A. Environment A is when a LAN or LAN segment, with all its associated interconnected equipment, is entirely contained within a single low-voltage power distribution system and within a single building. In many countries there are two low-voltage mains in a building so that high power appliances can be connected between the two supplies. The IEEE Standard [b-IEEE 802.3] considers such an arrangement to still be a single low-voltage power distribution system.

From the IEEE Standard [b-IEEE 802.3], the basic insulation test level impulse voltage should be 2.4 kV, 1.2/50. The ITU-T Recommendations typically have maximum test levels of 6 kV. For insulation coordination to occur with a 6 kV transient, the insulation barrier needs an enhanced rated impulse voltage of approximately 8 kV.

Insulation electrical strength testing can be done with the equipment unpowered as it will not make any major difference to the insulation withstand. Subsequent tests need to be made to check the insulation resistance value and to ensure that the equipment still meets its operation specification. Verifying the rated impulse voltage of an Ethernet port is comparatively simple. The impulse is applied to the Ethernet port terminals used for signal and power. The generator return is connected to the accessible electrically isolated parts of the equipment. These parts could be the Ethernet cable protective screen, functional or protective earth terminal, all other signal port terminals and the powering port terminals. Figure 6.7-1 shows this test arrangement. PoE powered devices having a single port for unshielded twisted pair Ethernet ($UTP_{E)}$ cable do not have a suitable reference earth terminal and should be tested with a metallic foil wrapping.

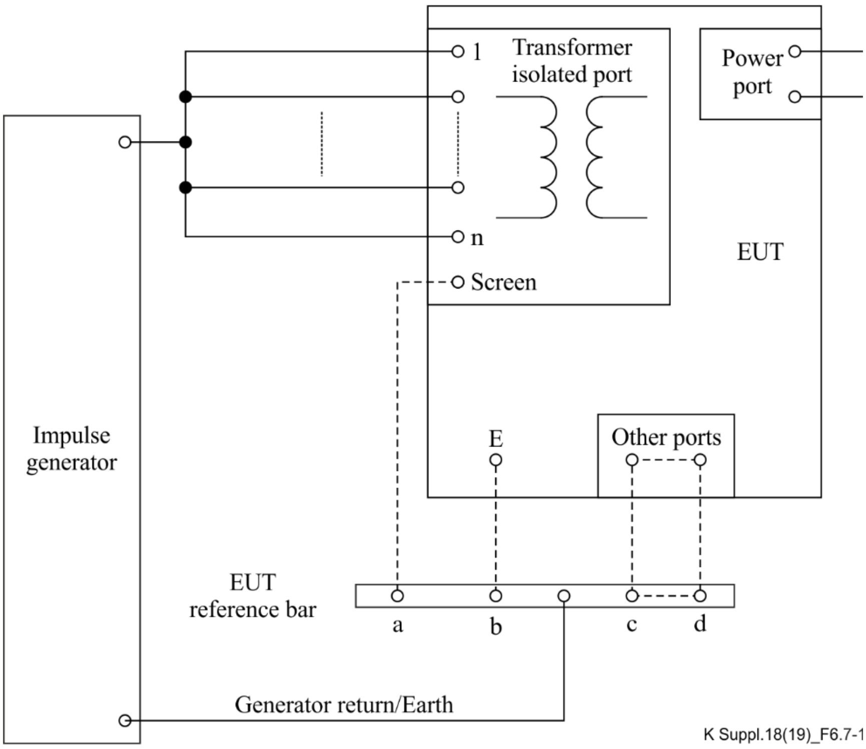

Figure 6.7-1 – Basic circuit for verifying Ethernet port rated impulse voltage

6.7.3 Ethernet overvoltages

An Ethernet LAN connection is direct, from one piece of equipment to another, and limited to 100 m.

6.7.3.1 Lightning

Lightning surges are likely introduced by induction, earth potential rise and via a series insulation barrier. These surges will inherently be longitudinal/common mode in nature. Longitudinal/common mode surge withstand is checked by test circuit (see Figure A.6.7-4 of [ITU-T K.44]). Transverse/differential surges are commonly the result of voltage limiter operation converting the surge (see clause 6.7.4). Manufacturers do not generally declare the use of surge protective component (SPCs) to bridge the Ethernet port insulation barrier and often external surge protective device (SPDs) are added because it is commonly believed that they will protect the port. To cater for the transverse/differential surges caused by these unknowns, manufactures can include transverse/differential surge protection on Ethernet ports that rely solely on insulation coordination for longitudinal/common mode surge protection. Power over Ethernet (PoE) equipment must be checked for inter-powering pair surges as shown in test circuit in Figure A.6.7-2 of [ITU-T K.44].

6.7.3.2 Power fault

The short length of LAN cables means that a.c. induction voltages from a.c. faults are likely to be low. Direct contact with the building a.c. supplies is possible via a direct connection or the failure of a powering source insulation barrier. If the port meets the required insulation resistance value with a test voltage greater than the peak voltage of the local a.c. mains supply power, cross testing is not done.

6.7.3.3 Unshielded twisted pair Ethernet (UTP_E) and shielded twisted pair Ethernet (STP_E) cables

The test approach used in this clause assumes UTP_E cables are used. Ethernet ports that provide a cable screen connection are tested for possible insulation breakdown between the screen terminal and the other terminals. If it is mandated that STP_E cables are to be used, that the connected Ethernet ports have a screen connection and any connected SPD maintains screen continuity, then such arrangements can be tested as a screened cable case.

6.7.4 SPCs and SPDs

Some designs include SPCs to protect the insulation barrier against excessive longitudinal/common mode voltage transients and signal and power pairs against transverse/differential transients. Inherently, transverse/differential transients will be caused by the asynchronous operation of the SPCs that bridge the insulation barrier. Figure 6.7-2 shows the action. The switching SPC on red Wire 1 switches first on the rising voltage front. The switching SPC on blue Wire 2 switches later because it has a higher limiting voltage. This asynchronous switching results in a 150 V transverse/differential transient between Wire 1 and Wire 2, which is the green shaded area.

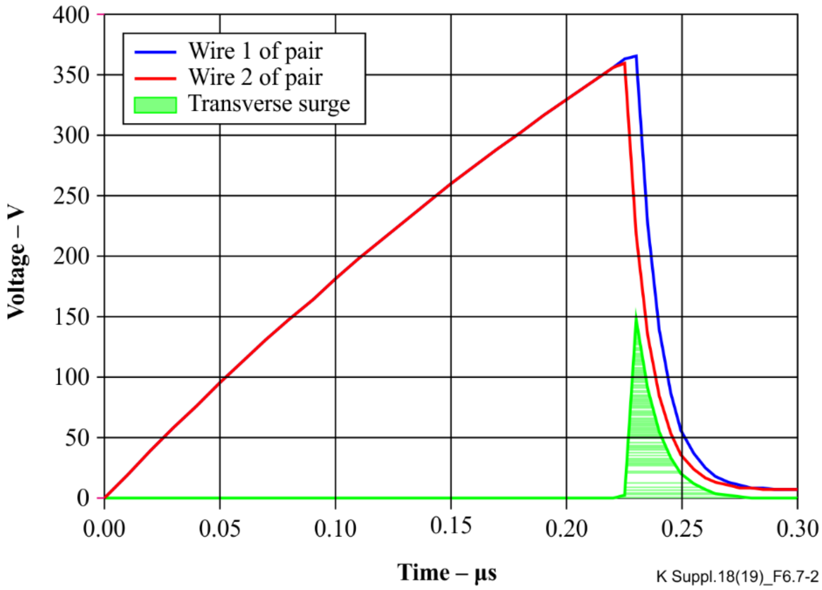

Figure 6.7-2 – Transverse/differential transient caused by asynchronous operation of the SPCs

The waveforms are more complicated for a twisted pair of wires due to coupling, but a transverse/differential transient between Wire 1 and Wire 2 will still be generated.

SPCs between wires (not bridging the insulation barrier) should not interact with insulation testing. SPCs that bridge the insulation barrier will draw current once their voltage threshold is exceeded. To allow for SPC operation during insulation testing, current limiting and sharing resistors need to be added to the generator output. The number of resistors will be four for ports that only use two of the twisted pairs and eight for ports that use four twisted pairs. External SPDs can have the same effect as port SPCs. Figures A.6.7-1 to A.6.7-4 of [ITU-T K.44] show the position and values for these resistors.

6.7.5 Insulation barriers in series

When a piece of equipment has a supplied class II powering adaptor, the full combination of equipment plus adaptor should be tested. Combination testing is needed as the resultant insulation voltage may be lower than the simple summation of the Ethernet port and the adaptor mains port insulation voltage values. The voltage sharing across two insulation barriers in series can be difficult to predict due to dynamic and static voltage distribution and should therefore be measured.

Ethernet ports containing SPCs that bridge the insulation barrier can effectively divert all the test voltage onto the adaptor insulation barrier when the SPCs operate. If this happens, then the adaptor insulation barrier should be rated for the total inter-port voltage. Likewise, if an Ethernet port solely relying on insulation is connected to one with SPCs bridging the insulation barrier, all the induced voltage would appear across the Ethernet port relying on insulation. If this happens, then the Ethernet port relying on insulation should be rated for the total inter-port voltage. Further complications on the mixed Ethernet port case is that the transverse/differential transients generated by the SPC port could damage the other port. External SPDs connected to a local earth and not the secondary circuit reference node can introduce surges into the equipment port due to local EPR voltages.

In summary, Ethernet ports with SPCs or fitted SPDs can increase the stress levels on the associated power adaptor and Ethernet ports. Increasing the insulation barrier voltage to the total inter-port voltage stops possible insulation breakdown. For Ethernet ports, including SPCs between the wires of a pair and pairs for PoE would mitigate any transverse/differential transients generated.

6.7.6 Increasing the rated impulse voltage

There are two common techniques for increasing the voltage, that is, an in-line higher voltage insulation barrier or a specially designed Ethernet SPD.

6.7.6.1 In-line higher voltage insulation barrier

This solution uses series isolating transformers of a higher voltage rating than the equipment Ethernet port. This is two isolation barriers in series again. To avoid voltage distribution problems, the series transformers can be made with a screen between the windings to decouple the equipment Ethernet port. Figure 6.7-3 shows the basic design approach.

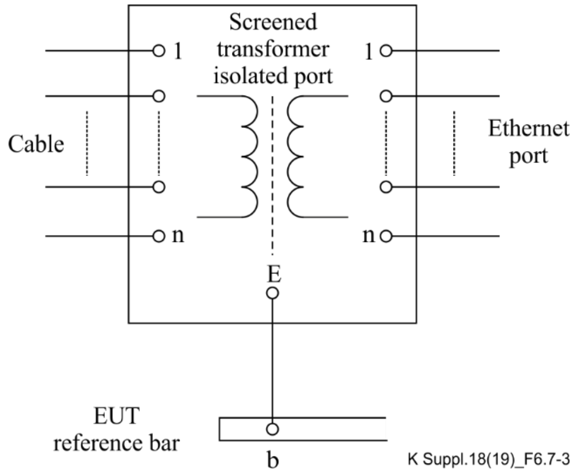

Figure 6.7-3 – In-line screened transformer isolation

SPCs could also be used on the Ethernet port side to limit the maximum longitudinal/common mode voltage.

6.7.6.2 Ethernet SPD

A carefully designed SPD can overcome the problems caused by switching SPC operation. Figure 6.7-4 shows a block diagram of such an arrangement.

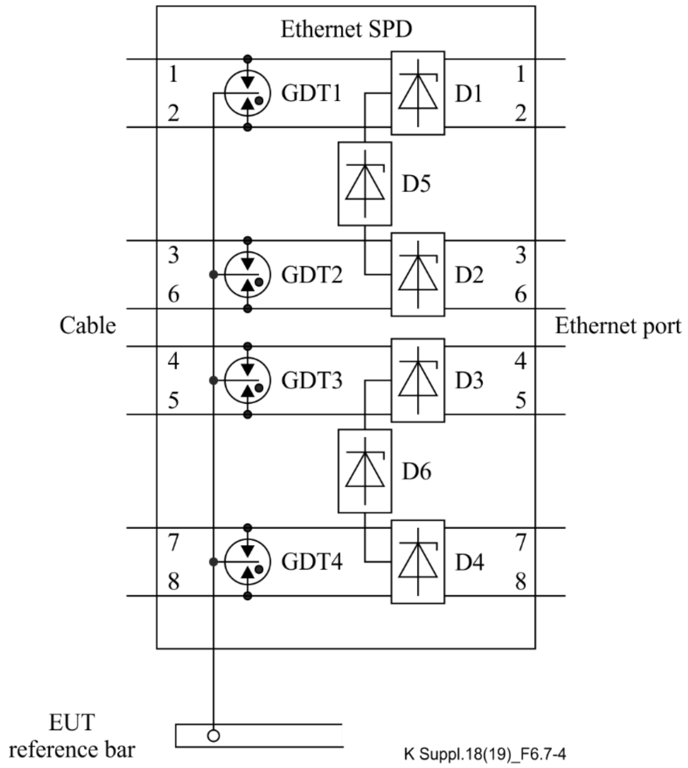

Figure 6.7-4 – Block diagram of an Ethernet SPD

GDT SPCs, GDT1, GDT2, GDT3 and GDT4 bridge the insulation. Single chamber three-electrode GDTs are used to minimize the transverse/differential transient generation on each twisted pair. A more complex GDT arrangement could reduce the transients between the PoE powering pairs, but in this figure, protection networks D5 and D6 limit those transients. Transients between the wires of a twisted pair are limited by protection networks D1 to D4. If GDT conduction occurs during a.c. power contact conditions, series input overcurrent protection should precede the GDTs.

Conventional plain old telephone system (POTS) primary protector design techniques are generally unsuitable for Ethernet use for the reasons explained in clause 6.7.3 and in this clause.

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