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Overvoltage protection guide for telecommunication equipment installed in customer premises

Recommendation ITU-T K.98

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Overvoltage protection guide for telecommunication equipment installed in customer premises

Summary

Recommendation ITU-T K.98 provides information which can help protect telecommunication equipment installed in the customer premises against damage due to the lightning strikes to the power and telecommunication lines/cables. It shows that, it is possible to protect equipment against a direct strike to power or telecommunication lines provided that the strike point is at a distance of more than a couple hundred metres from the customer premises in an urban area. The information provided takes into consideration the impact of different types of power distribution systems. It determines the impact of both the length of the telecommunication surge protection device (SPD) bonding conductor and the resistance to earth at the customer premises. The necessary isolation level for the protection of equipment without the use of primary protection is also calculated. It recommends the installation of a multiservice surge protective device (MSPD) or equivalent protection as the first level of protection. When necessary, primary protection is required to protect the MSPD or equivalent protection devices. For strikes to the services closer to the customer premises, an engineering solution is required.

History

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Introduction

This Recommendation can be used as a guide on how to protect telecommunication equipment from overvoltage damage due to lightning strikes to the power and telecommunication lines/cables.

For both the telecommunication and mains ports, only longitudinal surge voltages/currents are considered.

A number of different power distribution systems are used in the premises and ones where the neutral is not earthed at the structure, either directly or via a spark gap, may increase the probability of telecommunication equipment damage. This Recommendation investigates the issues of surge protection device (SPD) bond wire length and structure earth electrode resistance in relation to the different types of power distribution systems.

The available current at customer premises has been investigated in more detail than in Recommendation ITU-T K.67.

Recommendation ITU-T K.98

Overvoltage protection guide for telecommunication equipment installed in customer premises

1 Scope

This Recommendation provides guidance on how to protect telecommunication equipment installed in the customer premises from overvoltage damage due to lightning strikes to the power and telecommunication service lines/cables.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.12]	Recommendation ITU-T K.12 (2010), *Characteristics of gas discharge tubes for the protection of telecommunications installations*.
[ITU-T K.21]	Recommendation ITU-T K.21 (2011), *Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents*.
[ITU-T K.44]	Recommendation ITU-T K.44 (2012), *Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation*.
[ITU-T K.66]	Recommendation ITU-T K.66 (2011), *Protection of customer premises from overvoltages*.
[ITU-T K.67]	Recommendation ITU-T K.67 (2006), *Expected surges on telecommunications and signalling networks due to lightning*.
[ITU-T K.71]	Recommendation ITU-T K.71 (2011), *Protection of customer antenna installations*.
[ITU-T K.73]	Recommendation ITU-T K.73 (2008), *Shielding and bonding for cables between buildings*.
[ITU-T K.75]	Recommendation ITU-T K.75 (2008), *Classification of interface for application of standards on resistibility and safety of telecommunication equipment*.
[ITU-T K.85]	Recommendation ITU-T K.85 (2011), *Requirements for the mitigation of lightning effects on home networks installed in customer premises*.
[IEC 60364-4-44]	IEC 60364-4-44 ed2.0 (2007), *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*. <http://webstore.iec.ch/webstore/webstore.nsf/artnum/038219>
[IEC 60950-1]	IEC 60950-1 ed2.0 (2005), *Information technology equipment – Safety – Part 1: General requirements*. <http://webstore.iec.ch/webstore/webstore.nsf/ArtNum_PK/35320?OpenDocument>
[IEC 61643-21]	IEC 61643-21 ed1.2 (2012), *Low voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods*.

[IEC 61643-22] IEC 61643-22 ed1.0 (2004), *Low-voltage surge protective devices – Part 22: Surge protective devices connected to telecommunications and signalling networks – Selection and application principles.*
<http://webstore.iec.ch/webstore/webstore.nsf/artnum/033373>

[IEC 62305-2] IEC 62305-2 ed2.0 (2010), *Protection against lightning – Part 2: Risk management*.
<http://webstore.iec.ch/webstore/webstore.nsf/artnum/045856>

[IEC 62305-3] IEC 62305-3 ed2.0 (2010), *Protection against lightning – Part 2: Physical damage to structures and life hazard*.
<http://webstore.iec.ch/webstore/webstore.nsf/ArtNum_PK/46595?OpenDocument>

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 inherent protection [ITU-T K.44]: Inherent protection is protection that is provided within the equipment either by virtue of its intrinsic characteristics, by specific design, or by suitable protection components.

3.1.2 lightning flash [b-IEC 60479-4]: Atmospheric discharge consisting of one or more strokes.

3.1.3 lightning stroke (strike) [b-IEC 60479-4]: Single electrical discharge in a lightning flash.

3.1.4 multiservice surge protective device (MSPD) [ITU-T K.85]: A surge protective device (SPD) containing both telecommunications and mains protection. It may also include port protection for video or Ethernet.

3.1.5 primary protector [ITU-T K.44]: An SPD used for the primary protection of an installation at the location (preferably the building entrance point) where it diverts most of the surge current and prevents the majority of the surge stress from propagating further into the installation. This SPD must be accessible, removable and have equipotential bonding.

3.1.6 surge protective device (SPD) [ITU-T K.44]: Device that restricts the voltage of a designated port or ports, caused by a surge, when it exceeds a predetermined level: Secondary functions may be incorporated, such as a current-limiting device to restrict a terminal current. Typically, the protective circuit has at least one non-linear voltage-limiting surge protective component. Typically, the protective circuit has at least one non-linear voltage-limiting surge protective component. An SPD is a combination of a protection circuit and holder.

3.2 Terms defined in this Recommendation

There are no new terms defined in this Recommendation.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CICRÉ	Conseil Internationale des Grands Réseaux Électriques
CPE	Customer Premises Equipment
EPR	Earth Potential Rise
FXO	Foreign exchange Office
FXS	Foreign exchange Subscriber
GDT	Gas Discharge Tube

HV	High Voltage
IEEE	Institute of Electrical and Electronics Engineers
L	Line (phase) conductor
LPS	Lightning Protection System
LT	Line Termination
LV	Low Voltage (power line of a.c. voltage < 1 kV)
MB	Moisture Barrier
MET	Main Earth Terminal
MOV	Metal Oxide Varistor
MSB	Main Switch Board (Electrical)
MSPD	Multiservice Surge Protective Device
MV	Medium Voltage (power line of a.c. voltage > 1 kV and < 35 kV)
N	Neutral conductor
NT	Network Termination
NTD	Network Termination Device
PE	Earth conductor
PEN	combined PE and Neutral conductor
PoE	Power over Ethernet
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
SELV	Safety Extra Low Voltage
SPC	Surge Protective Component
SPD	Surge Protective Device
SSA	Solid State Arrester
TNV	Telecommunication Network Voltage
TVS	Transient Voltage Suppressor
USA	United States of America
USB	Universal Serial Bus
xDSL	x-type Digital Subscriber Line

5 Conventions

None.

6 Factors influencing surge levels

The purpose of this Recommendation is to provide a broad, but comprehensive, view of the essential ingredients necessary to protect equipment in a customer environment. Unlike a telecommunication building or outdoor cabinet, the network operator has no control over the mains power distribution, the installation of surge protective devices (SPDs) or the earthing and bonding.

The information given in this clause includes:

- Surge coupling, power installation and mechanisms of damage
- Elements of protection:
  - equipment resistibility;
  - correct classification and use of ports;
  - cable routing;
  - earthing and bonding;
  - SPDs;
  - direct strike protection of a structure;
  - installation of protection.

6.1 Surge coupling and mechanisms of damage

To be able to provide effective protection, it is necessary to understand how surges are coupled into a circuit and their possible impact on the equipment.

[IEC 62305-2] defines four sources of damage as follows:

- S1: flashes to a structure e.g., an air termination, antenna or metallic service pipe or conductor;
- S2: flashes near a structure;
- S3: flashes to a line e.g., power line, telecommunication cable, etc.;
- S4: flashes near a line.

6.1.1 Flashes to a structure (S1)

In this case, lightning will flash to an air termination, antenna, metallic service pipe or to a conductor. The structure will rise in potential with respect to remote earth. The net result is that current will be conducted in the external service conductors. If effective surge protection hasn't been installed, equipment with external conductors will almost certainly be damaged. Surges will also be magnetically coupled into wiring loops within the structure, see Figure 1. The magnitude of the voltage induced into the internal cabling depends on many factors such as lightning strike current, closeness of the strike, size of the loop, type of the cable and building shielding (surge S1 in Figure 1).

6.1.2 Flashes near a structure (S2)

In this case, lightning flashes to earth near the structure and surges are magnetically coupled into the wiring loops within the structure, see Figure 1. The magnitude of the voltage induced into the internal cabling depends on many factors such as lightning strike current, closeness of the strike, size of the loop, type of the cable and the building shielding (surge S2 in Figure 1).

6.1.3 Flashes to a line (S3)

In this case, an arc hits a telecommunication or power service line or cable. This coupling will be conductive, see Figure 1, surges S3. If there is no primary protection installed, the equipment will be subjected to the lightning surge entering the building. If the primary protection is installed at the telecommunication line termination/network termination (LT/NT), the equipment may be subjected to one or more of the following surges:

1) the let-through voltage of the primary protection (for surges below the operating voltage of the primary protector);
2) a truncated waveform caused by the primary protector operating;
3) the voltage caused by the primary protector current conducted in the primary protector bond wire.

6.1.4 Flashes near a line (S4)

In this case, a lightning flash hits the earth near a telecommunication or power service line or cable. This coupling will be inductive, see Figure 1, surge S4. If there is no primary protection installed, the equipment will be subjected to the lightning surge entering the building. If primary protection is installed at the telecommunication line termination/network termination (LT/NT), the equipment may be subjected to one or more of the following surges:

1) the let-through voltage of the primary protection (for surges below the operating voltage of the primary protector);
2) a truncated waveform caused by the primary protector operating;
3) the voltage caused by the primary protector current conducted in the primary protector bond wire.

6.1.5 Impact of actual installations

It is likely that the primary protector may be located in some distance from the equipment and that the primary protector installation may not be ideal. The issues are:

- Inductive drop across the SPD connecting leads: It is not expected that this will be a problem with network termination devices (NTDs) complying with [ITU-T K.65]. [ITU-T K.21] makes allowance for a total of one metre of connecting lead for mains SPDs during the coordination testing.
- The current conducted in the bonding conductor between the SPD and the main earth terminal (MET): The maximum recommended length of the bonding conductor is specified in [ITU-T K.66]. The length of this bonding conductor affects the current sharing between the primary protector and the equipment SPD or an SPD or multiservice surge protective device (MSPD) installed at the equipment. If the equipment has high input impedance, the peak voltage at the equipment is proportional to the length of the bonding conductor.
- The voltage induced in the cabling between the protection frame and the equipment: The magnitude of this voltage will depend on the magnitude of the current, the closeness of the lightning strike and whether the cable is shielded or unshielded. However, if a MSPD or equivalent is installed at the equipment as the first level of defence, there is no problem in limiting the voltage at the equipment.
- Surge reflection at equipment port between the equipment and the LT/NT: Some IEC standards have major consideration for voltage doubling at the equipment due to reflections. Due to the relatively short distance between the primary protection and the equipment, any voltage doubling for high impedance equipment will only occur for a short time (< 1 μs) and is unlikely to cause insulation breakdown in the equipment. Any current doubling into low impedance equipment will also only occur for a short time and will be easily handled by the equipment SPD. However, if a MSPD or equivalent is installed at the equipment as the first level of defence, there is not a problem in limiting the voltage at the equipment.
- Figure 1 shows two separated earth electrodes. Unless these are bonded together, a potential difference may occur between the electrodes and damage the ports of equipment A and equipment B. A ring earth can be a solution to achieve equipotentialization (see [ITU-T K.66]).
- Impact of electrode resistance (structure earth) and the need to bond to the MET.

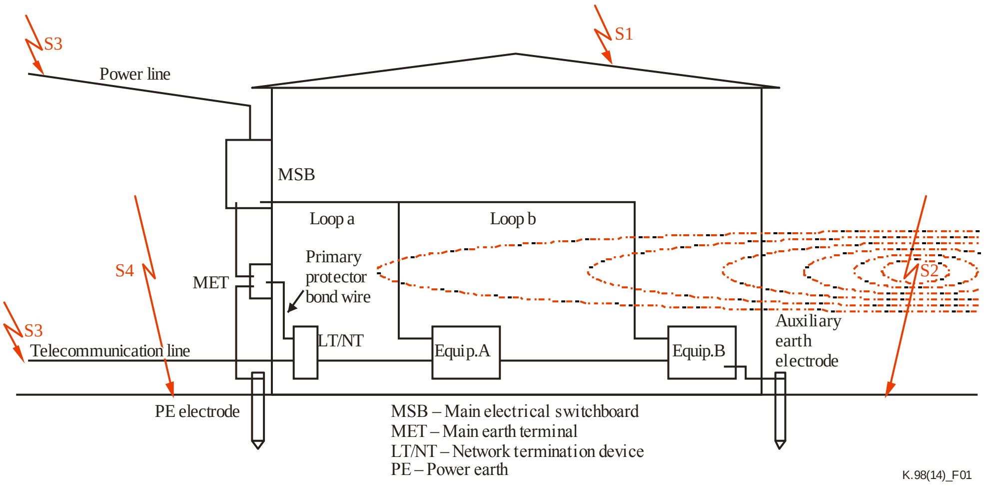


Figure 1 – Surge coupling

Power installation

A further consideration is the impact of the type of power installation. Installation methods for different power systems are described in Annex A of [ITU-T K.66] and [IEC 60950-1]. There are many different types of power systems and some do not have a neutral conductor and some have a phase conductor connected to earth. The systems discussed below have a neutral, but not an earthed phase conductor. For these excluded systems refer to [IEC 60950-1].

The meaning of the terms used to describe the power systems are given below.

First letter: relationship of the power distribution system to earth:

- T indicates direct connection of one pole to earth;
- I indicates system isolated from earth, or one point connected to earth through an impedance.

Second letter: earthing of the equipment:

- T indicates direct electrical connection of the equipment to earth, independently of the earthing of any point of the power distribution system;
- N indicates direct electrical connection of the equipment to the earthed point of the power distribution system (in a.c. systems, the earthed point of the power distribution system is normally the neutral point or, if a neutral point is not available, a phase conductor).

Subsequent letters if any: arrangement of neutral and protective conductors:

- S indicates the protective function is provided by a conductor separate from the neutral or from the earthed line (or in a.c. systems, earthed phase) conductor;
- C indicates the neutral and protective functions are combined in a single conductor (PEN conductor).

From the perspective of the equipment in the structure, systems considered in this Recommendation can be described as shown in Figures 2 to13.

- There are phase conductors (L1, L2 and L3), a neutral conductor (N) and an earth conductor (PE) in the distribution network. This illustrates a TN-S power system. There is no structure earth electrode shown in [IEC 60950-1], however there is likely to be a path to earth at the structure.
- There are phase conductors (L1, L2 and L3) and a combined PE and neutral conductor (PEN) in the distribution network. There is a neutral-earth link and this is connected to a structure earth electrode. The PEN conductor is split into an N and PE conductors after the neutral-earth link. This illustrates TN-C-S and TN-C power systems.

- There are phase conductors (L1, L2 and L3) and a neutral conductor (N) in the distribution network. The neutral is not connected to the structure earth electrode, but the PE is. There is no link between the PE and the neutral. This illustrates an IT and TT power system.

The impact of these different earthing systems will be considered for mains powered earthed and non-earthed equipment. Equipment powered from an external power adaptor may be earthed or non-earthed, depending on the equipment and power supply design.

Equipment powered by a power adaptor can be considered according to whether the power source supplies an earth to the equipment.

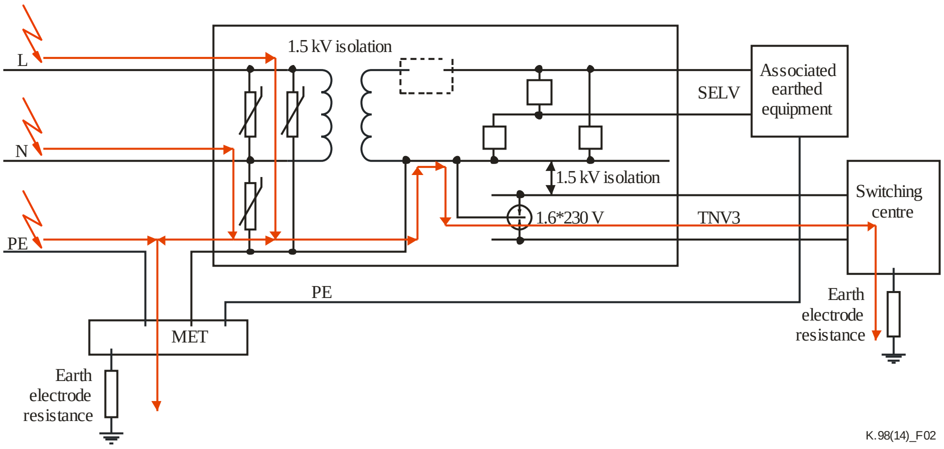


Figure 2 – Mains surge path for earthed equipment in a TN-S power system

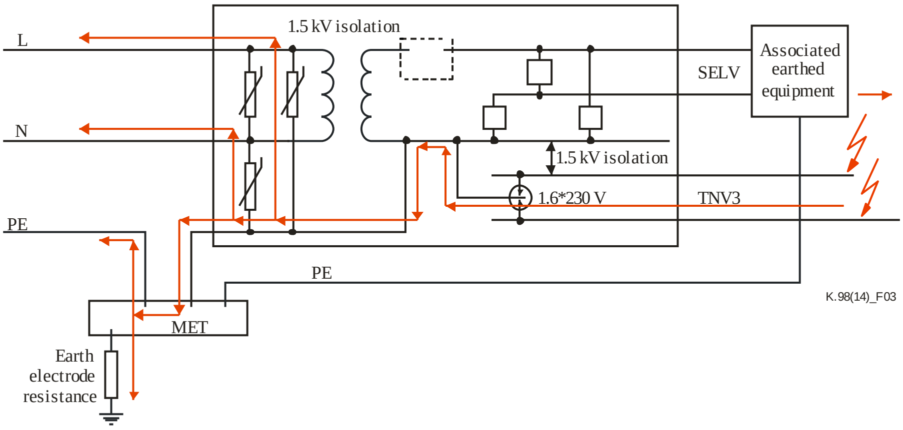


Figure 3 – Telecommunication surge path for earthed equipment in a TN-S power system

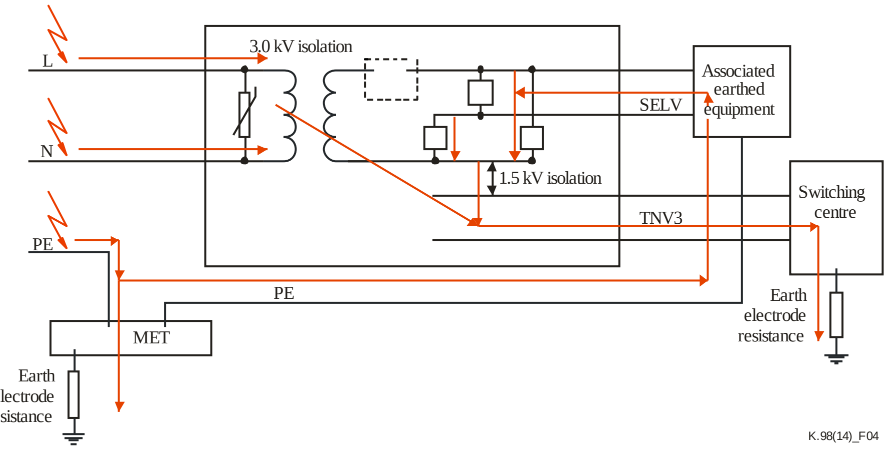


Figure 4 – Mains surge path for floating equipment in a TN-S power system

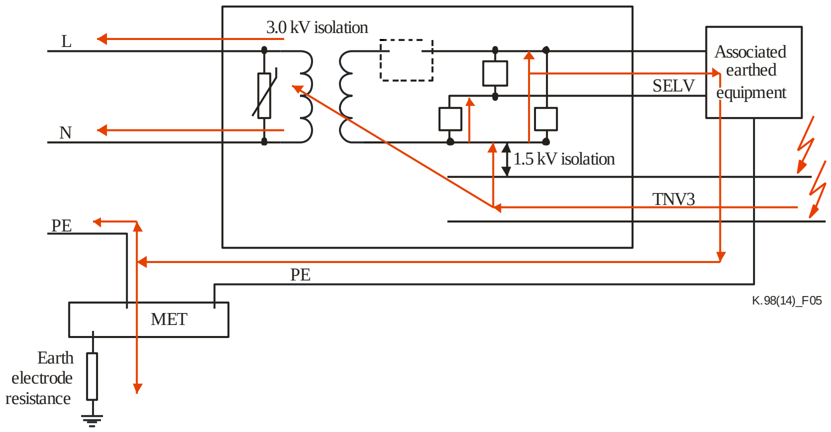


Figure 5 – Telecommunication surge path for floating equipment in a TN-S power system

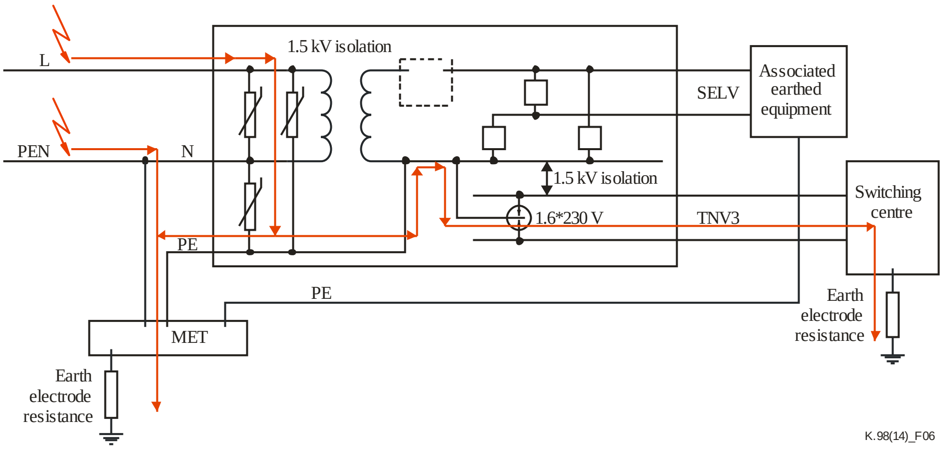


Figure 6 – Mains surge path for earthed equipment in a TN-C or TN-C-S power system

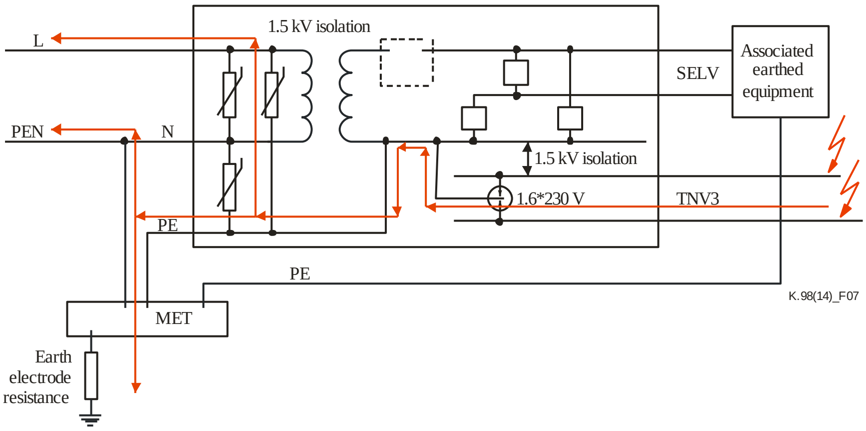


Figure 7 – Telecommunication surge path for earthed equipment in a TN-C or TN-C-S power system

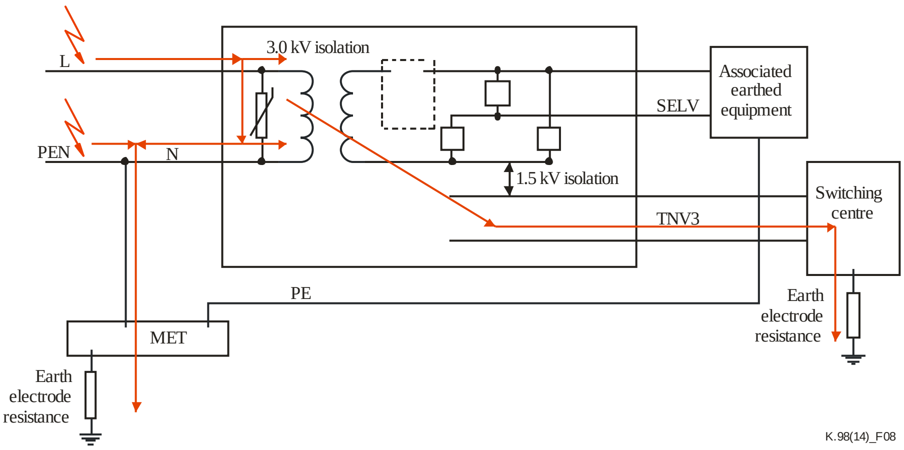


Figure 8 – Mains surge path for floating equipment in a TN-C or TN-C-S power system

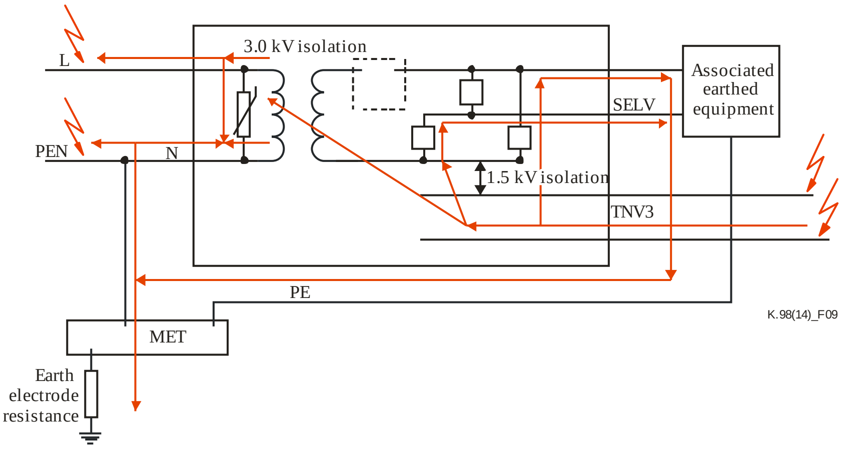


Figure 9 – Telecommunication surge path for floating equipment in a TN-C or TN-C-S power system

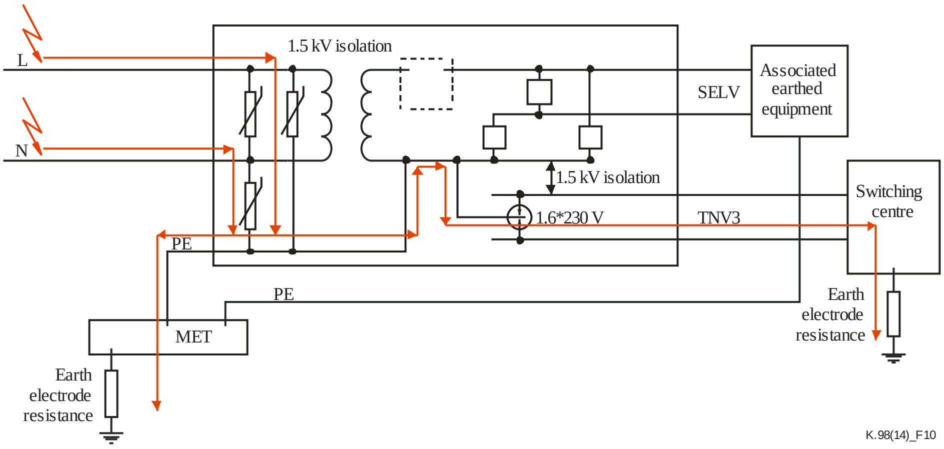


Figure 10 – Mains surge path for earthed equipment in a TT or IT power system

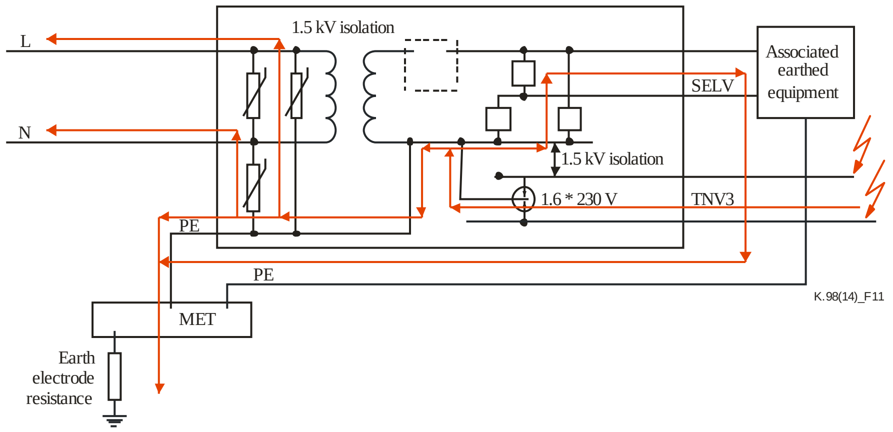


Figure 11 – Telecommunication surge path for earthed equipment in a TT or IT power system

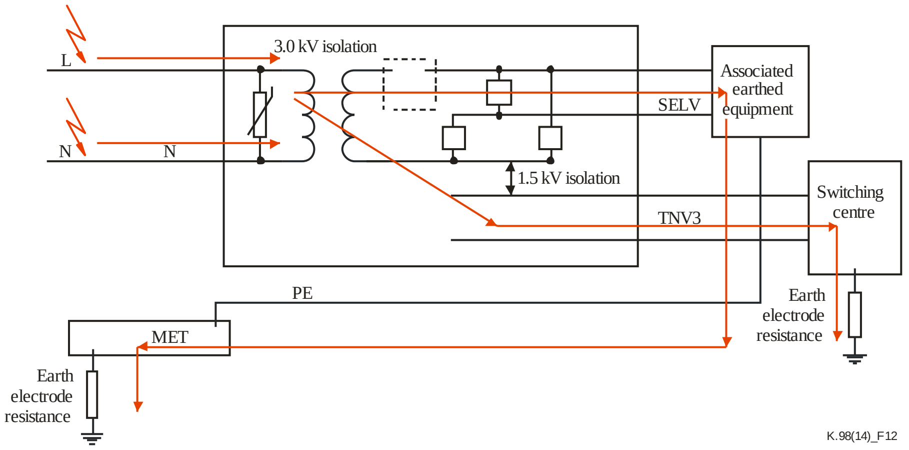


Figure 12 – Mains surge path for floating equipment in a TT or IT power system

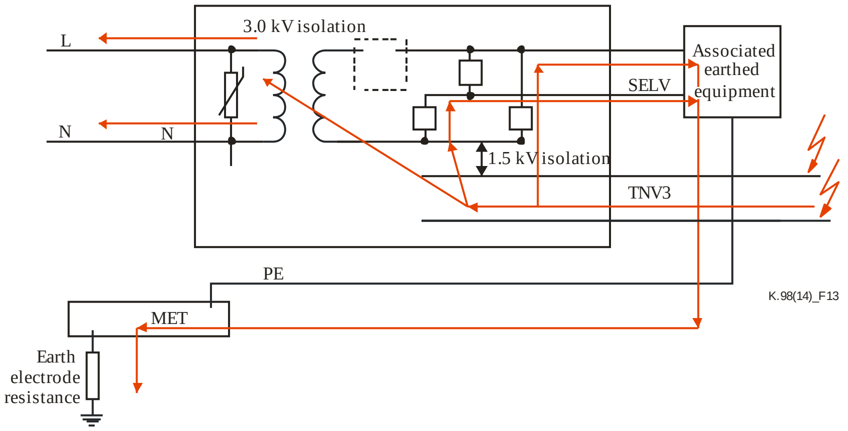


Figure 13 – Telecommunication surge path for floating equipment in a TT or IT power system

Annex A contains simulations of the schematics shown in Figures 2 to 13. Where applicable, the impact of the length of telecommunication SPD bond wire length, the length of the internal telecommunication cable from the building entry point to the equipment and the structure earth electrode resistance has been investigated. The standard case consists of a 10 metre telecommunication SPD bond wire conductor, 10 metres of telecommunication conductor and a 100 Ω earth electrode resistance.

NOTE – Table 8.1 of [ITU-T K.66] limits the maximum SPD bond wire conductor length to 1.5 m for direct strikes.

For the case when there is no primary protection, the simulation results would provide information on:

- How high the MET and safety extra low voltage (SELV) circuit rises above remote earth and local earth considering the earth potential rise of and around the local electrode.
- The power transformer stress (primary to secondary surge voltage). The stress applied to the telecommunication port.
- Current injected into the other external networks e.g., power network or telecommunication node.
- The voltage/current for an internal port to an internal port of associated earthed equipment. The voltage and current will be measured for an Ethernet port which has a complex impedance.
- The impact of an unearthed power outlet.

For the case when there is primary protection, the simulation results would provide information on:

- How high the MET and SELV circuit rises above remote earth and local earth considering the earth potential rise of and around the local electrode.
- The power transformer stress (primary to secondary surge voltage). The stress applied to the telecommunication port.
- Current injected into the other external networks e.g., power network or telecommunication node.
- The voltage/current for an internal port to an internal port of associated earthed equipment. The voltage and the current will be measured for an Ethernet port which has a complex impedance.
- The operation of any inherent SPDs, spark gap and metal oxide varistor (MOV) mains primary protectors and telecommunication primary protectors.
- The impact of an unearthed power outlet.

Results in Table 1 were obtained from simulations for three discrete resistances to earth as follows:

- Low earthing resistance, represented in the simulations by using a 2 Ω earthing resistance.
- High earthing resistance, represented in the simulations by using a 100 Ω earthing resistance.
- An infinite resistance, represented in the simulations by removing the connection to the earth.

Also, not every combination of the variables has been simulated. Only one change has been made from the standard case of a 100 Ω customer premises earth with a 10 m bond wire length. Where applicable, the simulations were performed as follows:

- 100 Ω customer premises earth and a 10 m bond wire length;
- 100 Ω customer premises earth and a 1.5 m bond wire length;
- 100 Ω customer premises earth and a 10 m bond wire length with the earth connection missing from the power outlet;
- 2 Ω customer premises earth and a 10 m bond wire length;
- No customer premises earth and a 10 m bond wire length.

No attempt should be made to draw any conclusion for a different set of variables because of the unexpected outcomes obtained during the simulations. For example, there is a case where damage occurred with a 2 Ω customer premises earth, but not with a 100 Ω customer premises earth.

Simulations have also been performed to investigate the prospective waveform at downstream SPDs for both the clamping and the switching type primary protector SPDs and the necessary rating of these downstream SPDs.

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TN-S	Mains	Earthed equipment	Without primary protection	n.a.	100 Ω	Damage to the telecommunication port. ☹
TN-S	Mains	Earthed equipment	Without primary protection	n.a.	100 Ω and earth missing from power outlet	Damage to the telecommunication and Ethernet ports. ☹
TN-S	Mains	Earthed equipment	Without primary protection	n.a.	2 Ω	Damage to the telecommunication port. ☹
TN-S	Mains	Earthed equipment	Without primary protection	n.a.	No path to earth.	Damage to the telecommunication port. ☹
TN-S	Mains	Earthed equipment	With primary protection	10 m	100 Ω	Damage to the telecommunication port. ☹
TN-S	Mains	Earthed equipment	With primary protection	1.5 m	100 Ω	Damage to the telecommunication port. ☹
TN-S	Mains	Earthed equipment	With primary protection	10 m	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TN-S	Mains	Earthed equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TN-S	Mains	Earthed equipment	With primary protection	10 m	No path to earth at the customer premises.	Damage to the telecommunication port. ☹
TN-S	Mains	Floating equipment	Without primary protection	n.a.	100 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TN-S	Mains	Floating equipment	Without primary protection	n.a.	2 Ω	Damage to mains, telecommunication and Ethernet ports. ☹

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TN-S	Mains	Floating equipment	Without primary protection	n.a.	No path to earth at the customer premises.	Damage to mains, telecommunication and Ethernet ports. ☹
TN-S	Mains	Floating equipment	With primary protection	10 m	100 Ω	The equipment is protected. ☺
TN-S	Mains	Floating equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TN-S	Mains	Floating equipment	With primary protection	10 m	No path to earth at the customer premises.	The equipment is protected. ☺
TN-C and TN-C-S	Mains	Earthed equipment	Without primary protection	n.a.	100 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Earthed equipment	Without primary protection	n.a.	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Earthed equipment	Without primary protection	n.a.	2 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Earthed equipment	Without primary protection	n.a.	No path to earth.	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Earthed equipment	With primary protection	10 m	100 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Earthed equipment	With primary protection	1.5 m	100 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Mains	Earthed equipment	With primary protection	10 m	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Earthed equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TN-C and TN-C-S	Mains	Earthed equipment	With primary protection	10 m	No path to earth at the customer premises.	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Mains	Floating equipment	Without primary protection	n.a.	100 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TN-C and TN-C-S	Mains	Floating equipment	Without primary protection	n.a.	2 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Mains	Floating equipment	Without primary protection	n.a.	No path to earth at the customer premises.	Damage to mains, telecommunication and Ethernet ports. ☹
TN-C and TN-C-S	Mains	Floating equipment	With primary protection	10 m	100 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Mains	Floating equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Mains	Floating equipment	With primary protection	10 m	No path to earth at the customer premises.	The equipment is protected. ☺
TT and IT	Mains	Earthed equipment	Without primary protection	n.a.	100 Ω	Damage to the telecommunication port. ☹
TT and IT	Mains	Earthed equipment	Without primary protection	n.a.	100 Ω and earth missing from power outlet	Damage to the telecommunication and Ethernet ports. ☹
TT and IT	Mains	Earthed equipment	Without primary protection	n.a.	2 Ω	Damage to the telecommunication port. ☹
TT and IT	Mains	Earthed equipment	Without primary protection	n.a.	No path to earth.	Damage to the telecommunication port. ☹
TT and IT	Mains	Earthed equipment	With primary protection	10 m	100 Ω	Damage to the telecommunication port. ☹

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TT and IT	Mains	Earthed equipment	With primary protection	1.5 m	100 Ω	Damage to the telecommunication port. ☹
TT and IT	Mains	Earthed equipment	With primary protection	10 m	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TT and IT	Mains	Earthed equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TT and IT	Mains	Earthed equipment	With primary protection	10 m	No path to earth at the customer premises.	Damage to the telecommunication port. ☹
TT and IT	Mains	Floating equipment	Without primary protection	n.a.	100 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TT and IT	Mains	Floating equipment	Without primary protection	n.a.	2 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TT and IT	Mains	Floating equipment	Without primary protection	n.a.	No path to earth at the customer premises.	Damage to mains, telecommunication and Ethernet ports. ☹
TT and IT	Mains	Floating equipment	With primary protection	10 m	100 Ω	The equipment is protected. ☺
TT and IT	Mains	Floating equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TT and IT	Mains	Floating equipment	With primary protection	10 m	No path to earth at the customer premises.	The equipment is protected. ☺
TN-S	Telecom	Earthed equipment	Without primary protection	n.a.	100 Ω	Damage to the telecommunication port. ☹
TN-S	Telecom	Earthed equipment	Without primary protection	n.a.	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TN-S	Telecom	Earthed equipment	Without primary protection	n.a.	2 Ω	Damage to the telecommunication port. ☹
TN-S	Telecom	Earthed equipment	Without primary protection	n.a.	No path to earth.	Damage to the telecommunication port. ☹
TN-S	Telecom	Earthed equipment	With primary protection	10 m	100 Ω	Damage to the telecommunication port. ☹
TN-S	Telecom	Earthed equipment	With primary protection	1.5 m	100 Ω	The equipment is protected. ☺
TN-S	Telecom	Earthed equipment	With primary protection	10 m	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TN-S	Telecom	Earthed equipment	With primary protection	10 m	2 Ω	Damage to the telecommunication port. ☹
TN-S	Telecom	Earthed equipment	With primary protection	10 m	No path to earth at the customer premises.	Damage to the telecommunication port. ☹
TN-S	Telecom	Floating equipment	Without primary protection	n.a.	100 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TN-S	Telecom	Floating equipment	Without primary protection	n.a.	2 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TN-S	Telecom	Floating equipment	Without primary protection	n.a.	No path to earth at the customer premises.	Damage to mains, telecommunication and Ethernet ports. ☹
TN-S	Telecom	Floating equipment	With primary protection	10 m	100 Ω	The equipment is protected. ☺
TN-S	Telecom	Floating equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TN-S	Telecom	Floating equipment	With primary protection	10 m	No path to earth at the customer premises.	The equipment is protected. ☺
TN-C and TN-C-S	Telecom	Earthed equipment	Without primary protection	n.a.	100 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Earthed equipment	Without primary protection	n.a.	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Earthed equipment	Without primary protection	n.a.	2 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Earthed equipment	Without primary protection	n.a.	No path to earth.	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Earthed equipment	With primary protection	10 m	100 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Earthed equipment	With primary protection	1.5 m	100 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Telecom	Earthed equipment	With primary protection	10 m	100 Ω and earth missing from power outlet	The equipment is protected. ☺
TN-C and TN-C-S	Telecom	Earthed equipment	With primary protection	10 m	2 Ω	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Earthed equipment	With primary protection	10 m	No path to earth at the customer premises.	Damage to the telecommunication port. ☹
TN-C and TN-C-S	Telecom	Floating equipment	Without primary protection	n.a.	100 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TN-C and TN-C-S	Telecom	Floating equipment	Without primary protection	n.a.	2 Ω	Damage to mains, telecommunication and Ethernet ports. ☹

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TN-C and TN-C-S	Telecom	Floating equipment	Without primary protection	n.a.	No path to earth at the customer premises.	Damage to mains, telecommunication and Ethernet ports. ☹
TN-C and TN-C-S	Telecom	Floating equipment	With primary protection	10 m	100 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Telecom	Floating equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TN-C and TN-C-S	Telecom	Floating equipment	With primary protection	10 m	No path to earth at the customer premises.	The equipment is protected. ☺
TT and IT	Telecom	Earthed equipment	Without primary protection	n.a.	100 Ω	Damage to the telecommunication port. ☹
TT and IT	Telecom	Earthed equipment	Without primary protection	n.a.	100 Ω and earth missing from power outlet	Damage to the telecommunication and Ethernet ports. ☹
TT and IT	Telecom	Earthed equipment	Without primary protection	n.a.	2 Ω	Damage to the telecommunication port. ☹
TT and IT	Telecom	Earthed equipment	Without primary protection	n.a.	No path to earth.	Damage to the telecommunication port. ☹
TT and IT	Telecom	Earthed equipment	With primary protection	10 m	100 Ω	Damage to the telecommunication port. ☹
TT and IT	Telecom	Earthed equipment	With primary protection	1.5 m	100 Ω	The equipment is protected. ☺
TT and IT	Telecom	Earthed equipment	With primary protection	10 m	100 Ω and earth missing from power outlet	Damage to the telecommunication port. ☹
TT and IT	Telecom	Earthed equipment	With primary protection	10 m	2 Ω	Damage to the telecommunication port. ☹

Table 1 – Simulation results

Power system	Surge to?	Equipment type	Primary protection?	Telecom SPD bond wire length	Resistance to earth at premises	Predicted result
TT and IT	Telecom	Earthed equipment	With primary protection	10 m	No path to earth at the customer premises.	Damage to the telecommunication port. ☹
TT and IT	Telecom	Floating equipment	Without primary protection	n.a.	100 Ω	Damage to mains, telecommunication and Ethernet ports. ☹
TT and IT	Telecom	Floating equipment	Without primary protection	n.a.	2 Ω	Damage to mains, telecommunications and Ethernet ports. ☹
TT and IT	Telecom	Floating equipment	Without primary protection	n.a.	No path to earth at the customer premises.	Damage to mains, telecommunication and Ethernet ports. ☹
TT and IT	Telecom	Floating equipment	With primary protection	10 m	100 Ω	The equipment is protected. ☺
TT and IT	Telecom	Floating equipment	With primary protection	10 m	2 Ω	The equipment is protected. ☺
TT and IT	Telecom	Floating equipment	With primary protection	10 m	No path to earth at the customer premises.	The equipment is protected. ☺
NOTE – In column 2 of the table, Telecom = Telecommunication						

6.2 Elements of protection

Protecting telecommunication equipment, within a structure, requires many components. Components in bullet points 1) through 4) provide good engineering practice and should be present in all installations. Components in bullet points 5) and 6) should be installed when required, usually as the result of a risk assessment.

1) Equipment resistibility: Equipment complies with the appropriate resistibility level of [ITU-T K.21].
2) Correct classification and use of ports: The equipment ports have been correctly classified and are used in accordance with [ITU-T K.75].
3) Cable routing: Cable routing practices comply with [ITU-T K.66].
4) Earthing and bonding: Earthing and bonding practices comply with [ITU-T K.66]. Earthing is the connection of the earth bar to earth, usually via an installed earth electrode. Bonding is the interconnection of earth electrodes and metallic parts to minimise potential differences.
5) SPDs: Overvoltage protection, when required, has been installed according to [ITU-T K.66]. This includes the use of both multi-service surge protective devices (MSPDs) and primary protectors.
6) Direct strike protection of the building, achieved by installing an external lightning protection system (LPS).

Some of these components are indicated pictorially in Figure 14.

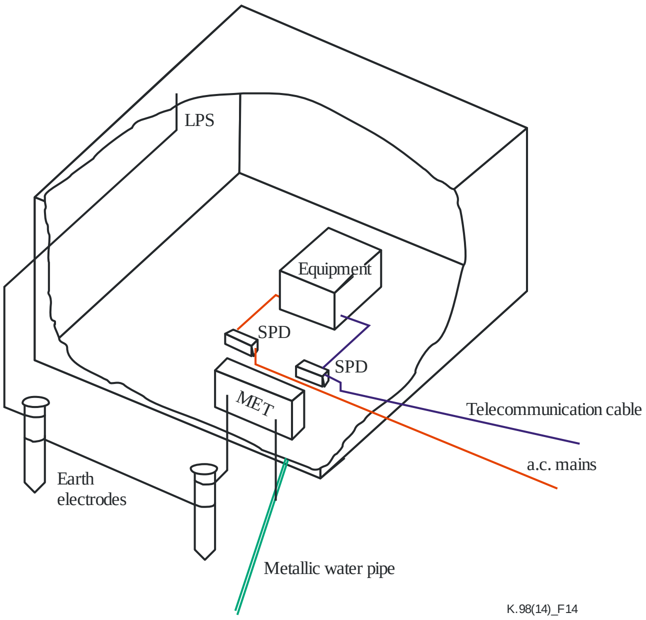


Figure 14 – Protection components

6.3 Equipment resistibility

6.3.1 Resistibility levels

To ensure that the equipment can be protected, it is necessary that it comply with the required resistibility level identified by [ITU-T K.21]. Ensuring compliance means that the 'external' ports of the equipment will coordinate with the primary protection which will be installed when required.

From the year 2000 forward, [ITU-T K.21] has contained both the "basic" and the "enhanced" requirements. The basic requirements were kept as they represent the general European environment which importantly includes good earthing and bonding and primary protection is installed when necessary to protect the equipment. The enhanced requirements were added to specifically take into account the following:

- Higher levels of power induction have been developing in Australia, France and Finland. The basic requirement is 1.0 A^2s and the enhanced requirement is 10 A^2s.
- A higher inherent resistibility level for customer equipment of 6 kV when the equipment does not contain earthed SPDs/ surge protective components (SPCs) in the telecommunication line port. This was requested by France and takes into consideration the nonbonding of the mains neutral conductor to the customer earth.

In 2008 "special' requirements were introduced in [ITU-T K.44]. These were requested by Japan as a result of problems experienced due to non-bonded (to the customer earth) power systems.

The required level of resistibility can be determined as shown in Figure 15 which has been reproduced from [ITU-T K.85]. Information on "Special requirements" is contained in [ITU-T K.44]. Noncompliance with [ITU-T K.66] could include:

- Non-bonded earths;
- Difficulty in installing SPDs at the building entry;
- Bonding wires in excess of 10 m.

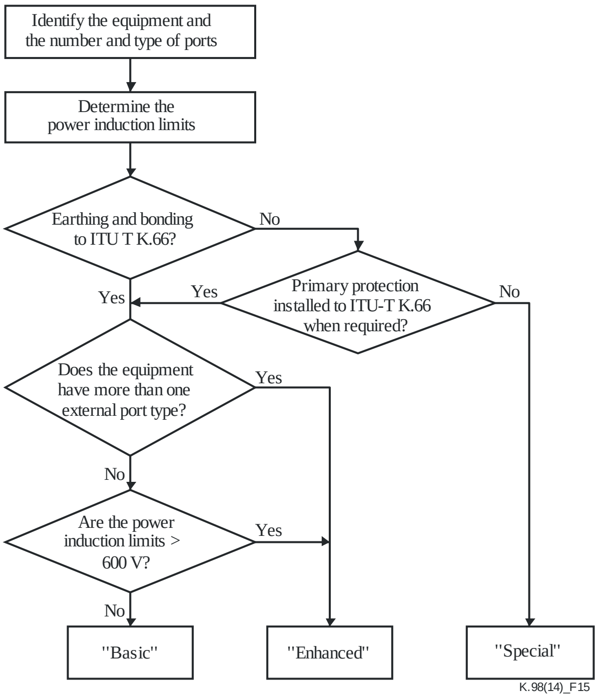


Figure 15 – Flowchart for determining required level of resistibility

6.3.2 Port types

Equipment can have two types of ports, 'external' and 'internal'. Within these port types, there can be different interface types. The reader is directed to clause A.2.1 of [ITU-T K.44] for information on this topic. It should be noted that external ports are tested to ensure that they will be protected by the addition of primary protection. Internal ports on the other hand, do not have this type of test and more care is required if additional protection is needed.

6.3.3 SPDs versus insulation

The protection level of the equipment itself is known as inherent protection. Inherent protection is defined in clause 3.1.1.

This inherent protection can be provided by using protection components or by insulation barriers or a combination of both within the equipment. The special requirements can be achieved by using a higher insulation withstand level within the equipment.

This principle can also be applied external to the equipment. For example, an external to the equipment mains isolation transformer can be used to increase the effective isolation between mains and the telecommunication ports. When an MSPD is used to protect the equipment, it is the combination of mains and telecommunication SPDs within the MSPD and the safety isolation barrier within the equipment which protects the equipment by preventing a breakdown of this insulation and the surge bypasses the equipment.

It should be noted that, the use of SPDs may actually increase the magnitude of the surge current being conducted in the installation wiring while the use of external isolation barriers may reduce the magnitude of the surge current being conducted in the wiring. However, if the insulation withstand level is exceeded, significant damage may take place and a may also result in safety hazard (fire and electric shock).

If higher insulation levels are being considered within the equipment (special requirements) or external to the equipment as a form of added protection, it is necessary to be aware of the voltages which may exist. An indication of the voltages which may arise can be found in Annex A.

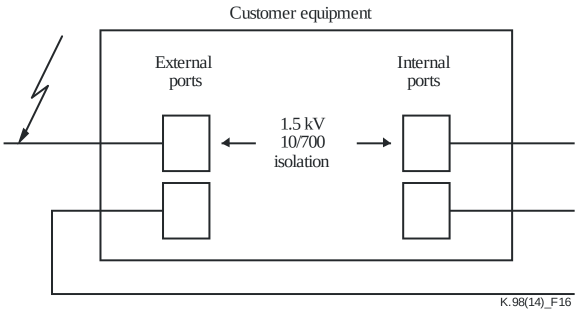
6.4 Correct classification and use of ports

As indicated above, equipment may have both external and internal ports. There are both damage and safety implications of not using the correct type of port. The equipment manufacturer should specify the correct use of the equipment ports. If this information is not available, [ITU-T K.75] provides information on classifying plain old telephone service (POTS), Ethernet and video ports. A mains port is always an external port.

Manufacturers of customer equipment in particular assume that non-network equipment ports will only be connected to intra-building cabling. A problem then occurs if the network operator, or the customer, decides to extend the service to an outbuilding facility. Equipment designed for connection to intra-building cabling may have insufficient isolation from the safety point of view and insufficient resistibility to overvoltages, when connected to inter-building cables. Therefore, it is imperative to only connect inter-building cables to external ports and intra-building cables to internal ports. The reason is that external ports have different isolation levels to earth and to other ports. Furthermore, there may not be any isolation between external ports of the same type and between internal ports of the same type, see Figure 16.

Correct classification of ports is important. If an inter-building cable is connected to an internal port, the internal port will be subjected to conductive lightning surges or a.c. surges resulting in equipment damage and human safety issues. It is also difficult to protect internal ports from damage. The safety hazard is due to the lower isolation requirement in safety standards for internal ports.

If an intra-building cable is connected to an external port, the internal cable may be exposed to lightning surges via another external port which is connected to an external cable. It can be seen in Figure 16 that there is only functional insulation between external ports of the same type.



Isolation levels	
Internal to internal	functional insulation
External to external	functional insulation
External to internal	1.5 kV 10/700

Figure 16 – Customer equipment port isolation

6.5 Cable routing

To reduce the magnitude of induced surges due to nearby strikes and strikes to the structure, it is necessary to reduce the loop area of the building cabling. Clause 6.7 of [ITU-T K.85] recommends that wiring be installed in accordance with [ITU-T K.66] with detailed information provided in [IEC 60364-4-44]. Where the loop area cannot be kept small, protection should be according to clause 6.8 of [ITU-T K.85]. Figures A.1 and I.1 of [ITU-T K.85] show examples of loop areas in an installation. The critical ones are the loop formed by the primary protector to the equipment wiring (loop a) and wiring between the equipments (Loop b).

Section 444.4 of [IEC 60364-4-44] gives advice on reducing the electric and magnetic influences on electrical equipment. Different techniques are given for the various power distribution systems.

6.6 Earthing and bonding

Earthing is the connection of the MET bar to earth, usually via an installed earth electrode. This electrode could have a resistance to earth in the range of tens of Ω to hundreds of Ω.

Bonding is the interconnection of the MET to other earth electrodes and interconnection of metallic parts to create an equipotential environment. Appendix I of [ITU-T K.66] shows examples of earthing and bonding scenarios. Figure I.1 of [ITU-T K.66] shows ideal earthing and bonding with a single earth bar and short bonding conductors. Figure I.6 of [ITU-T K.66] shows effective earthing and bonding which prevents equipment damage. Figure I.7 of [ITU-T K.66] shows poor earthing and bonding and describes how equipment damage occurs.

The problems with using an auxiliary earth electrode and not bonding it to the MET is that surge current conducted in the auxiliary earth electrode causes the external telecommunication port to rise in potential with respect to the MET. If an insulation path within the equipment breaks down, it may result in damage and safety hazard. It is essential that the telecommunication primary protector be bonded to the MET, preferably by a short bonding conductor.

Section 444.5 of [IEC 60364-4-44] recommends that all protective and functional earthing conductors should be connected to one single MET. It also recommends that all earth electrodes associated with a building be interconnected.

6.7 SPDs

6.7.1 General

A definition for SPDs is given in clause 3.1.6.

An SPD may be installed at the building entrance, at a boundary point or be contained within an MSPD or the equipment. It may be a gas discharge tube (GDT) type, a metal oxide varistor (MOV) type or a solid state arrester (SSA) type. Generally, an SPD can be classified as a clamping or switching type. A GDT is a switching type voltage limiting component and an MOV is a clamping type voltage limiting component. In some cases, an SPD may contain a combination of clamping and switching components. More information on this can be found in clause 8.2 of [ITU-T K.44]. An appropriate SPD can be installed on the mains or on the telecommunication service.

Other protection terms commonly used are primary protector, secondary protector and tertiary protector. The definition for primary protector is given in clause 3.1.5.

The terms secondary protector and tertiary protector are not used in this Recommendation.

The only other protection device to consider is the MSPD, which is defined in clause 3.1.4.

6.7.2 Location

[IEC 62305-2] partitions a large building into zones of homogeneous characteristics. As such, SPDs may be installed at the entrance to each zone which is expected that the surge level will be decreased at every SPD.

As this Recommendation refers mainly to residential buildings, zone protection will not be considered. When required, it is recommended that a MSPD, or equivalent protection, be installed to protect equipment clusters and that primary protection be installed at the building entry point to protect the downstream protection and the equipment wiring.

6.7.3 Rating

The SPD rating will depend on the level of protection required and the waveform for the downstream SPD. The protection level is discussed in clause 6.7.3.1. The waveform at the downstream SPDs is discussed in clause A.4.

6.7.3.1 Level of protection

As discussed in clause 6.1, the equipment maybe subjected to surges as a result of:

- a direct strike to the structure;
- a direct strike to the services close to the structure;
- a direct strike to the services remote from the structure;
- a strike near to the services, or;
- a strike near to the structure.

This clause discusses the maximum level of surge on the external ports.

6.7.3.1.1 Strike to the structure

This topic is discussed in clause 7.1 of [ITU-T K.67]. For a strike to the structure, it is assumed that 50 % of the lightning will be conducted to earth via the structure earthing system. The other 50 % will be divided by the number of metallic services *n*. For a structure with a power service and a telecommunication service provided by a metallic cable/line, the current per service will be 50 kA assuming a 200 kA strike. For a two-wire unshielded power system, the maximum surge current per conductor will be 25 kA. For a two-pair unshielded telecommunication service the current per conductor will be 12.5 kA per conductor. For shielded services, the current per conductor will be:

$$I_{cond} = \frac{5 \times 10^4 \times R_{shield}}{R_{cond} + m \times R_{shield}}$$

where m is the number of conductors.

6.7.3.1.2 Strikes to earth near a structure

[ITU-T K.67] provides information on likely maximum voltages. Due to the complexity of the required calculation, a risk assessment should be performed in accordance with [IEC 62305-2]. The current rating of SPDs and bonding conductors should be determined using [ITU-T K.67]. Table 2 of [ITU-T K.67] shows that induced short circuit currents of up to 100 A 10/350 waveform are possible within the internal cabling due to the lightning strikes near to the structure.

6.7.3.1.3 Strike to the services near to the structure

This situation is covered in detail in clause 7.3 of [ITU-T K.67]. Two types of constructions need to be considered, aerial and underground.

For an aerial lead-in, whether it be to the power line or the telecommunication cable, half of the surge current will be conducted into the network and the other half into the structure. In the worst case, this would be in the order of 100 kA 10/350 waveform divided by the number of conductors, m.

For underground services, half of the strike current will be conducted into the earth. In this case, a quarter of the surge current will be conducted into the network and the other quarter into the structure. In the worst case, this would be in the order of 50 kA 10/350 waveform divided by the number of conductors, m. If the cable is shielded, the worst case conductor current can be calculated by the following formula.

$$I_{cond} = \frac{5 \times 10^4 \times R_{shield}}{R_{cond} + m \times R_{shield}}$$

Furthermore, the maximum current that can be conducted by a conductor is $18 \times a$ (kA), where 'a' is the cross-sectional area of the conductor [mm^2]. This magnitude of the current will cause the conductor temperature to exceed 1'000 ºC and melt the conductor.

6.7.3.1.4 Strike to the services remote from the structure

For a strike to an underground telecommunication service, a 30 pair moisture barrier (MB) direct buried cable has been used to determine the current available at the customer end for a 100 kA direct strike. An MB cable has an internal metallic tubular sheath that provides some shielding to the telecommunication pairs. It has been assumed that cable breakdowns will not happen until the cable voltage is 100 kV as assumed in [ITU-T K.67]. The customer is assumed to be 150 m from the point where the cable voltage is 100 kV. A simple cable model is chosen in Appendix I assuming 15 customers connected to the 30 pairs. This model is used for the customer simulations performed in Annex A.

For this edition of the Recommendation, aerial telecommunication lines remote from the structure are not considered.

For a strike to a power line service, a much simpler model has been used. In this case, it is assumed that the voltage is 100 kV. This voltage is produced using a 5 kA surge with a 20 Ω shunt resistance. An inductance of 100 µH is used in each conductor of the power line. The current of 5 kA has been chosen assuming 50 customers connected to the line and a 100 kA strike to the line.

6.7.3.1.5 Strikes near to the services

This clause discusses the current levels for induced surges. It is necessary to separate the discussion for power line and telecommunication cable.

Traditionally, telecommunication cables have been in some cases tens of km long and it has been assumed that the half time of the surge current could be hundreds of microseconds due to attenuation of the high frequency of the surge. However, this may not be the case for the newer networks. Also, this long cable, limits the magnitude of the current to some tens of Amps.

For the power network, the low voltage (LV) line length is shorter and the current is often represented by an 8/20 waveform. Due to the low resistance of the line, the peak current can be kilo Amps in magnitude.

In general, it is expected that inductive coupling into the telecommunication cables will not result in currents greater than 35 A or voltages greater than a few kV (see Table 5 of [ITU-T K.67]).

6.7.3.1.6 Choice of protection levels

The various conductor currents determined above allow the SPD rating to be chosen depending on the mechanism that needs to be protected against. To reiterate, these mechanisms are:

- a direct strike to the structure;
- a direct strike to the services close to the structure;
- a direct strike to the services remote from the structure; and
- a strike near to the services.

6.8 Direct strike protection of a structure

Implementing direct strike protection of a structure is a complex task and it is unlikely to be required for most installations. Refer to [IEC 62305-3] if the risk assessment recommends that direct strike protection of the structure needs to be implemented.

6.9 Installation of protection

6.9.1 Philosophy of protection

The philosophy for protection of customer premises equipment (CPE) is as follows:

- Install a MSPD to protect the equipment when necessary. A MSPD can protect the equipment against surges magnetically coupled into the building wiring and service cables and lines. It may also provide some level of protection of the equipment against direct strikes to the service plant, provided the strike point is more than a few hundred metres from the building.
- Install primary protection at the building entry point on both the telecommunication and the power services, to protect the MSPD when the risk assessment requires it.

6.9.2 Risk Assessment

Performing a risk assessment is a complex operation and this will not be covered in detail in this Recommendation. Refer to [IEC 62305-2] for details on performing a risk assessment on a structure. Annex D of [ITU-T K.85] contains some information on performing a risk assessment to determine the need for protection of a home network. Figure D.2 of [ITU-T K.85] is a flowchart containing the procedure for selecting protection measures in a structure. Appendix I of [ITU-T K.85] contains a risk assessment example.

For towns and cities, it may not be necessary to perform a risk assessment for every structure. Due to their low cost, a cost effective option may be to simply install MSPDs to protect equipment clusters. A generic risk assessment, as has been performed in Appendix II of [ITU-T K.71], could be used to determine those areas which require MSPDs to be installed.

Likewise in rural areas, it is likely that both the MSPDs and the primary protection on both the telecommunication and the power services will be required. A generic risk assessment, as has been performed in Appendix II of [ITU-T K.71], could be used to determine the areas where primary protection is required

6.9.3 Waveform at downstream SPDs and coordination between SPDs

Clause A.4 contains simulations to investigate the waveform at downstream SPDs and coordination between SPDs for both the telecommunication and power services.

6.9.4 Protection of ports

6.9.4.1 External telecommunication ports

As described in clause 6.9.1, protection of an external port requires installing protection external to the equipment to reduce the magnitude of the surge voltage with respect to the equipment earth terminal, if it exists, and to provide equipotential bonding with respect to other external ports of the equipment. In most cases, the only other external port will be the mains port. A MSPD, or equivalent, performs these functions. When required by the risk assessment, primary protection will be required to protect the MSPD or equivalent protection.

As a result of the coordination requirement in [ITU-T K.21], the telecommunication port only requires a GDT bonded to the MET.

Where equipment is connected to other equipment in another building on the same site, particular problems may occur. Refer to [ITU-T K.73] for detailed information and solutions.

6.9.4.2 Mains ports

Mains ports are external ports and as described in clause 6.9.1, protection of an external port requires installing protection external to the equipment to reduce the magnitude of the surge voltage with respect to the equipment earth terminal, if it exists, and to provide equipotential bonding with respect to other external ports of the equipment. In most cases, the only other external port will be a metallic cable telecommunication port. A MSPD, or equivalent, performs these functions. When required by the risk assessment, primary protection will be required to protect the MSPD or equivalent protection.

[ITU-T K.66] provides installation methods for installing primary protection at the mains entry point. In [ITU-T K.66], Figures A.1-1 – A.1-2 (TN-S installation with separate neutral and protective conductors), A.4-1 – A.4-2 (Three-line and neutral TT power distribution system) and A.5-1 – A.5-2 (IT three-line (and neutral) power distribution system) all show phase to neutral SPDs and a neutral to earth SPD (no phase to earth SPDs). If the equipment, or MSPD, contains SPDs phase to neutral, phase to earth and neutral to earth, there is the possibility that the phase to earth SPD will be damaged, see Figure 17.

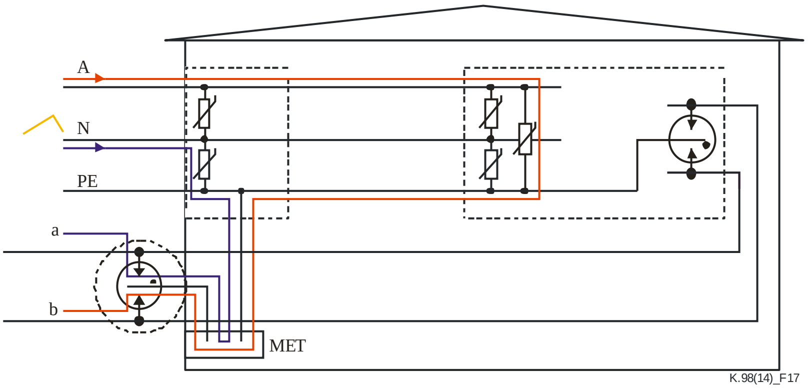


Figure 17 – Protection as per Figure A.1-1 of [ITU-T K.66]

In this case, the most direct path from the phase to the MET is via the A-PE SPD in the equipment (or an MSPD). If the main switchboard (MSB) neutral to earth SPD is a spark gap, the low clamping voltage of the spark gap will prevent damage to the equipment or MSPD A to PE SPD. Other solutions are:

- Delete the A-PE SPD at the equipment; or
- Add an A-PE SPD in the main switchboard.

6.9.4.3 Telecommunication antenna ports

For the case where the telecommunication service is provided via an antenna, refer to [ITU-T K.71].

6.9.4.4 Internal ports

Protection of the internal ports is not as simple as external ports as internal ports do not have a coordination requirement. Ports without a coordination requirement must be protected in accordance with [IEC 61643-21] and [IEC 61643-22]. Where off the shelf protection is not available, an engineering solution may be needed.

Common internal ports are universal serial bus (USB) and Ethernet ports.

USB ports have a reduced test requirement in [ITU-T K.21] due to their short cable length. Some MSPDs may include USB protection. Refer to clause 10 of [ITU-T K.66] for guidance on when USB protection maybe required.

Most Ethernet ports have a signal transformer which is generally sufficient to protect the port against line to earth surges. Power over Ethernet (PoE) equipment may be more susceptible to damage and where off the shelf protection is not available, an engineering solution may be needed.

6.9.5 Installation of MSPDs

The correct installation of MSPDs is covered in clause 10 of [ITU-T K.66].

6.9.6 Installation of primary protection SPDs

Correct installation of primary protection SPDs is covered in clause 9 of [ITU-T K.66].

There is a risk of a fire at the telecommunication SPD or in the wiring preceding this SPD. This is explained and mitigation techniques are recommended in clause 9.4 of [ITU-T K.66].

6.10 Conclusions

The following conclusions are based on calculations for a direct strike to the power or telecommunication services. The calculations were performed for 100 kA strike to the service within a hundred metres from the structure in a suburban area.

The ideal installation is class II equipment with equipment clusters protected by a MSPD and the MSPD protected by primary protection when necessary.

The following conclusions apply to equipment not protected by a MSPD or equivalent protection at the equipment.

When reading the conclusions below, it is necessary to understand that these results were obtained from simulations for three discrete resistances to earth:

- Low earthing resistance: represented in the simulations by using a 2 Ω earthing resistance;
- High earthing resistance: represented in the simulations by using 100 Ω earthing resistance;
- An infinite resistance: represented in the simulations by removing the connection to earth.

Also, not every combination of the variables has been simulated. Only one change has been made from the standard case of a 100 Ω customer premises earth with a 10 m bond wire length. When applicable, the simulations where performed as follows:

- 100 Ω customer premises earth and 10 m bond wire length;
- 100 Ω customer premises earth and 1.5 m bond wire length;
- 100 Ω customer premises earth and 10 m bond wire length with the earth connection missing from the power outlet;
- 2 Ω customer premises earth and 10 m bond wire length;
- No customer premises earth and 10 m bond wire length.

No attempt should be made to draw any conclusion for a different set of variables because of unexpected results obtained during the simulations. For example, there is a case where equipments were damaged with a 2 Ω customer premises earth, but not with a 100 Ω customer premises earth.

For equipment not protected by primary protection

Damage will always occur to the telecommunication equipment except for the combination of a direct strike to a TN-C power system with floating equipment.

For equipment protected by primary protection

Floating equipment

Floating equipment is always protected by the installation of primary protection, regardless of the power system and the resistance to earth at the customer premises.

Earthed equipment

Refer to Table 2 for the impact on earthed equipment.

Table 2 – Impact on earthed equipment protected by primary protection

Configuration	Installation requirements for earthed equipment to be protected
Strike to TN-S power system	Only protected for: • the combination of a 2 Ω customer premises earth and a telecommunication bond wire of 10 m.
Strike to telecommunication line and a TN-S power system.	Only protected for: • the combination of a 100 Ω customer premises earth and a 1.5 m telecommunication bond wire.
Strike to TN-C or TN-C-S power system.	Only protected for: • the combination of a 100 Ω customer premises earth and a 1.5 m telecommunication bond wire or • the combination of a 2 Ω customer premises earth and a telecommunication bond wire of 10 m.
Strike to telecommunication line and a TN-C or TN-C-S power system	Only protected for: • the combination of a 100 Ω customer premises earth and a 1.5 m telecommunication bond wire or • the combination of a 100 Ω customer premises earth, a telecommunication bond wire of 10 m with the earth missing from the power outlet.
Strike to TT or IT power system	Only protected for: • the combination of a 2 Ω customer premises earth and a telecommunication bond wire of 10 m.
Strike to telecommunication line and a TT or IT power system	Only protected for: • a 100 Ω customer premises earth and a 1.5 m telecommunication bond wire

Annex A

Simulations

(This annex forms an integral part of this Recommendation.)

A.1 Introduction

Appendix I contains simulations which are intended to help in determining the magnitude and waveform of a surge developed at the customer premises as a result of a direct strike to a 30 pair 0.64 mm MB direct buried telecommunication cable. The surge model, developed in Appendix I, is used in the customer premise simulations below.

Simulations have been performed to investigate the effect of different types of power distribution systems on the stress applied to the equipment. As described in clause 6.1.5, various power distribution systems can be described as shown below.

- Combination of phase conductors (L1, L2 and L3), a neutral conductor (N) and an earth conductor (PE) in the distribution network. This describes a TN-S power system. There is no structure earth electrode shown in [IEC 60950-1], however there is likely to be a path to earth at the structure.
- Combination of phase conductors (L1, L2 and L3) and a combined PE and neutral conductor (PEN) in the distribution network. There is a neutral-earth link and this is connected to a structure earth electrode. The PEN conductor is split into an N and PE conductor after the neutral-earth link. This describes TN-C-S and TN-C power systems.
- Combination of phase conductors (L1, L2 and L3) and a neutral conductor (N) in the distribution network. The neutral is not connected to the structure earth electrode, but the PE is. There is no link between the PE and the neutral. This describes an IT and TT power system.

Where applicable, the impact of the length of telecommunication SPD bond wire and the structure earth electrode resistance have been investigated. Two telecommunication SPD bond wires with lengths of 10 m and 1.5 m have been used. Earth electrode resistances of 100 Ω and 2 Ω have been used for the earthing of the equipment. Also, the case where there is no connection to the local earth at the structure. For earthed equipment, the impact of a faulty power outlet (no earth wire) has been investigated. The standard case consists of a 10 metre telecommunication SPD bond wire conductor, 10 metres of telecommunication conductor and a 100 Ω earth electrode resistance.

The measurements simulated without primary protection are:

- How high the MET and SELV circuit rises above remote earth and local earth considering the earth potential rise of and around the local electrode.
- The power transformer stress (primary to secondary surge voltage). The stress applied to the telecommunication port.
- Current injected into the other external networks e.g., power network or telecommunication node.
- The voltage/current for an internal port to an internal port of associated earthed equipment. The voltage and current will be measured for an Ethernet port which has a complex impedance.
- The impact of an unearthed power outlet.

The measurements simulated with primary protection are:

- How high the MET and SELV circuit rises above remote earth and local earth considering the earth potential rise of and around the local electrode.

- The power transformer stress (primary to secondary surge voltage). The stress applied to the telecommunication port.
- Current injected into the other external networks e.g., power network or telecommunication node.
- The voltage/current for an internal port to an internal port of associated earthed equipment. The voltage and the current will be measured for an Ethernet port which has a complex impedance.
- The operation of any inherent SPDs, spark gap and MOV mains primary protectors and telecommunication primary protectors.
- The impact of an unearthed power outlet.

In the simulations, some choices had to be made. To simulate a transient voltage suppressor (TVS) in the telecommunication port of class I (earthed) equipment, a simple switch is used and it is assumed that the TVS operates at 100 V. To simulate the action of a GDT, a simple switch is used and it is assumed that the primary protector operates at 600 V regardless of the risetime. For equipment mains port protection, a 275 V 12 kA MOV has been used. For the mains phase to neutral primary protection, a 275 V 80 kA MOV has been used as protection against direct strikes (to service lines) is being considered. However, the highest stress occurs for a direct strike to the building and this is not considered in this edition of the Recommendation. The particular MOV used is not necessarily suitable for direct connection across the mains, but it could be used as a component in a class I SPD. It was chosen for its high current rating and because the simulation model was available for use in the simulations.

Simulations have been performed, as described in clause A.4, to investigate the waveform at downstream SPDs for both clamping and switching type primary protector SPDs and the necessary rating of these downstream SPDs. This has been checked between the primary protector and the inherent SPDs in the equipment. For the equipment, [ITU-T K.21] has a requirement to check coordination between the primary and the inherent protection elements for the telecommunication port. Of particular interest is the level of coordination between an MSPD and the primary protector for the telecommunication port as there is no coordination requirement for MSPDs. This is particularly important for long waveforms. Coordination between primary protection and an MSPD has not been considered in this edition of the Recommendation.

Modern equipment can have both a POTS network port and an x-type digital subscriber line (xDSL) network port. The following simulations assume that these are connected in parallel and their parallel input impedance will be represented by a 1.5 nF capacitor to the internal common reference point. Customer equipment can be either class I (earthed equipment) or class II (floating equipment). Generally, class II customer equipment is used in residential premises while class I equipment is generally used in commercial premises. The major difference between class I equipment and class II equipment is that class I equipment usually has earthed SPDs as part of the inherent protection.

Earthed equipment will be simulated by considering the inherent protection SPDs in the equipment.

Modern customer non-earthed (floating) equipment can have the following external ports:

- xDSL: his would be isolated from the SELV module to 1'500 V rms for safety reasons. The level of isolation can also be affected by the resistibility requirement of [ITU-T K.21] being 1.5 kV basic and 6 kV enhanced impulse level. This isolation is achieved by the xDSL signal transformer.
- Public switched telephone network (PSTN), considered here as foreign exchange office (FXO): This would be isolated from the SELV module to 1'500 V rms for safety reasons. The level of isolation can also be affected by the resistibility requirement of [ITU-T K.21] being 1.5 kV basic and 6 kV enhanced impulse level. Capacitive coupling to SELV circuit is not uncommon.

- Mains: This would be isolated from the SELV module by double insulation for safety reasons.

and the following internal ports:

- POTS, considered here as foreign exchange subscriber (FXS): This would normally be a TNV2 port and not isolated from the SELV module, although complying with the relevant safety standard.
- USB: This would be an SELV port connected to the SELV module.
- Ethernet: This would be an SELV port and transformer coupled to the SELV module.

When performing simulations at a residential customer premises, one has to consider what happens with the other 28 pairs (30 pair cable) and how the screen is earthed. The effective resistance to earth for the three types of power systems can be different and can also be higher for floating equipment without primary protection.

With the TN-S power distribution network, all 15 telecommunication network customers are earthed via the power network and in some installations via a path to earth at the customer premises. It is assumed that the power network has 50 consumers. It is normal practice to bond all metallic services to the MET. If there are underground metallic services or a bonded conductive structure, a path to earth will exist. In some structures, this path to earth may be missing if plastic pipes have been retrofitted or installed. It is assumed that the surge current is conducted on the three power conductors due to lightning protection at the distribution transformer. It is also assumed that the conductors have a negligible resistance compared with an assumed earth resistance of 2 Ω at the power distribution transformer. It is assumed that, there are 50 power customers connected to this distribution system and that each customer has a 100 Ω earth electrode. In this case, the 15 telecommunication customers connected to the 30 pair MB cable will share the path to earth provided by the 50 power customers. In this case, each telecommunication customer has the equivalent of 3.33 electrodes with a resistance to earth of 30 Ω.

With the TN-C power distribution network, all 15 telecommunication network customers are earthed via the power network and via the customer premises earth electrode or via a bond to underground metallic services. In structures relying on a bond to underground services, this path to earth may be missing if plastic pipes have been retrofitted or installed. It is assumed that the surge current is conducted onto the two power conductors due to lightning protection at the distribution transformer. It is also assumed that, the conductors have a negligible resistance compared with an assumed earth resistance of 2 Ω at the power distribution transformer. It is assumed that, there are 50 power customers connected to this distribution system and that each customer has a 100 Ω earth electrode. In this case, the 15 telecommunication customers connected to the 30 pair MB cable will share the path to earth provided by the 50 power customers. In this case, each telecommunication customer has the equivalent of 3.33 electrodes with a resistance to earth of 30 Ω.

With the TT and IT power distribution network, the customer PE is only earthed via an earth electrode at the customer premises or via a bond to underground metallic services. In structures relying on a bond to underground services, this path to earth may be missing if plastic pipes have been retrofitted or installed. With the TT power system, the neutral is earthed at the distribution transformer. With the IT system the neutral is connected to earth at the distribution transformer via an impedance with a parallel surge suppressor. It is assumed that the surge current is conducted on the two power conductors due to lightning protection at the distribution transformer. It is also assumed that the conductors have a negligible resistance compared with an assumed earth resistance of 2 Ω at the power distribution transformer. It is assumed that each customer has a 100 Ω earth electrode.

As part of the analysis, it would be useful to predict whether damage to the equipment will occur. This analysis is different for earthed versus floating equipment and whether primary protection is installed or not installed.

For earthed equipment, the damage criteria are whether the simulation voltage or current exceeds the [ITU-T K.21] test voltage or current for either the inherent or coordination tests. For the mains port, damage is only likely if the power transformer flashes over the primary to the secondary. The flashover voltage of the mains transformer may be determined by either the [ITU-T K.21] test voltage or the safety test voltage. For the telecommunication port, damage may occur if the simulation voltage or current exceeds the [ITU-T K.21] test voltage or current.

For floating equipment, damage is only likely to occur if a flashover occurs for either the inherent or coordination tests. This flashover is port-to-port for floating equipment.

It is therefore necessary to know the approximate flashover voltage of the mains transformer and the Ethernet port, and the damage voltage and current for the telecommunication port. To predict damage to the floating equipment, it is necessary to determine the flashover voltage of two ports (associated insulation barriers) in series i.e., the mains port in series with the telecommunication port, the mains port in series with the Ethernet port and the telecommunication port in series with the Ethernet port. The two voltages cannot be simply added. The minimum flashover voltage will be between the higher flashover voltage and the sum of the flashover voltages of the two ports. The minimum flashover voltage of ports is given in Table A.1.

Table A.1 – Minimum flashover voltage of ports

Port to SELV or port-to-port	Minimum flashover voltage
Class I mains transformer	1.5 kV rms and 2.5 kV impulse
Class II mains transformer	3.0 kV rms and 5.0 kV impulse
Telecommunication port for floating equipment	2.5 kV impulse basic 6 kV impulse enhanced
Ethernet port	2.5 kV impulse
Mains to telecommunication	5 kV + 2.5 kV → > 5 kV for basic 5 kV + 6 kV → > 6 kV for enhanced
Mains to Ethernet	5 kV + 2.5 kV → > 5 kV for basic 5 kV + 2.5 kV → > 5 kV for enhanced
Telecommunication to Ethernet	2.5 kV + 2.5 kV → > 2.5 kV for basic 6 kV + 2.5 kV → > 6 kV for enhanced

To understand the stress on the equipment, it is useful to consider the stress during [ITU-T K.21] testing. Two test levels will be considered, 'basic' and 'enhanced'. There is both an inherent test and a coordination test for external ports.

For the mains port, it is assumed that the coordination test is performed as per Figure A.6.4-2 of [ITU-T K.44] i.e., with a MOV connected between the neutral and the MET. This would limit the voltage between neutral and the MET to < 800 V.

For the telecommunication port, it is assumed that the special test protector limits the voltage to 600 V during the coordination test.

The generator charge voltages and the peak voltages on the equipment ports and peak currents entering the equipment ports are given in Table A.2. The input resistance of the telecommunication pair above 100 V for earthed equipment is 10 Ω for the equipment being used for the simulation and the output resistance of the generator is 27.5 Ω. For the inherent test the peak current is 40 A (1'500 V/37.5 Ω).

A final point is that the actual amount of damaging voltage will be greater than the required resistibility voltage. The ratio of the damaging voltage to the resistibility voltage can vary from 1 to 2 in practice. It can vary from design to design and for earthed equipment versus floating equipment.

The conservative approach is to assume a ratio of 1, i.e., the damaging voltage is the same as the resistibility voltage. A ratio of 1 is assumed in the following analyses.

Table A.2 – [ITU-T K.21] test voltages and resulting surge current entering the equipment port

		Basic	**Enhanced**
Mains port	Inherent	Test voltage 2.5 kV Maximum current in earthed equipment is 1.25 kA Maximum voltage for floating equipment is 2.5 kV	6.0 kV Maximum current in earthed equipment is 3.0 kA Maximum voltage for floating equipment is 6.0 kV
	Coordination	Test voltage 6 kV Maximum current in earthed equipment is difficult to predict. Maximum voltage for floating equipment is < 800 V	Test voltage 10 kV Maximum current in earthed equipment is difficult to predict. Maximum voltage for floating equipment is < 800 V
Telecommunication port	Inherent	Test voltage 1.5 kV Maximum current in earthed equipment is 40 A Maximum voltage for floating equipment is 1.5 kV	Test voltage 1.5 kV Maximum current in earthed equipment is 40 A Maximum voltage for floating equipment is 6 kV
	Coordination	Test voltage 4 kV Maximum current in earthed equipment is 60 A Maximum voltage for floating equipment is 600 V	Test voltage 6 kV Maximum current in earthed equipment is 60 A Maximum voltage for floating equipment is 600 V
Ethernet port		Test voltage 1.0 kV Maximum voltage 1.0 kV	Test voltage 1.5 kV Maximum voltage 1.5 kV
Mains port to telecommunication port	Inherent	Test voltage 2.5 kV (mains port test) Maximum current in earthed equipment is < 208 A Maximum voltage for floating equipment is 2.5 kV	Test voltage 6 kV (mains port test) Maximum current in earthed equipment is < 500 A Maximum voltage for floating equipment is 6 kV
	Coordination	Test voltage 6 kV Maximum current in earthed equipment is difficult to predict. Maximum voltage for floating equipment is 1400 V (800 + 600 V)	Test voltage 10 kV Maximum current in earthed equipment is difficult to predict. Maximum voltage for floating equipment is 1400 V (800 + 600 V)
Mains port to Ethernet port	Inherent	Test voltage 2.5 kV (mains port test) Maximum current in earthed equipment is 1.25 kA Maximum voltage for floating equipment is 2.5 kV	Test voltage 6 kV (mains port test) Maximum current in earthed equipment is 3.0 kA Maximum voltage for floating equipment is 6.0 kV

Table A.2 – [ITU-T K.21] test voltages and resulting surge current entering the equipment port

		Basic	**Enhanced**
	Coordination	Test voltage 6 kV Maximum current in earthed equipment is difficult to predict. Maximum voltage for floating equipment is 800 V	Test voltage 10 kV Maximum current in earthed equipment is difficult to predict. Maximum voltage for floating equipment is 800 V
Telecommunication port to Ethernet port	Inherent	Test voltage 1.5 kV Maximum current in earthed equipment is 40 A Maximum voltage for floating equipment is 1.5 kV	Test voltage 1.5 kV Maximum current in earthed equipment is 40 A Maximum voltage for floating equipment is 6 kV
	Coordination	Test voltage 4 kV Maximum current in earthed equipment is 60 A Maximum voltage for floating equipment is 600 V	Test voltage 6 kV Maximum current in earthed equipment is 60 A Maximum voltage for floating equipment is 600 V

It is interesting to note that the stress for earthed equipment telecommunication ports is the same for both the 'basic' and the 'enhanced' tests. With the enhanced test, the voltage may be slightly higher as the firing voltage of the special test protector may increase due to the higher dv/dt of the 6 kV impulse compared with the 4 kV impulse. The time to half value of the test current is somewhere between 10/350 µs and 10/700 µs. This information is used in the following clause to determine if damage is likely.

A.2 Stress applied to the equipment via the mains port

The stress applied to the equipment via the mains port has been investigated by applying a 5 kA 5/75 µs surge to the line /neutral /earth conductors in parallel with a shunt of 20 Ω resistance to earth raising the power line voltage to 100 kV without an equipment load. This waveform is in line with [b-CIGRÉ TB 549] and refers to the most common downward negative first stroke. The telecommunication line termination assumes a 150 m 30 pair 0.64 mm MB cable as used in clause A.3. The customers are assumed to have two pairs terminating at the premises, one working pair and one unused pair. For the protected installations, it is assumed that the unused pair is protected. It is assumed that there are 50 customers connected to the power network. In this case the 50 customers share the telecommunication network node termination which is assumed to be 10 Ω. However, if one assumes that 50 kA goes to earth at the customer premises, then one can assume that the effective resistance is 10 times 10 Ω. Also, the screen is earthed at every customer premise so it will be assumed that the resistance to earth looking into the telecommunication network will be 20 Ω.

It is assumed that the equipment inherent SPD on the telecommunication line to the SELV module, where it exists, operates at 100 V. It is assumed that any spark gap between neutral and PE operates at 1.5 kV. It is assumed that any primary protection on the telecommunication pairs operates at 600 V. The main variables used in the simulations are given in Table A.3.

Table A.3 – Main variables used in the simulations

Variable	Description
I(I1)	Part of total lightning current impacting the structure
I(R33)	The current conducted into the telecommunication port of earthed equipment
I(R37)	The current conducted into the Ethernet port
I(R101)	The current conducted in the working pair
I(R102)	The current conducted in the spare pair
I(R103)	The current exiting the structure in the cable MB screen
I(R104)	The total current entering the telecommunication cable from the structure
I(R205)	The current entering the earth at the structure
V(N) – V(PE) V(N) – V(MET)	The voltage across the terminals of the spark gap connected between neutral and the MET/PE on non TN-C power systems
V(SELV)	The voltage of the SELV point relative to remote earth
V(MET)	The voltage of the MET relative to remote earth
V(V2) – V(SELV)	The voltage between the line side of the mains transformer and the SELV circuit
(V(MET) – V(SELV))/2	The voltage between the Ethernet port and the SELV circuit
V(SELV) – V(V5)	The voltage between the terminals of the TVS for class I (earthed) equipment The voltage between the telecommunication port and the SELV circuit for class II (floating) equipment. It is also voltage stress on the isolation capacitor for class II equipment.

Table A.3 – Main variables used in the simulations

Variable	Description
V(MET) – V(V6)	The voltage between the line terminal and the MET of the working pair primary protector
V(MET) – V(V7)	The voltage between the line terminal and the MET of the spare pair primary protector
V(SELV) – V(V8)	The voltage between the telecommunication port and the SELV circuit class I (earthed) equipment.

The simulation results have columns at the bottom of the graph, see Figure A.2. The titles of these columns are described in Table A.4.

Table A.4 – Column descriptions in the simulation results

Left	The left cursor lists the values of the variables and the time. (e.g., Time is 7.834 µs in Figure A.2).
Right	The right cursor lists the values of the variables and the time. (e.g., Time is 100 µs in Figure A.2).
Delta	Gives the difference in the values of the left and right cursors.
Slope	Gives the average gradient between the left and right cursors.

Key to the units and values for the components used in the simulation diagrams:

– 10*0.0069 calculates the resistance of 10 metres of internal mains conductor with a resistance of 6.9 mohm/m.

– 2.1E-3*.15 calculates the inductance of 150 metres of a single pair of the telecommunication line with an inductance of 2.1 µH/m.

– 26.5E-3*.15 calculates the resistance of 150 metres of a single pair of the telecommunication line with a conductor resistance of 53 Ω/ km.

– 10*0.043 calculates the resistance of 10 metres of a single pair of 0.5 mm internal telecommunication conductor with a single conductor resistance of 86 mohm/m.

– 10*1µ calculates the inductance of 10 metres of a conductor with an inductance of 1 µH/m.

– 10*.00287 calculates the resistance of 10 metres of the 6 mm² telecommunications bonding conductor with a resistance of 2.87 mΩ/m.

– X8 S20K275 is an MOV. S20K275 describes the MOV, 20 mm is the nominal diameter and 275 is the rated voltage.

– Unit for the capacitors is pico Farad (pF), unless indicated otherwise.

– Unit for the inductors is micro Henry (µH), unless indicated otherwise

– Unit for the resistors is ohm (Ω), unless indicated otherwise.

– Unit for time is micro second (µs), unless indicated otherwise.

A.2.1 TN-S power system

Simulation of the TN-S power system is difficult as [IEC 60950-1] does not show an electrode at the customer premises. However, the MET in the customer premises is bonded to the metallic services such as water pipes and gas pipes. Also, if the building has reinforced concrete, it should be bonded to the MET. These bonds provide a path to earth. Simulations were performed for 100 Ω, 2 Ω and infinity electrode resistance. The impact of an unearthed power outlet is also studied.

A.2.1.1 Earthed equipment

A.2.1.1.1 Without primary protection

Figure A.1 depicts a simulation model for a lightning strike to a TN-S power system with earthed equipment without primary protection.

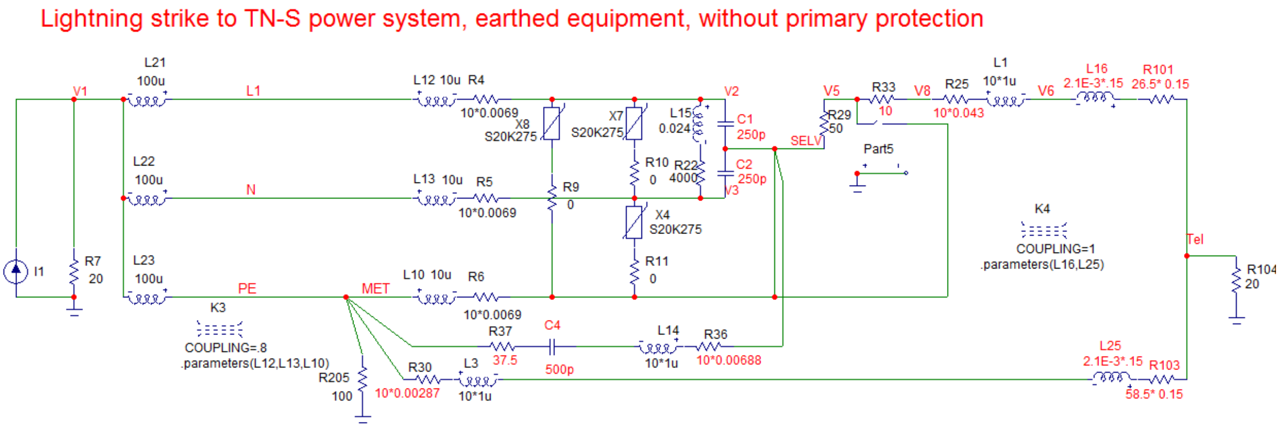
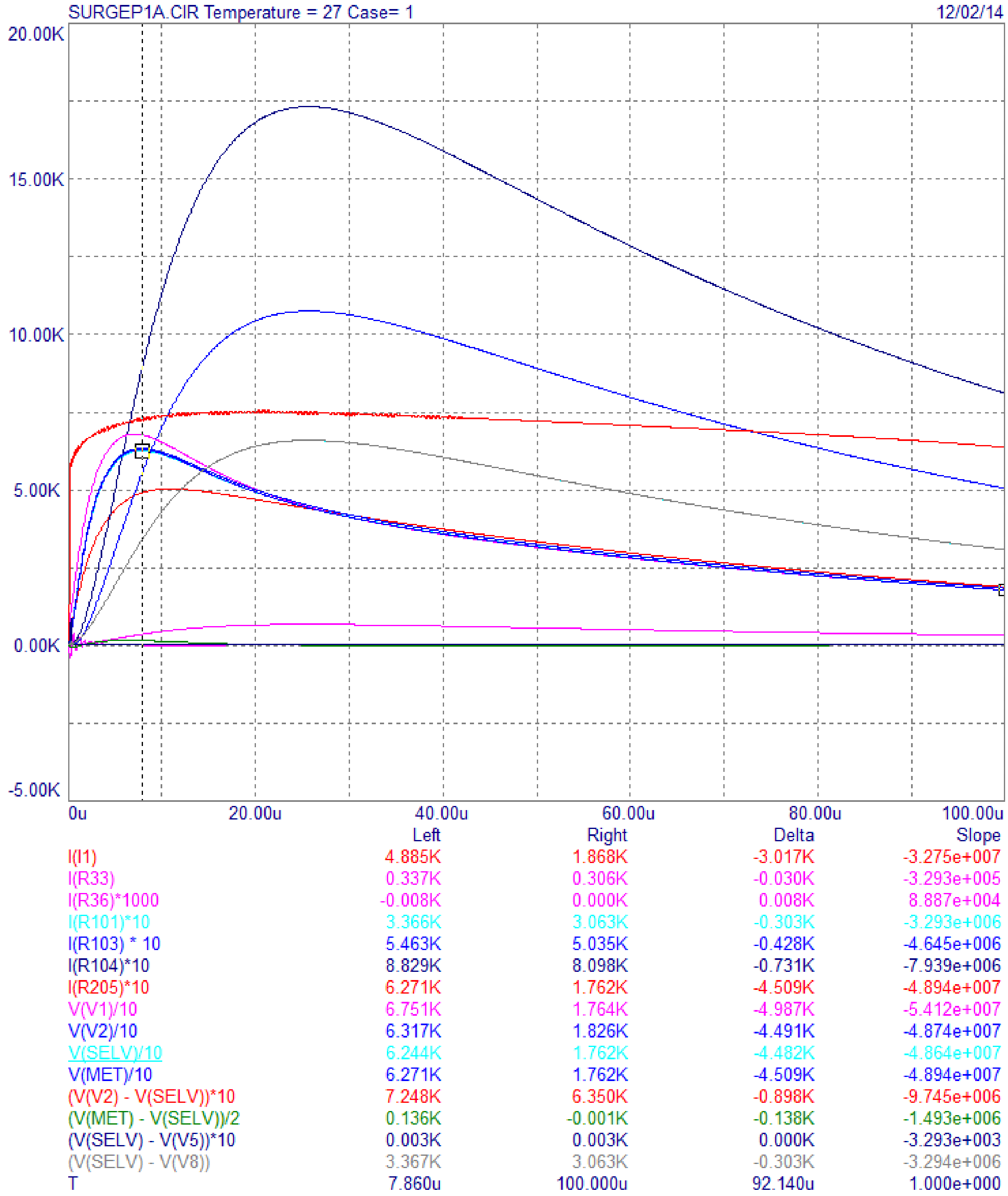


Figure A.1 – Simulation of a lightning strike to a TN-S power system with earthed equipment without primary protection

Description of the components related to Figure A.1:

- R7 represents the resistance to earth at the lightning strike point.
- L21, L22 and L23 simulate a length of power line.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R29 represents the internal resistance of the telecommunication circuit.
- Part5 is a TVS which operates at 100 V.
- R33 represents a fusible resistor and also provides a coordination resistance.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101 and L25, R103 represent a pair and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.2 shows the result for the simulation of a lightning strike to a TN-S power system with earthed equipment without primary protection.



	Left	Right	Delta	Slope
I(I1)	4.885K	1.868K	-3.017K	-3.275e+007
I(R33)	0.337K	0.306K	-0.030K	-3.293e+005
I(R36)*1000	-0.008K	0.000K	0.008K	8.887e+004
I(R101)*10	3.366K	3.063K	-0.303K	-3.293e+006
I(R103) * 10	5.463K	5.035K	-0.428K	-4.645e+006
I(R104)*10	8.829K	8.098K	-0.731K	-7.939e+006
I(R205)*10	6.271K	1.762K	-4.509K	-4.894e+007
V(V1)/10	6.751K	1.764K	-4.987K	-5.412e+007
V(V2)/10	6.317K	1.826K	-4.491K	-4.874e+007
V(SELV)/10	6.244K	1.762K	-4.482K	-4.864e+007
V(MET)/10	6.271K	1.762K	-4.509K	-4.894e+007
(V(V2) - V(SELV))*10	7.248K	6.350K	-0.898K	-9.745e+006
(V(MET) - V(SELV))/2	0.136K	-0.001K	-0.138K	-1.493e+006
(V(SELV) - V(V5))*10	0.003K	0.003K	0.000K	-3.293e+003
(V(SELV) - V(V8))	3.367K	3.063K	-0.303K	-3.294e+006
T	7.860u	100.000u	92.140u	1.000e+000

Figure A.2 – Result for simulation of a lightning strike to a TN-S power system with earthed equipment without primary protection

Customer earth 100 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 63 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 753 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 6.6 kV. The current conducted in this port is 659 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the telecommunication port is likely to occur.

The current injected into the telecommunication network node is 1.73 kA. The working pair contributes 657 A. The screen of the cable contributes 1.07 kA. The current entering the earth via the local earth point is 627 A.

The Ethernet port is subjected to a voltage peak of 144 V. The current is much less than 1 A. No damage to the Ethernet port.

Damage will occur to the telecommunication port.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 66 kV and 60 kV. Voltages of these magnitudes may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 707 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 7.25 kV, 725 A is conducted in the telecommunication network port. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 1.72 kA. The working pair contributes 725 A. The screen of the cable contributes 1.08 kA. The current entering the earth via the local earth point is 595 A.

The Ethernet port is subjected to a voltage peak of 3.3 kV which exceeds the nominal breakdown voltage of 2.5 kV. The current increased to 4.8 A (was less than 1 A). This could result in damage to the Ethernet ports.

Damage will occur to the telecommunication and Ethernet ports.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 8.8 kV and 8.7 kV.

The power transformer stress (primary to secondary surge voltage) is 815 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 1.08 kV. The current in this port is 108 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 274 A. The working pair contributes 107 A. The screen of the cable conducts 167 A back into the customer earth. The current entering the earth via the local earth point is 4.33 kA.

The Ethernet port is subjected to a voltage peak of 477 V which is less than the nominal breakdown voltage of 2.5 kV. The current is much less than 1 A. This is unlikely to result in damage to the Ethernet ports.

Damage will occur to the telecommunication ports.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 72 kV. Voltage of this magnitude is likely to result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 738 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 7.4 kV. The current in this port is 738 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 1.94 kA. The working pair contributes 736 A. The screen of the cable contributes 1.2 kA.

The Ethernet port is subjected to a voltage peak of 205 V. The current is much less than 1 A. No damage to the Ethernet port.

Damage will occur to the telecommunication port.

A.2.1.1.2 With primary protection

Figure A.3 depicts simulation of a lightning strike to a TN-S power system with earthed equipment with primary protection.

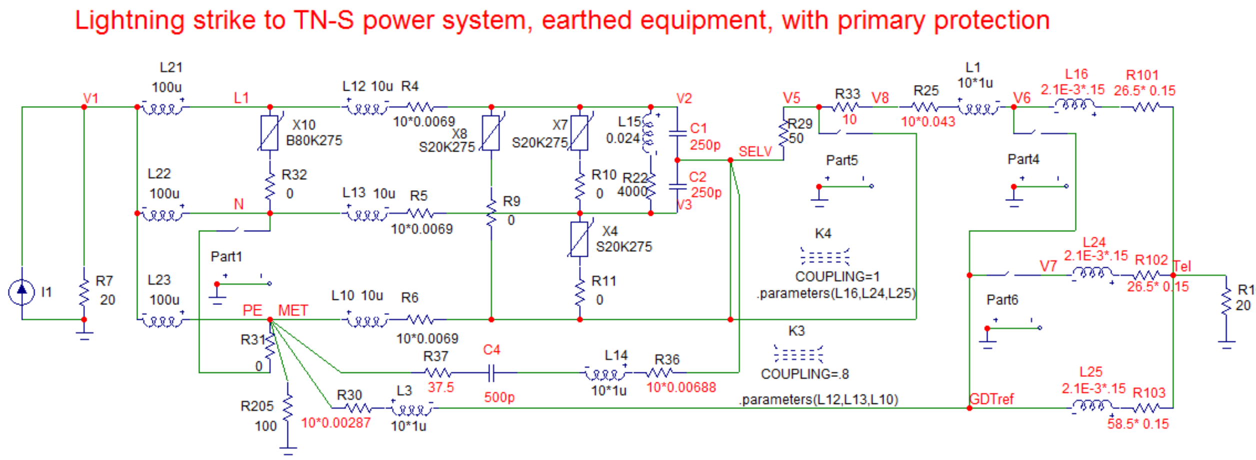


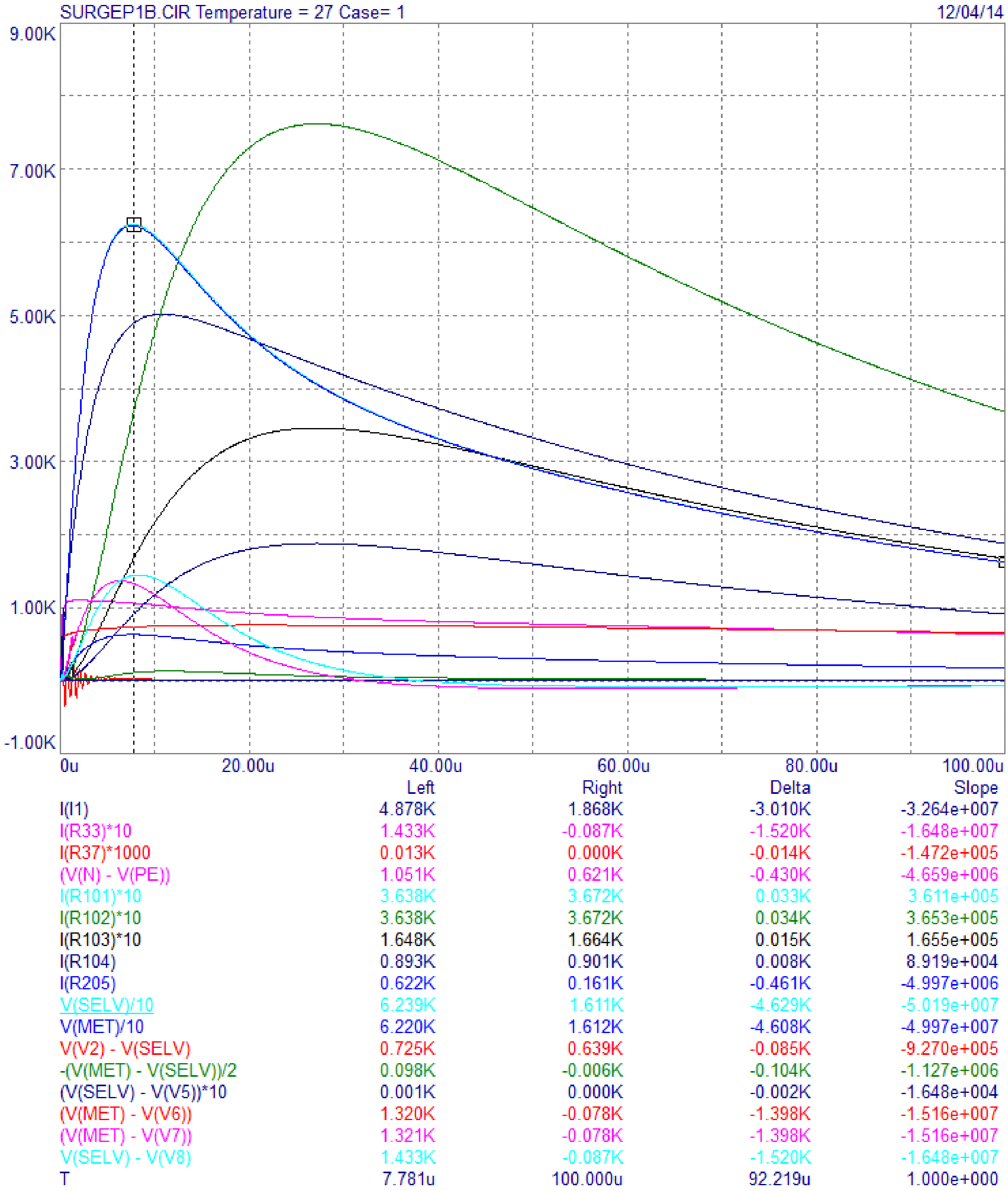
Figure A.3 – Simulation of a lightning strike to a TN-S power system with earthed equipment with primary protection

Description of the components related to Figure A.3:

- R7 represents the resistance to earth at the lightning strike point.
- L21, L22 and L23 simulate a length of power line.
- X10 represents an SPD installed between L1 and N at the MSB.
- Part1 is a spark gap connected between N and PE at the MSB. It operates at 1.5 kV.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R29 represents the internal resistance of the telecommunication circuit.
- Part5 is a TVS which operates at 100 V.
- R33 represents a fusible resistor and also provides a coordination resistance.

- Part4 is a GDT on the working telecommunication pair and Part6 is a GDT on the unused telecommunication pair. These GDTs operate at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101, L24, R102 and L25, R103 represent two pairs and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.4 shows the result for simulation of a lightning strike to a TN-S power system with earthed equipment with primary protection.



	Left	Right	Delta	Slope
I(I1)	4.878K	1.868K	-3.010K	-3.264e+007
I(R33)*10	1.433K	-0.087K	-1.520K	-1.648e+007
I(R37)*1000	0.013K	0.000K	-0.014K	-1.472e+005
(V(N) - V(PE))	1.051K	0.621K	-0.430K	-4.659e+006
I(R101)*10	3.638K	3.672K	0.033K	3.611e+005
I(R102)*10	3.638K	3.672K	0.034K	3.653e+005
I(R103)*10	1.648K	1.664K	0.015K	1.655e+005
I(R104)	0.893K	0.901K	0.008K	8.919e+004
I(R205)	0.622K	0.161K	-0.461K	-4.997e+006
V(SELV)/10	6.239K	1.611K	-4.629K	-5.019e+007
V(MET)/10	6.220K	1.612K	-4.608K	-4.997e+007
V(V2) - V(SELV)	0.725K	0.639K	-0.085K	-9.270e+005
-(V(MET) - V(SELV))/2	0.098K	-0.006K	-0.104K	-1.127e+006
(V(SELV) - V(V5))*10	0.001K	0.000K	-0.002K	-1.648e+004
(V(MET) - V(V6))	1.320K	-0.078K	-1.398K	-1.516e+007
(V(MET) - V(V7))	1.321K	-0.078K	-1.398K	-1.516e+007
V(SELV) - V(V8)	1.433K	-0.087K	-1.520K	-1.648e+007
T	7.781u	100.000u	92.219u	1.000e+000

Figure A.4 – Result for simulation of a lightning strike to a TN-S power system with earthed equipment with primary protection

Customer earth 100 Ω

The voltages and currents shown are for a 10 m telecommunication bond wire length. If the bond wire length is reduced to 1.5 m, the values change. These values are shown in parentheses.

The telecommunication port inherent protection operates at 100 V. The spark gap between the neutral and PE does not operate as X4, the neutral – PE inherent protection MOV clamps its voltage to a maximum of 1.1 kV. The primary protectors on the unused telecommunication pair and the telecommunication working pair operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 62 (62) kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 751 (751) V (no flashover of the transformer). The voltage between the telecommunication network ports and SELV is 1.54 kV (647 V). The current entering the telecommunication port is 154 (65) A. With the long bond wire the current is well in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port will occur. With the short bond wire the current is just in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the telecommunication network node is 1.87 kA. The current entering the earth via the local earth point is 622 (619) A. The working pair contributes 761 (765) A. The spare pair terminated on a primary protector contributes 761 (765) A. The screen of the cable contributes 345 (347) A.

The Ethernet port is subjected to a voltage peak of 125 (212) V. The current is just less than 1 A for the 10 m bond wire case and just over 1.3 for the 1.5 m bond wire case. No damage to the Ethernet port.

Damage will occur to the telecommunication port of equipment when the bond wire is 10 m long and may occur for the short bond wire case.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V. The spark gap between the neutral and PE operates at 1.5 kV. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 62 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 653 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 1.25 kV. The current entering the telecommunication port is 125 A. This current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port will occur.

The current injected into the telecommunication network is 1.88 kA. The current entering the earth via the local earth point is 625 A. The working pair contributes 765 A. The spare pair terminated on a primary protector contributes 765 A after its protector operates. The screen of the cable contributes 347 A.

The Ethernet port is subjected to a voltage peak of 221 V. The current is 4.2 A. No damage to the Ethernet port.

Interestingly, the loss of the equipment earth has minimal impact from a lightning perspective apart from the current impulse on the Ethernet port.

Damage will occur to the telecommunication port of equipment when the bond wire is 10 m long.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V. The spark gap between the neutral and PE operates at 1.5 kV. Only the telecommunication spare pair primary protector operates. The voltage on the working telecommunication pair does not exceed 498 V.

The MET and the SELV circuit both rise to 8.7 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 641 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 488 V. The current entering the port is 49 A which is less than the coordination test current of 60 A.

The current injected into the telecommunication network is 301 A. The current entering the earth via the local earth point is 4.36 kA. The working pair contributes 49 A. The spare pair terminated on a primary protector contributes 174 A. The screen of the cable contributes 79 A.

The Ethernet port is subjected to a voltage peak of 216 V. The current is 3.1 A just after the neutral to PE spark gap operates. No damage to the Ethernet port.

The equipment appears to be protected.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V. The spark gap between the neutral and PE does not operate. The telecommunication primary protector on the spare pair and the working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 71 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 743 V (no flashover of the transformer). The voltage between the telecommunication network ports and the SELV circuit is 1.65 kV. The current entering the telecommunication port is 165 A. This current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 2.08 kA. The working pair contributes 848 A. The spare pair contributes 848 A. The screen of the cable contributes 384 A.

The Ethernet port is subjected to a voltage peak of 128 V. The current is much less than 1 A. No damage to the Ethernet port.

Damage will occur to the telecommunication port of equipment when the bond wire is 10 m long.

A.2.1.2 Floating equipment

A.2.1.2.1 Without primary protection

Figure A.5 shows the simulation of a lightning strike to a TN-S power system with floating equipment without primary protection.

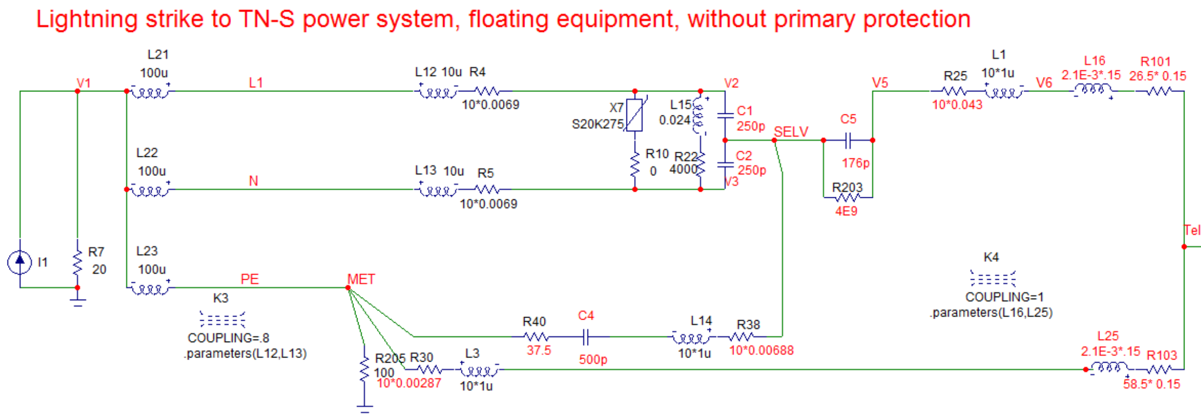
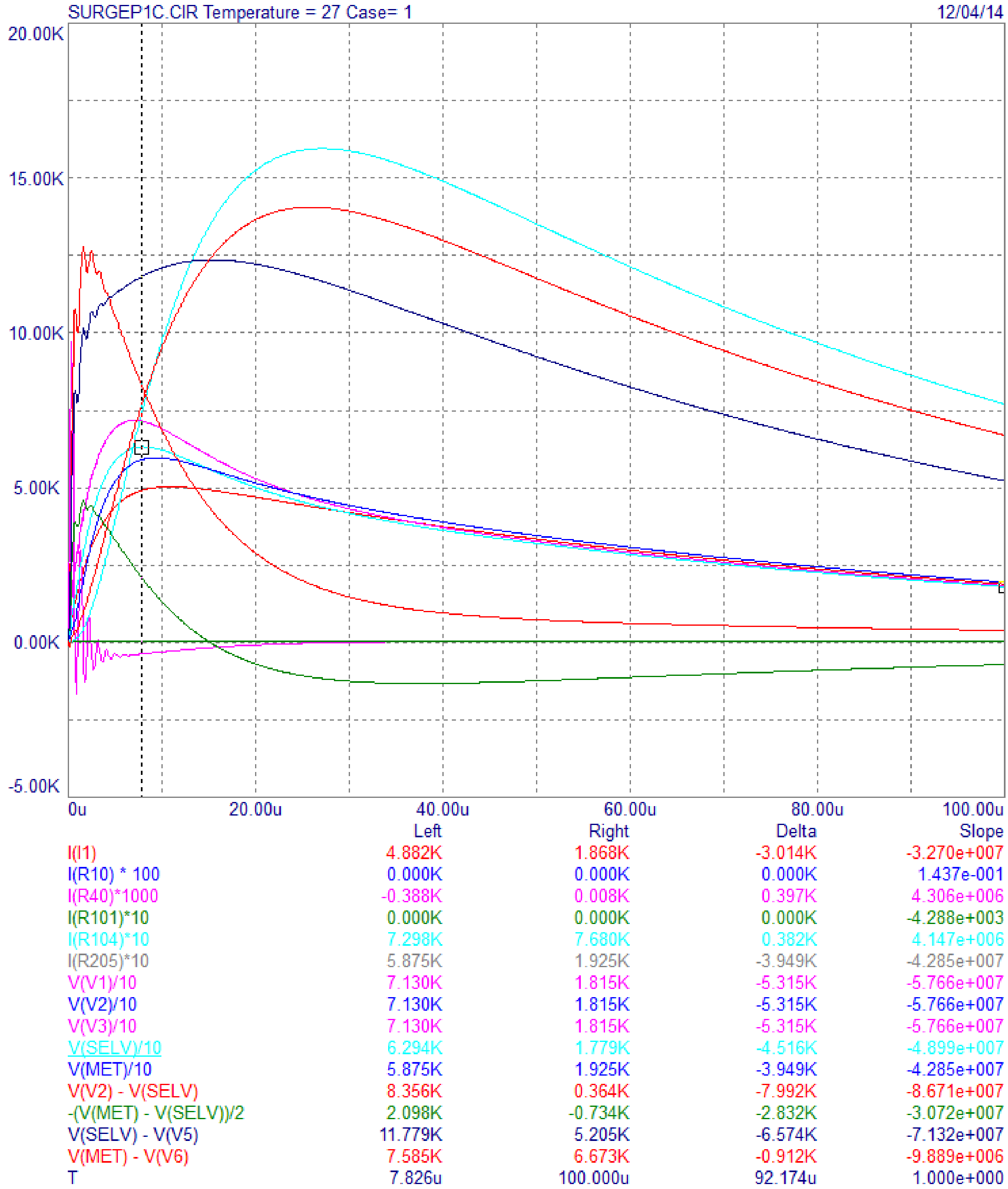


Figure A.5 – Simulation of a lightning strike to a TN-S power system with floating equipment without primary protection

Description of the components related to Figure A.5:

- R7 represents the resistance to earth at the lightning strike point.
- L21, L22 and L23 simulate a length of power line.
- R4, R5 and L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOV X7 is an inherent protection MOV in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- C5 and R203 represent the telecommunication input circuit.
- R40 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R38, represent 10 metres of Ethernet cable.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101 and L25, R103 represent a pair and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.6 shows result for simulation of a lightning strike to a TN-S power system with floating equipment without primary protection.



	Left	Right	Delta	Slope
I(I1)	4.882K	1.868K	-3.014K	-3.270e+007
I(R10) * 100	0.000K	0.000K	0.000K	1.437e-001
I(R40)*1000	-0.388K	0.008K	0.397K	4.306e+006
I(R101)*10	0.000K	0.000K	0.000K	-4.288e+003
I(R104)*10	7.298K	7.680K	0.382K	4.147e+006
I(R205)*10	5.875K	1.925K	-3.949K	-4.285e+007
V(V1)/10	7.130K	1.815K	-5.315K	-5.766e+007
V(V2)/10	7.130K	1.815K	-5.315K	-5.766e+007
V(V3)/10	7.130K	1.815K	-5.315K	-5.766e+007
V(SELV)/10	6.294K	1.779K	-4.516K	-4.899e+007
V(MET)/10	5.875K	1.925K	-3.949K	-4.285e+007
V(V2) - V(SELV)	8.356K	0.364K	-7.992K	-8.671e+007
-(V(MET) - V(SELV))/2	2.098K	-0.734K	-2.832K	-3.072e+007
V(SELV) - V(V5)	11.779K	5.205K	-6.574K	-7.132e+007
V(MET) - V(V6)	7.585K	6.673K	-0.912K	-9.889e+006
T	7.826u	100.000u	92.174u	1.000e+000

Figure A.6 – Result for simulation of a lightning strike to a TN-S power system with floating equipment without primary protection

Customer earth 100 Ω

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 63 kV and 59 kV. Voltages of these magnitudes may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is nearly 13 kV. The voltage between the telecommunication network ports and the SELV circuit is over 12 kV. The voltage between the two ports is 25 kV. As this is in excess of the port-to-port isolation voltage of 5 kV and 6 kV respectively, a flashover will occur and damage to the ports is highly likely.

The current injected into the telecommunication network node is 1.59 kA. The current entering the earth via the local earth point is 594 A. The working pair contributes 0 A. The screen of the cable contributes 1.59 kA.

The Ethernet port is subjected to a voltage peak of 4.53 kV. The current is 9.7 A. As this is in excess of the test isolation voltage of 2.5 kV, damage to this port is likely to occur.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering the mains port will exit via the telecommunication and Ethernet ports, thus damaging all ports.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering the mains port will exit via the telecommunication and Ethernet ports, thus damaging all ports.

Customer earth 2 Ω

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 23.6 kV and 8.25 kV. These are significant reductions with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 28.5 kV. Flashover of this port will occur. The voltage between the telecommunication network ports and the SELV circuit is 21 kV. The voltage between the two ports is nearly 50 kV. As this is in excess of the port-to-port isolation of 5 kV and 6 kV respectively, a flashover will occur and damage to the ports is highly likely.

The current injected into the telecommunication network node is 246 A. The current entering the earth via the local earth point is just over 4.1 kA. The working pair contributes 4 A. The screen of the cable contributes 246 A.

The Ethernet port is subjected to a voltage peak of 10.4 kV. The current is 12.9 A. Damage to this port is likely to occur.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering on the mains port will exit via the telecommunication and Ethernet ports damaging all ports.

No path to earth at the customer premises

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 71 kV and 67 kV. Voltages of these magnitudes may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 9.8 kV. Flashover of this port will occur. The voltage between the telecommunication network ports and the SELV circuit is 14.5 kV. The voltage between the two ports is 24.3 kV. As this is in excess of the port-to-port isolation, a flashover will occur and damage to the ports is highly likely.

The current injected into the telecommunication network node is 1.79 kA. The working pair contributes 1.3 A. The screen of the cable contributes 1.78 kA.

The Ethernet port is subjected to a voltage peak of 2.9 kV. The current is 2.9 A. Damage to this port may occur.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering into the mains port will exit via the telecommunication and Ethernet ports damaging all ports.

A.2.1.2.2 With primary protection

Figure A.7 shows the simulation of a lightning strike to a TN-S power system with floating equipment with primary protection.

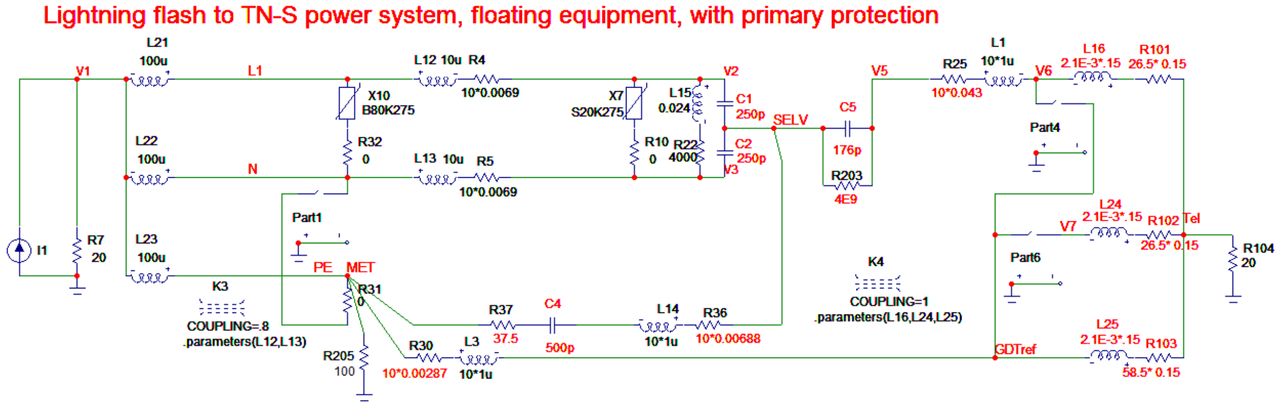
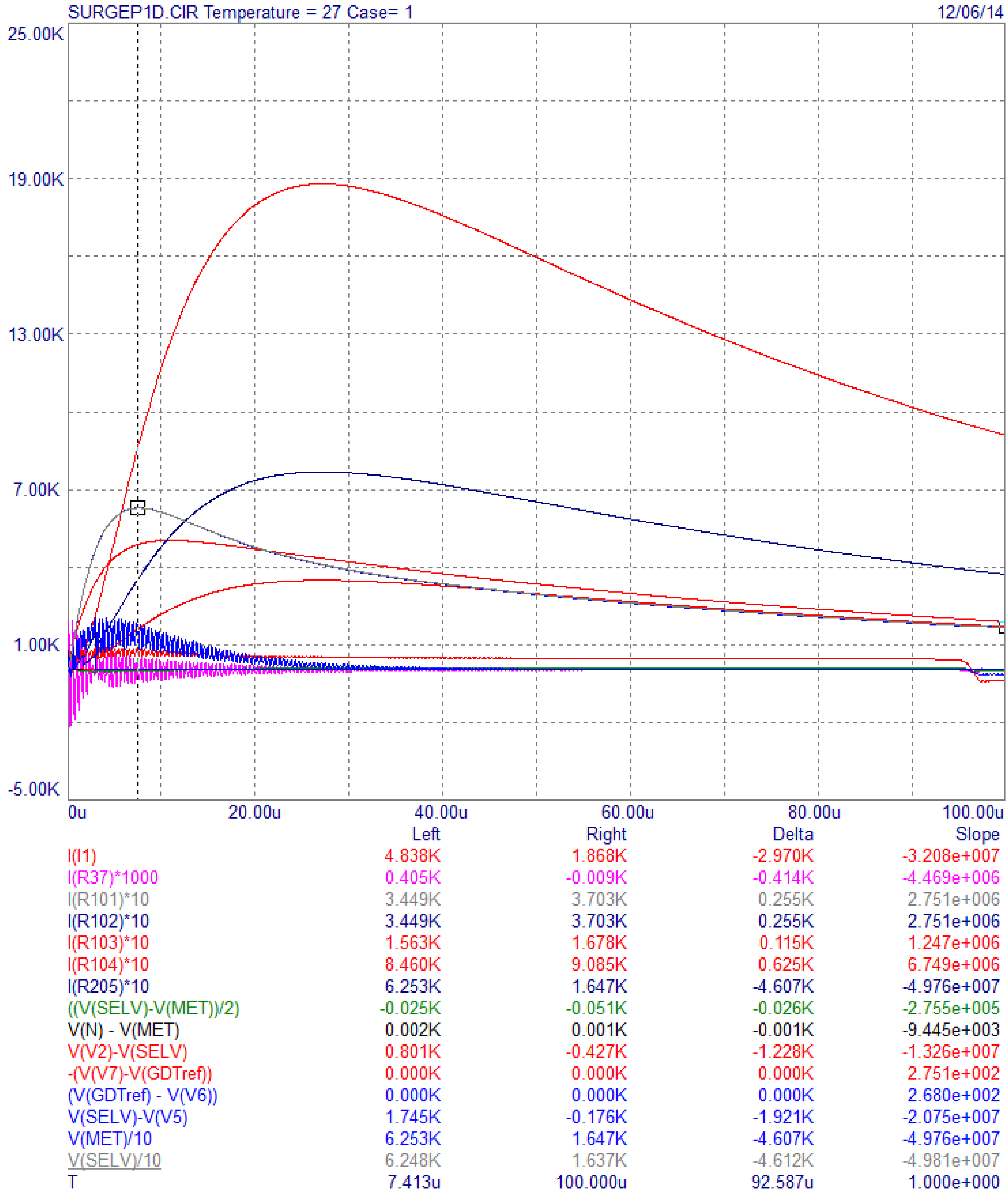


Figure A.7 – Simulation of a lightning strike to a TN-S power system with floating equipment with primary protection

Description of the components related to Figure A.7:

- R7 represents the resistance to earth at the lightning strike point.
- L21, L22 and L23 simulate a length of power line.
- X10 represents an SPD installed between L1 and N at the MSB.
- Part1 is a spark gap connected between N and PE at the MSB. It operates at 1.5 kV.
- R4, R5 and L12, L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOV X7 is an inherent protection MOV in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- C5 and R203 represent the telecommunication input circuit.
- Part4 is a GDT on the working telecommunication pair and Part6 is a GDT on the unused telecommunication pair. These GDTs operate at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101, L24, R102 and L25, R103 represent two pairs and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.8 shows result for simulation of a lightning strike to a TN-S power system with floating equipment with primary protection.



	Left	Right	Delta	Slope
I(I1)	4.838K	1.868K	-2.970K	-3.208e+007
I(R37)*1000	0.405K	-0.009K	-0.414K	-4.469e+006
I(R101)*10	3.449K	3.703K	0.255K	2.751e+006
I(R102)*10	3.449K	3.703K	0.255K	2.751e+006
I(R103)*10	1.563K	1.678K	0.115K	1.247e+006
I(R104)*10	8.460K	9.085K	0.625K	6.749e+006
I(R205)*10	6.253K	1.647K	-4.607K	-4.976e+007
((V(SELV)-V(MET))/2)	-0.025K	-0.051K	-0.026K	-2.755e+005
V(N) - V(MET)	0.002K	0.001K	-0.001K	-9.445e+003
V(V2)-V(SELV)	0.801K	-0.427K	-1.228K	-1.326e+007
-(V(V7)-V(GDTref))	0.000K	0.000K	0.000K	2.751e+002
(V(GDTref) - V(V6))	0.000K	0.000K	0.000K	2.680e+002
V(SELV)-V(V5)	1.745K	-0.176K	-1.921K	-2.075e+007
V(MET)/10	6.253K	1.647K	-4.607K	-4.976e+007
V(SELV)/10	6.248K	1.637K	-4.612K	-4.981e+007
T	7.413u	100.000u	92.587u	1.000e+000

Figure A.8 – Result for simulation of a lightning strike to a TN-S power system with floating equipment with primary protection

Customer earth 100 Ω

The spark gap between the neutral and PE operates at 1500 V. The primary protectors, on the working and unused telecommunication pairs, operate at 600 V.

Because of the relatively high resistance to earth the MET and the SELV circuit voltages with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 62 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 878 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 2.15 kV. The voltage between the two ports is 2.9 kV. As this is less than the port-to-port isolation of 5 kV, a flashover is unlikely to occur.

The current injected into the telecommunication network node is 1.88 kA. The current entering the earth via the local earth point is 625 A. The working pair contributes 765 A. The spare pair terminated on a primary protector contributes 765 A. The screen of the cable contributes 346 A.

The Ethernet port is subjected to a voltage peak of 336 V. The current is 2.8 A. No damage is likely to occur.

The equipment appears to be protected.

Customer earth 2 Ω

The spark gap between the neutral and PE operates at 1.5 kV. The primary protectors, on the working and unused telecommunication pairs, operate at 600 V.

The MET and the SELV circuit both rise to 8.8 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 883 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 865 V (no flashover). The voltage between the two ports is 1.7 kV. As this is less than the port-to-port isolation of 5 kV, a flashover is unlikely to occur.

The current injected into the telecommunication network node is 307 A. The current entering the earth via the local earth point is 4.35 kA. The working pair contributes 125 A. The spare pair terminated on a primary protector contributes 125 A. The screen of the cable contributes 57 A.

The Ethernet port is subjected to a voltage peak of 335 V just prior to the neutral – PE spark gap operating. The current is more than 2.5 A.

The equipment appears to be protected.

No path to earth at the customer premises

The spark gap between the neutral and PE operates at 1.5 kV. The telecommunication primary protectors on the working and spare pairs operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 71 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 875 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 2 kV. The voltage between the two ports is 2.9 kV. As this is less than the port-to-port isolation of 5 kV, a flashover is unlikely to occur and damage to the ports is highly unlikely.

The current injected into the telecommunication network node is 2.1 kA. The working pair contributes 852 A. The spare pair contributes 852 A. The screen of the cable contributes 386 A.

The Ethernet port is subjected to a voltage peak of 309 V just prior to the neutral – PE spark gap operating. The current is 3.82 A.

The equipment is protected.

A.2.2 TN-C and TN-C-S power systems

A.2.2.1 Earthed equipment

A.2.2.1.1 Without primary protection

Figure A.9 shows the simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment without primary protection.

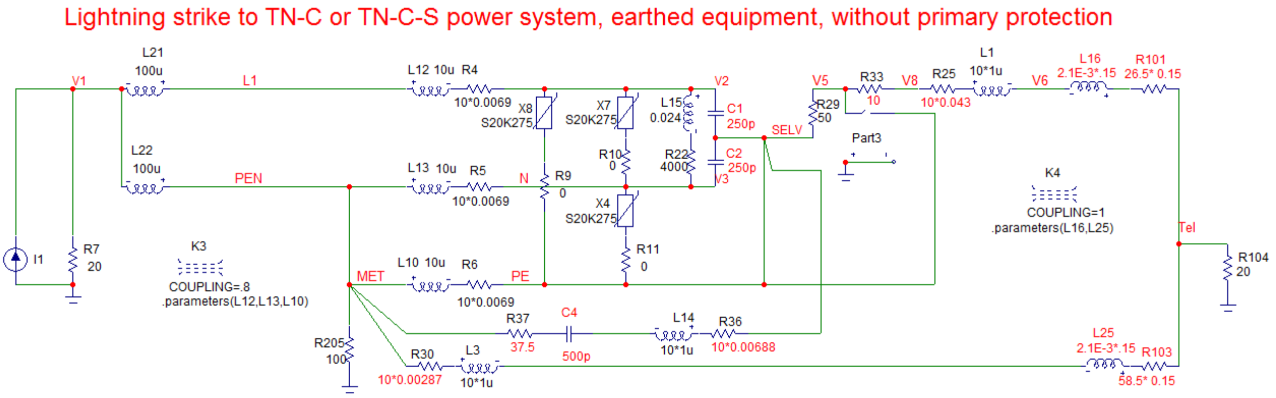
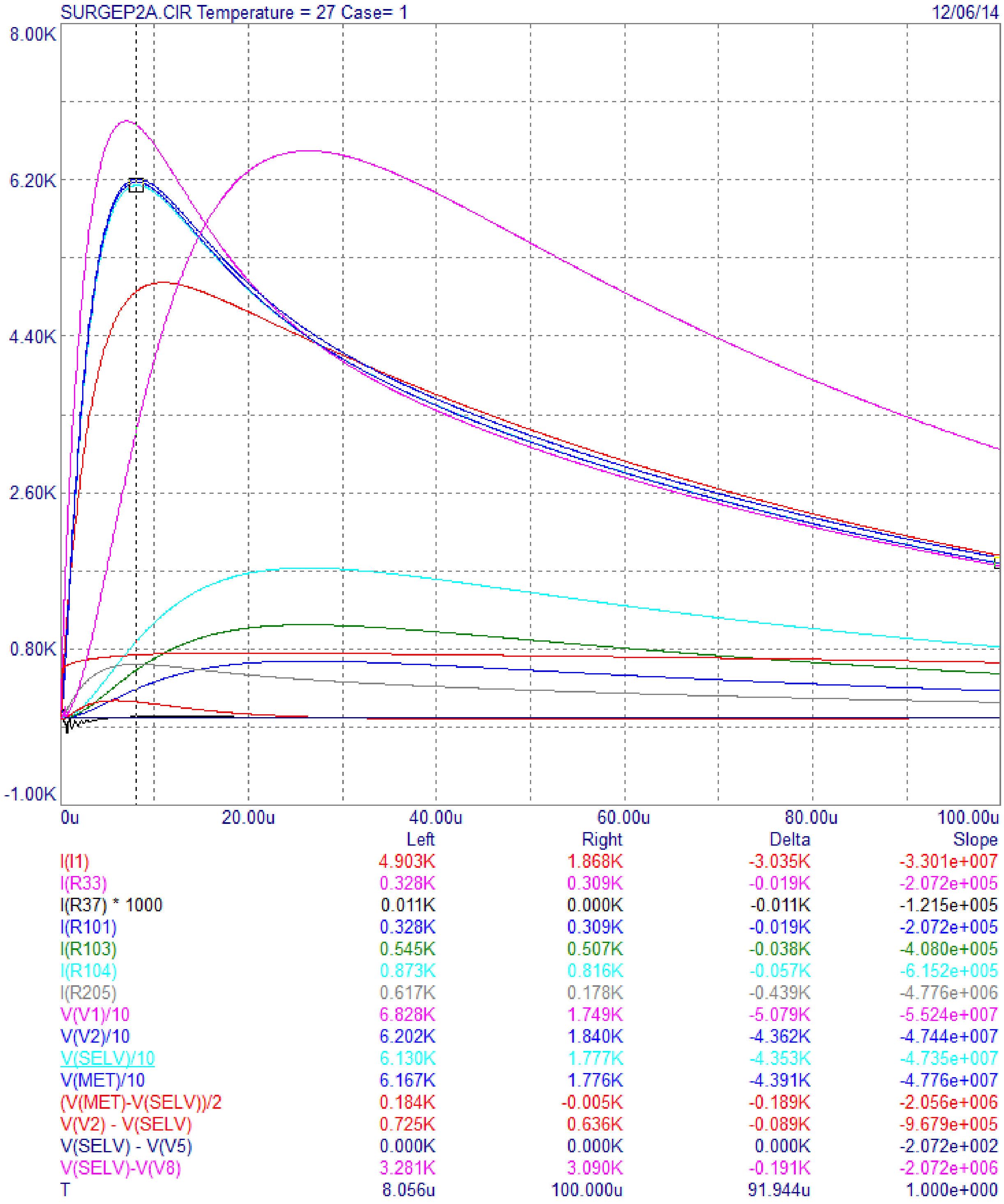


Figure A.9 – Simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment without primary protection

Description of the components related to Figure A.9:

- R7 represents the resistance to earth at the lightning strike point.
- L21 and L22 simulate a length of power line.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOVs X8, X7 and X4 are inherent MOVs in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R29 represents the internal resistance of the telecommunication circuit.
- Part3 is a TVS which operates at 100 V.
- R33 represents a fusible resistor and also provides a coordination resistance.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101 and L25, R103 represent a pair and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.10 shows result for simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment without primary protection.



	Left	Right	Delta	Slope
I(I1)	4.903K	1.868K	-3.035K	-3.301e+007
I(R33)	0.328K	0.309K	-0.019K	-2.072e+005
I(R37) * 1000	0.011K	0.000K	-0.011K	-1.215e+005
I(R101)	0.328K	0.309K	-0.019K	-2.072e+005
I(R103)	0.545K	0.507K	-0.038K	-4.080e+005
I(R104)	0.873K	0.816K	-0.057K	-6.152e+005
I(R205)	0.617K	0.178K	-0.439K	-4.776e+006
V(V1)/10	6.828K	1.749K	-5.079K	-5.524e+007
V(V2)/10	6.202K	1.840K	-4.362K	-4.744e+007
V(SELV)/10	6.130K	1.777K	-4.353K	-4.735e+007
V(MET)/10	6.167K	1.776K	-4.391K	-4.776e+007
(V(MET)-V(SELV))/2	0.184K	-0.005K	-0.189K	-2.056e+006
V(V2) - V(SELV)	0.725K	0.636K	-0.089K	-9.679e+005
V(SELV) - V(V5)	0.000K	0.000K	0.000K	-2.072e+002
V(SELV)-V(V8)	3.281K	3.090K	-0.191K	-2.072e+006
T	8.056u	100.000u	91.944u	1.000e+000

Figure A.10 – Result for simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment without primary protection

Customer earth 100 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 62 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 748 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 6.5 kV. The current

entering the port is 653 A. This current is significantly higher than the inherent test current in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network is 1.7 kA. The current entering the earth via the local earth point is 617 A. The working pair contributes 653 A. The screen of the cable contributes 1.07 kA.

The Ethernet port is subjected to a voltage peak of 198 V. The current is much less than 1 A.

Damage is likely to occur to the telecommunication port.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 62 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 747 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 6.5 kV. The current conducted in the telecommunication port is 654 A. This current is significantly higher than the inherent test current in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network is 1.72 kA. The current entering the earth via the local earth point is 805 A. The working pair contributes 653 A. The screen of the cable contributes 1.07 kA.

The Ethernet port is subjected to a voltage peak of 327 V. The current is under 1 A.

Interestingly, the loss of the equipment earth has minimal impact from a lightning perspective apart from a higher voltage and a higher current impulse on the Ethernet port.

Damage is likely to occur to the telecommunication port.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V.

The MET and the SELV circuit both rise to 8.6 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 792 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.05 kV. The current conducted in the telecommunication port is 105 A. This current is in excess of the inherent test current in [ITU-T K.21] and damage to the port may occur.

The current injected into the telecommunication network is 273 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 105 A. The screen of the cable contributes 169 A.

The Ethernet port is subjected to a voltage peak of 149 V. The current is less than 1 A.

Damage may occur to the telecommunication port.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 70 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 740 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 7.3 kV. The current conducted in the telecommunication port is 730 A. This current is significantly higher than the inherent test current in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network is 1.93 kA. The working pair contributes 730 A. The screen of the cable contributes 1.2 kA.

The Ethernet port is subjected to a voltage peak of 246 V. The current is much less than 1 A.

Damage is likely to occur to the telecommunication port.

A.2.2.1.2 With primary protection

Figure A.11 shows the simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment with primary protection.

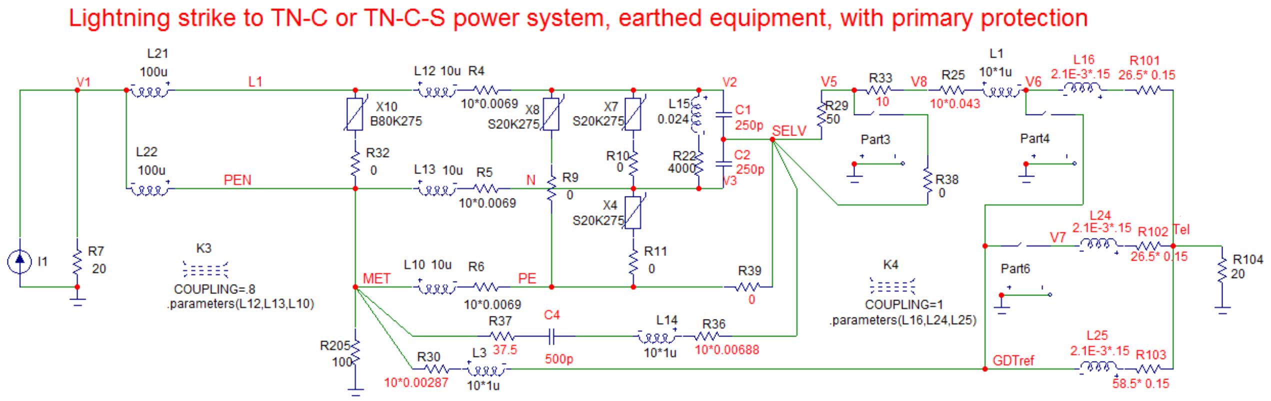


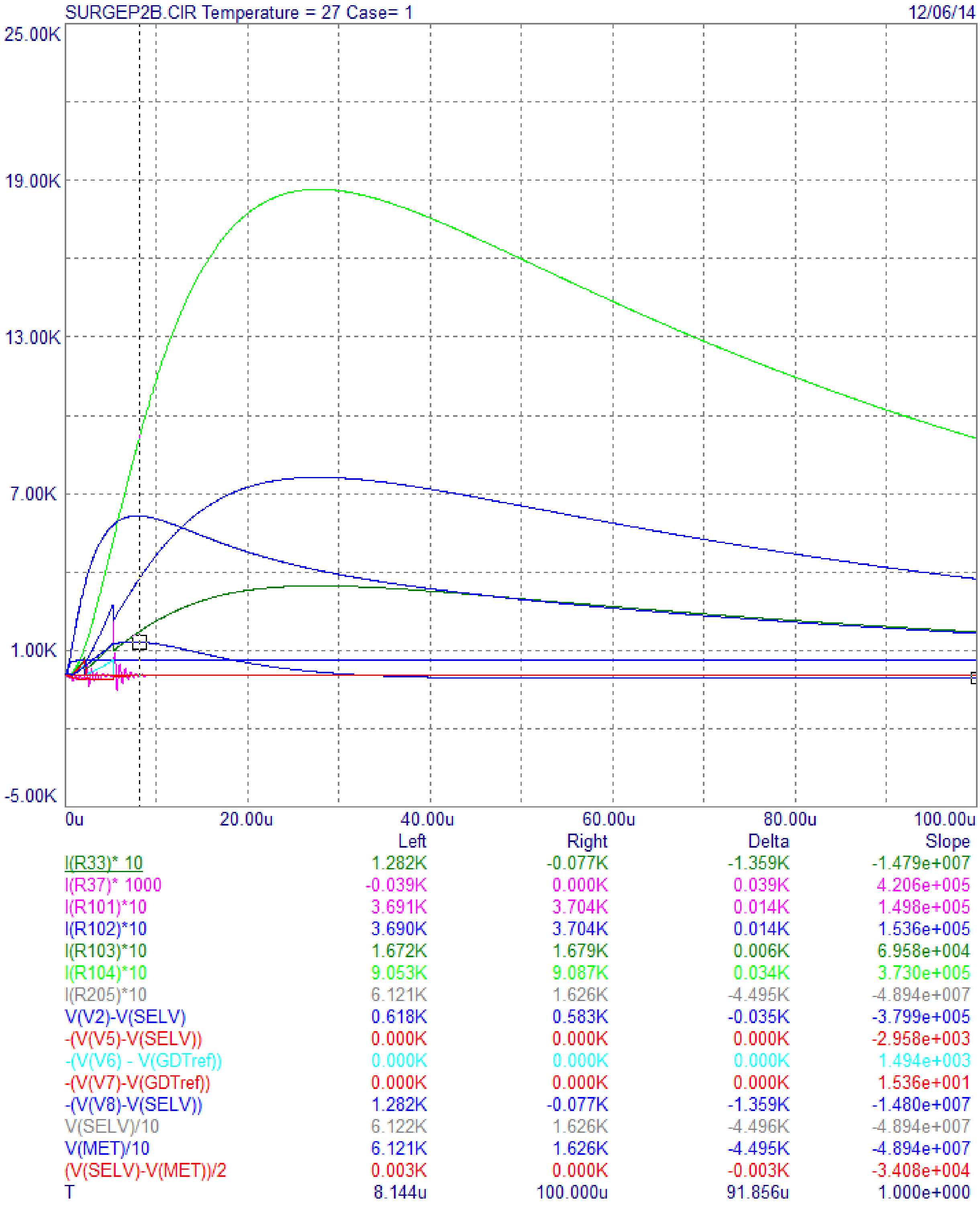
Figure A.11 – Simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment with primary protection

Description of the components related to Figure A.11:

- R7 represents the resistance to earth at the lightning strike point.
- L21 and L22 simulate a length of power line.
- X10 represents an SPD installed between L1 and N at the MSB.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R29 represents the internal resistance of the telecommunication circuit.
- Part3 is a TVS which operates at 100 V.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part4 is a GDT on the working telecommunication pair and Part6 is a GDT on the unused telecommunication pair. These GDTs operate at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.

- L16, R101, L24, R102 and L25, R103 represent two pairs and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.12 shows result for simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment with primary protection.



	Left	Right	Delta	Slope
I(R33)* 10	1.282K	-0.077K	-1.359K	-1.479e+007
I(R37)* 1000	-0.039K	0.000K	0.039K	4.206e+005
I(R101)*10	3.691K	3.704K	0.014K	1.498e+005
I(R102)*10	3.690K	3.704K	0.014K	1.536e+005
I(R103)*10	1.672K	1.679K	0.006K	6.958e+004
I(R104)*10	9.053K	9.087K	0.034K	3.730e+005
I(R205)*10	6.121K	1.626K	-4.495K	-4.894e+007
V(V2)-V(SELV)	0.618K	0.583K	-0.035K	-3.799e+005
-(V(V5)-V(SELV))	0.000K	0.000K	0.000K	-2.958e+003
-(V(V6) - V(GDTref))	0.000K	0.000K	0.000K	1.494e+003
-(V(V7)-V(GDTref))	0.000K	0.000K	0.000K	1.536e+001
-(V(V8)-V(SELV))	1.282K	-0.077K	-1.359K	-1.480e+007
V(SELV)/10	6.122K	1.626K	-4.496K	-4.894e+007
V(MET)/10	6.121K	1.626K	-4.495K	-4.894e+007
(V(SELV)-V(MET))/2	0.003K	0.000K	-0.003K	-3.408e+004
T	8.144u	100.000u	91.856u	1.000e+000

Figure A.12 – Result for simulation of a lightning strike to a TN-C and TN-C-S power system with earthed equipment with primary protection

Customer earth 100 Ω

The voltages and currents shown are for a 10 m telecommunication bond wire length. If the bond wire length is reduced to 1.5 m, the values change. These values are shown in parentheses.

The telecommunication port inherent protection operates at 100 V. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 (61) kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 621 (624) V (no flashover). The voltage between the telecommunication network ports and SELV is 1.286 kV (416 V). The current entering the telecommunication port is 129 (41.6) A. With the long bond wire the current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the telecommunication network node is 1.86 (1.87) kA. The current entering the earth via the local earth point is 612 (609) A. The working pair contributes 759 (763) A. The spare pair terminated on a primary protector contributes 759 (763) A. The screen of the cable contributes 344 (346) A.

The Ethernet port is subjected to a voltage peak of 164 (74) V. The current is much less than 1 A with a long bond wire, but has a peak of 1.2 A with the short bond wire.

Damage is likely to occur to the telecommunication port if the telecommunication bond wire is 10 m long. The current is 129 A compared with the test current of 60 A.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 653 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.23 kV. The current entering the telecommunication port is 123 A. This current is in excess of the coordination test current in [ITU-T K.21] and damage to the port may occur.

The current injected into the telecommunication network node is 1.86 kA. The current entering the earth via the local earth point is 612 A. The working pair contributes 759 A. The spare pair terminated on a primary protector contributes 759 A after its protector operates. The screen of the cable contributes 344 A.

The Ethernet port is subjected to a voltage peak of 188 V. The current is much less than 1 A.

Interestingly, the loss of the equipment earth has minimal impact from a lightning perspective.

Damage is likely to occur to the telecommunication port. The current is 123 A compared with the coordination test current of 60 A.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V. The telecommunication spare pair primary protector operates and prevents the telecommunication working pair primary protector from operating.

The MET and the SELV circuit both rise to 8.6 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 651 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 488 V. The current entering the port is 48.8 A.

The current injected into the telecommunication network is 300 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 49 A. The spare pair terminated on a primary protector contributes 173 A. The screen of the cable contributes 78 A.

The Ethernet port is subjected to a voltage peak of 50 V just after the telecommunication spare pair primary protector operates. The current is less than 1 A.

The equipment is protected.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V. The telecommunication primary protectors on the spare and working pairs operate at 600 V.

Because of the relatively high resistance to earth the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 69 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 611 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.42 kV. The current entering the telecommunication port is 143 A. This current is in excess of the coordination test current in [ITU-T K.21] and damage to the port may occur.

The current injected into the telecommunication network is 2.07 kA. The working pair contributes 845 A. The spare pair contributes 845 A. The screen of the cable contributes 383 A.

The Ethernet port is subjected to a voltage peak of 187 V just prior to the telecommunications spare pair primary protector operating. The current is much less than 1 A.

Damage may occur to the telecommunication port. The current is 143 compared with the coordination test current of 60 A.

A.2.2.2 Floating equipment

A.2.2.2.1 Without primary protection

Figure A.13 shows the simulation of a lightning strike to a TN-C and TN-C-S power system with floating equipment without primary protection.

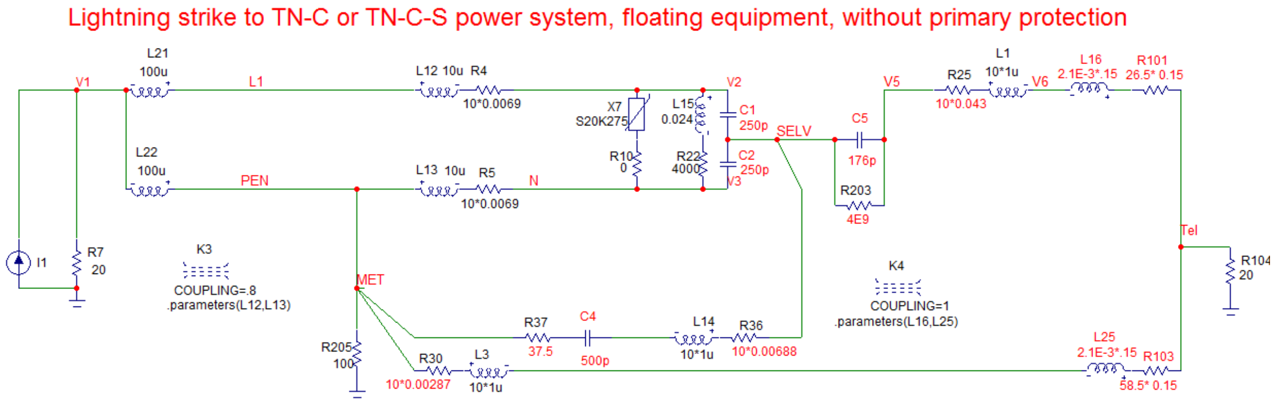


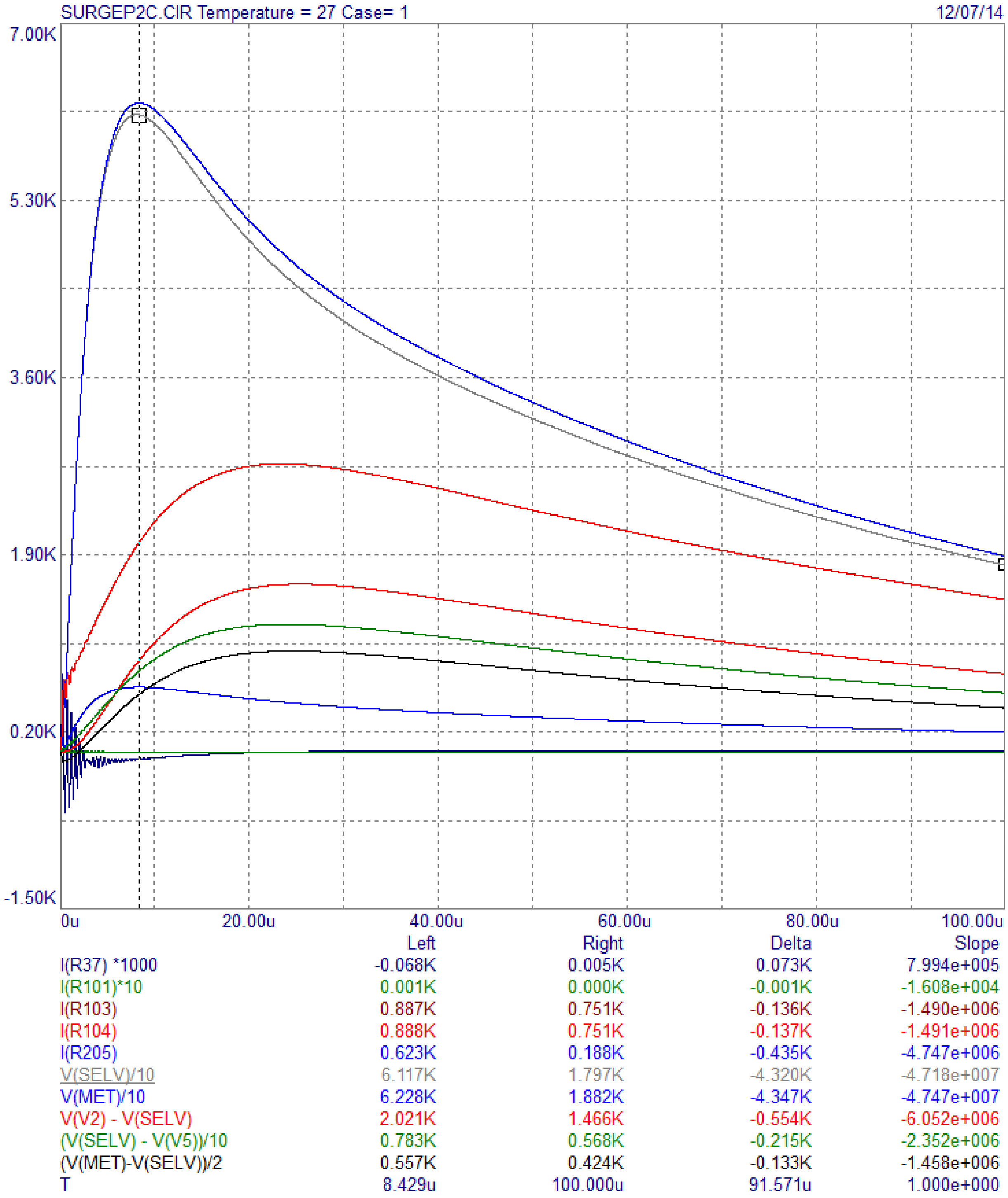
Figure A.13 – Simulation of a lightning strike to a TN-C and TN-C-S power system with floating equipment without primary protection

Description of the components related to Figure A.13:

- R7 represents the resistance to earth at the lightning strike point.
- L21and L22 simulate a length of power line.

- R4, R5 and L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOV X7 is an inherent protection MOV in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- C5 and R203 represent the telecommunication input circuit.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101 and L25, R103 represent a pair and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.14 shows result for simulation of a lightning strike to a TN-C and TN-C-S power system with floating equipment without primary protection.



	Left	Right	Delta	Slope
I(R37) *1000	-0.068K	0.005K	0.073K	7.994e+005
I(R101)*10	0.001K	0.000K	-0.001K	-1.608e+004
I(R103)	0.887K	0.751K	-0.136K	-1.490e+006
I(R104)	0.888K	0.751K	-0.137K	-1.491e+006
I(R205)	0.623K	0.188K	-0.435K	-4.747e+006
V(SELV)/10	6.117K	1.797K	-4.320K	-4.718e+007
V(MET)/10	6.228K	1.882K	-4.347K	-4.747e+007
V(V2) - V(SELV)	2.021K	1.466K	-0.554K	-6.052e+006
(V(SELV) - V(V5))/10	0.783K	0.568K	-0.215K	-2.352e+006
(V(MET)-V(SELV))/2	0.557K	0.424K	-0.133K	-1.458e+006
T	8.429u	100.000u	91.571u	1.000e+000

Figure A.14 – Result for simulation of a lightning strike to a TN-C and TN-C-S power system with floating equipment without primary protection

Customer earth 100 Ω

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 62 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 2.77 kV. The voltage between the telecommunication network ports and the SELV circuit is 12.3 kV. The voltage between the two ports is 15 kV. As this in excess of the port-to-port isolation, a flashover will occur and damage to the ports is highly likely.

The current injected into the telecommunication network node is 1.61 kA. The current entering the earth via the local earth point is 623 A. The working pair contributes 0 A. The screen of the cable contributes 1.61 kA.

The Ethernet port is subjected to a voltage peak of 970 V. The current is just less than 1 A.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port (the SELV circuit will suddenly rise in voltage). The resulting surge current entering on the mains port will exit via the telecommunication and the Ethernet ports damaging all ports.

Customer earth 2 Ω

The MET and the SELV circuit both rise to 8.6 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 1.05 kV. The voltage between the telecommunication network ports and the SELV circuit is 2.07 kV. The voltage between the two ports is 3.1 kV compared with the isolation voltage of 5 kV for basic equipment.

The current injected into the telecommunication network is 248 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 0 A. The screen of the cable contributes 248 A.

The Ethernet port is subjected to a voltage peak of 217 V. The current is nearly 1 A.

Damage is unlikely.

No path to earth at the customer premises

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 70 kV. Voltage of this magnitude will result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 3 kV. The voltage between the telecommunication network port and the SELV circuit is 13.8 kV. The voltage between the two ports is nearly 17 kV. As this is in excess of the port-to-port isolation, a flashover will occur and damage to the ports is highly likely.

The current injected into the telecommunication network is 1.8 kA. The working pair contributes 0 A. The screen of the cable contributes 1.8 kA.

The Ethernet port is subjected to a voltage peak of 1.1 kV. The current is less than 1 A.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port (the SELV circuit will suddenly rise in voltage). The resulting surge current entering on the mains port will exit via the telecommunication and Ethernet ports damaging all ports.

A.2.2.2.2 With primary protection

Figure A.15 shows the simulation of a lightning strike to a TN-C or TN-C-S power system with floating equipment with primary protection.

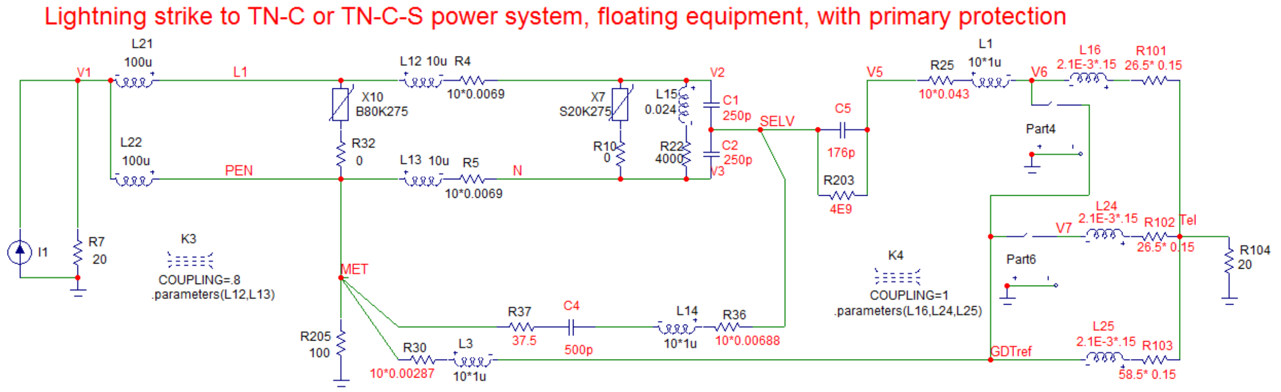


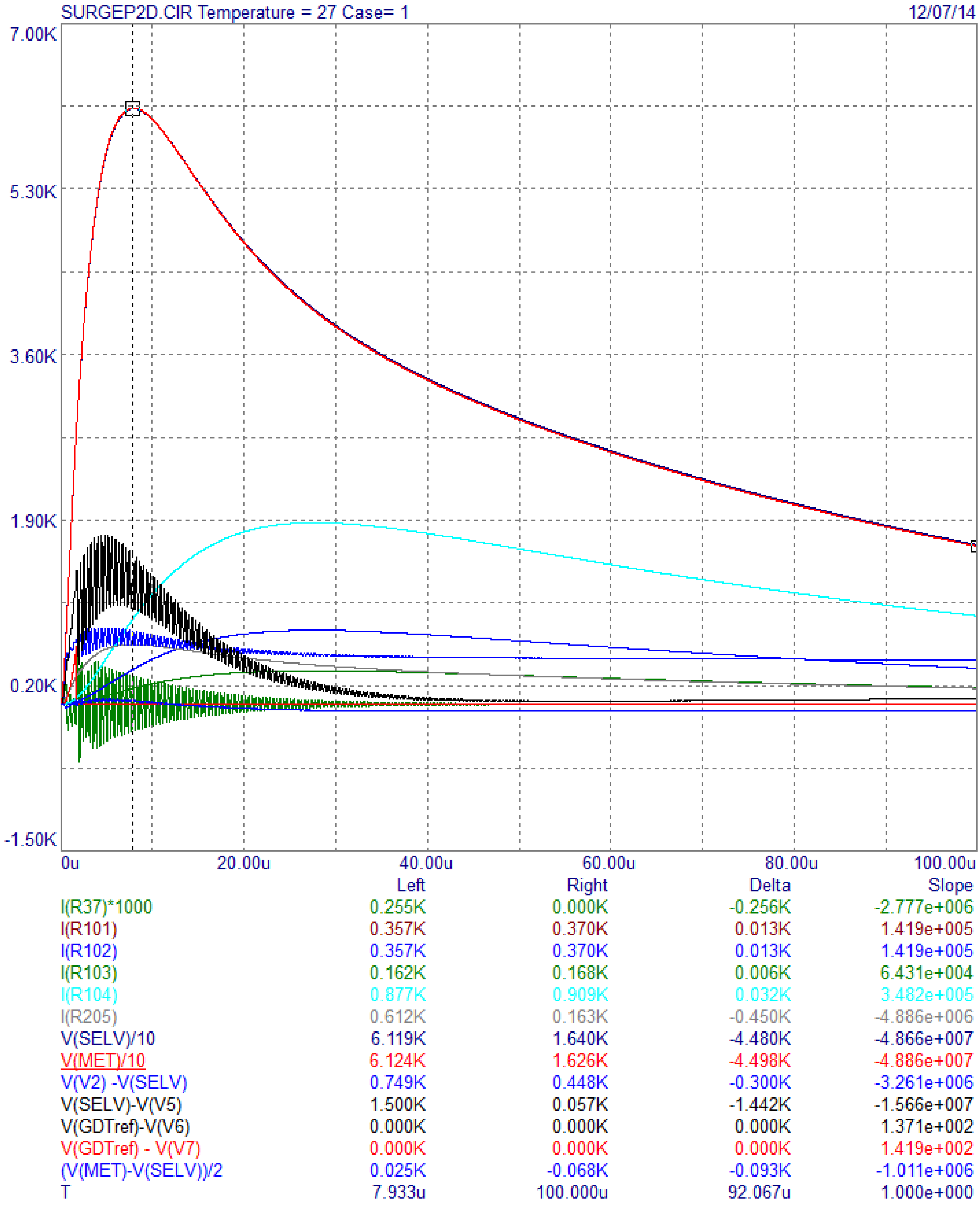
Figure A.15 – Simulation of a lightning strike to a TN-C or TN-C-S power system with floating equipment with primary protection

Description of the components related to Figure A.15:

R7 represents the resistance to earth at the lightning strike point.

- L21 and L22 simulate a length of power line.
- X10 represents an SPD installed between L1 and N at the MSB.
- Part1 is a spark gap connected between N and PE at the MSB. It operates at 1.5 kV.
- R4, R5 and L12, L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOV X7 is an inherent protection MOV in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- C5 and R203 represent the telecommunication input circuit.
- Part4 is a GDT on the working telecommunication pair and Part6 is a GDT on the unused telecommunication pair. These GDTs operate at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101, L24, R102 and L25, R103 represent two pairs and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.16 shows result for simulation of a lightning strike to a TN-C or TN-C-S power system with floating equipment with primary protection.



```
                                  Left        Right       Delta        Slope
I(R37)*1000                     0.255K      0.000K     -0.256K   -2.777e+006
I(R101)                         0.357K      0.370K      0.013K    1.419e+005
I(R102)                         0.357K      0.370K      0.013K    1.419e+005
I(R103)                         0.162K      0.168K      0.006K    6.431e+004
I(R104)                         0.877K      0.909K      0.032K    3.482e+005
I(R205)                         0.612K      0.163K     -0.450K   -4.886e+006
V(SELV)/10                      6.119K      1.640K     -4.480K   -4.866e+007
V(MET)/10                       6.124K      1.626K     -4.498K   -4.886e+007
V(V2) -V(SELV)                  0.749K      0.448K     -0.300K   -3.261e+006
V(SELV)-V(V5)                   1.500K      0.057K     -1.442K   -1.566e+007
V(GDTref)-V(V6)                 0.000K      0.000K      0.000K    1.371e+002
V(GDTref) - V(V7)               0.000K      0.000K      0.000K    1.419e+002
(V(MET)-V(SELV))/2              0.025K     -0.068K     -0.093K   -1.011e+006
T                               7.933u    100.000u     92.067u    1.000e+000
```

Figure A.16 – Result for simulation of a lightning strike to a TN-C or TN-C-S power system with floating equipment with primary protection

Customer earth 100 Ω

The primary protectors, on the working and unused telecommunication pairs, operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 781 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.74 kV. The voltage between the two ports is 2.5 kV. As this is less than the port-to-port isolation of 5 kV, a flashover is unlikely to occur.

The current injected into the telecommunication network node is 1.86 kA. The current entering the earth via the local earth point is 612 A. The working pair contributes 760 A. The spare pair terminated on a primary protector contributes 760 A. The screen of the cable contributes 344 A.

The Ethernet port is subjected to a voltage peak of 54 V. The current is much less than 1 A.

The equipment is protected.

Customer earth 2 Ω

The primary protectors, on the working and unused telecommunication pairs, operate at 600 V.

The MET and the SELV circuit both rise to 8.7 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 651 V. The voltage between the telecommunication network ports and the SELV circuit is 787 V. The voltage between the two ports is less than 1.5 kV. As this is less than the port-to-port isolation of 5 kV, a flashover is unlikely to occur.

The current injected into the telecommunication network node is 307 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 125 A. The spare pair terminated on a primary protector contributes 125 A. The screen of the cable contributes 57 A.

The Ethernet port is subjected to a voltage peak of 70 V. The current is much less than 1 A.

The equipment is protected.

No path to earth at the customer premises

The telecommunication primary protectors on the working and spare pairs operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 69 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 791 V. The voltage between the telecommunication network ports and the SELV circuit is 1.88 kV. The voltage between the two ports is 2.6 kV. As this is less than the port-to-port isolation of 5 kV, a flashover is unlikely to occur.

The current injected into the telecommunication network node is 2.07 kA. The working pair contributes 845 A. The spare pair contributes 845 A. The screen of the cable contributes 383 A.

The Ethernet port is subjected to a voltage peak of 71 V. The current is much less than 1 A.

The equipment is protected.

A.2.3 TT and IT power systems

A.2.3.1 Earthed equipment

A.2.3.1.1 Without primary protection

Figure A.17 shows the simulation of a lightning strike to a TT and IT power system with earthed equipment without primary protection.

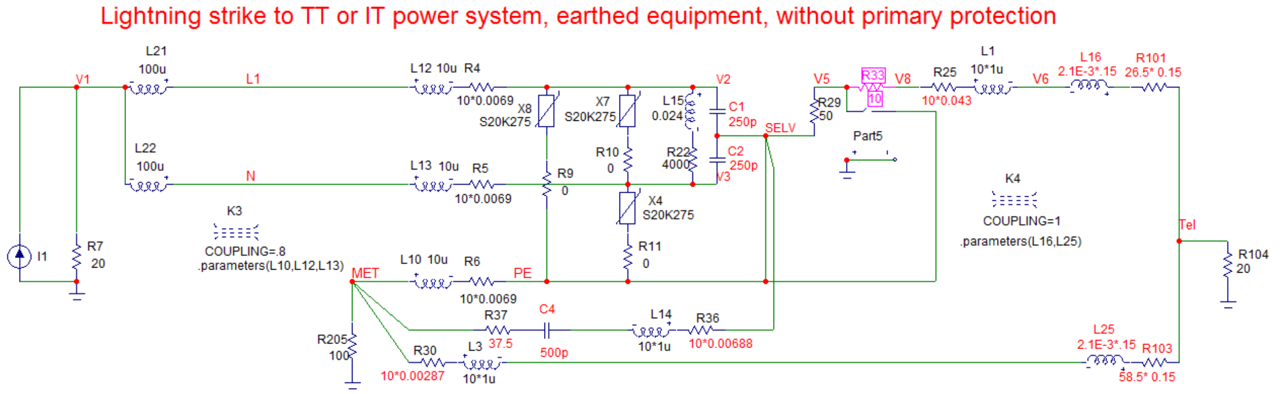
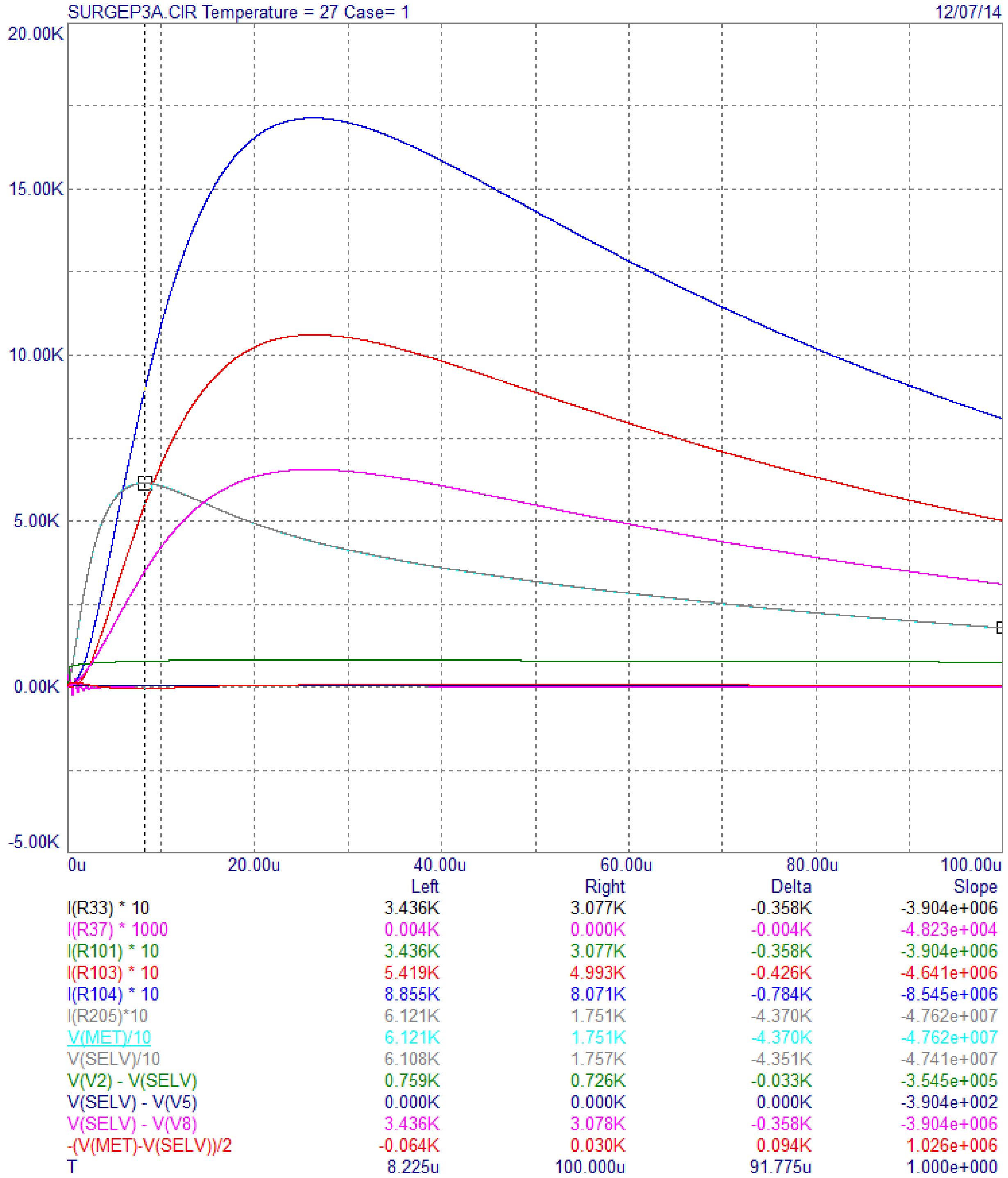


Figure A.17 – Simulation of a lightning strike to a TT and IT power system with earthed equipment without primary protection

Description of the components related to Figure A.17:

- R7 represents the resistance to earth at the lightning strike point.
- L21 and L22 simulate a length of power line.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R29 represents the internal resistance of the telecommunication circuit.
- Part5 is a TVS which operates at 100 V.
- R33 represents a fusible resistor and also provides a coordination resistance.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101 and L25, R103 represent a pair and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.18 shows result for simulation of a lightning strike to a TT and IT power systems with earthed equipment without primary protection.



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                                 Left       Right       Delta        Slope
I(R33) * 10                    3.436K      3.077K     -0.358K   -3.904e+006
I(R37) * 1000                  0.004K      0.000K     -0.004K   -4.823e+004
I(R101) * 10                   3.436K      3.077K     -0.358K   -3.904e+006
I(R103) * 10                   5.419K      4.993K     -0.426K   -4.641e+006
I(R104) * 10                   8.855K      8.071K     -0.784K   -8.545e+006
I(R205)*10                     6.121K      1.751K     -4.370K   -4.762e+007
V(MET)/10                      6.121K      1.751K     -4.370K   -4.762e+007
V(SELV)/10                     6.108K      1.757K     -4.351K   -4.741e+007
V(V2) - V(SELV)                0.759K      0.726K     -0.033K   -3.545e+005
V(SELV) - V(V5)                0.000K      0.000K      0.000K   -3.904e+002
V(SELV) - V(V8)                3.436K      3.078K     -0.358K   -3.904e+006
-(V(MET)-V(SELV))/2           -0.064K      0.030K      0.094K    1.026e+006
T                              8.225u    100.000u     91.775u    1.000e+000
```

Figure A.18 – Result for simulation of a lightning strike to a TT and IT power systems with earthed equipment without primary protection

Customer earth 100 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 791 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 6.53 kV. The current

entering the telecommunication port is 653 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 1.7 kA. The current entering the earth via the local earth point is 612 A. The working pair contributes 653 A. The screen of the cable contributes 1.06 kA.

The Ethernet port is subjected to a voltage peak of 122 V. The peak current is less than 1 A.

Damage will occur to the telecommunication port as the current is 653 A compared with the inherent test current of 40 A.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 45 kV and 67 kV. Voltages of these magnitudes may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 770 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 17.3 kV. The current entering the telecommunication port is 1.73 kA. This current is significantly higher than the inherent test current in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 1.45 kA. The current entering the earth via the local earth point is 451 A. The working pair contributes 1.72 kA. The screen of the cable contributes – 450 A.

The Ethernet port is subjected to a voltage peak of 13.7 kV. The peak current is 5.77 A. This is likely to result in failure of the Ethernet port isolation and damage to the port.

The loss of the equipment earth has an impact with significantly higher voltage and current impulses on the telecommunication and Ethernet ports.

Damage will occur to both the telecommunication and the Ethernet ports.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V.

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 8.8 kV and 8.5 kV. These are significant reductions with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 874 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.11 kV. The current in the port is 111 A. This current is in excess of the inherent test current of 40 A in [ITU-T K.21] and damage to the port will occur.

The current injected into the telecommunication network node is 274 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 111 A. The screen of the cable contributes 162 A.

The Ethernet port is subjected to a voltage peak of 643 V. The current is less than 1 A.

Damage is likely to occur to the telecommunication port. The current is 111 A compared with the inherent test current of 40 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 69 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 779 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 7.3 kV. The current in the port is 731 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network node is 1.92 kA. The working pair contributes 731 A. The screen of the cable contributes 1.19 kA.

The Ethernet port is subjected to a voltage peak of 137 V. The current is less than 1 A.

Damage is likely to the telecommunication port. The current is 731 A compared with the inherent test current of 40 A.

A.2.3.1.2 With primary protection

Figure A.19 shows the simulation of a lightning strike to a TT and IT power systems with earthed equipment with primary protection.

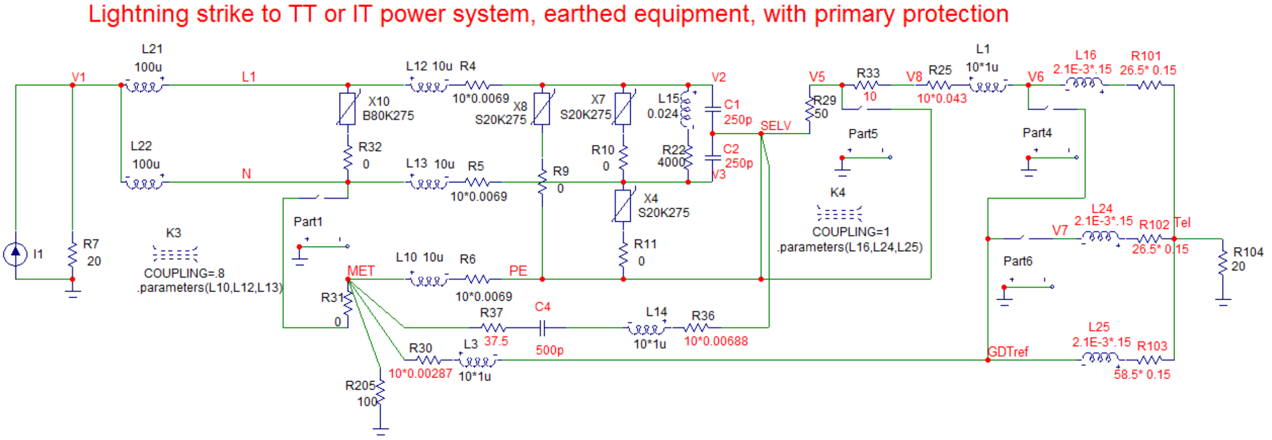


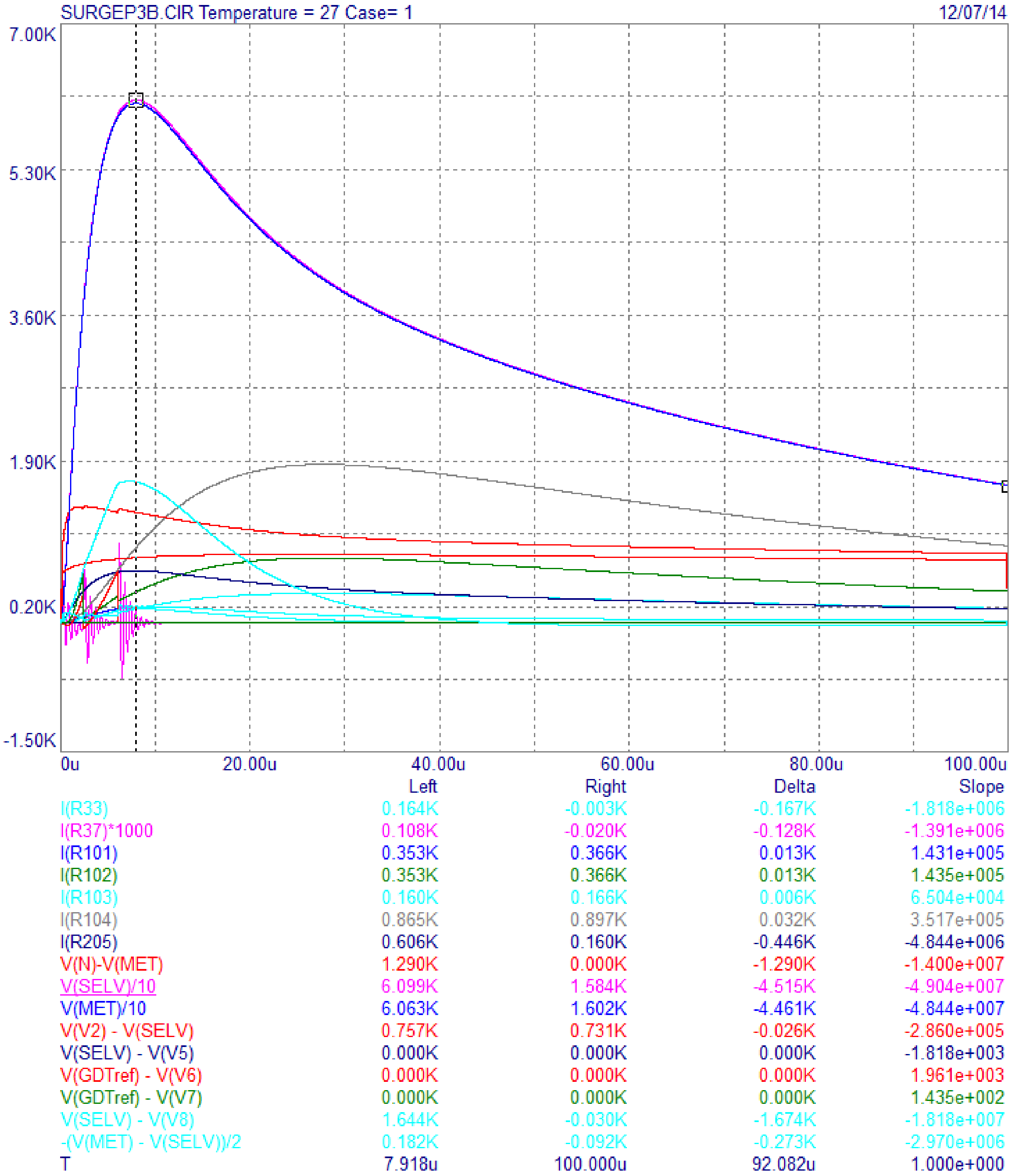
Figure A.19 – Simulation of a lightning strike to a TT and IT power systems with earthed equipment with primary protection

Description of the components related to Figure A.19:

- R7 represents the resistance to earth at the lightning strike point.
- L21 and L22 simulate a length of power line.
- X10 represents an SPD installed between L1 and N at the MSB.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R29 represents the internal resistance of the telecommunication circuit.
- Part5 is a TVS which operates at 100 V.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part4 is a GDT on the working telecommunication pair and Part6 is a GDT on the unused telecommunication pair. These GDTs operate at 600 V.

- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101, L24, R102 and L25, R103 represent two pairs and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.20 shows result for simulation of a lightning strike to a TT and IT power systems with earthed equipment with primary protection.



	Left	Right	Delta	Slope
I(R33)	0.164K	-0.003K	-0.167K	-1.818e+006
I(R37)*1000	0.108K	-0.020K	-0.128K	-1.391e+006
I(R101)	0.353K	0.366K	0.013K	1.431e+005
I(R102)	0.353K	0.366K	0.013K	1.435e+005
I(R103)	0.160K	0.166K	0.006K	6.504e+004
I(R104)	0.865K	0.897K	0.032K	3.517e+005
I(R205)	0.606K	0.160K	-0.446K	-4.844e+006
V(N)-V(MET)	1.290K	0.000K	-1.290K	-1.400e+007
V(SELV)/10	6.099K	1.584K	-4.515K	-4.904e+007
V(MET)/10	6.063K	1.602K	-4.461K	-4.844e+007
V(V2) - V(SELV)	0.757K	0.731K	-0.026K	-2.860e+005
V(SELV) - V(V5)	0.000K	0.000K	0.000K	-1.818e+003
V(GDTref) - V(V6)	0.000K	0.000K	0.000K	1.961e+003
V(GDTref) - V(V7)	0.000K	0.000K	0.000K	1.435e+002
V(SELV) - V(V8)	1.644K	-0.030K	-1.674K	-1.818e+007
-(V(MET) - V(SELV))/2	0.182K	-0.092K	-0.273K	-2.970e+006
T	7.918u	100.000u	92.082u	1.000e+000

Figure A.20 – Result for simulation of a lightning strike to a TT and IT power systems with earthed equipment with primary protection

Customer earth 100 Ω

The voltages and currents shown are for a 10 m telecommunication bond wire length. If the bond wire length is reduced to 1.5 m, the values change. These values are shown in parentheses.

The telecommunication port inherent protection operates at 100 V. The spark gap between neutral and PE does not operate. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 (61) kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 795 (796) V (no flashover). The voltage between the telecommunication network ports and SELV is 1.65 kV (799 V). The current entering the telecommunication port is 165 (80) A. These currents are in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the telecommunication port may occur

The current injected into the telecommunication network node is 1.85 (1.85) kA. The current entering the earth via the local earth point is 606 (603) A. The working pair contributes 753 (757) A. The spare pair terminated on a primary protector contributes 753 (757) A. The screen of the cable contributes 341 (343) A.

The Ethernet port is subjected to a peak voltage of 206 (287) V. The peak current is just less than 1 A for the 10 m bond wire but increases to 1.3 A for the 1.5 m bond wire case.

Damage may occur to the telecommunication port, particularly if the telecommunication bond wire is 10 m long. The currents are 165 (80) A compared with the coordination test current of 60 A.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V. The spark gap between neutral and PE operates at 1.5 kV. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 653 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.24 kV. The current entering the telecommunication is 124 A. This current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port will occur.

The current injected into the telecommunication network node is 1.86 kA. The current entering the earth via the local earth point is 612 A. The working pair contributes 759 A. The spare pair terminated on a primary protector contributes 759 A after its protector operates. The screen of the cable contributes 344 A.

The Ethernet port is subjected to a peak voltage of 375 V. The peak current is 3.9 A.

Interestingly, the loss of the equipment earth has minimal impact from a lightning perspective apart from the higher peak voltage and current in the Ethernet port.

Damage will occur to the telecommunication port. The current is 124 A compared with the coordination test current of 60 A.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V. The spark gap between neutral and PE operates at 1.5 kV. The telecommunication spare pair primary protector operates at 600 V and prevents the telecommunication working pair primary protector from operating.

The MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 8.6 kV. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 657 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 489 V. The current entering the port is 49 A. This is less than the coordination test current of 60 in [ITU-T K.21].

The current injected into the telecommunication network node is 300 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 48 A. The spare pair terminated on a primary protector contributes 173 A. The screen of the cable contributes 78 A.

The Ethernet port is subjected to a voltage peak of 220 V just prior to the spark gap between neutral and PE operating. The current is 3.2 A.

The equipment is protected.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V. The spark gap between neutral and PE does not operate. The telecommunication primary protectors on the spare and working pairs operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 69 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 786 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.72 kV. The current entering the telecommunication port is 172 A. This current is significantly higher than the coordination test current of 60 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the telecommunication network is 2.05 kA. The working pair contributes 838 A. The spare pair contributes 838 A. The screen of the cable contributes 380 A.

The Ethernet port is subjected to a voltage peak of 190 V. The current is much less than 1 A.

Damage is likely to the telecommunication port. The current is 172 A compared with the coordination test current of 60 A.

A.2.3.2 Floating equipment

A.2.3.2.1 Without primary protection

Figure A.21 shows the simulation of a lightning strike to a TT and IT power system with floating equipment without primary protection.

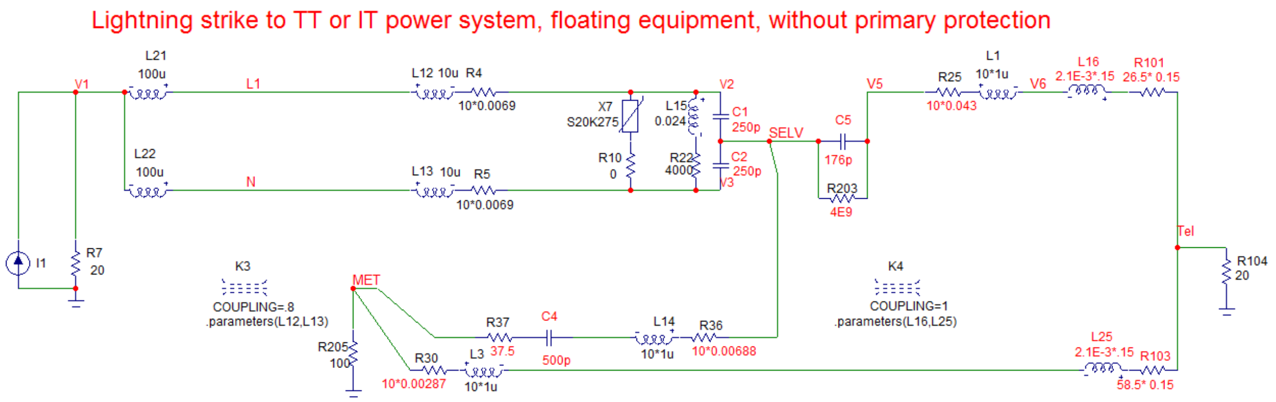


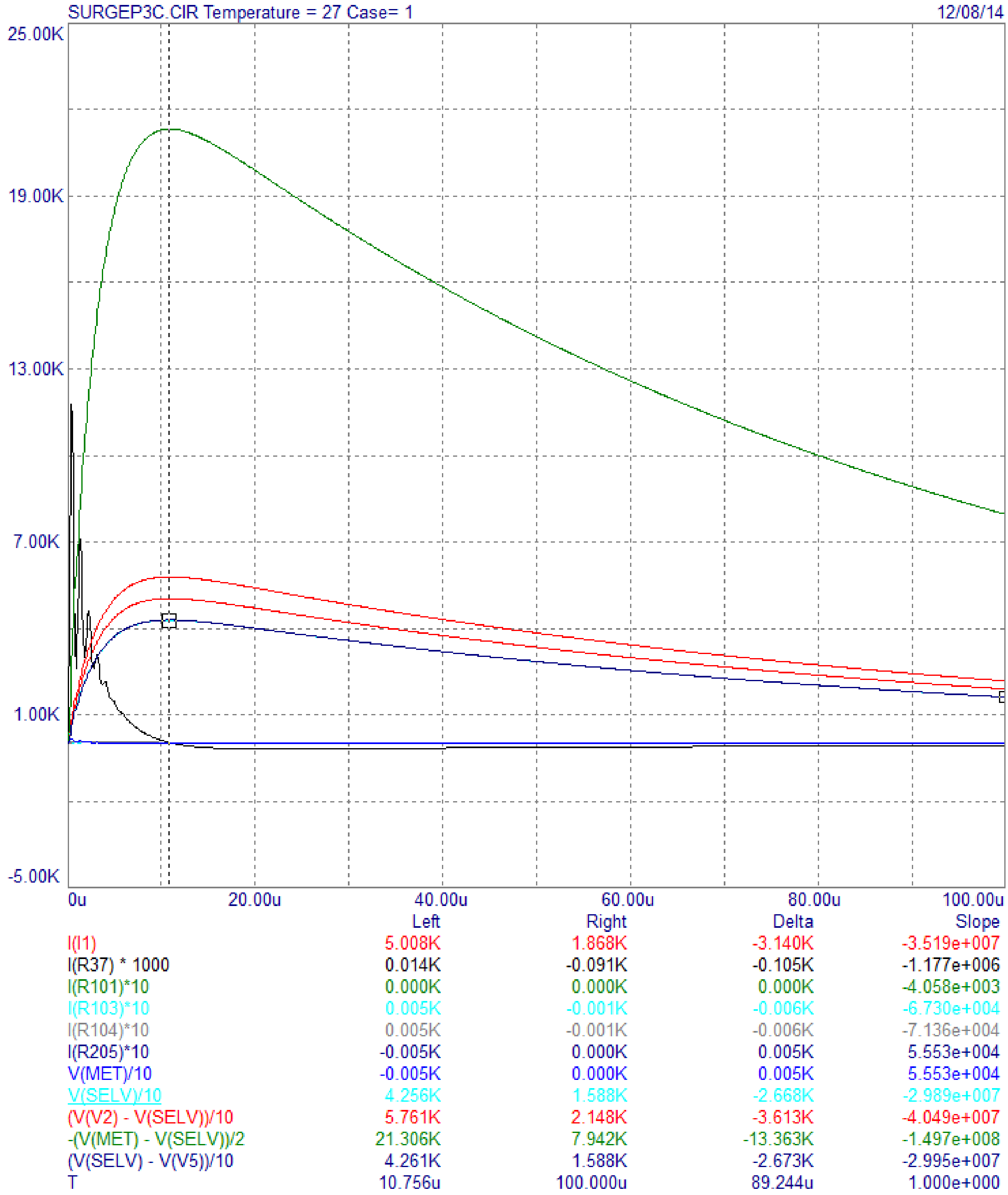
Figure A.21 – Simulation of a lightning strike to a TT and IT power system with floating equipment without primary protection

Description of the components related to Figure A.21:

- R7 represents the resistance to earth at the lightning strike point.
- L21 and L22 simulate a length of power line.

- R4, R5 and L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOV X7 is an inherent protection MOV in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- C5 and R203 represent the telecommunication input circuit.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36, represent 10 metres of Ethernet cable.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101 and L25, R103 represent a pair and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.22 shows result for simulation of a lightning strike to a TT and IT power systems with floating equipment without primary protection.



	Left	Right	Delta	Slope
I(I1)	5.008K	1.868K	-3.140K	-3.519e+007
I(R37) * 1000	0.014K	-0.091K	-0.105K	-1.177e+006
I(R101)*10	0.000K	0.000K	0.000K	-4.058e+003
I(R103)*10	0.005K	-0.001K	-0.006K	-6.730e+004
I(R104)*10	0.005K	-0.001K	-0.006K	-7.136e+004
I(R205)*10	-0.005K	0.000K	0.005K	5.553e+004
V(MET)/10	-0.005K	0.000K	0.005K	5.553e+004
V(SELV)/10	4.256K	1.588K	-2.668K	-2.989e+007
(V(V2) - V(SELV))/10	5.761K	2.148K	-3.613K	-4.049e+007
-(V(MET) - V(SELV))/2	21.306K	7.942K	-13.363K	-1.497e+008
(V(SELV) - V(V5))/10	4.261K	1.588K	-2.673K	-2.995e+007
T	10.756u	100.000u	89.244u	1.000e+000

Figure A.22 – Result for simulation of a lightning strike to a TT and IT power systems with floating equipment without primary protection

Customer earth 100 Ω

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise to 42.6 kV for the SELV circuit and remains close to 0 V for the MET.

The power transformer stress (primary to secondary surge voltage) is 57.6 kV. The voltage between the telecommunication network ports and the SELV circuit is 42.6 kV. The voltage between the two ports is nearly 100 kV. As this is in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the telecommunication network node is 3.3 A. The current entering the earth via the local earth point is 14.5 A.

The Ethernet port is subjected to a voltage peak of 21 kV. The peak current is 11.8 A. This is likely to result in damage to the Ethernet and other ports.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering on the mains port will exit via the telecommunication and Ethernet ports, damaging all ports.

Customer earth 2 Ω

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise to 42.6 kV for the SELV circuit and remains close to 0 V for the MET.

The power transformer stress (primary to secondary surge voltage) is 57.6 kV. The voltage between the telecommunication network ports and the SELV circuit is 42.6 kV. The voltage between the two ports is nearly 100 kV. As this is in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the telecommunication network node is less than 1 A. The current entering the earth via the local earth point is18 A.

The Ethernet port is subjected to a voltage peak of 21.32 kV. The peak current is 13.5 A. This is likely to result in damage to the Ethernet and other ports.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering on the mains port will exit via the telecommunication and Ethernet ports damaging all ports.

No path to earth at the customer premises

The SELV circuit and the MET voltages, with respect to remote earth and the local earth outside the area of influence of the current entering the earth, rise to 44.5 kV for the SELV circuit and remains close to 0 V for the MET.

The power transformer stress (primary to secondary surge voltage) is 60 kV. The voltage between the telecommunication network ports and the SELV circuit is 44.5 kV. The voltage between the two ports is in excess of 100 kV. As this is in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the telecommunication network node is 16.6 A.

The Ethernet port is subjected to a voltage peak of nearly 22.3 kV. The peak current is 12.4 A. This is likely to result in damage to the Ethernet and other ports.

The surge voltage on the mains conductors will cause a flashover of the mains transformer, telecommunication port isolation and the Ethernet port. The resulting surge current entering on the mains port will exit via the telecommunication and Ethernet ports damaging all ports.

A.2.3.2.2 With primary protection

Figure A.23 shows the simulation of a lightning strike to a TT and IT power systems with floating equipment with primary protection.

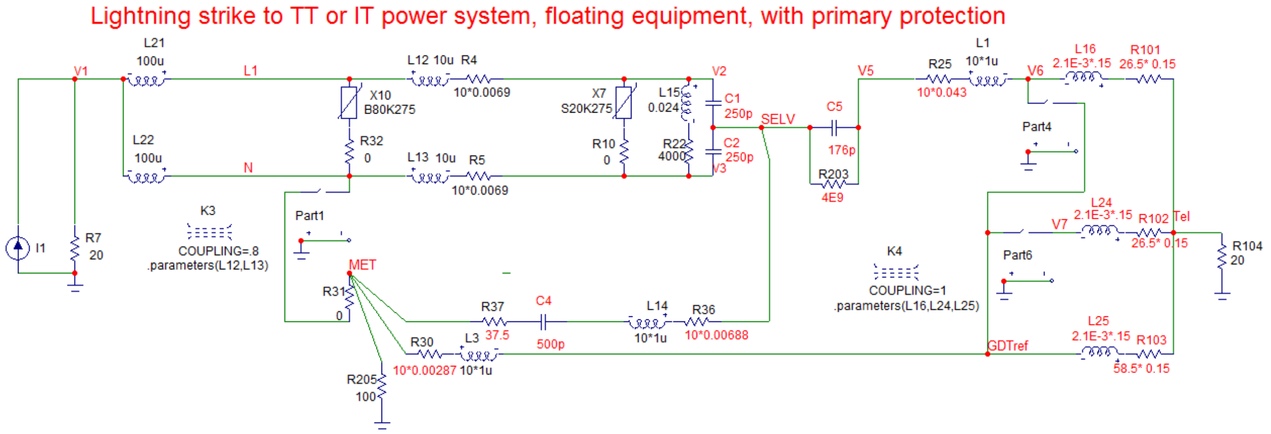
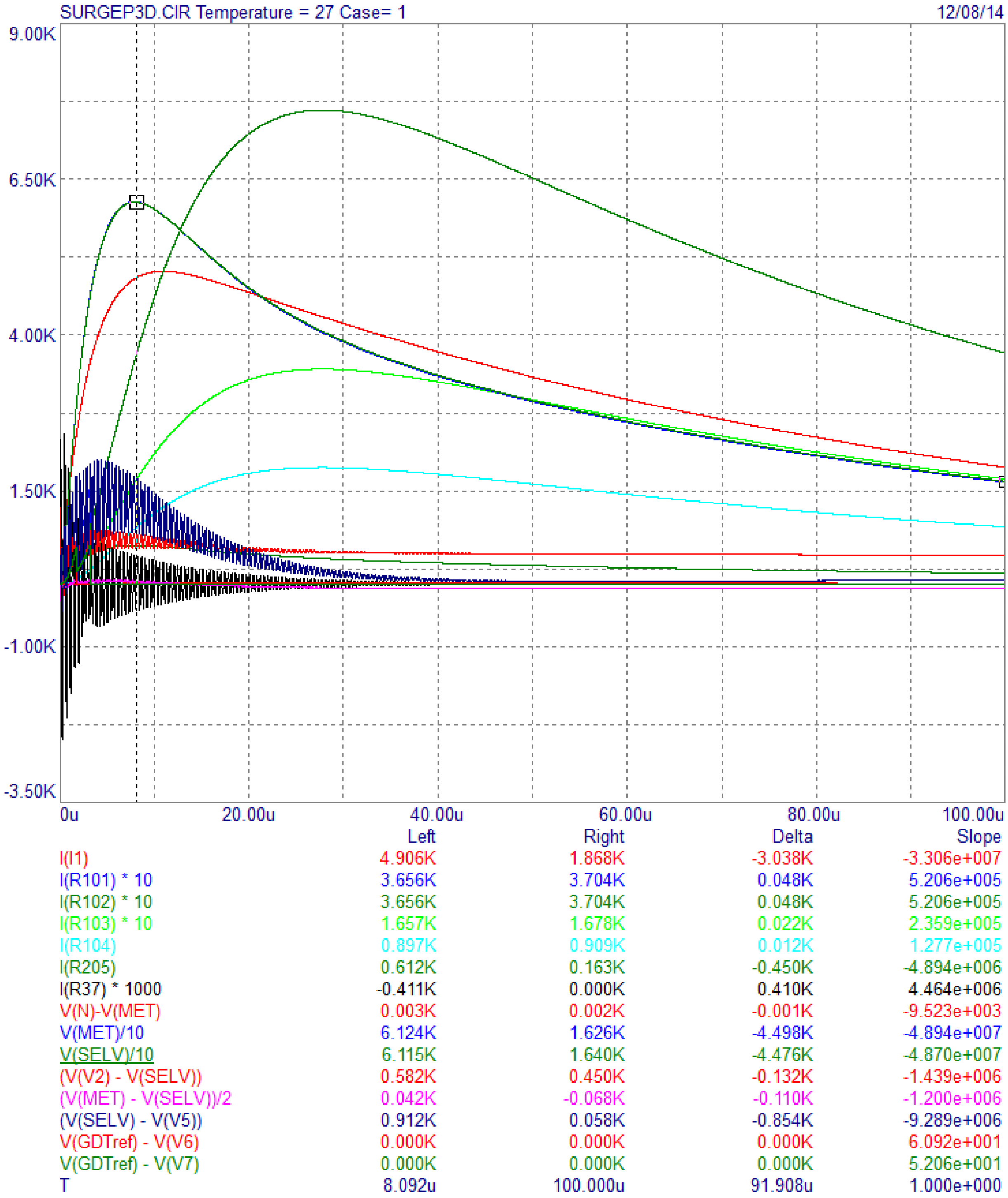


Figure A.23 – Simulation of a lightning strike to a TT and IT power systems with floating equipment with primary protection

Description of the components related to Figure A.23:

- R7 represents the resistance to earth at the lightning strike point.
- L21 and L22 simulate a length of power line.
- X10 represents an SPD installed between L1 and N at the MSB.
- Part1 is a spark gap connected between N and PE at the MSB. It operates at 1.5 kV.
- R4, R5 and L12, L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- MOV X7 is an inherent protection MOV in the equipment.
- L15, R22, C1 and C2 represent the power transformer.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- C5 and R203 represent the telecommunication input circuit.
- Part4 is a GDT on the working telecommunication pair and Part6 is a GDT on the unused telecommunication pair. These GDTs operate at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- L16, R101, L24, R102 and L25, R103 represent two pairs and the cable screen respectively (it is assumed that 15 customers are using the screen). The coupling factor for the telecommunication cable is assumed to be 1.
- R104 is the resistance to earth looking into the telecommunication network.
- R30 and L3 represent the bonding conductor from the LT to the MET.
- R205 is the customer earth electrode.

Figure A.24 shows result for simulation of a lightning strike to a TT and IT power systems with floating equipment with primary protection.



	Left	Right	Delta	Slope
I(I1)	4.906K	1.868K	-3.038K	-3.306e+007
I(R101) * 10	3.656K	3.704K	0.048K	5.206e+005
I(R102) * 10	3.656K	3.704K	0.048K	5.206e+005
I(R103) * 10	1.657K	1.678K	0.022K	2.359e+005
I(R104)	0.897K	0.909K	0.012K	1.277e+005
I(R205)	0.612K	0.163K	-0.450K	-4.894e+006
I(R37) * 1000	-0.411K	0.000K	0.410K	4.464e+006
V(N)-V(MET)	0.003K	0.002K	-0.001K	-9.523e+003
V(MET)/10	6.124K	1.626K	-4.498K	-4.894e+007
V(SELV)/10	6.115K	1.640K	-4.476K	-4.870e+007
(V(V2) - V(SELV))	0.582K	0.450K	-0.132K	-1.439e+006
(V(MET) - V(SELV))/2	0.042K	-0.068K	-0.110K	-1.200e+006
(V(SELV) - V(V5))	0.912K	0.058K	-0.854K	-9.289e+006
V(GDTref) - V(V6)	0.000K	0.000K	0.000K	6.092e+001
V(GDTref) - V(V7)	0.000K	0.000K	0.000K	5.206e+001
T	8.092u	100.000u	91.908u	1.000e+000

Figure A.24 – Result for simulation of a lightning strike to a TT and IT power systems with floating equipment with primary protection

Customer earth 100 Ω

The spark gap between neutral and PE operates at 1.5 kV. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 61 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 911 V. The voltage between the telecommunication network ports and SELV is 1.975 kV. The voltage between the two ports is 2.9 kV which is less than the basic port to port isolation voltage of 5 kV. A flashover is unlikely to occur.

The current injected into the telecommunication network node is 1.86 kA. The current entering the earth via the local earth point is 613 A. The working pair contributes 760 A. The spare pair terminated on a primary protector contributes 760 A. The screen of the cable contributes 344 A.

The Ethernet port is subjected to a peak voltage of 338 V. The peak current is 2.5 A.

The equipment is protected.

Customer earth 2 Ω

The spark gap between neutral and PE operates at 1.5 kV. The telecommunication spare pair and telecommunication working pair primary protectors operate at 600 V.

The MET and the SELV circuit both rise to 8.6 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 885 V. The voltage between the telecommunication network ports and SELV is 753 V. The voltage between the telecommunication network ports and SELV is 1.65 kV. The voltage between the two ports is far less than the basic port to port isolation of 5 kV. A flashover will not occur.

The current injected into the telecommunication network node is 306 A. The current entering the earth via the local earth point is 4.3 kA. The working pair contributes 125 A. The spare pair terminated on a primary protector contributes 125 A. The screen of the cable contributes 57 A.

The Ethernet port is subjected to a voltage peak of 335 V just prior to the spark gap between neutral and PE operating. The current is 2.5 A.

The equipment is protected.

No path to earth at the customer premises

The spark gap between neutral and PE operates at 1.5 kV. The telecommunication primary protectors on the spare and working pairs operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 69 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 970 V. The voltage between the telecommunication network ports and the SELV circuit is 2.32 kV. The voltage between the two ports is 3.2 kV. This is less than the basic port-to-port isolation of 5 kV. A flashover is unlikely to occur.

The current injected into the telecommunication network is 2.07 kA. The working pair contributes 845 A. The spare pair contributes 845 A. The screen of the cable contributes 383 A.

The Ethernet port is subjected to a voltage peak of 319 V. The current peak is 3.4 A.

The equipment is protected.

A.3 Stress applied to the equipment via the telecommunication port

The stress applied to the equipment via the telecommunication port has been investigated by applying a 100 kA 5/75 µs surge to the telecommunication cable and by recording the applicable voltages and currents at the equipment. This waveform is in line with [b-CICRÉ TB 549] and refers to the most common downward negative first stroke. It has been shown in Appendix I and in clause A.1 that a simple cable model can be used to simulate the different conditions at the customer end. The current generator for this simple cable model has a peak current of 88.5 kA, a risetime of 8 µs and a falltime of 64 µs. This provides the same simulation result as a 100 kA lightning current at the strike point. Main variables used in the simulation are given in Table A.5.

Table A.5 – Main variables used in the simulation

Variable	Description
I(R1) + I(R111)	Current entering the power network from the structure
I(R33)	The current conducted into the telecommunication port of earthed equipment
I(R37)	The current conducted into the Ethernet port
I(R101)	The current conducted in the working pair
I(R102)	The current conducted in the spare pair
I(R103)	The current entering the structure from the cable MB screen
I(R34)	The current entering the earth at the structure
V(N) – V(PE) V(N) – V(MET)	The voltage across the terminals of the spark gap connected between neutral and the MET/PE on non TN-C power systems
V(SELV)	The voltage of the SELV circuit relative to remote earth
V(MET)	The voltage of the MET relative to remote earth
V(V2) – V(SELV)	The voltage between the line side of the mains transformer and the SELV circuit
(V(MET) – V(SELV))/2	The voltage between the Ethernet port and SELV circuit
V(SELV) – V(V5)	The voltage between the terminals of the TVS for class I (earthed) equipment The voltage between the telecommunication port and the SELV circuit for class II (floating) equipment. It is also voltage stress on the isolation capacitor for class II equipment.
V(MET) – V(V6)	The voltage between the line terminal and the MET of the working pair primary protector
V(MET) – V(V7)	The voltage between the line terminal and the MET of the spare pair primary protector
V(SELV) – V(V8)	The voltage between the telecommunication port and the SELV circuit class I (earthed) equipment.

A.3.1 TN-S power system

Simulation of the TN-S power system is difficult as [IEC 60950.1] does not show an electrode at the customer premises. However, the MET in customer premises is bonded to the metallic services such as water pipes and gas pipes. Also, if the building has reinforced concrete, it should also be bonded to the MET. These bonds provide a path to earth. Therefore, the simulations will be performed for the following electrode resistance conditions; 100 Ω, 2 Ω and infinity. The impact of an unearthed power outlet is also studied.

A.3.1.1 Earthed equipment

A.3.1.1.1 Without primary protection

The simulation model is shown in Figure A.25.

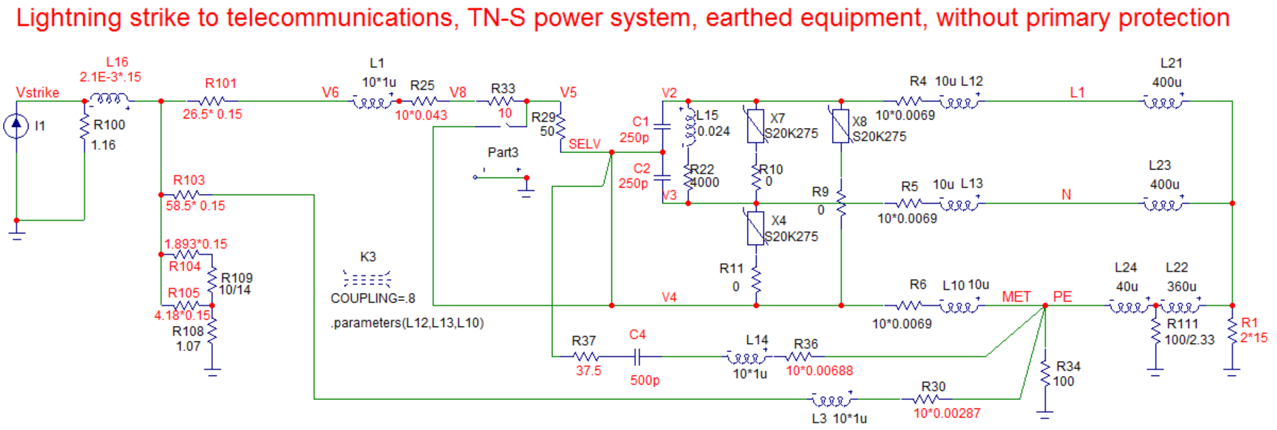
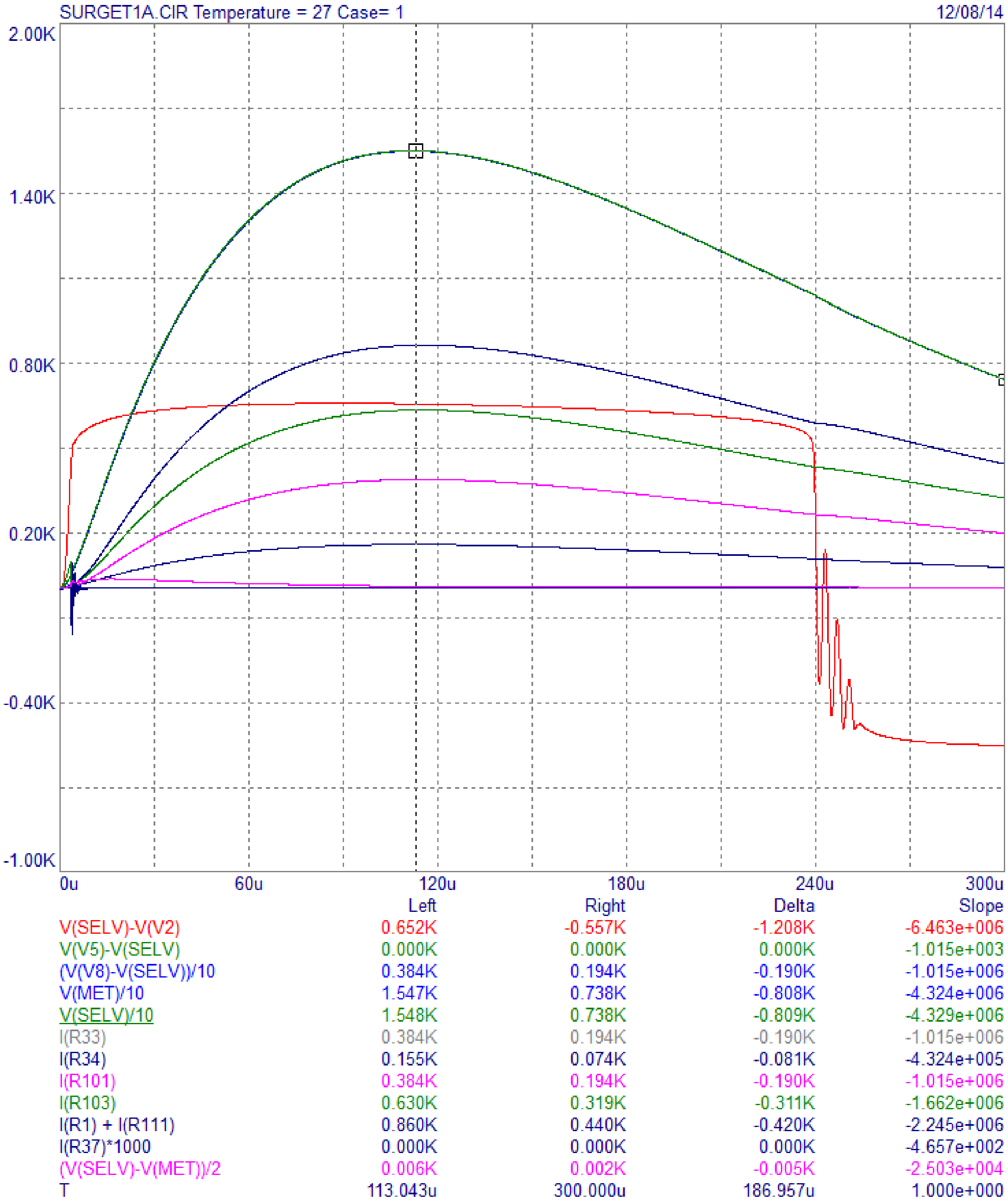


Figure A.25 – Simulation of a lightning strike to the telecommunication network (TN-S power system with earthed equipment without primary protection)

Description of the components related to Figure A.25:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 14 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R109 is the parallel resistance of R33 in the other 14 pieces of customer equipment.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- R33 represents a fusible resistor and also provides a coordination resistance.
- R34 is the customer earth electrode.
- Part3 is a TVS which operates at 100 V.
- R29 represents the internal resistance of the telecommunication circuit.
- L15, R22, C1 and C2 represent the power transformer.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4-R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21, L22 and L23 simulate the length of power line back to the high voltage/low voltage (HV/LV) transformer.
- L24 represents the inductance of the PE conductor to the neighbouring properties with earth electrodes represented by R111.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.26 shows the simulation result for a lightning strike to the telecommunication network (TN-S power system with earthed equipment without primary protection).



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                         Left        Right       Delta       Slope
V(SELV)-V(V2)            0.652K      -0.557K     -1.208K     -6.463e+006
V(V5)-V(SELV)            0.000K      0.000K      0.000K      -1.015e+003
(V(V8)-V(SELV))/10       0.384K      0.194K      -0.190K     -1.015e+006
V(MET)/10                1.547K      0.738K      -0.808K     -4.324e+006
V(SELV)/10               1.548K      0.738K      -0.809K     -4.329e+006
I(R33)                   0.384K      0.194K      -0.190K     -1.015e+006
I(R34)                   0.155K      0.074K      -0.081K     -4.324e+005
I(R101)                  0.384K      0.194K      -0.190K     -1.015e+006
I(R103)                  0.630K      0.319K      -0.311K     -1.662e+006
I(R1) + I(R111)          0.860K      0.440K      -0.420K     -2.245e+006
I(R37)*1000              0.000K      0.000K      0.000K      -4.657e+002
(V(SELV)-V(MET))/2       0.006K      0.002K      -0.005K     -2.503e+004
T                        113.043u    300.000u    186.957u    1.000e+000
```

Figure A.26 – Result for simulation of a lightning strike to the telecommunication network (TN-S power system with earthed equipment without primary protection)

Customer earth 100 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 15.5 kV.

The power transformer stress (primary to secondary surge voltage) is 654 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 3.84 kV. The current

conducted in this port is 384 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 860 A. The current entering the earth via the local earth point is 155 A. The working telecommunication pair contributes 384 A. The screen of the cable contributes 630 A.

The Ethernet port is subjected to a voltage peak of 32 V. The current is much less than 1 A.

The telecommunication port will be damaged. The current is 384 A compared with the inherent test current of 40 A.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the SELV circuit rises to around 15.9 kV and the MET rises to around 15.2 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth.

The power transformer stress (primary to secondary surge voltage) is 669 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 3.56 kV. The current conducted in this port is 356 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 861 A. The current entering the earth via the local earth point is 152 A. The working telecommunication pair contributes 356 A. The screen of the cable contributes 658 A.

The Ethernet port is subjected to a voltage peak of 354 V. The current is less than 1 A.

The telecommunication port will be damaged. The current is 356 A compared with the inherent test current of 40 A.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 4.8 kV.

The power transformer stress (primary to secondary surge voltage) is 591 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 10 kV. The current conducted in this port is 1 kA. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 261 A. The current entering the earth via the local earth point is 2.39 kA. The working telecommunication pair contributes 1 kA. The screen of the cable contributes 1.65 kA.

The Ethernet port is subjected to a voltage peak of 103 V. The current is less than 1 A.

The telecommunication port will be damaged. The current is 1 kA compared with the inherent test current of 40 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 16.2 kV.

The power transformer stress (primary to secondary surge voltage) is 656 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 3.4 kV. The current conducted in this port is 342 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 902 A. The working telecommunication pair contributes 342 A. The screen of the cable contributes 560 A.

The Ethernet port is subjected to a voltage peak of 27 V. The current is much less than 1 A.

The telecommunication port will be damaged. The current is 342 A compared with the inherent test current of 40 A.

A.3.1.1.2 With primary protection

The simulation model is shown in Figure A.27.

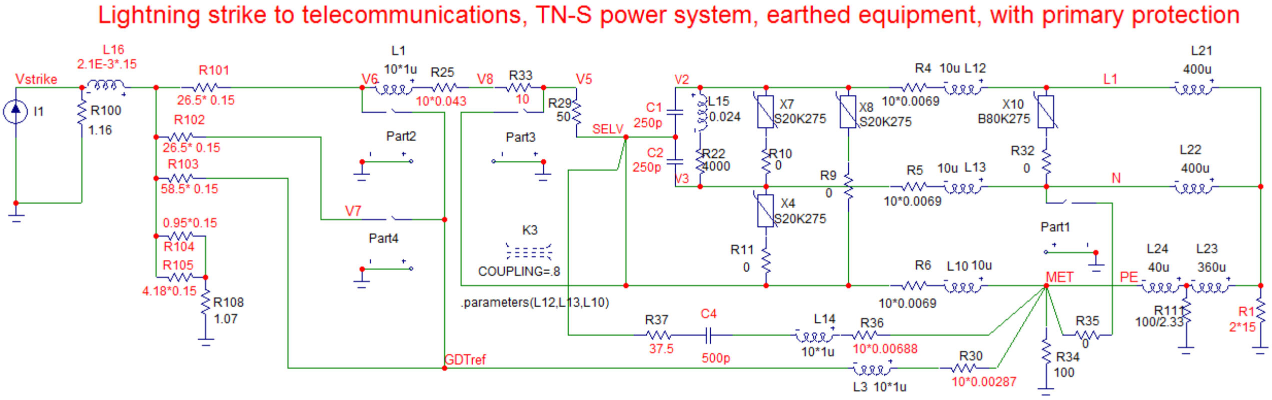


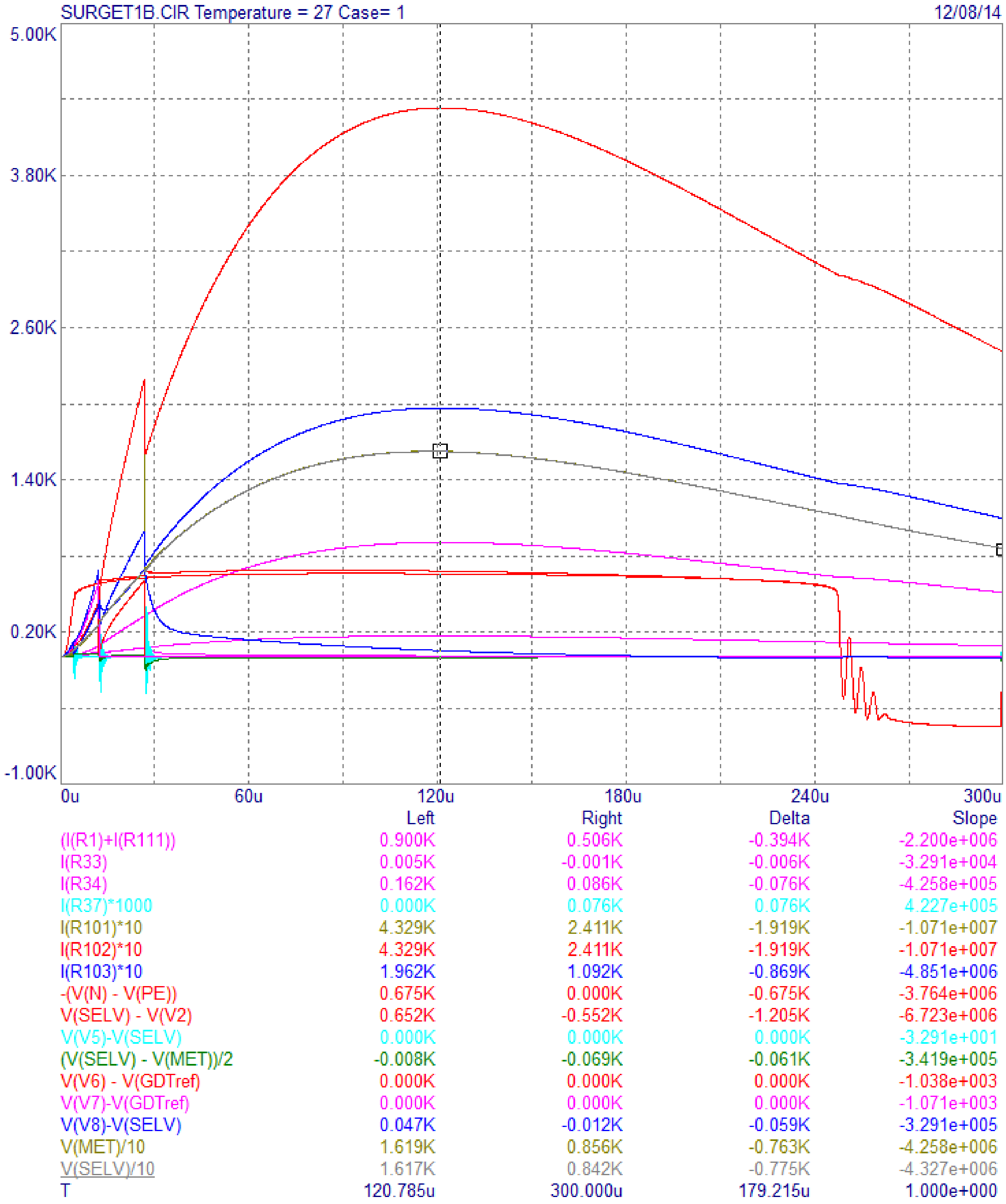
Figure A.27 – Simulation of a lightning strike to the telecommunication network (TN-S power system with earthed equipment with primary protection)

Description of the components related to Figure A.27:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R102 is the spare pair resistance terminated on a primary protector.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 28 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R109 is the parallel resistance of R33 in the other 14 pieces of customer equipment.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part3 is a TVS which operates at 100 V.
- R29 represents the internal resistance of the telecommunication circuit.

- Part2 is the primary protector installed on the working pair.
- Part4 is the primary protector installed on the spare pair.
- L15, R22, C1 and C2 represent the power transformer.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- Part1 is a spark gap primary protector installed between the neutral and the PE.
- X10 is an MOV type primary protector installed between L1 and neutral.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21, L22 and L23 simulate the length of power line back to the HV/LV transformer.
- L24 represents the inductance of the PE conductor to neighbouring properties with earth electrodes represented by R111.
- R111 represents the resistance of the other 2.33 electrodes.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.
- R1 has been multiplied by 15 as all 15 customers are connected to earth through the same 2 Ω.
- R34 is the customer earth electrode.

Figure A.28 shows result for simulation of a lightning strike to the telecommunication network (TN-S power system with earthed equipment with primary protection).



	Left	Right	Delta	Slope
(I(R1)+I(R111))	0.900K	0.506K	-0.394K	-2.200e+006
I(R33)	0.005K	-0.001K	-0.006K	-3.291e+004
I(R34)	0.162K	0.086K	-0.076K	-4.258e+005
I(R37)*1000	0.000K	0.076K	0.076K	4.227e+005
I(R101)*10	4.329K	2.411K	-1.919K	-1.071e+007
I(R102)*10	4.329K	2.411K	-1.919K	-1.071e+007
I(R103)*10	1.962K	1.092K	-0.869K	-4.851e+006
-(V(N) - V(PE))	0.675K	0.000K	-0.675K	-3.764e+006
V(SELV) - V(V2)	0.652K	-0.552K	-1.205K	-6.723e+006
V(V5)-V(SELV)	0.000K	0.000K	0.000K	-3.291e+001
(V(SELV) - V(MET))/2	-0.008K	-0.069K	-0.061K	-3.419e+005
V(V6) - V(GDTref)	0.000K	0.000K	0.000K	-1.038e+003
V(V7)-V(GDTref)	0.000K	0.000K	0.000K	-1.071e+003
V(V8)-V(SELV)	0.047K	-0.012K	-0.059K	-3.291e+005
V(MET)/10	1.619K	0.856K	-0.763K	-4.258e+006
V(SELV)/10	1.617K	0.842K	-0.775K	-4.327e+006
T	120.785u	300.000u	179.215u	1.000e+000

Figure A.28 – Result for simulation of a lightning strike to the telecommunication network (TN-S power system with earthed equipment with primary protection)

Customer earth 100 Ω

The voltages and currents shown are for a 10 m telecommunication bond wire length. If the bond wire length is reduced to 1.5 m, the values change. These values are shown in parentheses.

The telecommunication port inherent protection operates at 100 V. The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE does not operate.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.18 (16.20) kV.

The power transformer stress (primary to secondary surge voltage) is 655 (655) V (no flashover). The voltage between the telecommunication network ports and SELV is 683 (555) V. The current conducted in this port is 68 (56) A. This is less than the coordination test current of 60 A in [ITU-T K.21] for the 1.5 m bond wire but greater than 60 A for the 10 m bond wire. No damage to either port for the short bond wire but possible damage to the telecommunications port, but not the mains port, for the long bond wire.

The current injected into the power network is 900 (902) A. The current entering the earth via the local earth point is 162 (162) A. The working telecommunication pair contributes 433 (433) A. The telecommunication spare pair contributes 433 (433) A. The screen of the cable contributes 196 (197) A.

The Ethernet port is subjected to a voltage peak of 105 (155) V. The current is just less than 1 A for the long bond wire, but 1.3 A for the short bond wire.

The equipment is protected apart from possible damage to the telecommunication port for the long bond wire.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V. The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE operates at 1.5 kV.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 16.16 kV.

The power transformer stress (primary to secondary surge voltage) is 632 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 1.3 kV. 127 A is conducted in the telecommunication network port. This current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the power network is 908 A. The current entering the earth via the local earth point is 162 A. The working telecommunication pair contributes 436 A. The telecommunication spare pair contributes 436 A. The screen of the cable contributes 198 A.

The Ethernet port is subjected to a voltage peak of 429 V. The current peak is 3.6 A.

The telecommunication port may be damaged. The current is 127 A compared with the coordination test current of 60 A.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V. The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE does not operate.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 7.8 kV.

The power transformer stress (primary to secondary surge voltage) is 613 V no flashover). The voltage between the telecommunication network ports and the SELV circuit is 905 V. The current in this port is 90.5 A. This current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the power network is 427 A. The current entering the earth via the local earth point is 3.9 kA. The working telecommunication pair contributes 1.76 kA. The telecommunication spare pair contributes 1.76 kA. The screen of the cable contributes 799 A.

The Ethernet port is subjected to a voltage peak of 63 V. The current is less than 1 A.

The telecommunication port may be damaged. The current is 90.5 A compared with the coordination test current of 60 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V. The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE does not operate.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 16.6 kV.

The power transformer stress (primary to secondary surge voltage) is 656 V (no flashover. The voltage between the telecommunication network ports and the SELV circuit is 671 V. The current in this port is 67.1 A, and below the coordination [ITU-T K.21] test current of 60 A. Damage may occur to the telecommunication port.

The current injected into the power network is 921 A. The working telecommunication pair contributes 375 A. The telecommunication spare pair contributes 375 A. The screen of the cable contributes 170 A.

The Ethernet port is subjected to a voltage peak of 115 V. The current is just less than 1 A.

The equipment is protected, except that damage may occur to the telecommunication port.

A.3.1.2 Floating equipment

A.3.1.2.1 Without primary protection

The simulation model is shown in Figure A.29.

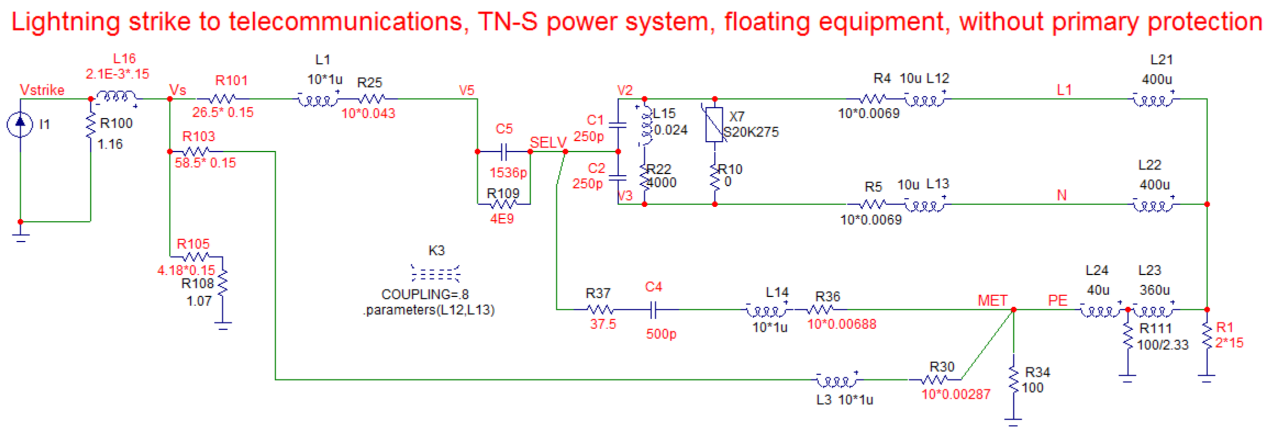
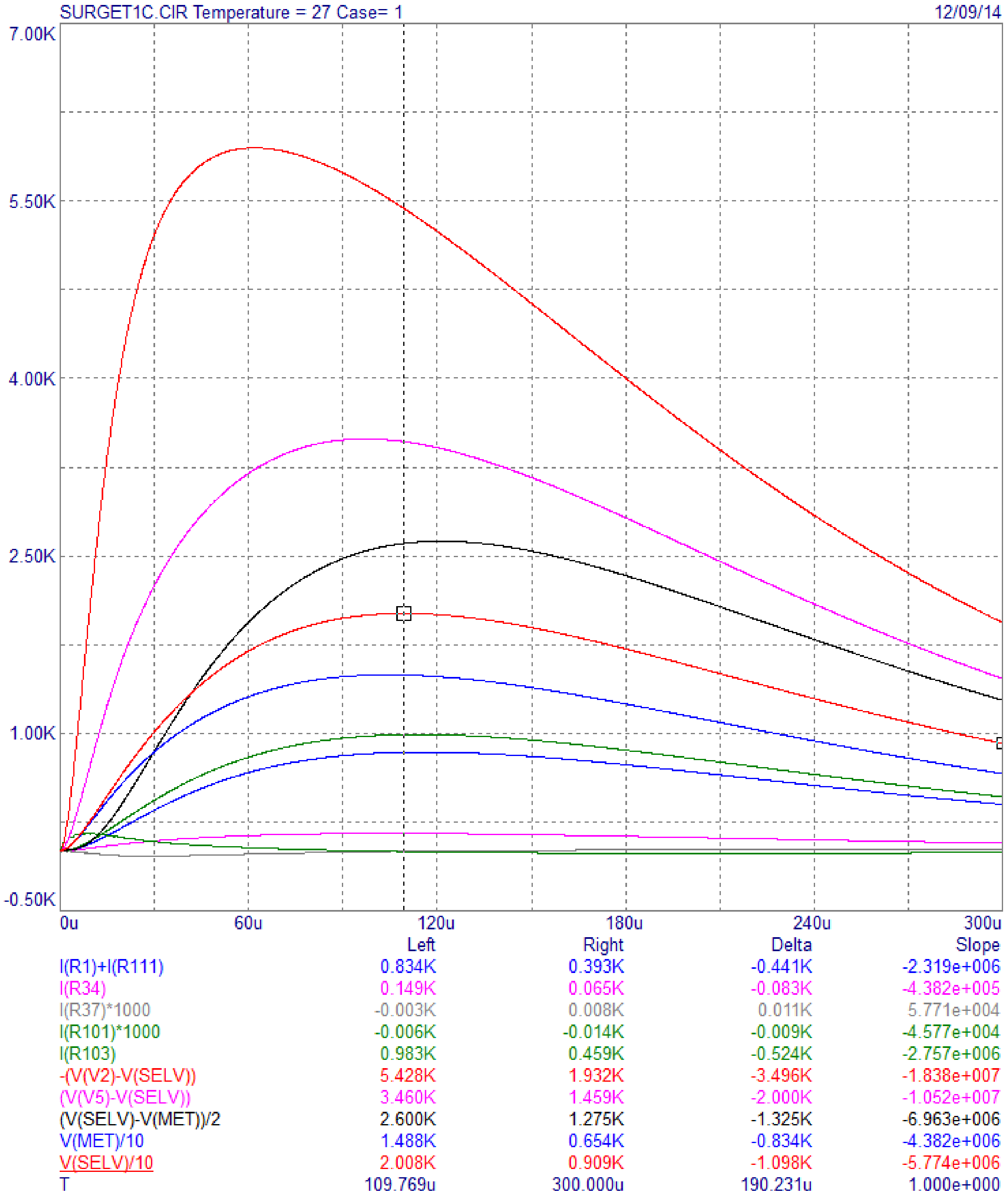


Figure A.29 – Simulation of a lightning strike to the telecommunication network (TN-S power system with floating equipment without primary protection)

Description of the components related to Figure A.29:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- C5 and R203 represent the telecommunication input circuit.
- L15, R22, C1 and C2 represent the power transformer.
- MOV X7 is an inherent protection MOV in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 and R5, L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21, L22 and L23 simulate the length of power line back to the HV/LV transformer.
- L24 represents the inductance of the PE conductor to neighbouring properties with earth electrodes represented by R111.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.30 shows result for simulation of a lightning strike to the telecommunication network (TN-S power system with floating equipment without primary protection).



	Left	Right	Delta	Slope
I(R1)+I(R111)	0.834K	0.393K	-0.441K	-2.319e+006
I(R34)	0.149K	0.065K	-0.083K	-4.382e+005
I(R37)*1000	-0.003K	0.008K	0.011K	5.771e+004
I(R101)*1000	-0.006K	-0.014K	-0.009K	-4.577e+004
I(R103)	0.983K	0.459K	-0.524K	-2.757e+006
-(V(V2)-V(SELV))	5.428K	1.932K	-3.496K	-1.838e+007
(V(V5)-V(SELV))	3.460K	1.459K	-2.000K	-1.052e+007
(V(SELV)-V(MET))/2	2.600K	1.275K	-1.325K	-6.963e+006
V(MET)/10	1.488K	0.654K	-0.834K	-4.382e+006
V(SELV)/10	2.008K	0.909K	-1.098K	-5.774e+006
T	109.769u	300.000u	190.231u	1.000e+000

Figure A.30 – Result for simulation of a lightning strike to the telecommunication network (TN-S power system with floating equipment without primary protection)

Customer earth 100 Ω

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 20 kV and 14.9 kV.

The power transformer stress (primary to secondary surge voltage) is 5.94 kV. The voltage between the telecommunication network ports and SELV is 3.48 kV. The voltage between the two ports is greater than 9 kV. As this in excess of the basic and enhanced port to port isolation voltage of 5 kV and 6 kV respectively a flashover will occur and damage to these ports will occur.

The current injected into the power network is 836 A. The current entering the earth via the local earth point is 149 A. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 984 A.

The Ethernet port is subjected to a voltage peak of 2.62 kV. The current is much less than 1 A. This magnitude of voltage may cause damage.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering on the telecommunication port will exit via the power and Ethernet ports damaging all ports.

Customer earth 2 Ω

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 14.9 kV and 3.8 kV.

The power transformer stress (primary to secondary surge voltage) is 11.2 kV. The voltage between the telecommunication network ports and the SELV circuit is 7.3 kV. The voltage between the two ports is greater than 18 kV. As this is in excess of the port-to-port isolation of 5 kV and 6 kV respectively, a flashover will occur and damage to these ports will occur.

The current injected into the power network is 212 A. The current entering the earth via the local earth point is 1.9 kA. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 2.1 kA.

The Ethernet port is subjected to a voltage peak of 5.6 kV. The current is much less than 1 A. This magnitude of voltage is likely to damage the Ethernet ports of both pieces of equipment.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering the telecommunication port will exit via the power and Ethernet ports damaging all ports.

No path to earth at the customer premises

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to around 20.5 kV and 16 kV.

The power transformer stress (primary to secondary surge voltage) is 5.6 kV. The voltage between the telecommunication network ports and SELV is 3.2 kV. The voltage between the two ports is greater than 8 kV. As this in excess of the port to port isolation of 5 kV and 6 kV respectively a flashover will occur and damage to these ports will occur.

The current injected into the power network is 889 A. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 889 A.

The Ethernet port is subjected to a voltage peak of 2.4 kV. The current is much less than 1 A.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering on the telecommunication port will exit via the power and Ethernet ports damaging all ports.

A.3.1.2.2 With primary protection

The simulation model is shown in Figure A.31.

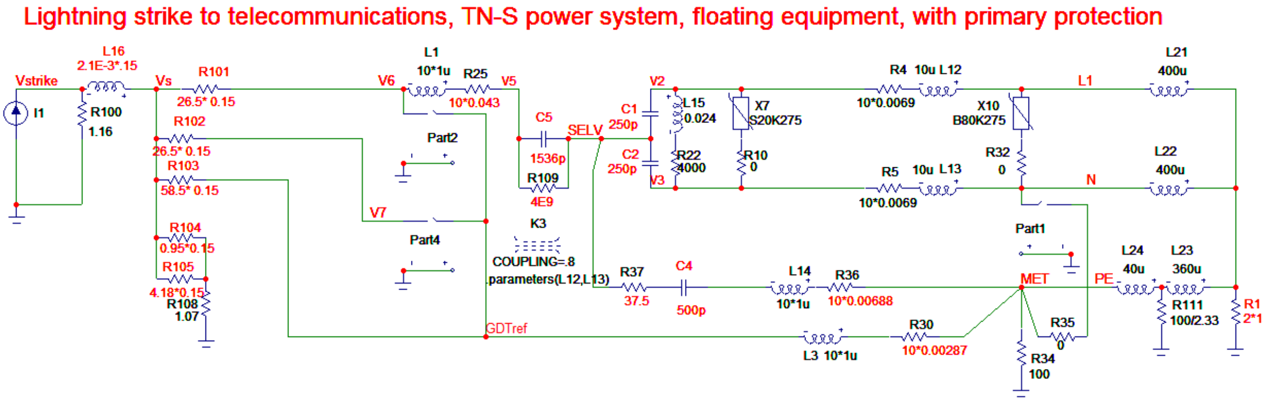
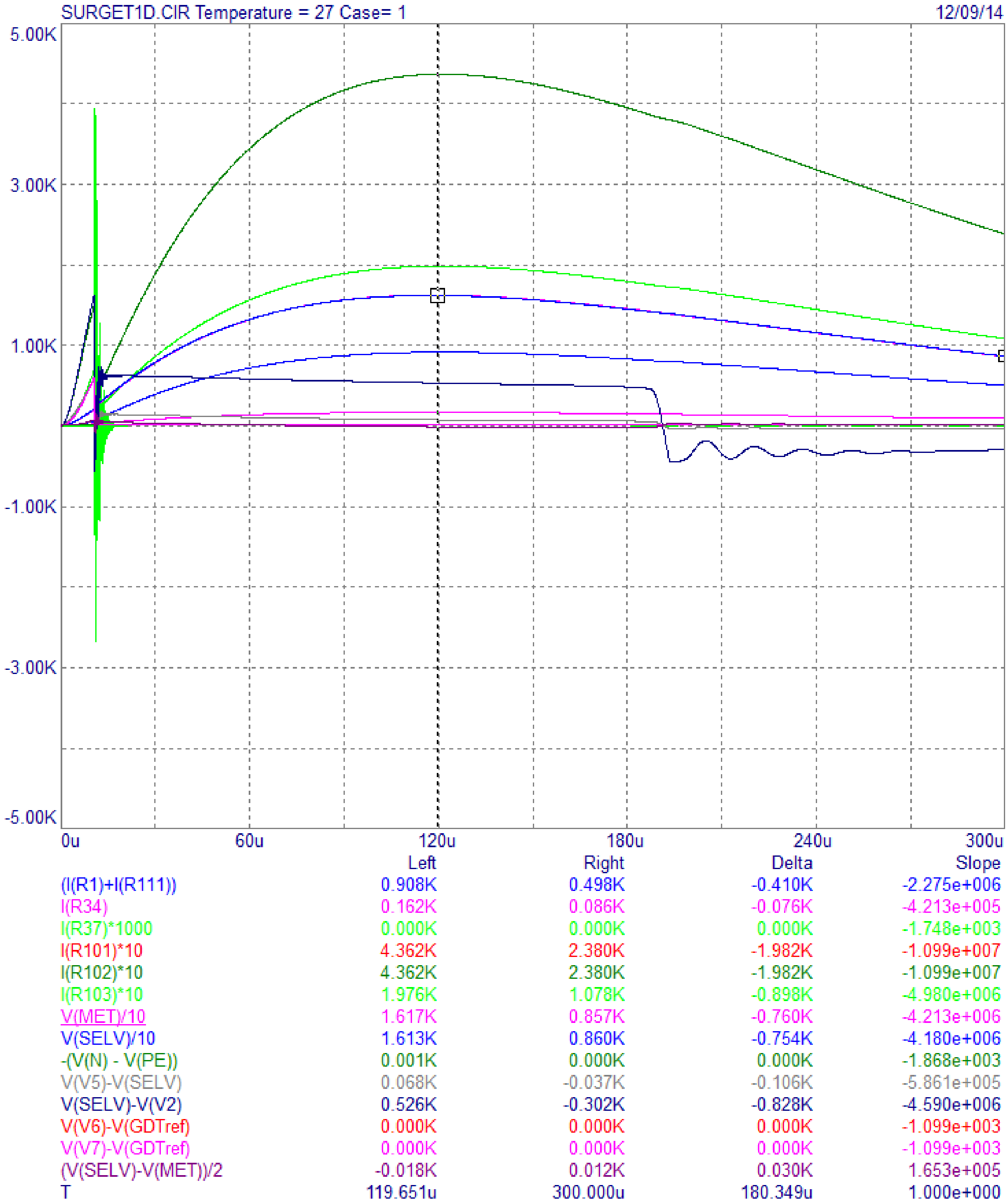


Figure A.31 – Simulation of a lightning strike to the telecommunication network (TN-S power system with floating equipment with primary protection)

Description of the components related to Figure A.31:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R102 is the spare pair resistance terminated on a primary protector.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 28 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- Part2 is the primary protector installed on the working pair.
- Part4 is the primary protector installed on the spare pair.
- L15, R22, C1 and C2 represent the power transformer.
- MOV X7 is an inherent protection MOV in the equipment.
- Part1 is a spark gap primary protector installed between the neutral and the PE.
- X10 is an MOV type primary protector installed between L1 and neutral.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 and R5, L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21, L22 and L23 simulate the length of power line back to the HV/LV transformer.
- L24 represents the inductance of the PE conductor to neighbouring properties with earth electrodes represented by R111.
- R111 represents the resistance of the other 2.33 electrodes.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.
- R1 has been multiplied by 15 as all 15 customers are connected to earth through the same 2 Ω.
- R34 is the customer earth electrode.

Figure A.32 shows result for simulation of a lightning strike to the telecommunication network (TN-S power system with floating equipment with primary protection).



	Left	Right	Delta	Slope
(I(R1)+I(R111))	0.908K	0.498K	-0.410K	-2.275e+006
I(R34)	0.162K	0.086K	-0.076K	-4.213e+005
I(R37)*1000	0.000K	0.000K	0.000K	-1.748e+003
I(R101)*10	4.362K	2.380K	-1.982K	-1.099e+007
I(R102)*10	4.362K	2.380K	-1.982K	-1.099e+007
I(R103)*10	1.976K	1.078K	-0.898K	-4.980e+006
V(MET)/10	1.617K	0.857K	-0.760K	-4.213e+006
V(SELV)/10	1.613K	0.860K	-0.754K	-4.180e+006
-(V(N) - V(PE))	0.001K	0.000K	0.000K	-1.868e+003
V(V5)-V(SELV)	0.068K	-0.037K	-0.106K	-5.861e+005
V(SELV)-V(V2)	0.526K	-0.302K	-0.828K	-4.590e+006
V(V6)-V(GDTref)	0.000K	0.000K	0.000K	-1.099e+003
V(V7)-V(GDTref)	0.000K	0.000K	0.000K	-1.099e+003
(V(SELV)-V(MET))/2	-0.018K	0.012K	0.030K	1.653e+005
T	119.651u	300.000u	180.349u	1.000e+000

Figure A.32 – Result for simulation of a lightning strike to the telecommunication network (TN-S power system with floating equipment with primary protection)

Customer earth 100 Ω

The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE operates at 1.5 kV.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.14 kV.

The power transformer stress (primary to secondary surge voltage) is 1.632 kV. The voltage between the telecommunication network ports and SELV is 575 V. The voltage between the two ports is just over 2.2 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 908 A. The current entering the earth via the local earth point is 162A. The working telecommunication pair contributes 436 A. The telecommunication spare pair contributes 436 A. The screen of the cable contributes 198 A.

The Ethernet port is subjected to a voltage peak of 322 V. The current peak is 5 A.

The equipment is protected.

Customer earth 2 Ω

The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE operates at 1.5 kV.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 7.9 kV.

The power transformer stress (primary to secondary surge voltage) is 1.67 kV. The voltage between the telecommunication network ports and SELV is 598 V. The voltage between the two ports is 2.2 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 440 A. The current entering the earth via the local earth point is 3.9 kA. The working telecommunication pair contributes 1.77 kA. The telecommunication spare pair contributes 1.77 kA. The screen of the cable contributes 800 A.

The Ethernet port is subjected to a voltage peak of 356 V. The current peak is 4.6 A.

The equipment is protected.

No path to earth at the customer premises

The primary protectors on the telecommunication spare pair and the working pair operate at 600 V. The spark gap between the neutral and PE operates at 1.5 kV.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 16.5 kV.

The power transformer stress (primary to secondary surge voltage) is 1.5 kV. The voltage between the telecommunication network ports and SELV is 496 V. The voltage between the two ports is less than 2 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 929A. The working telecommunication pair contributes 379 A. The telecommunication spare pair contributes 379 A. The screen of the cable contributes 172 A.

The Ethernet port is subjected to a voltage peak of 332 V. The current peak is 4.7 A.

The equipment is protected.

A.3.2 TN-C and TN-C-S power systems

A.3.2.1 Earthed equipment

A.3.2.1.1 Without primary protection

The simulation model is shown in Figure A.33.

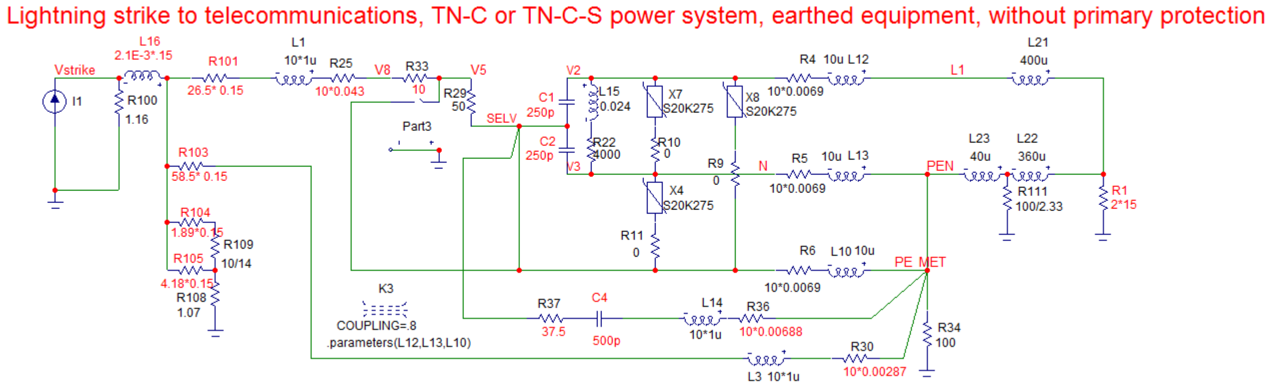
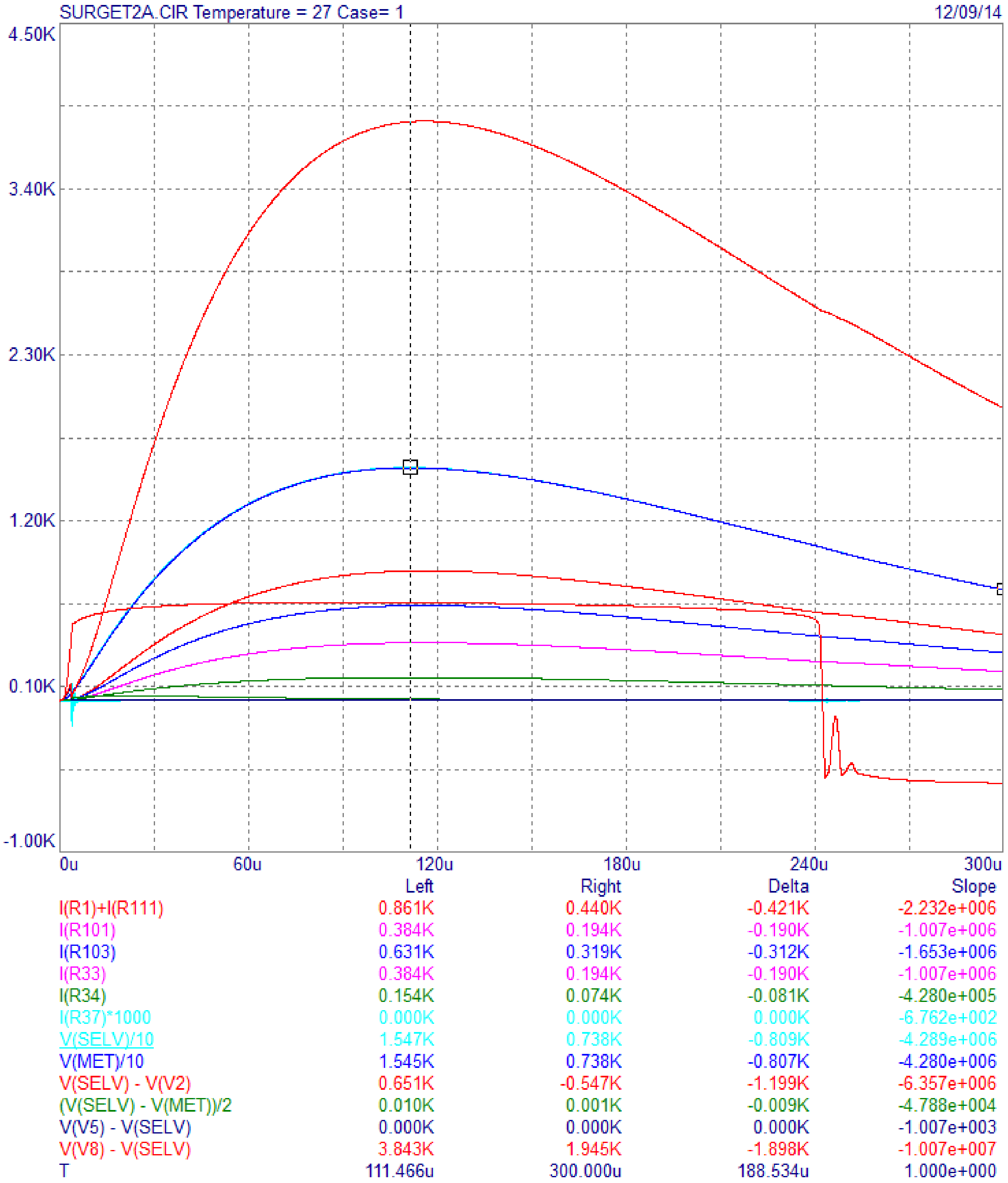


Figure A.33 – Simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with earthed equipment without primary protection)

Description of the components related to Figure A.33:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 14 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R109 is the parallel resistance of R33 in the other 14 pieces of customer equipment.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part3 is a TVS which operates at 100 V.
- R29 represents the internal resistance of the telecommunication circuit.
- L15, R22, C1 and C2 represent the power transformer.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4-R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- L23 represents the inductance of the PE conductor to neighbouring properties with earth electrodes represented by R111.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.34 shows results for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with earthed equipment without primary protection).



	Left	Right	Delta	Slope
I(R1)+I(R111)	0.861K	0.440K	-0.421K	-2.232e+006
I(R101)	0.384K	0.194K	-0.190K	-1.007e+006
I(R103)	0.631K	0.319K	-0.312K	-1.653e+006
I(R33)	0.384K	0.194K	-0.190K	-1.007e+006
I(R34)	0.154K	0.074K	-0.081K	-4.280e+005
I(R37)*1000	0.000K	0.000K	0.000K	-6.762e+002
V(SELV)/10	1.547K	0.738K	-0.809K	-4.289e+006
V(MET)/10	1.545K	0.738K	-0.807K	-4.280e+006
V(SELV) - V(V2)	0.651K	-0.547K	-1.199K	-6.357e+006
(V(SELV) - V(MET))/2	0.010K	0.001K	-0.009K	-4.788e+004
V(V5) - V(SELV)	0.000K	0.000K	0.000K	-1.007e+003
V(V8) - V(SELV)	3.843K	1.945K	-1.898K	-1.007e+007
T	111.466u	300.000u	188.534u	1.000e+000

Figure A.34 – Result for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with earthed equipment without primary protection)

Customer earth 100 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltage, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 15.5 kV.

The power transformer stress (primary to secondary surge voltage) is 653 V (no flashover). The voltage between the telecommunication network ports and SELV is 3.85 kV. The current conducted in this port is 385 A. This current is way in excess of the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 862 A. The current entering the earth via the local earth point is 154 A. The working telecommunication pair contributes 385 A. The screen of the cable contributes 631 A.

The Ethernet port is subjected to a voltage peak of 35 V. The current is much less than 1 A.

The telecommunication port will be damaged. The current is 385 A compared with the inherent test current of 40 A.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to around 15.9 kV and to around 15.2 kV.

The power transformer stress (primary to secondary surge voltage) is 688 V (no flashover). The voltage between the telecommunication network ports and SELV is 3.56 kV. 356 A is conducted in the telecommunication network port. This current is way in excess of the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 860 A. The current entering the earth via the local earth point is 152 A. The working telecommunication pair contributes356 A. The screen of the cable contributes 656 A.

The Ethernet port is subjected to a voltage peak of 335 V. The current is less than 1 A.

The telecommunication port will be damaged. The current is 356 A compared with the inherent test current of 40 A.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V.

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 4.8 kV and 4.78 kV.

The power transformer stress (primary to secondary surge voltage) is 600 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 10 kV. The current in this port is 1 kA. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 261 A. The current entering the earth via the local earth point is 2.39 kA. The working telecommunication pair contributes 1 kA. The screen of the cable contributes 1.65 kA.

The Ethernet port is subjected to a voltage peak of 103 V. The current is less than 1 A.

The telecommunication port will be damaged. The current is 1 kA compared with the inherent test current of 40 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 16.2 kV.

The power transformer stress (primary to secondary surge voltage) is 654 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 3.4 kV. The current in this port is 342 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 904 A. The working telecommunication pair contributes 342 A. The screen of the cable contributes 562 A.

The Ethernet port is subjected to a voltage peak of 31 V. The current is much less than 1 A.

The telecommunication port will be damaged. The current is 342 A compared with the inherent test current of 40 A.

A.3.2.1.2 With primary protection

The simulation model is shown in Figure A.35.

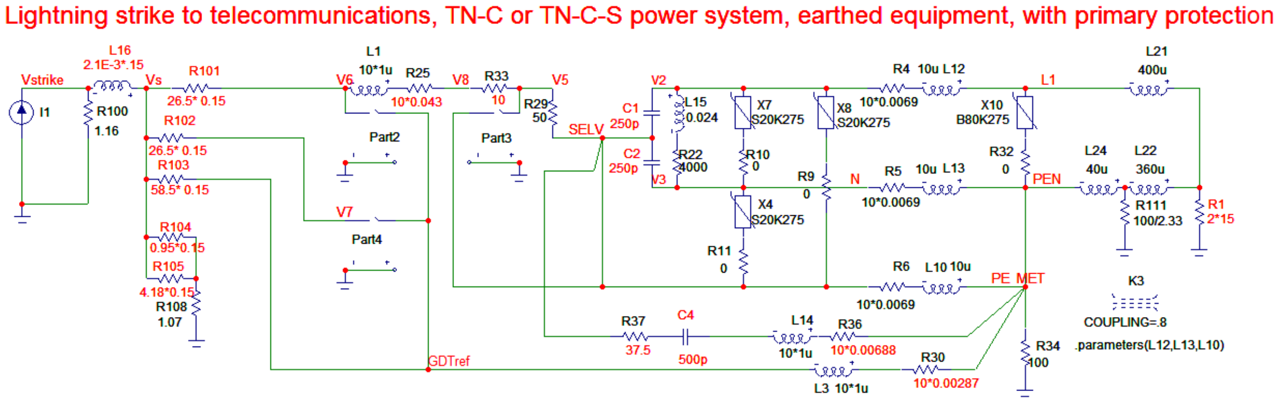


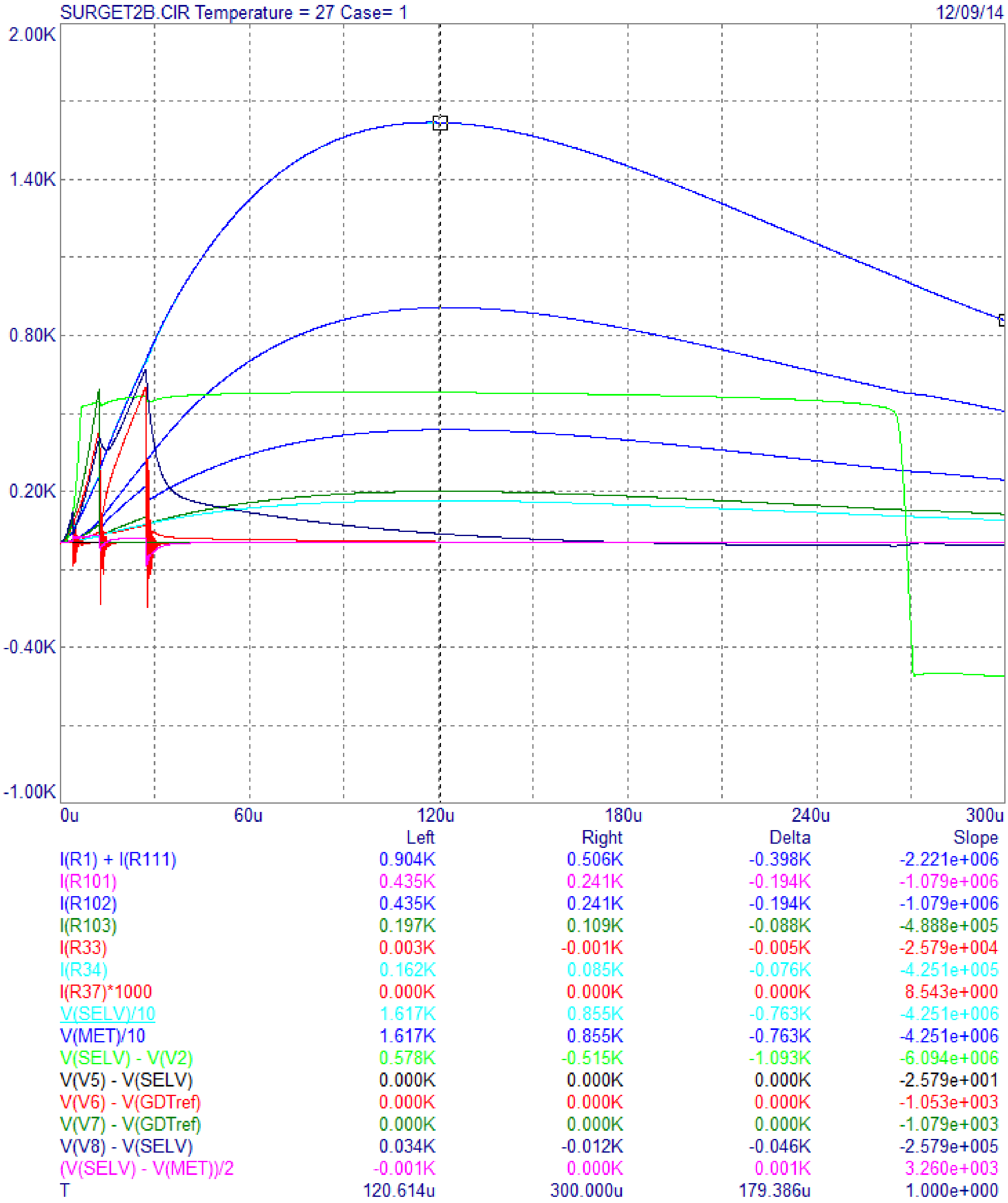
Figure A.35 – Simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with earthed equipment with primary protection)

Description of the components related to Figure A.35:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R102 is the spare pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 28 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R109 is the parallel resistance of R33 in the other 14 pieces of customer equipment.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- Part2 is a primary protector on the working pair which operates at 600 V.
- Part4 is a primary protector on the spare pair which operates at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part3 is a TVS which operates at 100 V.
- R29 represents the internal resistance of the telecommunication circuit.
- L15, R22, C1 and C2 represent the power transformer.

- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- L23 represents the inductance of the PE conductor to neighbouring properties with earth electrodes represented by R111.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.36 shows result for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with earthed equipment with primary protection).



	Left	Right	Delta	Slope
I(R1) + I(R111)	0.904K	0.506K	-0.398K	-2.221e+006
I(R101)	0.435K	0.241K	-0.194K	-1.079e+006
I(R102)	0.435K	0.241K	-0.194K	-1.079e+006
I(R103)	0.197K	0.109K	-0.088K	-4.888e+005
I(R33)	0.003K	-0.001K	-0.005K	-2.579e+004
I(R34)	0.162K	0.085K	-0.076K	-4.251e+005
I(R37)*1000	0.000K	0.000K	0.000K	8.543e+000
V(SELV)/10	1.617K	0.855K	-0.763K	-4.251e+006
V(MET)/10	1.617K	0.855K	-0.763K	-4.251e+006
V(SELV) - V(V2)	0.578K	-0.515K	-1.093K	-6.094e+006
V(V5) - V(SELV)	0.000K	0.000K	0.000K	-2.579e+001
V(V6) - V(GDTref)	0.000K	0.000K	0.000K	-1.053e+003
V(V7) - V(GDTref)	0.000K	0.000K	0.000K	-1.079e+003
V(V8) - V(SELV)	0.034K	-0.012K	-0.046K	-2.579e+005
(V(SELV) - V(MET))/2	-0.001K	0.000K	0.001K	3.260e+003
T	120.614u	300.000u	179.386u	1.000e+000

Figure A.36 – Result for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with earthed equipment with primary protection)

Customer earth 100 Ω

The voltages and currents shown are for a 10 m telecommunication bond wire length. If the bond wire length is reduced to 1.5 m, the values change. These values are shown in parentheses.

The telecommunication port inherent protection operates at 100 V. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.2 (16.2) kV.

The power transformer stress (primary to secondary surge voltage) is 579 (579) V (no flashover). The voltage between the telecommunication network ports and SELV is 665 (541) V. The current entering the telecommunication port is 67 (54) A. The current for the long bond wire is 67 A and greater than the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur. The current for the short bond wire is 54 A and is less than the coordination test current of 60 A in [ITU-T K.21] and damage to the port is unlikely to occur.

The current injected into the power network is 904 (906) A. The current entering the earth via the local earth point is 162 (162) A. The working pair contributes 435 (435) A. The spare pair terminated on a primary protector contributes 435 (435) A. The screen of the cable contributes 197 (197) A.

The Ethernet port is subjected to a voltage peak of 91 (132) V. The current is less than 1 A (1.3 A).

The equipment is protected with a short bond wire but not with a long bond wire.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.2 kV.

The power transformer stress (primary to secondary surge voltage) is 625 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 578 V. The current entering the telecommunication port is 58 A. This is less than the [ITU-T K.21] coordination test current of 60 A.

The current injected into the power network is 904 A. The working pair contributes 435 A. The spare pair terminated on a primary protector contributes 435 A. The screen of the cable contributes 197 A. The current entering the earth via the local earth point is 162 A.

The Ethernet port is subjected to a voltage peak of 248 V. The current is much less than 1 A.

Interestingly the loss of the equipment earth has minimal impact from a lightning perspective.

The equipment is protected.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V. The telecommunication primary protectors on both the spare and working pairs operate at 600 V.

The MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 7.79 V. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 556 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 908 V. The current entering the telecommunication port is 91 A. This current is in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the power network is 431 A. The current entering the earth via the local earth point is 3.895 kA. The working pair contributes 1.76 kA. The spare pair terminated on a primary protector contributes 1.76 kA. The screen of the cable contributes 799 A.

The Ethernet port is subjected to a voltage peak of 63 V just prior to the telecommunication inherent protector operating. The current is less than 1 A.

Damage may occur to the telecommunication port. The current is 91 A compared with the coordination test current of 60 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V. The telecommunication primary protectors on the spare and working pairs operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.5 kV.

The power transformer stress (primary to secondary surge voltage) is 579 V (no flashover). The voltage between the telecommunication network ports and SELV is 653 V. The current entering the telecommunication port is 65 A. This current is more than the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the power network is 925 A. The working pair contributes 377 A. The spare pair contributes 377 A. The screen of the cable contributes 171 A.

The Ethernet port is subjected to a voltage peak of 96 V. The current is less than 1 A.

The current entering the telecommunication port is in excess of the test current and the equipment may be damaged.

A.3.2.2 Floating equipment

A.3.2.2.1 Without primary protection

The simulation model is shown in Figure A.37.

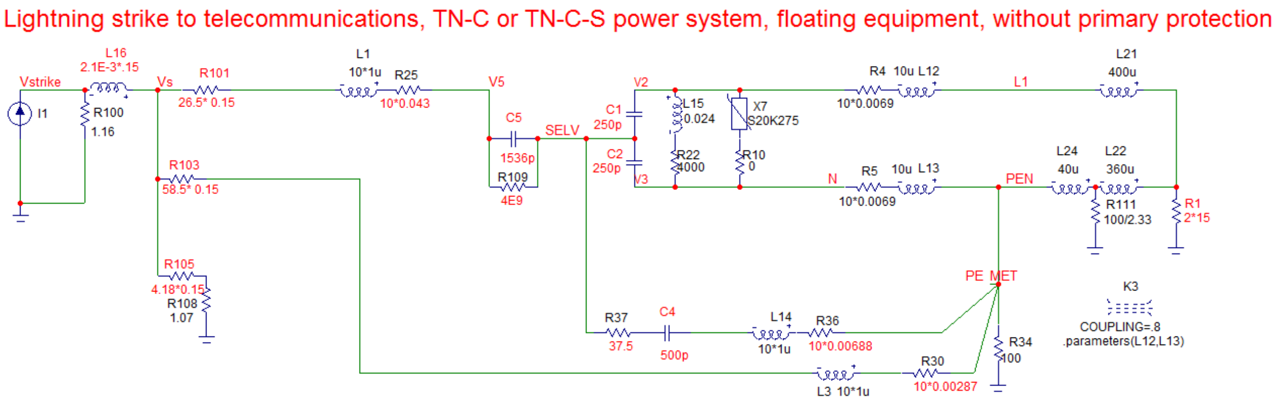


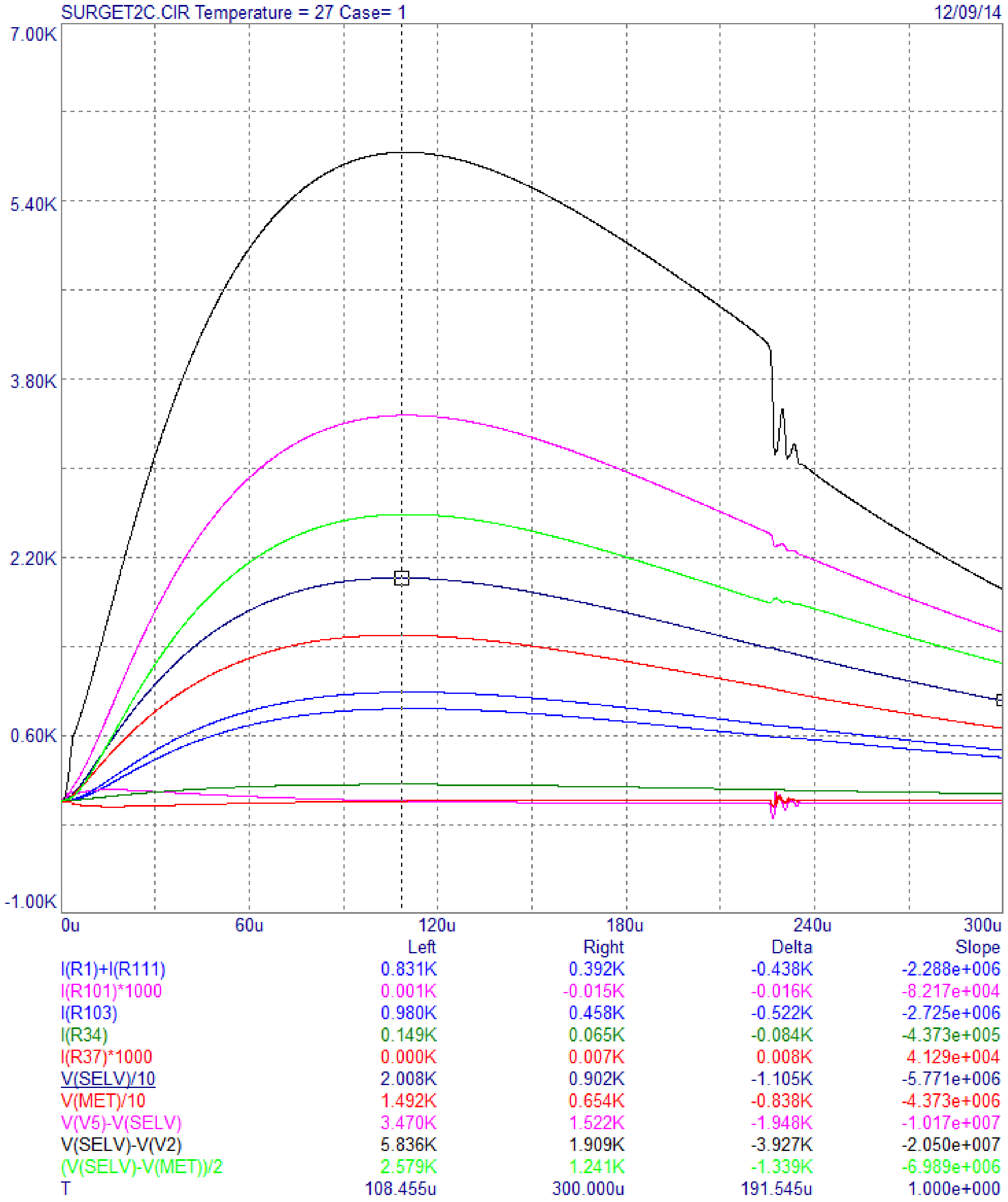
Figure A.37 – Simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with floating equipment without primary protection)

Description of the components related to Figure A.37:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.

- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- C5 and R203 represent the telecommunication input circuit.
- L15, R22, C1 and C2 represent the power transformer.
- MOV X7 is an inherent protection MOV in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 and R5, L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- L23 represents the inductance of the PE conductor to neighbouring properties with earth electrodes represented by R111.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.38 shows results for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with floating equipment without primary protection).



	Left	Right	Delta	Slope
I(R1)+I(R111)	0.831K	0.392K	-0.438K	-2.288e+006
I(R101)*1000	0.001K	-0.015K	-0.016K	-8.217e+004
I(R103)	0.980K	0.458K	-0.522K	-2.725e+006
I(R34)	0.149K	0.065K	-0.084K	-4.373e+005
I(R37)*1000	0.000K	0.007K	0.008K	4.129e+004
V(SELV)/10	2.008K	0.902K	-1.105K	-5.771e+006
V(MET)/10	1.492K	0.654K	-0.838K	-4.373e+006
V(V5)-V(SELV)	3.470K	1.522K	-1.948K	-1.017e+007
V(SELV)-V(V2)	5.836K	1.909K	-3.927K	-2.050e+007
(V(SELV)-V(MET))/2	2.579K	1.241K	-1.339K	-6.989e+006
T	108.455u	300.000u	191.545u	1.000e+000

Figure A.38 – Result for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with floating equipment without primary protection)

Customer earth 100 Ω

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 15 kV and 20 kV.

The power transformer stress (primary to secondary surge voltage) is 5.8 kV. The voltage between the telecommunication network ports and SELV is 3.47 kV. The voltage between the two ports is greater than 9 kV. As this in excess of the port to port isolation of 5 kV and 6 kV respectively a flashover will occur.

The current injected into the power network is 831 A. The current entering the earth via the local earth point is 149 A. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 980 A.

The Ethernet port is subjected to a voltage peak of 2.58 kV. The current is much less than 1 A.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering on the telecommunication port will exit via the power and Ethernet ports damaging all ports.

Customer earth 2 Ω

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 14.9 kV and 3.8 kV.

The power transformer stress (primary to secondary surge voltage) is 11.4 kV. The voltage between the telecommunication network ports and the SELV circuit is 7.3 kV. The voltage between the two ports is nearly 19 kV. As this is in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the power network is 211 A. The current entering the earth via the local earth point is 1.89 kA. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 2.1 kA.

The Ethernet port is subjected to a voltage peak of 5.6 kV. The current is much less than 1 A. This level of voltage magnitude is likely to result in damage to the Ethernet port of both pieces of equipment.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering the telecommunication port will exit via the power and Ethernet ports damaging all ports.

No path to earth at the customer premises

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 20.5 kV and 15.9 kV.

The power transformer stress (primary to secondary surge voltage) is 5.3 kV. The voltage between the telecommunication network ports and the SELV circuit is 3.1 kV. The voltage between the two ports is more than 8 kV compared with the isolation voltage of 5 kV and 6 kV respectively. As this is in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the power network is 885 A. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 885 A.

The Ethernet port is subjected to a voltage peak of 2.3 kV. The current is much less than 1 A.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering on the telecommunication port will exit via the power and Ethernet ports damaging all ports.

A.3.2.2.2 With primary protection

The simulation model is shown in Figure A.39.

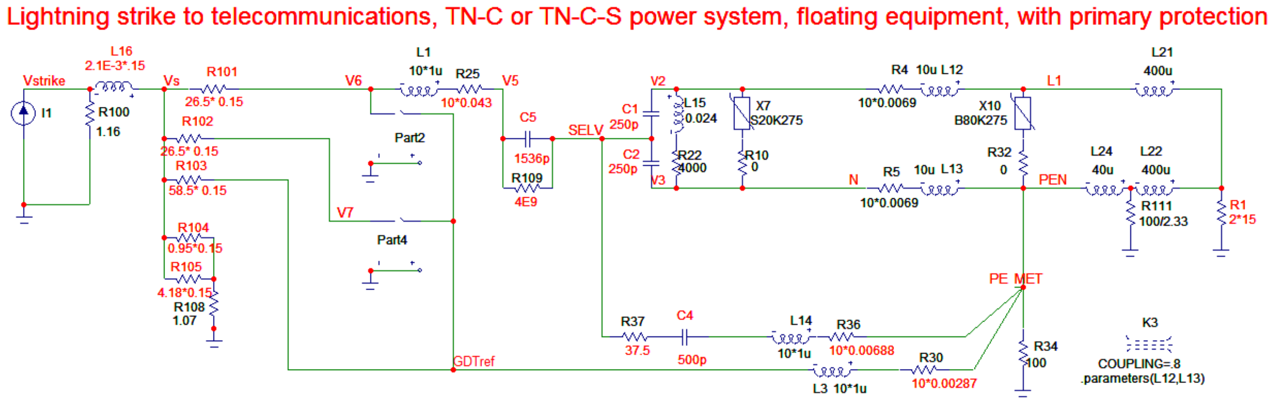
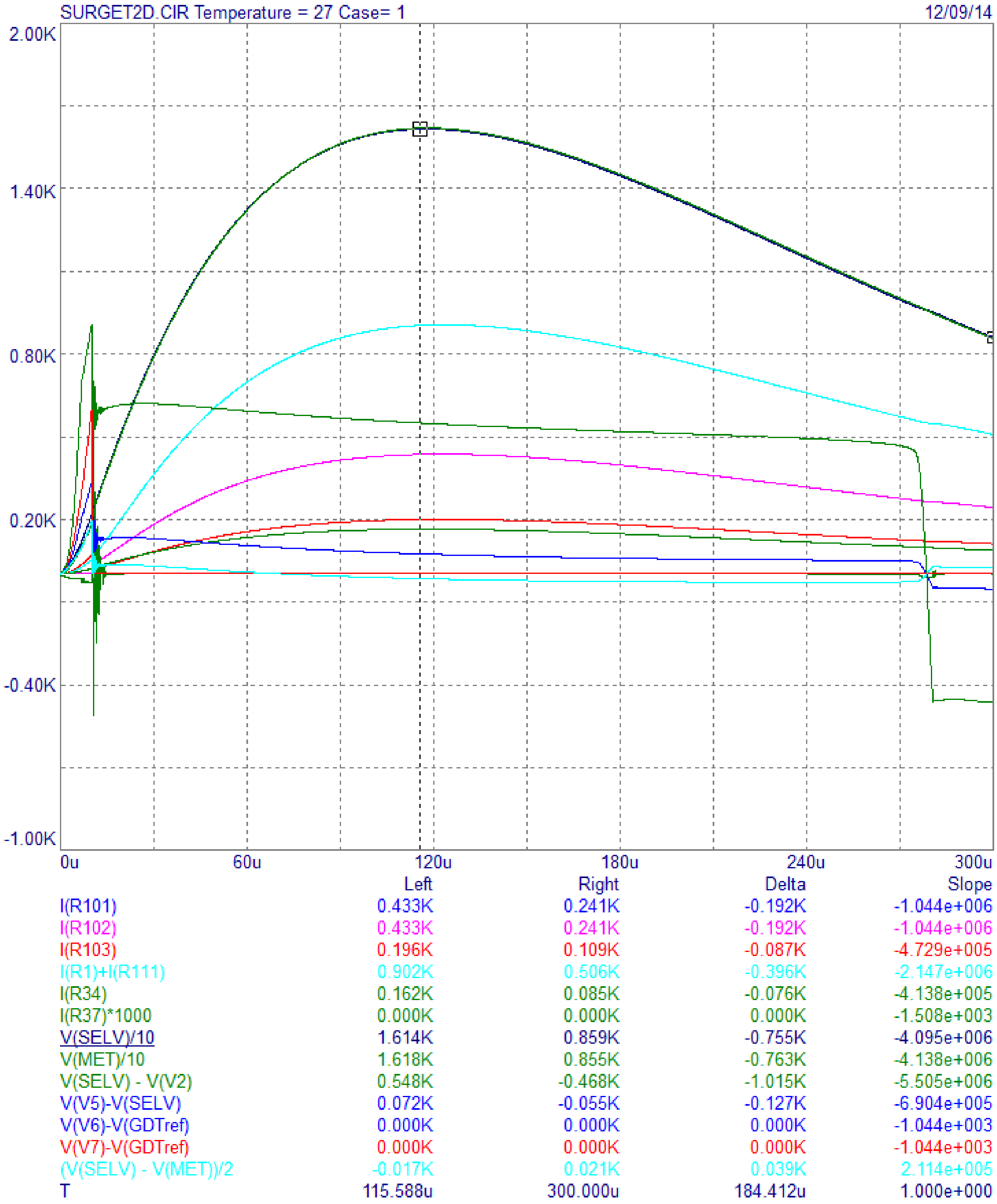


Figure A.39 – Simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with floating equipment with primary protection)

Description of the components related to Figure A.39:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R102 is the spare pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 28 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other 46.67 electrodes in parallel with the equivalent proportion of the 2 Ω seen by 14 customers.
- Part2 is a primary protector on the working pair which operates at 600 V.
- Part4 is a primary protector on the spare pair which operates at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- C5 and R203 represent the telecommunication input circuit.
- L15, R22, C1 and C2 represent the power transformer.
- MOV X7 is an inherent protection MOV in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 and R5, L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- L24 represents the inductance of the PE conductor to the neighbouring properties with earth electrodes represented by R111.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.40 shows results for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with floating equipment with primary protection).



	Left	Right	Delta	Slope
I(R101)	0.433K	0.241K	-0.192K	-1.044e+006
I(R102)	0.433K	0.241K	-0.192K	-1.044e+006
I(R103)	0.196K	0.109K	-0.087K	-4.729e+005
I(R1)+I(R111)	0.902K	0.506K	-0.396K	-2.147e+006
I(R34)	0.162K	0.085K	-0.076K	-4.138e+005
I(R37)*1000	0.000K	0.000K	0.000K	-1.508e+003
V(SELV)/10	1.614K	0.859K	-0.755K	-4.095e+006
V(MET)/10	1.618K	0.855K	-0.763K	-4.138e+006
V(SELV) - V(V2)	0.548K	-0.468K	-1.015K	-5.505e+006
V(V5)-V(SELV)	0.072K	-0.055K	-0.127K	-6.904e+005
V(V6)-V(GDTref)	0.000K	0.000K	0.000K	-1.044e+003
V(V7)-V(GDTref)	0.000K	0.000K	0.000K	-1.044e+003
(V(SELV) - V(MET))/2	-0.017K	0.021K	0.039K	2.114e+005
T	115.588u	300.000u	184.412u	1.000e+000

Figure A.40 – Result for simulation of a lightning strike to the telecommunication network (TN-C and TN-C-S power system with floating equipment with primary protection)

Customer earth 100 Ω

The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.2 kV.

The power transformer stress (primary to secondary surge voltage) is 908 V. The voltage between the telecommunication network ports and SELV is 335 V. The voltage between the two ports is just over 1 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 904 A. The working pair contributes 434 A. The spare pair terminated on a primary protector contributes 434. The screen of the cable contributes 197 A. The current entering the earth via the local earth point is 162 A.

The Ethernet port is subjected to a voltage peak of 192 V. The current is just less than 1 A.

The equipment is protected.

Customer earth 2 Ω

Both the telecommunication working and spare pair primary protectors operate at 600 V.

The MET and the SELV circuit both rise to around 7.8 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 961V. The voltage between the telecommunication network ports and SELV is 333 V. The voltage between the two ports is just under 1.3 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 430 A. The working pair contributes 1.76 kA. The spare pair terminated on a primary protector contributes 1.76 kA. The screen of the cable contributes 799 A. The current entering the earth via the local earth point is 3.9 kA.

The Ethernet port is subjected to a voltage peak of 250 V. The current is much less than 1 A.

The equipment is protected.

No path to earth at the customer premises

The telecommunication primary protectors on the spare and working pairs operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 16.5 kV.

The power transformer stress (primary to secondary surge voltage) is 906 V. The voltage between the telecommunication network ports and SELV is 332 V. The voltage between the two ports is just over 1.2 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 924 A. The working pair contributes 377 A. The spare pair contributes 377 A. The screen of the cable contributes 171 A.

The Ethernet port is subjected to a voltage peak of 189 V. The peak current is around 1.2 A.

The equipment is protected.

A.3.3 TT and IT power systems

A.3.3.1 Earthed equipment

A.3.3.1.1 Without primary protection

The simulation model is shown in Figure A.41.

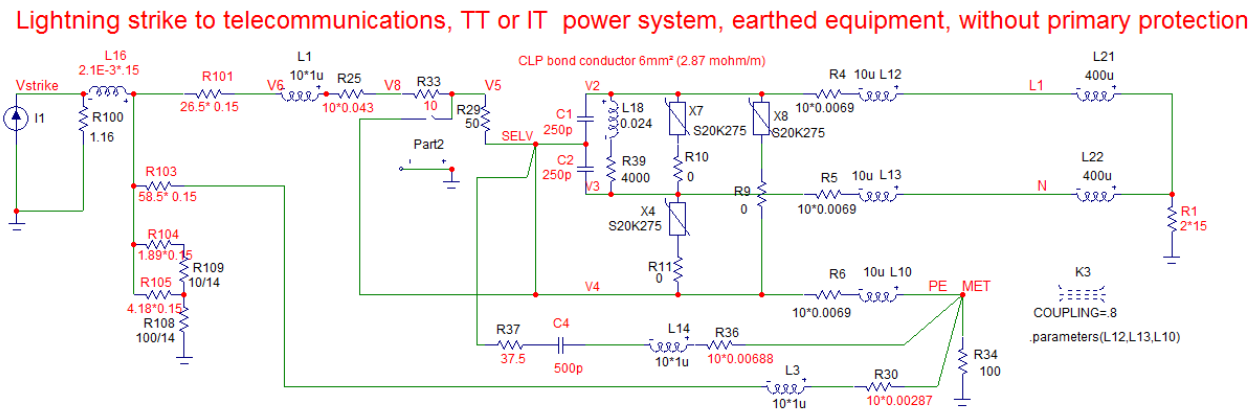
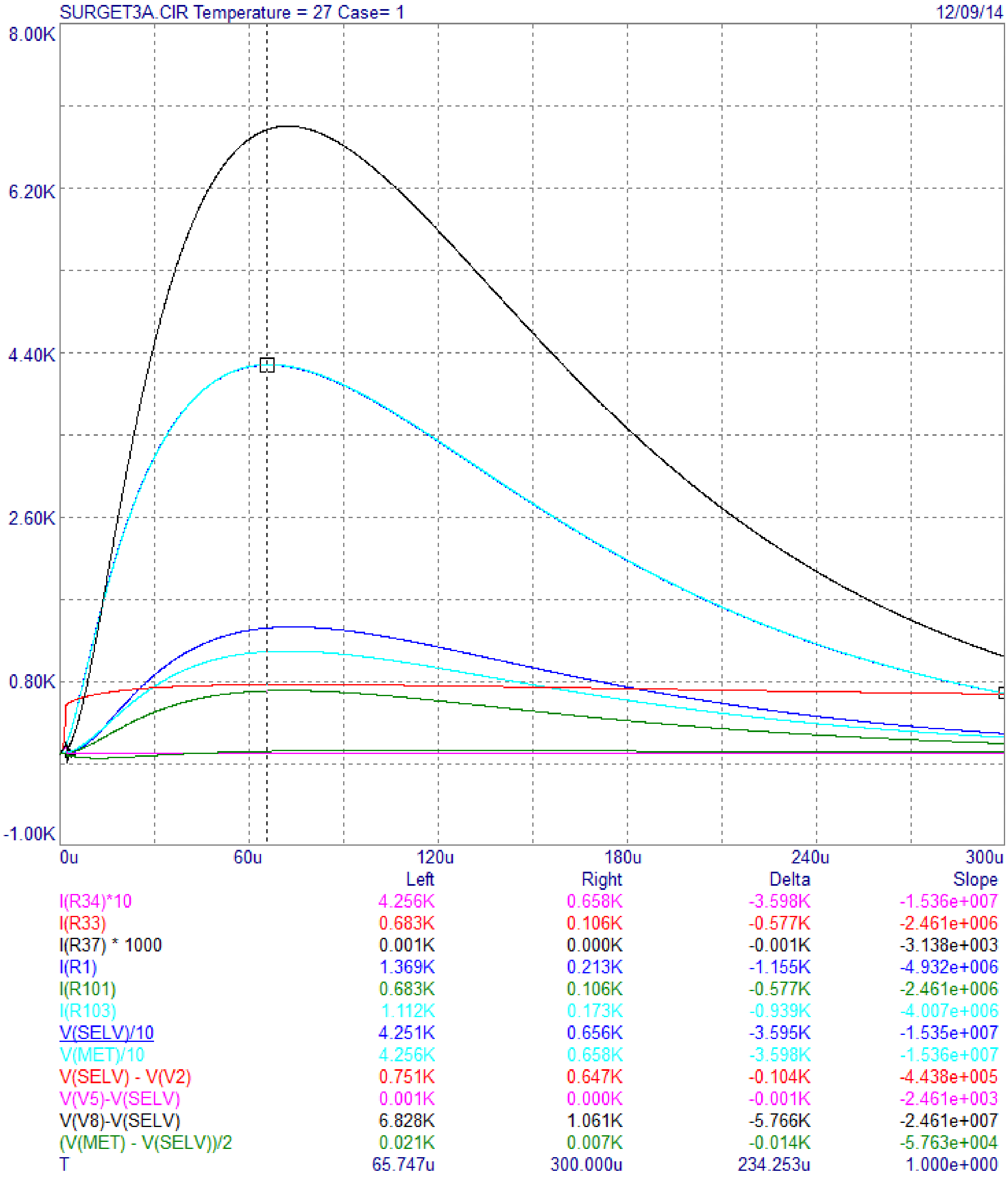


Figure A.41 – Simulation of a lightning strike to the telecommunication network (TT or IT power system with earthed equipment without primary protection)

Description of the components related to Figure A.41:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 14 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R109 is the parallel resistance of R33 in the other 14 pieces of customer equipment.
- R108 represents the resistance to earth of the other fourteen 100 Ω electrodes in parallel seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part2 is a TVS which operates at 100 V.
- R29 represents the internal resistance of the telecommunication circuit.
- L18, R39, C1 and C2 represent the power transformer.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.42 shows results for simulation of a lightning strike to the telecommunication network (TT or IT power system with earthed equipment without primary protection).



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                          Left        Right       Delta        Slope
I(R34)*10               4.256K       0.658K     -3.598K   -1.536e+007
I(R33)                  0.683K       0.106K     -0.577K   -2.461e+006
I(R37) * 1000           0.001K       0.000K     -0.001K   -3.138e+003
I(R1)                   1.369K       0.213K     -1.155K   -4.932e+006
I(R101)                 0.683K       0.106K     -0.577K   -2.461e+006
I(R103)                 1.112K       0.173K     -0.939K   -4.007e+006
V(SELV)/10              4.251K       0.656K     -3.595K   -1.535e+007
V(MET)/10               4.256K       0.658K     -3.598K   -1.536e+007
V(SELV) - V(V2)         0.751K       0.647K     -0.104K   -4.438e+005
V(V5)-V(SELV)           0.001K       0.000K     -0.001K   -2.461e+003
V(V8)-V(SELV)           6.828K       1.061K     -5.766K   -2.461e+007
(V(MET) - V(SELV))/2    0.021K       0.007K     -0.014K   -5.763e+004
T                      65.747u     300.000u    234.253u    1.000e+000
```

Figure A.42 – Result for simulation of a lightning strike to the telecommunication network (TT or IT power system with earthed equipment without primary protection)

Customer earth 100 Ω

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 43 kV.

The power transformer stress (primary to secondary surge voltage) is 751 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 6.9 kV. The current conducted in this port is 687 A. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 1.38 kA. The current entering the earth via the local earth point is 426 A. The working telecommunication pair contributes 687 A. The screen of the cable contributes 1.12 kA.

The Ethernet port is subjected to a voltage peak of 55 V. The current is much less than 1 A.

Damage to the telecommunication port will occur. The current is 687 A compared with the test current of 40 A.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 36 kV and to around 48.6 kV.

The power transformer stress (primary to secondary surge voltage) is 739 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 11.7 kV. 1.17 kA is conducted in the telecommunication network port. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 1.17 kA. The current entering the earth via the local earth point is 487 A. The working telecommunication pair contributes 1.17 A. The screen of the cable contributes 487 A. It is noted that the only path to earth for the working pair current is the power network and for the cable screen current the local earth.

The Ethernet port is subjected to a voltage peak of 6.3 kV. The current is less than 1 A. This magnitude of voltage is likely to damage the port.

Damage to the telecommunication port and Ethernet port will occur. The telecommunication port current is 1.17 kA compared with the test current of 40 A.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V.

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 10.5 kV.

The power transformer stress (primary to secondary surge voltage) is 665 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 21.1 kV. The current in this port is 2.11 kA. This current is significantly higher than the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 330 A. The current entering the earth via the local earth point is 5.25 kA. The working telecommunication pair contributes 2.11 kA. The screen of the cable contributes 3.47 kA.

The Ethernet port is subjected to a voltage peak of 282 V. The current is much less than 1 A.

Damage to the telecommunication port will occur. The current is 2.11 kA compared with the test current of 40 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 45 kV.

The power transformer stress (primary to secondary surge voltage) is 757 V (no flashover). The voltage between the telecommunication network ports and SELV is 5.6 kV. The current in this port is 562 A. This current is way in excess of the inherent test current of 40 A in [ITU-T K.21] and damage to the port is likely to occur.

The current injected into the power network is 1.47 kA. The working telecommunication pair contributes 562 A. The screen of the cable contributes 912 A.

The Ethernet port is subjected to a voltage peak of 35 V. The current is much less than 1 A.

Damage to the telecommunications port will occur. The current is 562 A compared with the test current of 40 A.

A.3.3.1.2 With primary protection

The simulation model is shown in Figure A.43.

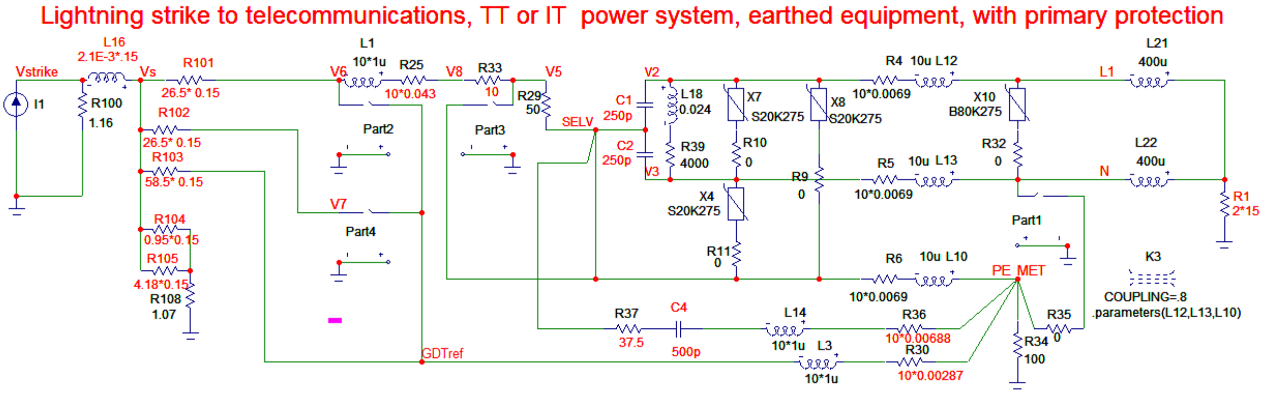


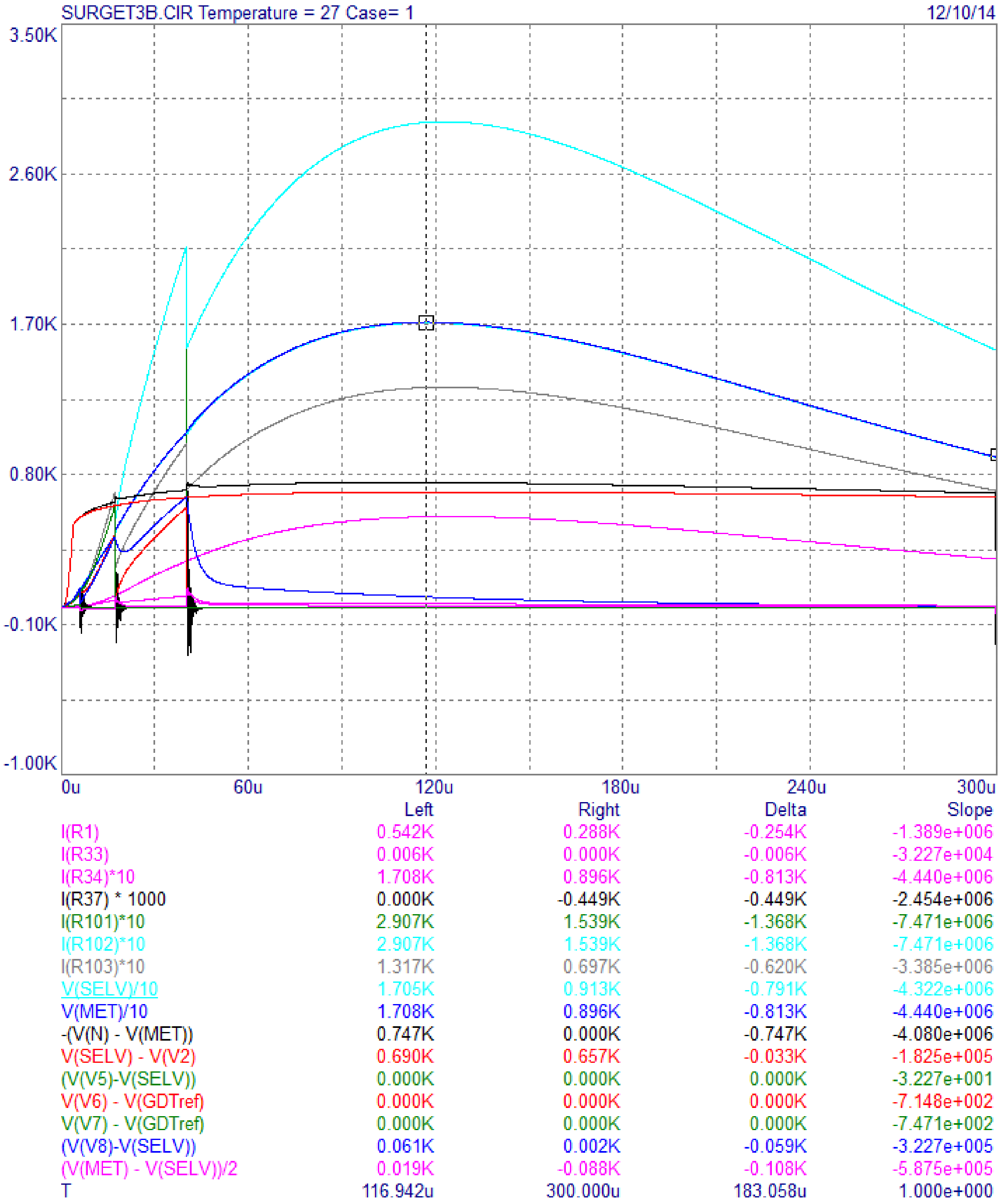
Figure A.43 – Simulation of a lightning strike to the telecommunication network (TT or IT power system with earthed equipment with primary protection)

Description of the components related to Figure A.43:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R102 is the spare pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 28 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other fourteen 100 Ω electrodes in parallel seen by 14 customers.
- Part2 is a primary protector on the working pair which operates at 600 V.
- Part4 is a primary protector on the spare pair which operates at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- R33 represents a fusible resistor and also provides a coordination resistance.
- Part3 is a TVS which operates at 100 V.
- R29 represents the internal resistance of the telecommunication circuit.
- L118, R39, C1 and C2 represent the power transformer.
- MOVs X8, X7 and X4 are inherent protection MOVs in the equipment.

- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 – R6 and L12, L13 and L10 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.44 shows result for simulation of a lightning strike to the telecommunication network (TT or IT power system with earthed equipment with primary protection operating).



	Left	Right	Delta	Slope
I(R1)	0.542K	0.288K	-0.254K	-1.389e+006
I(R33)	0.006K	0.000K	-0.006K	-3.227e+004
I(R34)*10	1.708K	0.896K	-0.813K	-4.440e+006
I(R37) * 1000	0.000K	-0.449K	-0.449K	-2.454e+006
I(R101)*10	2.907K	1.539K	-1.368K	-7.471e+006
I(R102)*10	2.907K	1.539K	-1.368K	-7.471e+006
I(R103)*10	1.317K	0.697K	-0.620K	-3.385e+006
V(SELV)/10	1.705K	0.913K	-0.791K	-4.322e+006
V(MET)/10	1.708K	0.896K	-0.813K	-4.440e+006
-(V(N) - V(MET))	0.747K	0.000K	-0.747K	-4.080e+006
V(SELV) - V(V2)	0.690K	0.657K	-0.033K	-1.825e+005
(V(V5)-V(SELV))	0.000K	0.000K	0.000K	-3.227e+001
V(V6) - V(GDTref)	0.000K	0.000K	0.000K	-7.148e+002
V(V7) - V(GDTref)	0.000K	0.000K	0.000K	-7.471e+002
(V(V8)-V(SELV))	0.061K	0.002K	-0.059K	-3.227e+005
(V(MET) - V(SELV))/2	0.019K	-0.088K	-0.108K	-5.875e+005
T	116.942u	300.000u	183.058u	1.000e+000

Figure A.44 – Result for simulation of a lightning strike to the telecommunication network (TT or IT power system with earthed equipment with primary protection operating)

Customer earth 100 Ω

The voltages and currents shown are for a 10 m telecommunication bond wire length. If the bond wire length is reduced to 1.5 m, the values change. These values are shown in parentheses.

The telecommunication port inherent protection operates at 100 V. The primary protector on the unused telecommunication pair and the telecommunication working pair operates at 600 V. The spark gap between the neutral and the MET does not operate.

Because of the relatively high resistance to earth the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 17 (17) kV.

The power transformer stress (primary to secondary surge voltage) is 690 (690) V (no flashover). The voltage between the telecommunication network ports and SELV is 661 (585) V. The current entering the telecommunication port is 66 (59) A. This is less than the coordination test current of 60 A in [ITU-T K.21] for the short bond wire but greater than the test current for the long bond wire, Damage may occur for the long bond wire.

The current injected into the power network is 544 (544) A. The current entering the earth via the local earth point is 171 (171) A. The working pair contributes 291 (291) A. The spare pair terminated on a primary protector contributes 291 (291) A. The screen of the cable contributes 132 (132) A.

The Ethernet port is subjected to a voltage peak of 123 (166) V. The current is just less than 1 A for the long bond wire but 1.3 A for the short bond wire.

The equipment is protected for the short bond but not for the long bond wire.

Unearthed power outlet and customer earth 100 Ω

The loss of an earth is simulated by changing R6 to 1 GΩ.

The telecommunication port inherent protection operates at 100 V. The spark gap between the neutral and the MET operates at 1.5 kV. The primary protectors on the unused telecommunication pair and the telecommunication working pair operate at 600 V.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 17 kV.

The power transformer stress (primary to secondary surge voltage) is 624 V (no flashover). The voltage between the telecommunication network ports and SELV is 570 V. The current entering the telecommunication port is 57 A. This is less than the coordination test current of 60 A in [ITU-T K.21] so damage is unlikely to occur.

The current injected into the power network is 558 A. The current entering the earth via the local earth point is 171 A. The working pair contributes 297A. The spare pair terminated on a primary protector contributes 297 A. The screen of the cable contributes 134 A.

The Ethernet port is subjected to a voltage peak of 408 V. The current peak is 4.7 A.

The equipment is protected.

Customer earth 2 Ω

The telecommunication port inherent protection operates at 100 V. The telecommunication spare pair and working pair primary protectors operate at 600 V. The spark gap between the neutral and the MET does not operate.

The MET and the SELV circuit both rise to 8 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 652 V (no flashover). The voltage between the telecommunication network ports and the SELV circuit is 903 V. The peak current entering the telecommunication port is 90 A. This current is in excess of the coordination test current of 60 A in [ITU-T K.21]. Damage may occur.

The current injected into the power network is 244 A. The current entering the earth via the local earth point is 4 kA. The working pair contributes 1.73 kA. The spare pair terminated on a primary protector contributes 1.73 kA. The screen of the cable contributes 798 A.

The Ethernet port is subjected to a voltage peak of 63 V. The current is much less than 1 A.

The equipment is not protected as damage occurs to the telecommunication port. The current is in excess of the coordination test current of 60 A.

No path to earth at the customer premises

The telecommunication port inherent protection operates at 100 V. The telecommunication primary protectors on the spare and working pairs operate at 600 V. The spark gap between the neutral and the MET does not operate.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 17.5 kV.

The power transformer stress (primary to secondary surge voltage) is 691 V (no flashover). The voltage between the telecommunication network ports and SELV is 646 V. The current entering the telecommunication port is 65 A. This current is more than the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur.

The current injected into the power network is 557 A. The working pair contributes 227 A. The spare pair contributes 227 A. The screen of the cable contributes 103 A.

The Ethernet port is subjected to a voltage peak of 133 V. The current is just less than 1 A.

The equipment is not protected as damage occurs to the telecommunication port. The current is in excess of the coordination test current of 60 A.

A.3.3.2 Floating equipment

A.3.3.2.1 Without primary protection

The simulation model is shown in Figure A.45.

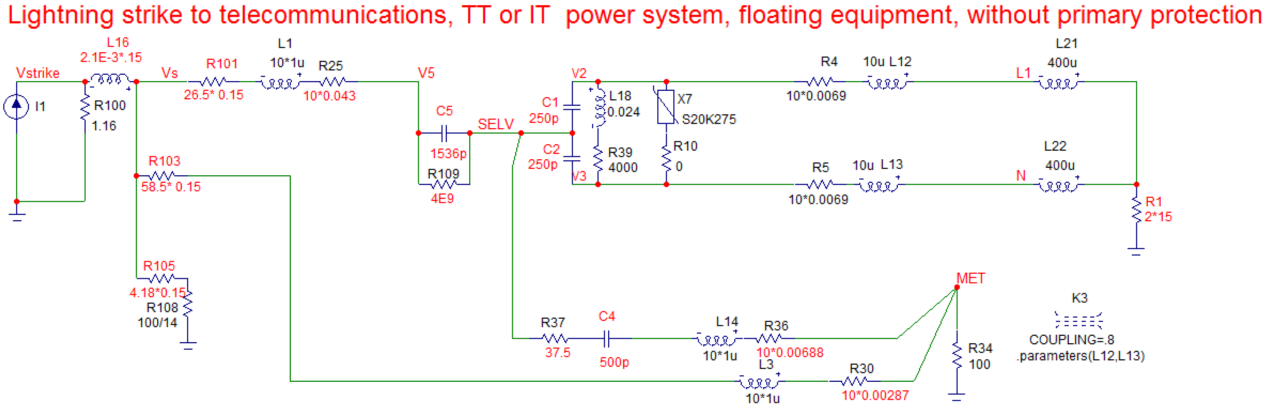


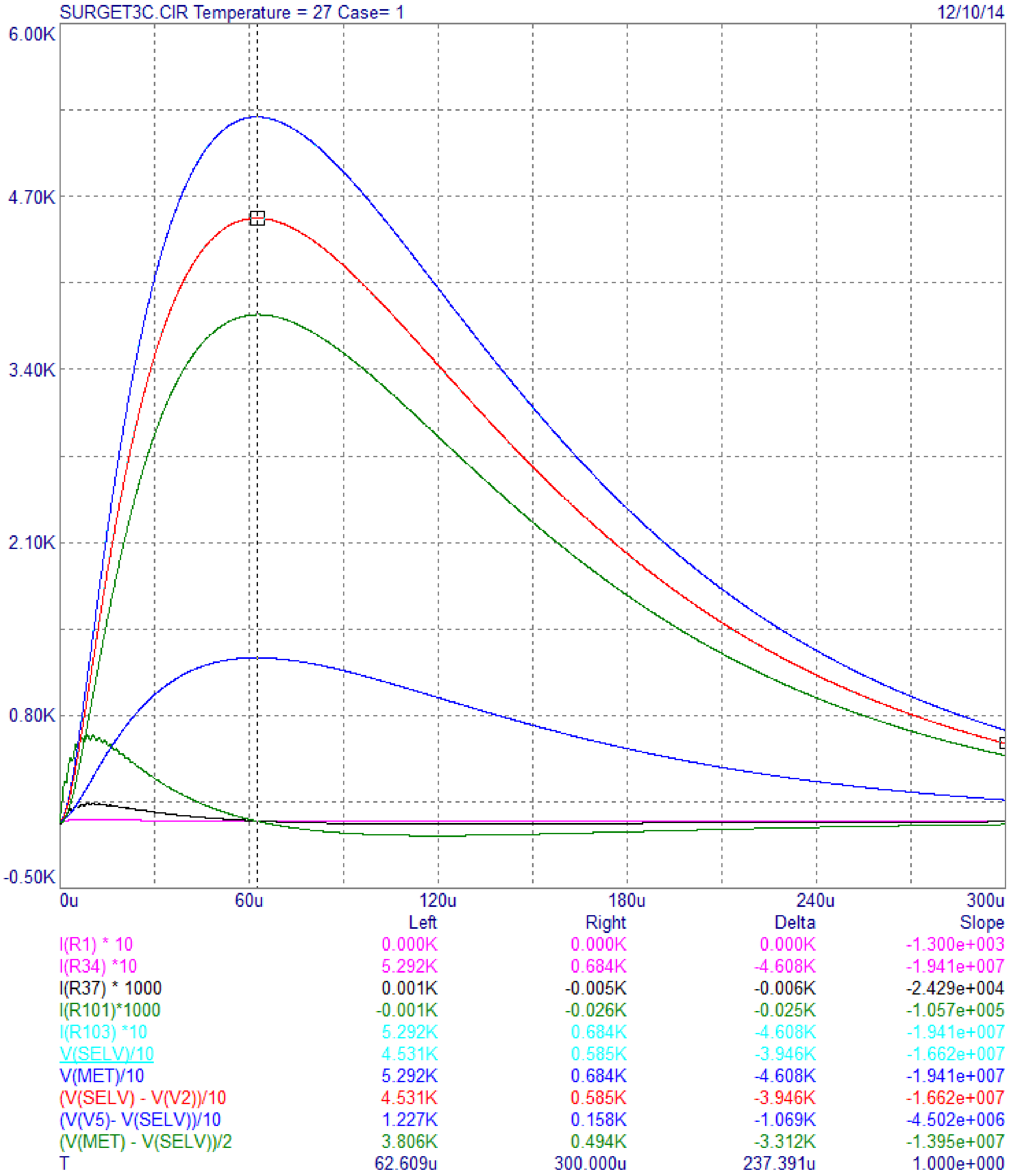
Figure A.45 – Simulation of a lightning strike to the telecommunication network (TT or IT power system with floating equipment without primary protection)

Description of the components related to Figure A.45:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).

- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other fourteen 100 Ω electrodes in parallel seen by 14 customers.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- C5 and R109 represent the telecommunication input circuit.
- L18, R39, C1 and C2 represent the power transformer.
- MOV X7 is an inherent protection MOV in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 and R5, L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.46 shows results for simulation of a lightning strike to the telecommunication network (TT or IT power system with floating equipment without primary protection).



	Left	Right	Delta	Slope
I(R1) * 10	0.000K	0.000K	0.000K	-1.300e+003
I(R34) *10	5.292K	0.684K	-4.608K	-1.941e+007
I(R37) * 1000	0.001K	-0.005K	-0.006K	-2.429e+004
I(R101)*1000	-0.001K	-0.026K	-0.025K	-1.057e+005
I(R103) *10	5.292K	0.684K	-4.608K	-1.941e+007
V(SELV)/10	4.531K	0.585K	-3.946K	-1.662e+007
V(MET)/10	5.292K	0.684K	-4.608K	-1.941e+007
(V(SELV) - V(V2))/10	4.531K	0.585K	-3.946K	-1.662e+007
(V(V5)- V(SELV))/10	1.227K	0.158K	-1.069K	-4.502e+006
(V(MET) - V(SELV))/2	3.806K	0.494K	-3.312K	-1.395e+007
T	62.609u	300.000u	237.391u	1.000e+000

Figure A.46 – Results for simulation of a lightning strike to the telecommunication network (TT or IT power system with floating equipment without primary protection)

Customer earth 100 Ω

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 53 kV and 45 kV. Voltages of these magnitudes may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 45 kV. The voltage between the telecommunication network ports and SELV is 12 kV. The voltage between the two ports is 57 kV. As this is well in excess of the port-to-port isolation of 5 kV and 6 kV respectively, a flashover will occur.

The current injected into the power network is less than 1 A. The current entering the earth via the local earth point is 5.3 kA. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 5.3 kA.

The Ethernet port is subjected to a voltage peak of 3.8 kV. The current is much less than 1 A. This level of voltage magnitude may cause damage to the Ethernet port of both pieces of the equipment.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering on the telecommunication port will exit via the power and Ethernet ports damaging all ports.

Customer earth 2 Ω

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 29 kV and 8.5 kV.

The power transformer stress (primary to secondary surge voltage) is 29 kV. The voltage between the telecommunication network ports and the SELV circuit is 16 kV. As this is well in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the power network is less than 1 A. The current entering the earth via the local earth point is 4.3 kA. The working telecommunication pair contributes less than 1 A. The screen of the cable contributes 4.3 kA.

The Ethernet port is subjected to a voltage peak of 10.5 kV. The current is much less than 1 A. This level of voltage magnitude is likely to result in damage to the Ethernet port of both pieces of the equipment.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering the telecommunication port will exit via the power and Ethernet ports damaging all ports.

No path to earth at the customer premises

The SELV circuit and the MET voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, rise respectively to 48 kV and 59 kV. Voltages of these magnitudes may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 48 kV. The voltage between the telecommunication network ports and the SELV circuit is 12 kV. The voltage between the two ports is 60 kV. As this is well in excess of the port-to-port isolation, a flashover will occur and damage to these ports will occur.

The current injected into the power network is less than 1 A.

The Ethernet port is subjected to a voltage peak of 5.8 kV. The current is much less than 1 A. This level of voltage magnitude is likely to result in damage to the Ethernet port of both pieces of the equipment.

The surge voltage on the telecommunication conductors will cause a flashover of the telecommunication isolation components, the mains transformer and the Ethernet port. The resulting surge current entering on the telecommunication port will exit via the power and Ethernet ports damaging all ports.

A.3.3.2.2 With primary protection

The simulation model is shown in Figure A.47.

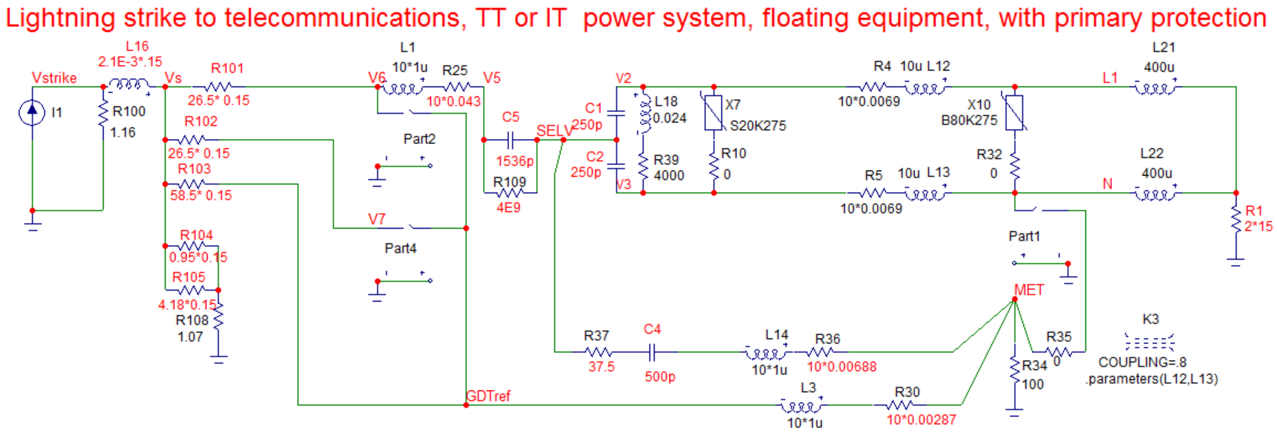
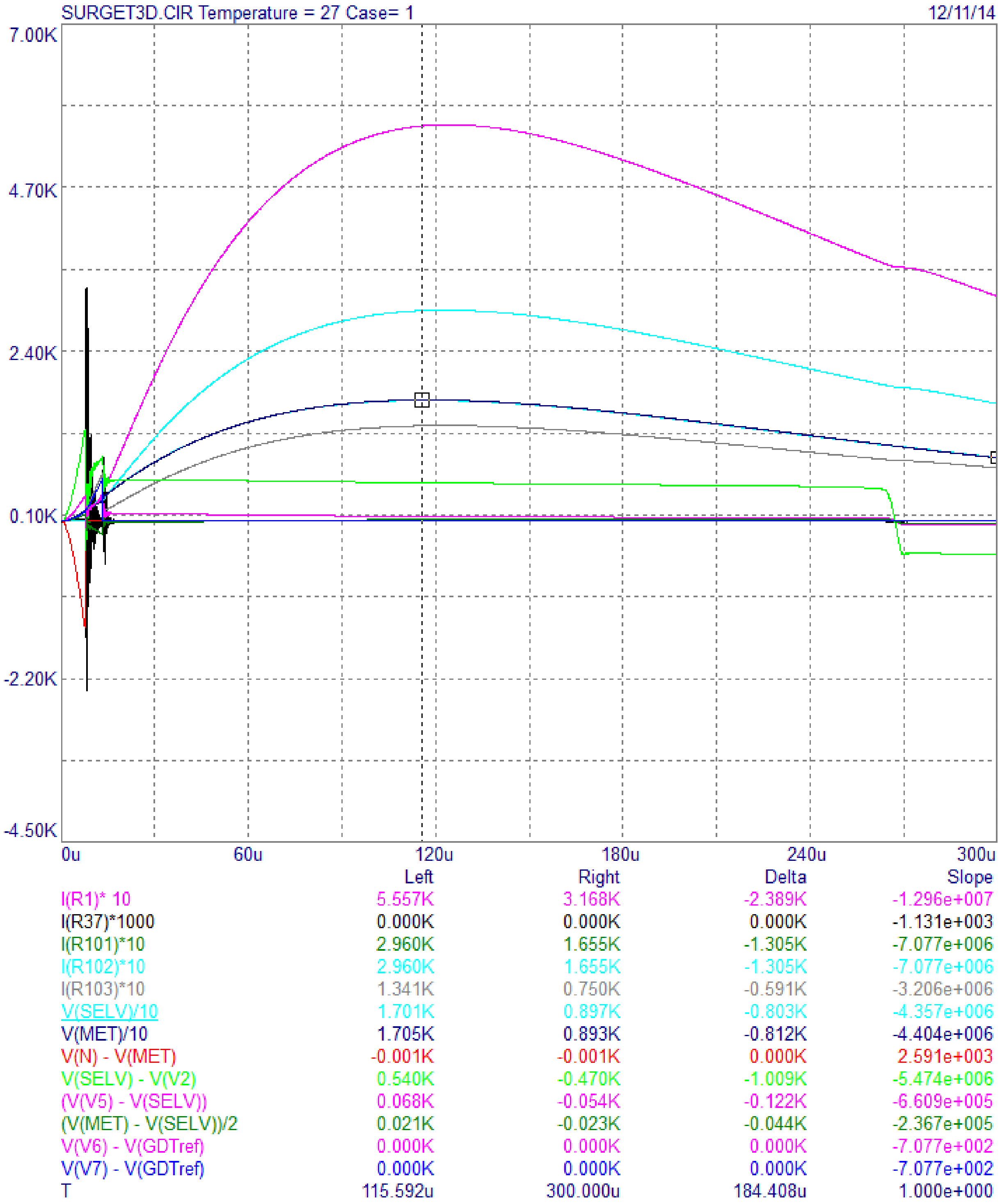


Figure A.47 – Simulation of a lightning strike to the telecommunication network (TT or IT power system with floating equipment and primary protection)

Description of the components related to Figure A.47:

- R100 represents the resistance to earth at the lightning strike point and subsequent flashover points.
- L16 represents the inductance of the telecommunication cable.
- R101 is the working pair resistance.
- R102 is the spare pair resistance.
- R103 represents that part of the cable screen resistance seen by the customer (it is assumed that 15 customers are using the screen).
- R104 is the resistance of the other 28 pairs in parallel.
- R105 is that part of the screen resistance seen by the other 14 customers.
- R108 represents the resistance to earth of the other fourteen 100 Ω electrodes in parallel seen by 14 customers.
- Part2 is a primary protector on the working pair which operates at 600 V.
- Part4 is a primary protector on the spare pair which operates at 600 V.
- R25 and L1 represent the internal 10 metre telecommunication cable between the line termination (LT) and the equipment.
- C5 and R109 represent the telecommunication input circuit.
- L18, R39, C1 and C2 represent the power transformer.
- MOV X7 is an inherent protection MOV in the equipment.
- R37 and C4 represent the impedance of the Ethernet circuit taking into account the associated equipment.
- L14 and R36 represent 10 metres of Ethernet cable.
- R4 and R5, L12 and L13 simulate a 10 metre length of flat power cable with a coupling factor of 0.8.
- L21 and L22 simulate the length of power line back to the HV/LV transformer.
- R1 is the resistance of the LV/HV transformer earth seen by the customer.

Figure A.48 shows result for simulation of a lightning strike to the telecommunication network (TT or IT power system with floating equipment and primary protection).



	Left	Right	Delta	Slope
I(R1)* 10	5.557K	3.168K	-2.389K	-1.296e+007
I(R37)*1000	0.000K	0.000K	0.000K	-1.131e+003
I(R101)*10	2.960K	1.655K	-1.305K	-7.077e+006
I(R102)*10	2.960K	1.655K	-1.305K	-7.077e+006
I(R103)*10	1.341K	0.750K	-0.591K	-3.206e+006
V(SELV)/10	1.701K	0.897K	-0.803K	-4.357e+006
V(MET)/10	1.705K	0.893K	-0.812K	-4.404e+006
V(N) - V(MET)	-0.001K	-0.001K	0.000K	2.591e+003
V(SELV) - V(V2)	0.540K	-0.470K	-1.009K	-5.474e+006
(V(V5) - V(SELV))	0.068K	-0.054K	-0.122K	-6.609e+005
(V(MET) - V(SELV))/2	0.021K	-0.023K	-0.044K	-2.367e+005
V(V6) - V(GDTref)	0.000K	0.000K	0.000K	-7.077e+002
V(V7) - V(GDTref)	0.000K	0.000K	0.000K	-7.077e+002
T	115.592u	300.000u	184.408u	1.000e+000

Figure A.48 – Result for simulation of a lightning strike to the telecommunication network (TT or IT power system with floating equipment and primary protection)

Customer earth 100 Ω

The primary protectors, on the working and unused telecommunication pairs, operate at 600 V. The spark gap between the neutral and the MET operates at 1.5 kV.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to 17 kV. Voltage of this magnitude may result in flashovers.

The power transformer stress (primary to secondary surge voltage) is 1.3 kV. The voltage between the telecommunication network ports and SELV is 360 V. The voltage between the two ports is less than 2 kV. As this is less than the basic port to port isolation of 5 kV a flashover will not occur.

The current injected into the power network is 557 A. The current entering the earth via the local earth point is 171 A. The working pair contributes 297 A. The spare pair terminated on a primary protector contributes 297 A. The screen of the cable contributes 134 A.

The Ethernet port is subjected to a voltage peak of 186 V. The peak current is 4.2 A.

The equipment is protected.

Customer earth 2 Ω

The primary protectors, on the working and unused telecommunication pairs, operate at 600 V. The spark gap between the neutral and the MET operates at 1.5 kV.

The MET and the SELV circuit both rise to 8 kV with respect to remote earth and the local earth outside the area of influence of the current entering the earth. This is a significant reduction with respect to that which occurred with a 100 Ω customer earth.

The power transformer stress (primary to secondary surge voltage) is 1.68 kV. The voltage between the telecommunication network ports and SELV is 603 V. The voltage between the two ports is 2.3 kV. As this is less than the basic port to port isolation of 5 kV a flashover will occur.

The current injected into the power network is 257 A. The current entering the earth via the local earth point is 4 kA. The working pair contributes 1.73 kA. The spare pair terminated on a primary protector contributes 1.73 kA. The screen of the cable contributes 785 A.

The Ethernet port is subjected to a voltage peak of 359 V. The peak current is 4.6 A.

The equipment is protected.

No path to earth at the customer premises

The primary protectors, on the working and unused telecommunication pairs, operate at 600 V. The spark gap between the neutral and the MET operates at 1.5 kV.

Because of the relatively high resistance to earth, the MET and the SELV circuit voltages, with respect to the remote earth and the local earth outside the area of influence of the current entering the earth, both rise to around 17.4 kV.

The power transformer stress (primary to secondary surge voltage) is 1.2 kV. The voltage between the telecommunication network ports and SELV is 328 V. The voltage between the two ports is less than 2 kV. As this is less than the basic port to port isolation of 5 kV a flashover will occur.

The current injected into the power network is 571 A. The working pair contributes 233 A. The spare pair contributes 233 A. The screen of the cable contributes 105 A.

The Ethernet port is subjected to a voltage peak of 186 V. The current peak is 4.7 A.

The equipment is protected.

A.4 Waveform after primary protection and coordination

There is a perception that the current waveform after the primary protector has a much shorter half time compared with the current waveform conducted by the primary protector. The waveform at the downstream SPD is more or less influenced by:

- whether the primary protector is a switching or clamping type SPD;
- the magnitude of the surge current;
- the firing/clamping voltage of the primary protector;

- the length of the bond wire connecting the primary protector to the MET;
- the length and gauge of the cabling between the primary protector and the equipment.

The following figures describe this influence for both the mains and the telecommunication circuits.

The mains circuit considered is a TN-C-S type system which has a neutral earth link. The installation has a phase to neutral/earth MOV type primary SPD followed by MOV type SPDs at the equipment connected phase to neutral, phase to earth and neutral to earth. The neutral to earth MOV does not conduct current in this type of installation. The installation has one metre of 2.5 mm² connecting leads for the primary SPD and 10 metres of 2.5 mm² cabling connecting the primary protector to the equipment SPDs. The telecommunication line primary protectors are connected to the MET with a 10 m 6 mm² bond wire. The simulation has been performed using the waveform and current used in clause A.2 i.e., 5 kA 5/75 µs surge to the line /PEN conductors in parallel with a shunt 20 Ω resistance to earth raising the power line voltage to 100 kV without an equipment load to simulate a strike to the power line a hundred metres or more from the structure.

The telecommunication bond wire is reduced to 1.5 m and the simulation repeated if coordination is not achieved.

A.4.1 Strike to power line

Figure A.49 shows the simulation of a lightning strike to TN-C or TN-C-S power system with earthed equipment with primary protection.

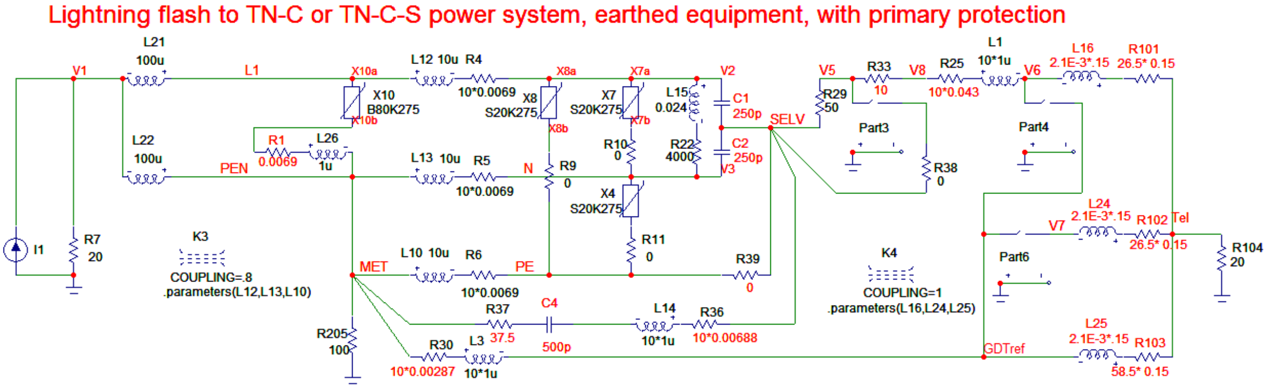
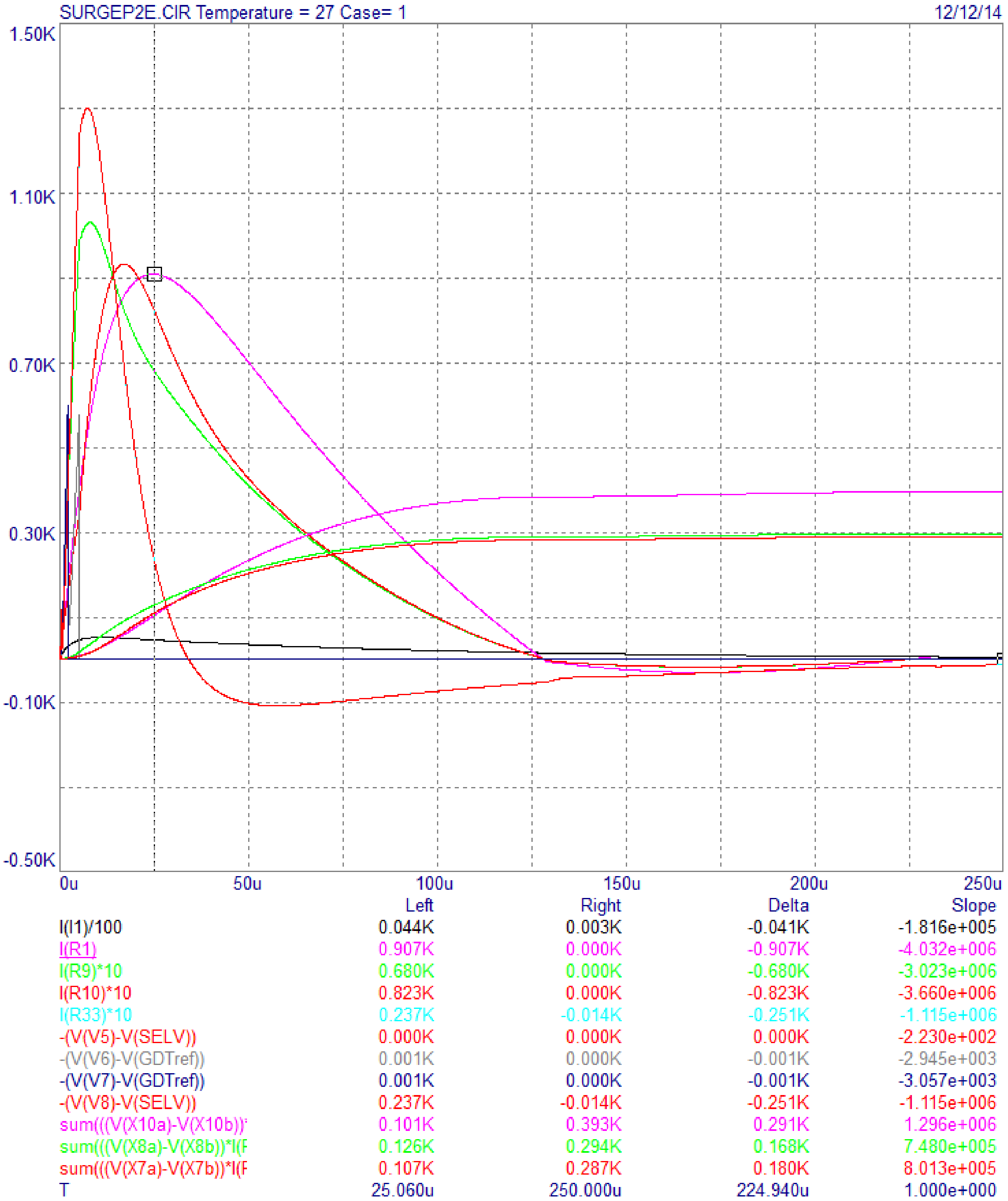


Figure A.49 – Simulation of a lightning strike to TN-C or TN-C-S power system with earthed equipment with primary protection

This circuit is identical to that shown in Figure A.11 except that R1 and L26 have been added to include the effects of the cabling for X10. The total connecting cable length is 1 m.

Figure A.50 shows result for simulation of a lightning strike to TN-C or TN-C-S power system with earthed equipment with primary protection.



	Left	Right	Delta	Slope
I(I1)/100	0.044K	0.003K	-0.041K	-1.816e+005
I(R1)	0.907K	0.000K	-0.907K	-4.032e+006
I(R9)*10	0.680K	0.000K	-0.680K	-3.023e+006
I(R10)*10	0.823K	0.000K	-0.823K	-3.660e+006
I(R33)*10	0.237K	-0.014K	-0.251K	-1.115e+006
-(V(V5)-V(SELV))	0.000K	0.000K	0.000K	-2.230e+002
-(V(V6)-V(GDTref))	0.001K	0.000K	-0.001K	-2.945e+003
-(V(V7)-V(GDTref))	0.001K	0.000K	-0.001K	-3.057e+003
-(V(V8)-V(SELV))	0.237K	-0.014K	-0.251K	-1.115e+006
sum(((V(X10a)-V(X10b))	0.101K	0.393K	0.291K	1.296e+006
sum(((V(X8a)-V(X8b))*I(F	0.126K	0.294K	0.168K	7.480e+005
sum(((V(X7a)-V(X7b))*I(F	0.107K	0.287K	0.180K	8.013e+005
T	25.060u	250.000u	224.940u	1.000e+000

Figure A.50 – Result for simulation of a lightning strike to TN-C or TN-C-S power system with earthed equipment with primary protection

The lightning strike current has a time to half value of 75 µs. The current in the primary MOV has a peak of 907 A and a half time of 75 µs. The energy rating of this MOV is 1'400 J for a 2 ms pulse. The energy dissipated is just under 40 J.

The current in the equipment L1 – PE MOV has a peak of 103 A and a half time of 39 µs. The energy dissipation is just under 3 J. The current in the equipment L1 – N MOV has a peak of 93 A and a half time of 47 µs. The energy dissipation is just under 2.9 J. The inherent protection MOVs have an energy rating of 260 J for a 2 ms pulse.

A primary MOV installed to protect against a direct strike should be a Type 1 device. These are tested with a 10/350 waveform. Normally, Type 2 SPDs are used downstream of the primary MOV. These are tested with an 8/20 waveform. It can be seen that while the primary MOV has to withstand a longer waveform it is not significantly longer (75 µs versus 47 µs for the L1 – N MOV).

For a direct strike to the power line more than 100 m from the structure, the MOVs are well within their ratings. The MOV connected phase to neutral, is a 275 V 80 kA MOV. This size MOV has been used as protection against direct strikes (to service lines) is being considered. However, the highest stress occurs for a direct strike to the building and this is not considered in this edition of the Recommendation.

The voltage between the telecommunication port and SELV is 1300 V and the current entering the port is 130 A. This current is well in excess of the coordination test current of 60 A in [ITU-T K.21] and damage to the port may occur. Coordination has not been achieved with a 10 m telecommunications bonding conductor.

With a 1.5 m telecommunication bonding conductor the voltage between the telecommunication port and SELV reduces to 432 V and the current entering the port is 43.2 A. As this current is less than the coordination test current of 60 A in [ITU-T K.21], coordination has been achieved with a 1.5 m telecommunication bonding conductor.

To show the effectiveness of using an MSPD to protect the equipment, Part7 has been added to simulate the GDT in the MSPD. Extra MOVs have not been added as these would directly parallel X4, X7 and X8.

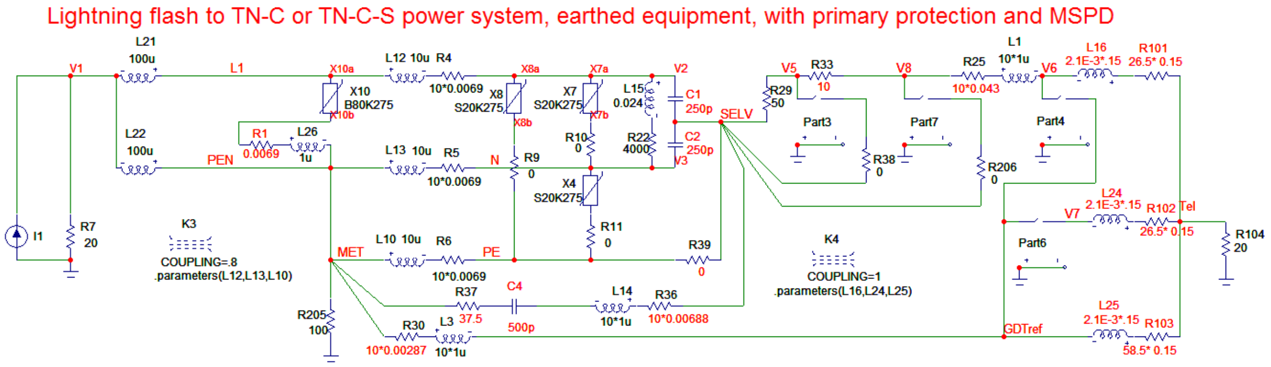
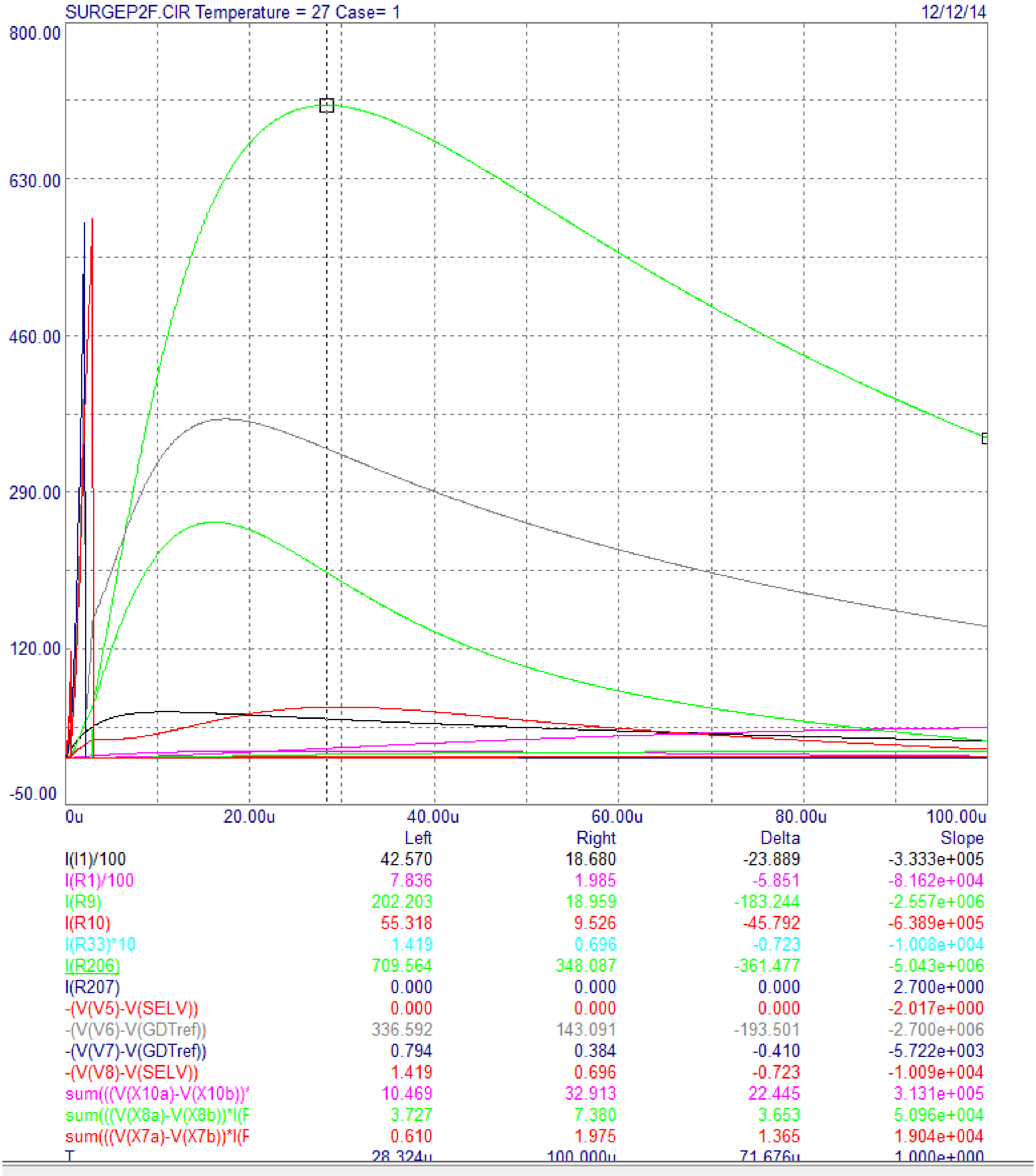


Figure A.51 – Simulation of a lightning strike to TN-C or TN-C-S power system with earthed equipment with primary protection and MSPD



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                              Left        Right        Delta          Slope
I(I1)/100                   42.570       18.680      -23.889     -3.333e+005
I(R1)/100                    7.836        1.985       -5.851     -8.162e+004
I(R9)                      202.203       18.959     -183.244     -2.557e+006
I(R10)                      55.318        9.526      -45.792     -6.389e+005
I(R33)*10                    1.419        0.696       -0.723     -1.008e+004
I(R206)                    709.564      348.087     -361.477     -5.043e+006
I(R207)                      0.000        0.000        0.000      2.700e+000
-(V(V5)-V(SELV))             0.000        0.000        0.000     -2.017e+000
-(V(V6)-V(GDTref))         336.592      143.091     -193.501     -2.700e+006
-(V(V7)-V(GDTref))           0.794        0.384       -0.410     -5.722e+003
-(V(V8)-V(SELV))             1.419        0.696       -0.723     -1.009e+004
sum(((V(X10a)-V(X10b))'     10.469       32.913       22.445      3.131e+005
sum(((V(X8a)-V(X8b))*I(F     3.727        7.380        3.653      5.096e+004
sum(((V(X7a)-V(X7b))*I(F     0.610        1.975        1.365      1.904e+004
T                          28.324u     100.000u      71.676u      1.000e+000
```

Figure A.52 – Result of a simulation of a lightning strike to TN-C or TN-C-S power system with earthed equipment with primary protection and MSPD

The addition of the MSPD limits the telecommunication port to SELV voltage to the MSPD GDT firing voltage which in this case is 600 V and the maximum current entering the port is 60 A. This protects the telecommunication port and this voltage is unaffected by the length of the telecommunication bonding conductor. The length of the telecommunication bonding conductor only affects the current conducted by the MSPD GDT. In this case (10 m telecommunication bonding conductor) the MSPD GDT conducts 710 A and the current has a time to half value of 76 µs. This would require a Class 2 GDT which has a 5 kA 8/20 rating, see Table 5 of [ITU-T K.12].

Interestingly, the MSPD GDT prevents the primary protector on the working pair from operating. The voltage on the primary protector rises to 445 V and then drops to 32 V when the primary protector on the spare operates and then slowly rises to 152 V at which point the MSPD GDT operates. The voltage then rises to a maximum of 368 V.

In conclusion,

- Adding an MSPD will protect the equipment.
- The telecommunications GDT in the MSPD needs to have a 5 kA 8/20 rating.

A.4.2 Strike to the telecommunication cable

Figure A.53 shows the simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protection.

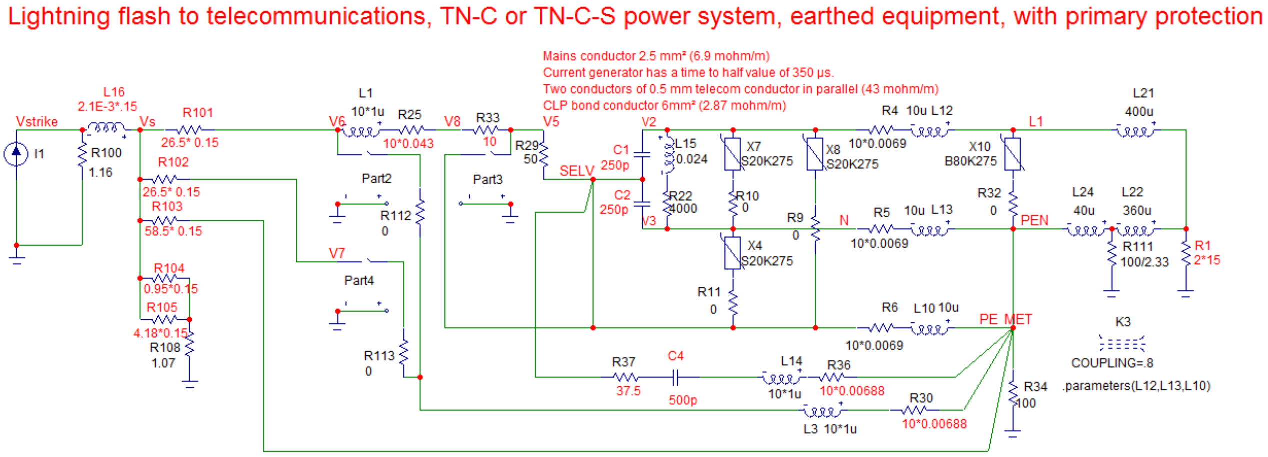
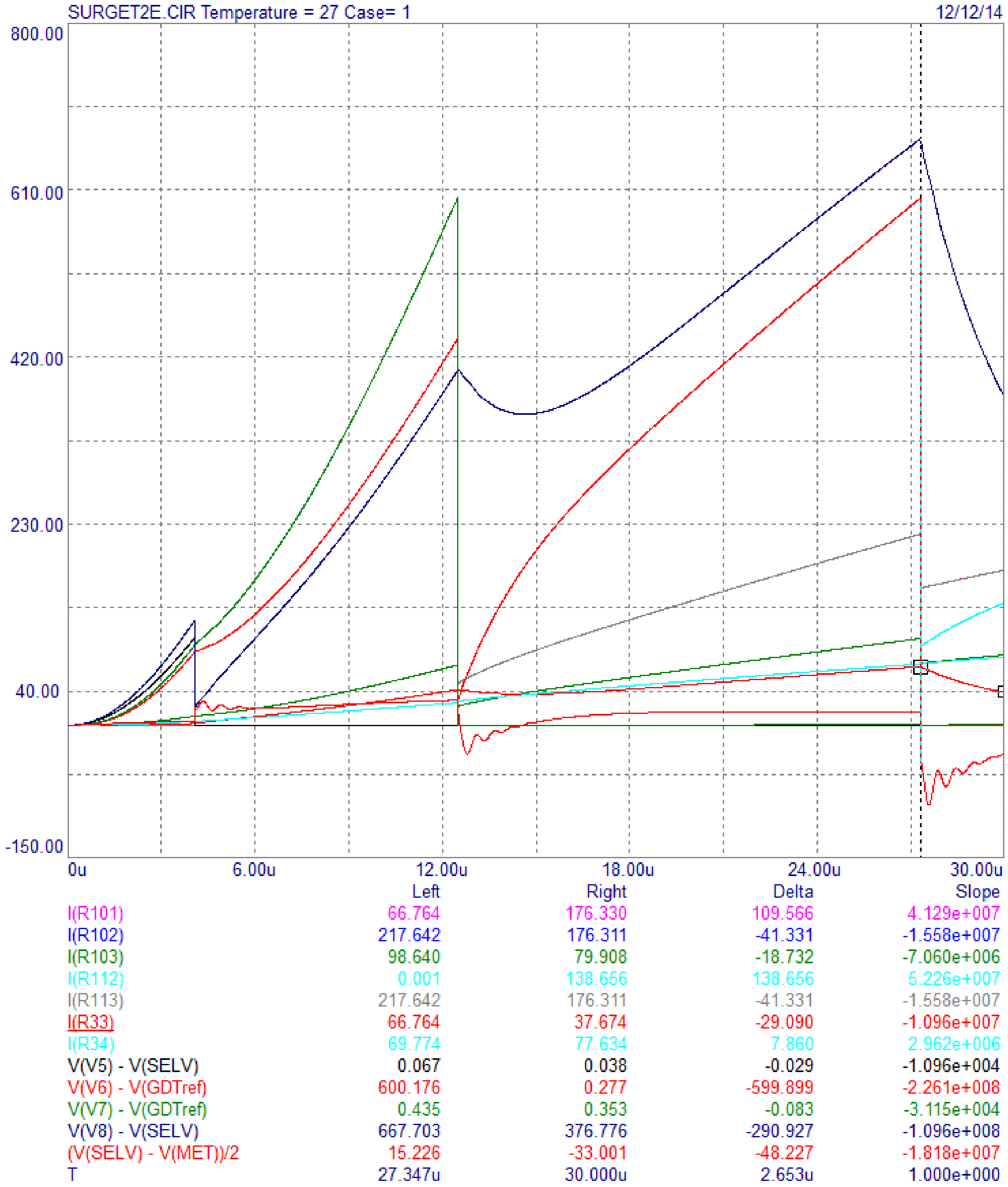


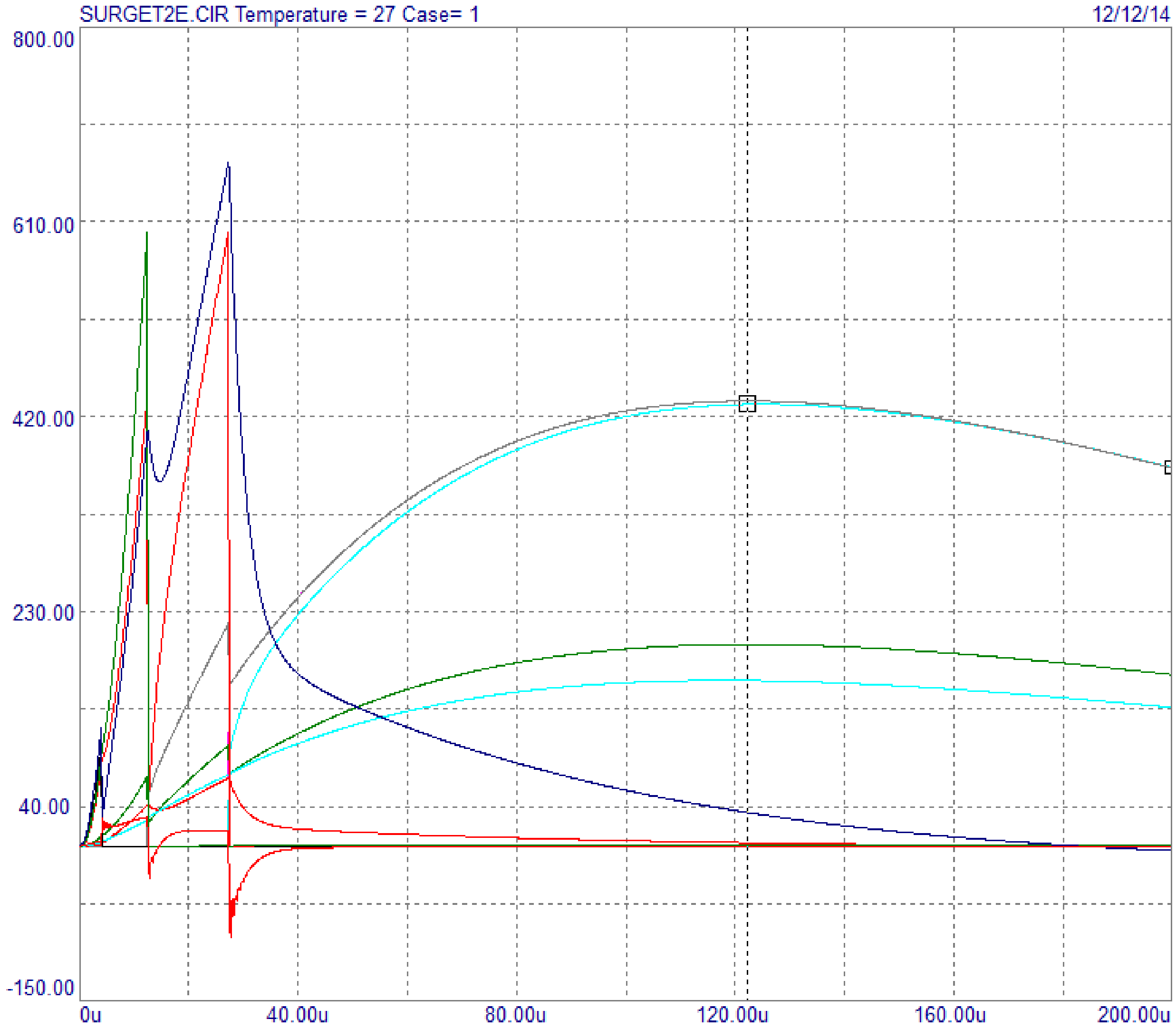
Figure A.53 – Simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protection

Figures A.54 and A.55 show results for simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protections.



	Left	Right	Delta	Slope
I(R101)	66.764	176.330	109.566	4.129e+007
I(R102)	217.642	176.311	-41.331	-1.558e+007
I(R103)	98.640	79.908	-18.732	-7.060e+006
I(R112)	0.001	138.656	138.656	5.226e+007
I(R113)	217.642	176.311	-41.331	-1.558e+007
I(R33)	66.764	37.674	-29.090	-1.096e+007
I(R34)	69.774	77.634	7.860	2.962e+006
V(V5) - V(SELV)	0.067	0.038	-0.029	-1.096e+004
V(V6) - V(GDTref)	600.176	0.277	-599.899	-2.261e+008
V(V7) - V(GDTref)	0.435	0.353	-0.083	-3.115e+004
V(V8) - V(SELV)	667.703	376.776	-290.927	-1.096e+008
(V(SELV) - V(MET))/2	15.226	-33.001	-48.227	-1.818e+007
T	27.347u	30.000u	2.653u	1.000e+000

Figure A.54 – Result for simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protection



```
                          Left        Right       Delta       Slope
I(R101)                434.538      369.654     -64.884  -8.379e+005
I(R102)                434.536      369.655     -64.882  -8.379e+005
I(R103)                196.940      167.535     -29.406  -3.797e+005
I(R112)                431.257      370.085     -61.172  -7.899e+005
I(R113)                434.536      369.655     -64.882  -8.379e+005
I(R33)                   3.281       -0.430      -3.711  -4.793e+004
I(R34)                 161.656      135.642     -26.014  -3.359e+005
V(V5) - V(SELV)          0.003        0.000      -0.004  -4.793e+001
V(V6) - V(GDTref)        0.863        0.740      -0.122  -1.580e+003
V(V7) - V(GDTref)        0.869        0.739      -0.130  -1.676e+003
V(V8) - V(SELV)         32.813       -4.305     -37.118  -4.793e+005
(V(SELV) - V(MET))/2    -0.617       -0.235       0.383   4.940e+003
T                     122.562u     200.000u     77.438u   1.000e+000
```

Figure A.55 – Result for simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protection

The simulation has been performed with a 10 m and a 1.5 m telecommunication bond conductor. The results for the short bond conductor are in parenthesis. Figures A.54 and A.55 are the same simulation but displayed with different time scales.

For a direct strike to the cable, 150 m from the structure, the peak current entering the telecommunication port of the equipment is 67 (54) A. With the short bond wire the current is less than 60 A and coordination has been achieved. With the long bond wire the current is more than 60 A and coordination has not been achieved. The peak current in the primary protector connected to the working pair is 431 (435) A with a half value of 320 µs. According to [ITU-T K.12] the primary protector should survive.

To show the effectiveness of using an MSPD to protect the equipment Part7 has been added to simulate the GDT in the MSPD. Extra MOVs have not been added as these would directly parallel X4, X7 and X8.

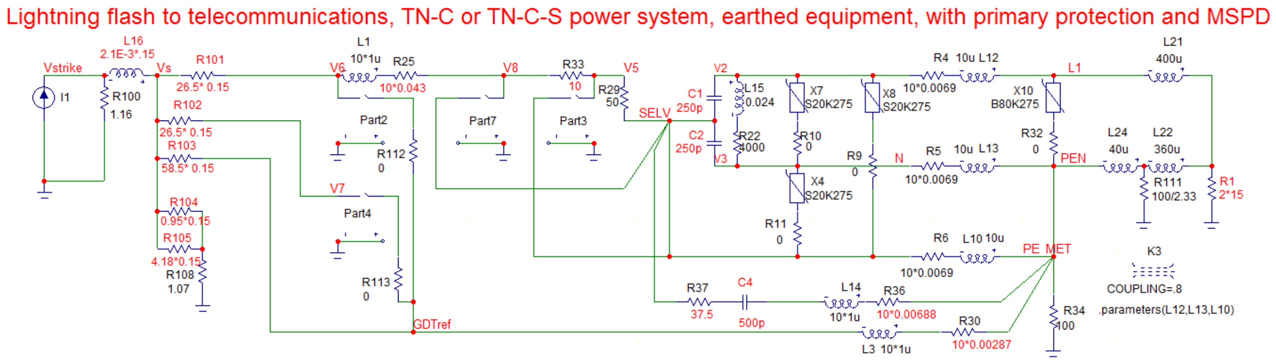
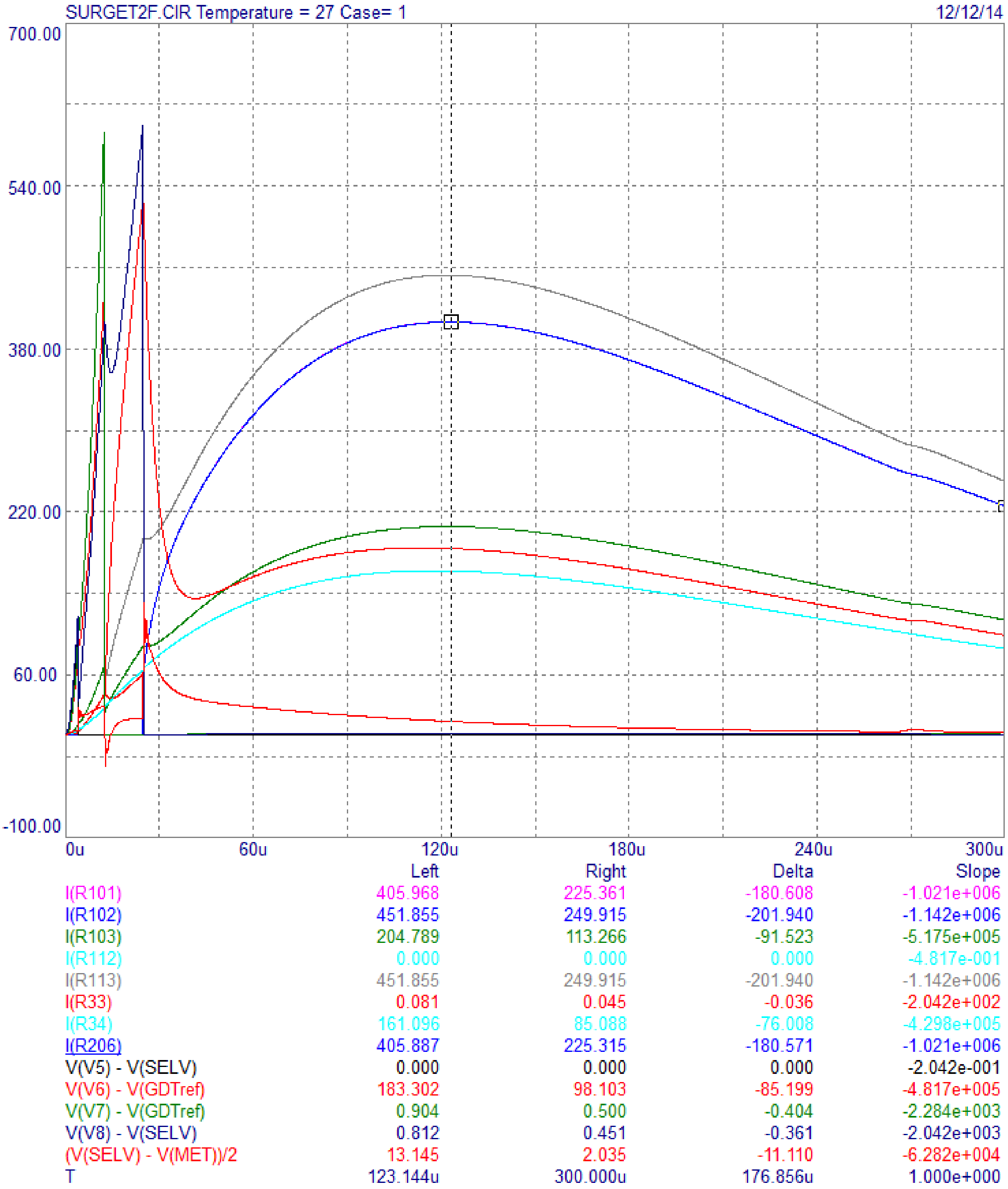


Figure A.56 – Result of a simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protection and MSPD



```
                         Left       Right      Delta       Slope
I(R101)               405.968     225.361   -180.608  -1.021e+006
I(R102)               451.855     249.915   -201.940  -1.142e+006
I(R103)               204.789     113.266    -91.523  -5.175e+005
I(R112)                 0.000       0.000      0.000  -4.817e-001
I(R113)               451.855     249.915   -201.940  -1.142e+006
I(R33)                  0.081       0.045     -0.036  -2.042e+002
I(R34)                161.096      85.088    -76.008  -4.298e+005
I(R206)               405.887     225.315   -180.571  -1.021e+006
V(V5) - V(SELV)         0.000       0.000      0.000  -2.042e-001
V(V6) - V(GDTref)     183.302      98.103    -85.199  -4.817e+005
V(V7) - V(GDTref)       0.904       0.500     -0.404  -2.284e+003
V(V8) - V(SELV)         0.812       0.451     -0.361  -2.042e+003
(V(SELV) - V(MET))/2   13.145       2.035    -11.110  -6.282e+004
T                    123.144u    300.000u   176.856u   1.000e+000
```

Figure A.57 – Result of a simulation of a lightning strike to telecommunication cable for TN-C or TN-C-S power system with earthed equipment with primary protection and MSPD

The addition of the MSPD limits the telecommunication port to SELV voltage to the MSPD GDT firing voltage which in this case is 600 V and the maximum current entering the port is 60 A. This protects the telecommunications port and this voltage is unaffected by the length of the telecommunication bonding conductor. The length of the telecommunication bonding conductor only affects the current conducted by the MSPD GDT. In this case (10 m telecommunication bonding conductor) the MSPD conducts 406 A and the current has a time to half value of 320 µs. This would require a Class 1 GDT with a 2.5 kA 8/20 rating, see Table 5 of [ITU-T K.12].

Interestingly the MSPD GDT prevents the primary protector on the working pair from operating. The voltage on the primary protector rises to 440 V and then drops to 33 V when the primary protector on the spare operates and then rises to 526 V at which point the MSPD GDT operates. The voltage then slowly falls down to 134 and then slowly rises to a maximum of 184 V.

In conclusion,

- Adding an MSPD will protect the equipment.
- The telecommunications GDT in the MSPD needs to have at least a 2.5 kA 8/20 rating. A 5 kA rating is preferred.

A.4.3 Strike to the structure

This is under study.

Appendix I

Calculation of cable current in a telecommunication line versus distance from the strike point

(This appendix does not form an integral part of this Recommendation.)

I.1 Introduction

This clause provides information on the levels of current in a telecommunication line to assist in selecting the rating for SPDs and to determine the appropriate surge generator model for the simulation circuits in Annex A.

The current available at the customer premises depends on the following:

- the peak current of the lightning strike;
- the resistance to earth at the strike point;
- the earth resistivity;
- the cable length between the strike point and the customer premises;
- the number of pairs in the cable conducting the current and their resistance;
- whether the cable is screened and the screened connected to the premises earth;
- the resistance to earth at the customer premises taking into account the influence of other earthed services; and
- whether primary protection is installed.

The peak current of the lightning strike can vary from a few kA up to 200 kA or higher. Fifty per cent of the lightning strikes have peak current of 30 kA or less. It could therefore be useful to perform simulations for a 30 kA and a 100 kA lightning strike.

The resistance to earth at the strike point depends on the current entering the earth. This will be considered in the simulations to calculate the current available at the customer premises.

Earth resistivity on the other hand can also vary from a few Ω.m to greater than a 1'000 Ω.m. As the interest is in the maximum current available, simulations are performed for 1'000 Ω.m. It is the resistivity at the strike point which affects the current in the cable.

In traditional telecommunication networks, cable lengths could vary from a few hundred metres to many km. In modern telecommunication networks, the cable length is becoming shorter. Simulations are performed for a cable length of 200 m as this causes the maximum current.

Cables in the main cable network may have hundreds of pairs with conductor diameters as small as 0.32 mm. In the rural network, conductor diameters could be as large as 0.9 mm, but 0.64 mm and 30 pair cable are common. Screened cables are common as this screen is often a water barrier. A 30 pair MB cable may have 0.64 mm conductors and a moisture barrier screen of 0.15 mm thickness, giving a screen resistance of 3.9 ohm/km. As a rural network is likely to be exposed to the more severe environment, a 30 pair 0.64 mm conductor size MB cable is used in the simulations. The cable simulated is assumed to have a screen resistance of 3.9 Ω/km and a conductor resistance of 53 Ω/km (0.64 mm conductor). This gives a parallel resistance of 0.72 Ω/km.

The resistance to earth at the customer premises depends on the type of power network and whether the building itself has a low resistance to earth and is bonded to the premises earth electrode. A single earth stake could have a resistance as high as few hundred ohms. A single earth stake resistance of 100 Ω has been chosen. To reduce the level of a.c. earth potential rise (EPR) under fault conditions, it is common for the medium voltage (MV)/LV transformer and the LV neutral conductor to have a 1 ohm or less resistance to earth. In this Recommendation, it is assumed that the neutral has a resistance to earth of 2 Ω. In the case of an IT power distribution system, this would be via a surge limiter as it is required to protect the LV network against faults in the MV/LV transformer. [b-Mansoor] uses 10 Ω for the customer earth and 5 Ω for the power distribution transformer. Using 10 Ω for customer earth is probably realistic when the current entering the earth via the electrode is tens of kA. It is considered more realistic to use 100 Ω when the current is less than 1 kA. If one assumes that residential customers have two pairs each, then 15 customers would share a 30 pair cable. The different types of power system can be described as having:

- Phase conductors (L1, L2 and L3), a neutral conductor (N) and an earth conductor (PE) in the distribution network. This illustrates a TN-S power system. There is no structure earth electrode shown in [IEC 60950-1], however there is likely to be a path to earth at the structure.
- Phase conductors (L1, L2 and L3) and a combined PE and neutral conductor (PEN) in the distribution network. There is a neutral-earth link and this is connected to a structure earth electrode. The PEN conductor is split into a N and PE conductor after the neutral-earth link. This illustrates TN-C-S and TN-C power systems.
- Phase conductors (L1, L2 and L3) and a neutral conductor (N) in the distribution network. The neutral is not connected to the structure earth electrode, but the PE is. There is no link between the PE and the neutral. This illustrates an IT and TT power system.

The installation of telecommunication primary protectors is often determined by the administration or the network operator. In some countries earthed primary protection is usually always installed, e.g., in the United States of America (USA), never installed or installed according to some form of risk assessment.

Clause 7.3 of [ITU-T K.67] provides some information on the current in a line or cable due to a direct strike to the line or cable. It considers two possible situations when considering the magnitude of the current entering a structure and these are:

1) the striking point is far away from the structure;
2) the striking point is close to the structure.

For case 1), [ITU-T K.67] states that the total line current is given, in the worst case, by twice the line to earth breakdown voltage divided by the line surge impedance (e.g., 2 × 100 kV/400 Ω = 500 A). [ITU-T K.67] assumes that the surge impedance of an aerial line or cable is 400 Ω and that the breakdown voltage of an aerial line or underground cable is 100 kV. For an underground cable the surge impedance drops to 100 Ω and the current increases to 2 kA.

It does not provide any information on the distances involved and it also calculates the current assuming that that the line or cable behaves like a transmission line and that the current will double as a result of a 100 % reflection. This appendix attempts to provide more information on the magnitudes of the current involved and whether one needs to consider the line as a transmission line.

It would be useful to know the profile of the current magnitude as the strike point moves away from the structure. This will enable the SPD rating to be selected according to the level of protection required.

I.2 Resistance to earth at the strike point

A lightning strike to earth can be represented by the schematic shown in Figure I.1.

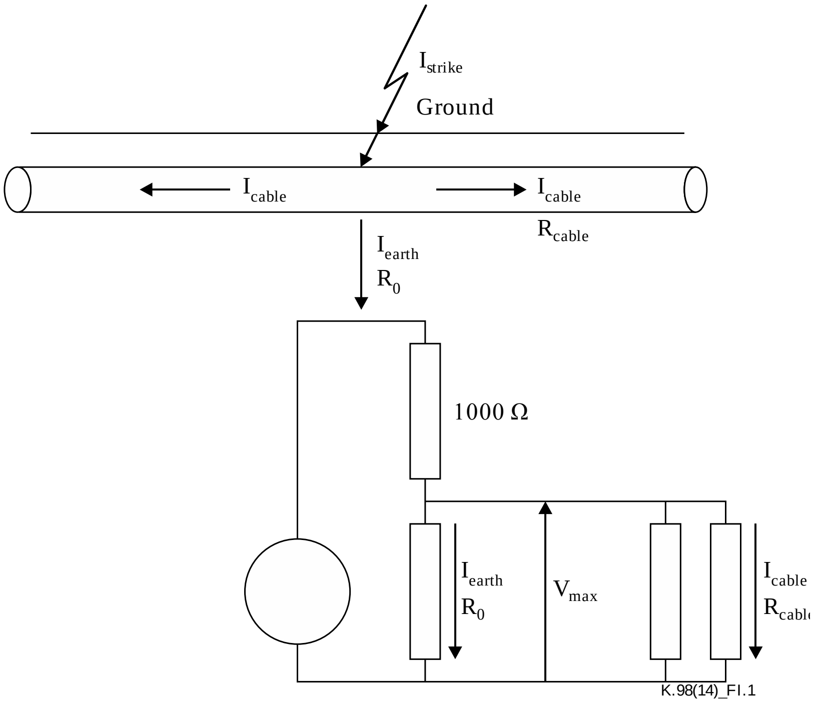


Figure I.1 – Equivalent circuit of a lightning strike

The resistance Ro can be determined by using Equation 1 from page 33 of chapter 3 of the ITU-T lightning handbook [b-CCITT].

$$R_o = \sqrt{\frac{\rho * E_0}{2 * \pi * I_{earth}}}$$ [Equation 1, page 33 of chapter 3 of the ITU-T lightning handbook]

where:

ρ is in Ω.m
E_0 is in kV/m
I is in kA

E_0 is in kV/m and has the values given in Table I.1.

Table I.1 – Value of E_0 versus resistivity

ρ (Ω.m)	E_0 (kV/m)
100	250
1'000	500

For ρ = 100 Ω.m and I_{earth} = 100 kA, R_o = 6.3 Ω.

For ρ = 1'000 Ω.m and I_{earth} = 100 kA, R_o = 28.2 Ω.

For ρ = 1'000 Ω.m and I_{earth} = 10 kA, R_o = 89.2 Ω.

I.3 Equivalent circuit of a strike to earth

While the lightning strike itself is a current generator, the discharge resistance to earth creates a voltage generator with an output resistance of 5 – 100 Ω considering the likely range of currents and resistivities.

For the purposes of calculation, it is assumed that the resistance to earth is either 25 Ω or 100 Ω. For currents up to 30 kA, a 100 Ω resistance to earth is used and for strikes from 30 kA to 100 kA, a 25 Ω resistance to earth will be used.

To determine the magnitude of current entering a structure, it is assumed that the primary protector for both the telecommunication line and the power line has a resistance of 0.001 Ω under surge conditions.

The calculations are performed using a 5/75 µs waveform and using a lumped element simulation. This waveform is in line with [b-CICRÉ TB 549] and refers to the most common downward negative first stroke.

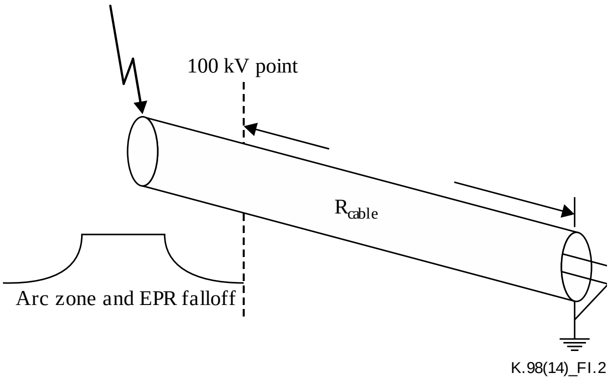


Figure I.2 – Schematic of a lightning strike to a shielded underground cable

When lightning strikes the earth within the arc distance of an underground cable, a flashover will occur to the cable. Typically, the plastic sheath of a cable will have a breakdown voltage in the order of 100 kV. The plastic insulated conductor will have a breakdown voltage to the screen and to other conductors in the order of 10 kV. At the strike point, the conductors and the screen are effectively shorted together. It is assumed that there is no shield (guard) wire as described in [ITU-T K.47]. It is also assumed that there are no other metallic buried conductors near the cable.

In Figure I.2, only one direction of the cable is shown. In reality, the cable will go to the customer premises and back to the node. In this case, a proportion of the lightning current will be conducted to earth and the rest will be shared between both directions of the cable. The arc distance between the strike point and the cable is determined in the Lightning Handbook. Depending on the value of the soil resistivity and the magnitude of the strike current, the arc zone could be in the order of 10 m.

When current is conducted to earth, an earth potential rise (EPR) occurs. The maximum voltage at the point of the strike is U_o. The formula to calculate U_o is given in [b-CCITT] which is copied below.

$$U_o = \sqrt{\frac{\rho * I * E_o}{2 * \pi}}$$

where E_o is given in Table I.1. Outside the arc zone the value of the voltage EPR is also given in the Lightning Handbook and the formula is given below.

$$V_{EPR} = \frac{\rho * I_{earth}}{2 * \pi * x}$$

The voltage on the cable with respect to earth is nominally equal to or less than the breakdown voltage of the cable which is assumed to be 100 kV. However, within the EPR zone, the voltage with respect to remote earth, e.g., at the customer premises, is 100 kV + V_{EPR}. With this information, it is possible to predict the available current at the customer structure with respect to how far along the cable that lightning strikes.

For ρ = 1'000 Ω.m and a current of 50 kA entering the earth at the strike point, the 100 kV EPR point is 80 m from the strike point. The almost continuous cable breakdowns could almost double this distance. Therefore, the minimum cable length chosen for the simulations will be 200 m. For cable lengths less than 200 m, a different method needs to be used to calculate the cable current.

I.4 Simulation results for a 30 pair 0.64 mm MB cable with a zero ohm resistance to earth at the customer end

The first stage is to determine the model of the underground cable to allow a lumped element simulation to be performed. This has been done for a 30 pair 0.64 mm MB cable direct buried rural cable. As discussed above, the simulations are performed for a short circuit and an open circuit at the customer end.

The velocity of propagation for the MB cable is slower than for the PE cable due to the order of magnitude higher capacitance for the MB cable.

Consider a 200 m MB cable. This is modelled in Figure I.3 for a short circuit at the customer end.

The sections consisting of components like R1, L1, L2 and R2 are intended to mimic the frequency-dependent series impedance of the buried cable. This circuit has been validated against exact formulations for the frequency range from DC up to 100 kHz.

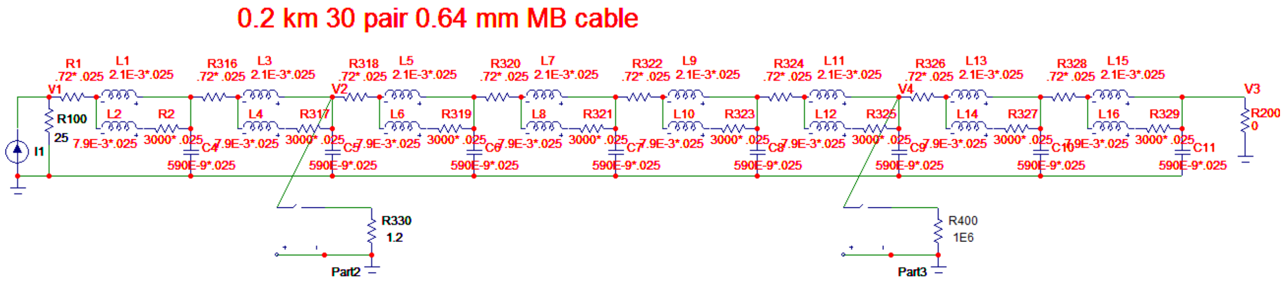
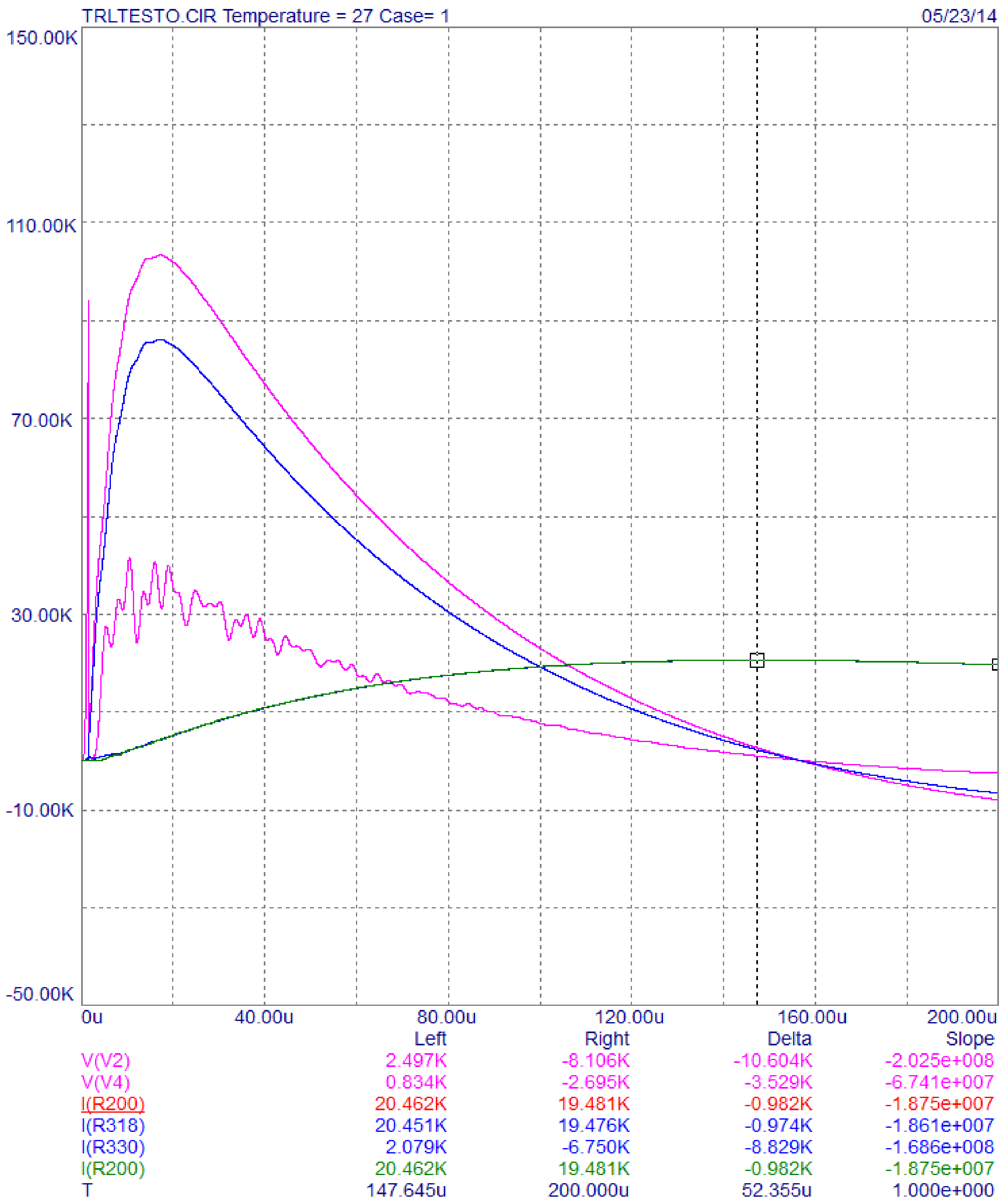


Figure I.3 – Simulation model for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA lightning strike (short circuit at the customer end)

Part2 is a switch to simulate a cable breakdown to earth when the cable voltage exceeds 100 kV 50 m from the strike point. Part3 is a switch to simulate a joint breakdown to earth 50 m from the customer end when the cable voltage exceeds 20 kV. In the simulation below the strike current is 100 kA 5/75 µs. The resistance to earth at the strike point is 25 Ω. The voltage at the injection point is around 1.7 MV. In this case cable breakdowns will occur until the voltage is 100 kV or less.

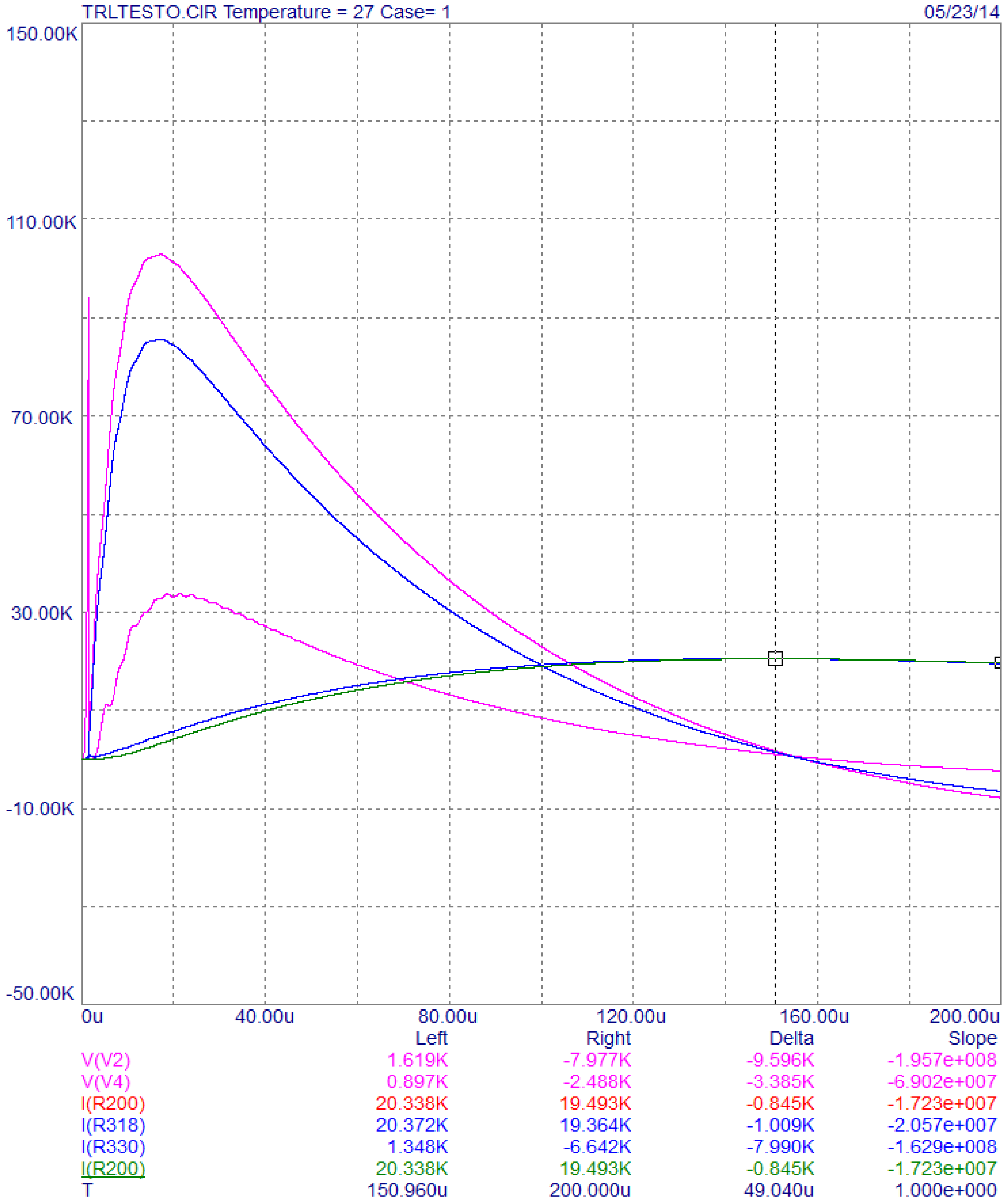
Taking into account cable breakdowns a 1.2 Ω resistance is required to pull the cable down to 100 kV. In reality the resistances to earth at breakdown points are likely to be in the order of tens of Ω so many breakdown points would be required. The voltage 50 m from the customer end is 41 kV. The current at the customer end is 20.5 kA, see Figure I.4. The pair current is equal to 2.7 % of the cable current and is 553 A.



```
                    Left       Right       Delta       Slope
V(V2)              2.497K    -8.106K    -10.604K   -2.025e+008
V(V4)              0.834K    -2.695K     -3.529K   -6.741e+007
I(R200)           20.462K    19.481K     -0.982K   -1.875e+007
I(R318)           20.451K    19.476K     -0.974K   -1.861e+007
I(R330)            2.079K    -6.750K     -8.829K   -1.686e+008
I(R200)           20.462K    19.481K     -0.982K   -1.875e+007
T                147.645u   200.000u     52.355u    1.000e+000
```

Figure I.4 – Simulation result for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA strike taking into account cable breakdowns (short circuit at the customer end)

Taking into account joint breakdowns above 20 kV, the voltage at the joint breakdown point is now a maximum of 33 kV assuming a joint breakdown resistance of 20 Ω. The peak cable current at the customer end is 20.3 kA, see Figure I.5. The peak pair current is 2.7 % of the cable current and is equal to 548 A. The risetime of this current is approximately 80 µs due to smearing off the waveform.



	Left	Right	Delta	Slope
V(V2)	1.619K	-7.977K	-9.596K	-1.957e+008
V(V4)	0.897K	-2.488K	-3.385K	-6.902e+007
I(R200)	20.338K	19.493K	-0.845K	-1.723e+007
I(R318)	20.372K	19.364K	-1.009K	-2.057e+007
I(R330)	1.348K	-6.642K	-7.990K	-1.629e+008
I(R200)	20.338K	19.493K	-0.845K	-1.723e+007
T	150.960u	200.000u	49.040u	1.000e+000

Figure I.5 – Simulation result for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA strike taking into account cable and joint breakdowns (short circuit at the customer end)

Consider a 200 m MB cable. This is modelled, shown in Figure I.6, for an open circuit at the customer end.

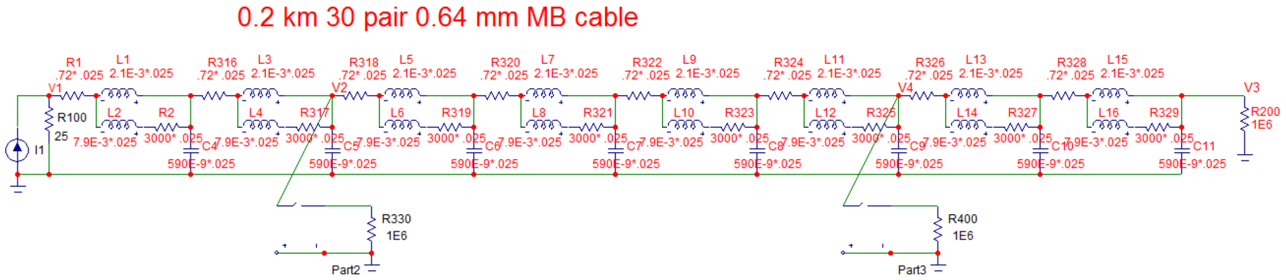
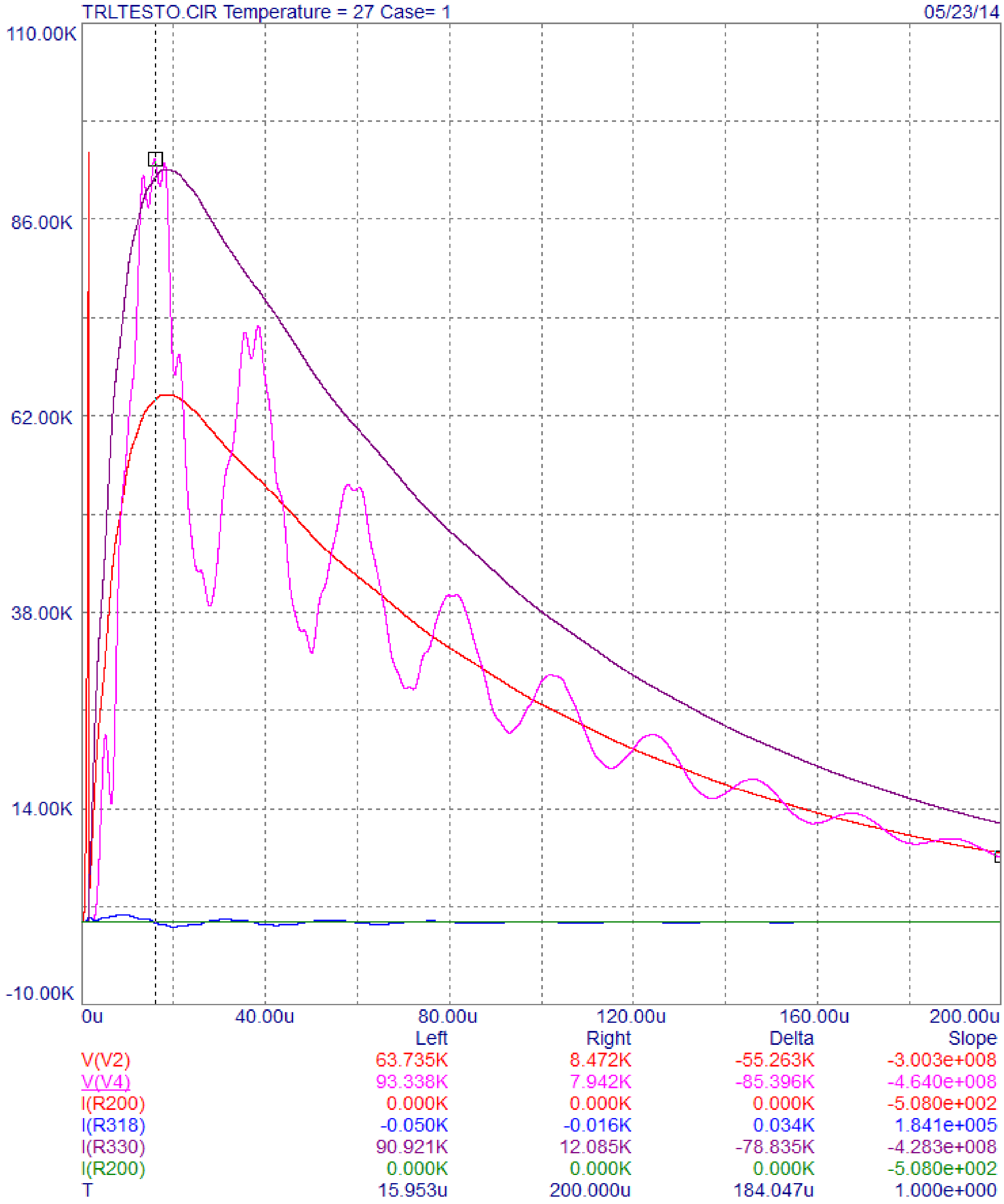


Figure I.6 – Simulation model for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA lightning strike (open circuit at the customer end)

Part2 is a switch to simulate a cable breakdown to earth when the cable voltage exceeds 100 kV 50 m from the strike point. Part3 is a switch to simulate a joint breakdown to earth 50 m from the customer end when the cable voltage exceeds 20 kV. In the simulation below the strike current is 100 kA 5/75. The resistance to earth at the strike point is 25 Ω. The voltage at the injection point is around 2.8 MV and at the customer end is 3.4 MV. In this case cable breakdowns will occur until the voltage is 100 kV or less.

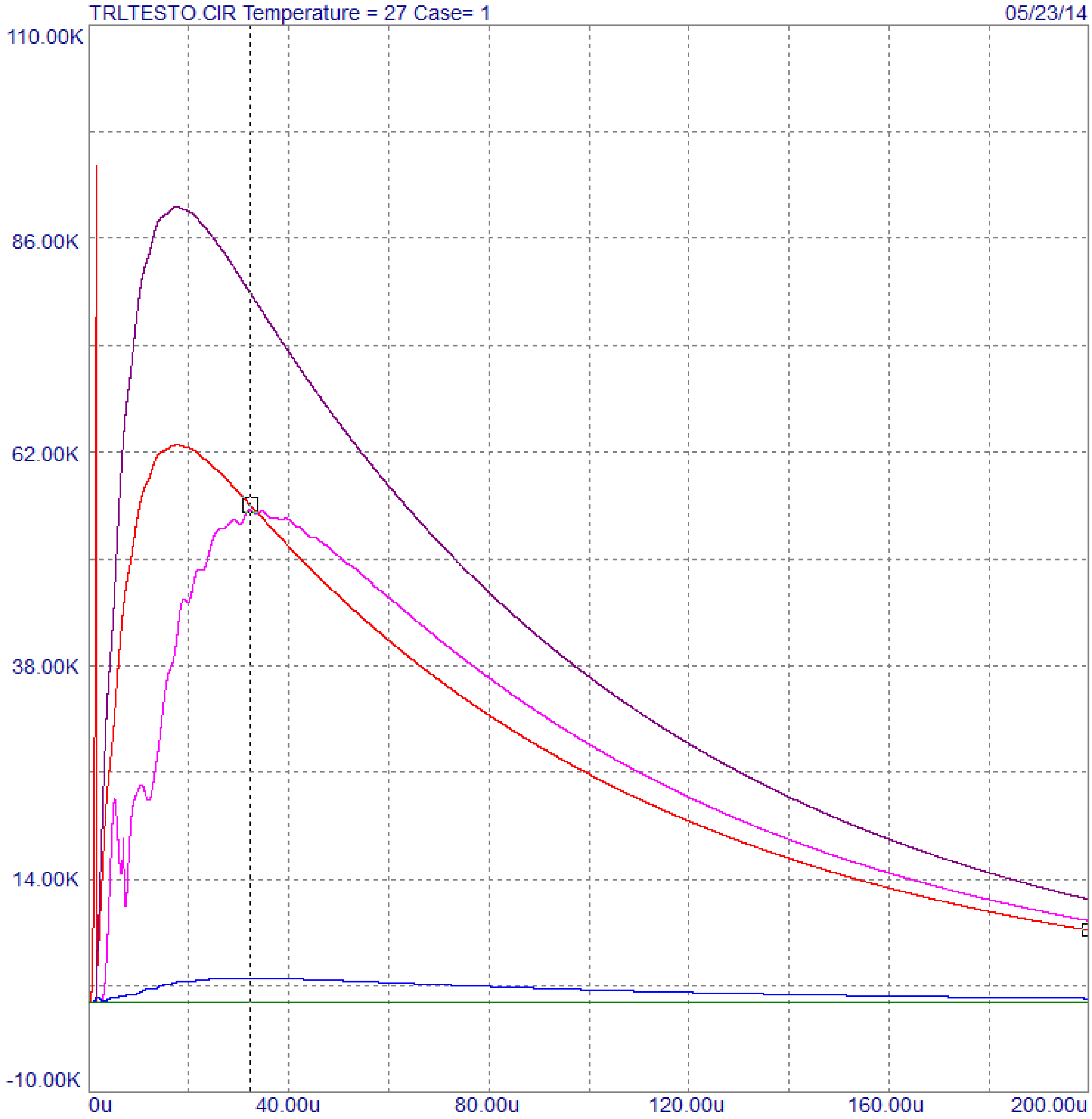
Taking into account the cable breakdowns, a 0.7 Ω resistance is required to pull the cable down to 100 kV, see Figure I.6. In reality, the resistances to earth at breakdown points are likely to be in the order of tens of Ω, so many breakdown points would be required. The voltage 50 m from the customer end is 93 kV and joint breakdowns are likely, see Figure I.7.



```
                  Left       Right      Delta      Slope
V(V2)             63.735K    8.472K     -55.263K   -3.003e+008
V(V4)             93.338K    7.942K     -85.396K   -4.640e+008
I(R200)           0.000K     0.000K     0.000K     -5.080e+002
I(R318)           -0.050K    -0.016K    0.034K     1.841e+005
I(R330)           90.921K    12.085K    -78.835K   -4.283e+008
I(R200)           0.000K     0.000K     0.000K     -5.080e+002
T                 15.953u    200.000u   184.047u   1.000e+000
```

Figure I.7 – Simulation result for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA strike taking into account cable breakdowns (open circuit at customer end)

Taking into account joint breakdowns and a 20 Ω resistance to earth reduces the voltage at the customer end to 55 kV, see Figure I.8.



	Left	Right	Delta	Slope
V(V2)	56.038K	8.153K	-47.885K	-2.854e+008
V(V4)	55.431K	9.226K	-46.205K	-2.754e+008
I(R200)	0.000K	0.000K	0.000K	-2.718e+002
I(R318)	2.753K	0.452K	-2.301K	-1.371e+007
I(R330)	79.940K	11.630K	-68.309K	-4.071e+008
I(R200)	0.000K	0.000K	0.000K	-2.718e+002
T	32.201u	200.000u	167.799u	1.000e+000

Figure I.8 – Simulation result for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA strike taking into account cable and joint breakdowns (open circuit at the customer end)

It is very difficult to accurately estimate the open circuit voltage at the customer end as it is dependent on a finite number of joint breakdowns with a resistance to earth dependent on the available current and earth resistivity. Cable breakdowns on the other hand will continue to occur until the voltage is below the cable breakdown voltage which is assumed to be 100 kV. Therefore, the open circuit voltage will be below 100 kV, but how low is difficult to estimate.

I.5 Simulation results for a 30 pair 0.4 mm non-shielded cable

Simulations for a 30 pair 0.4 mm non-shielded cable have shown that the current is lower than for a 30 pair 0.64 mm MB cable, so the results of these simulations are not included.

I.6 Conclusions drawn from the simulations

For strikes to an underground cable as close as 200 m from a structure, the peak cable current at the customer end can be as high as 20.5 kA for a 100 kA lightning strike and a short circuit at the customer end. This significant reduction in current is a result of cable and joint breakdowns. However, joint breakdowns only reduce the current from 20.5 kA down to 20.4 kA. So, joint breakdowns can be neglected for a zero ohm resistance to earth at the customer premises.

For strikes to an underground cable as close as 200 m from a structure, the peak voltage can be some tens of kV for a 100 kA strike and an open circuit at the customer end.

I.7 Calculation of cable current

- For distances greater than 200 m, a maximum cable current of 20.5 kA will be used. For a 30 pair MB cable, this is equal to 553 A per pair. This current will be used in the customer structure installations.
- For distances less than 200 m, a maximum cable current of 25 kA will be used. This is based on half the current entering the earth at the strike point and the other half of the remaining current being conducted into the cable. Half of this current will be conducted into the customer premises and the other half conducted into the telecommunication node.

In either of the cases, as stated in 6.7.3.1.3, the conductor current cannot exceed $I = 18 * a$ where I is in kA and 'a' is the cross sectional area of the conductor [mm^2]. This magnitude of the current will cause the conductor temperature to exceed 1'000 ºC and melt the conductor.

I.8 Determination of the cable surge generator.

In Figure I.9, the model has been simplified by directly shunting the cable to earth via a 1.16 Ω resistor 50 m from the strike point. This resistance value pulls the cable voltage down to 100 kV, simulating continuous cable breakdowns along the cable. Joint breakdowns are ignored as it was shown above that they have little impact for a short to earth condition at the customer end. The current at the strike point is 100 kA 5/75 µs (I1).

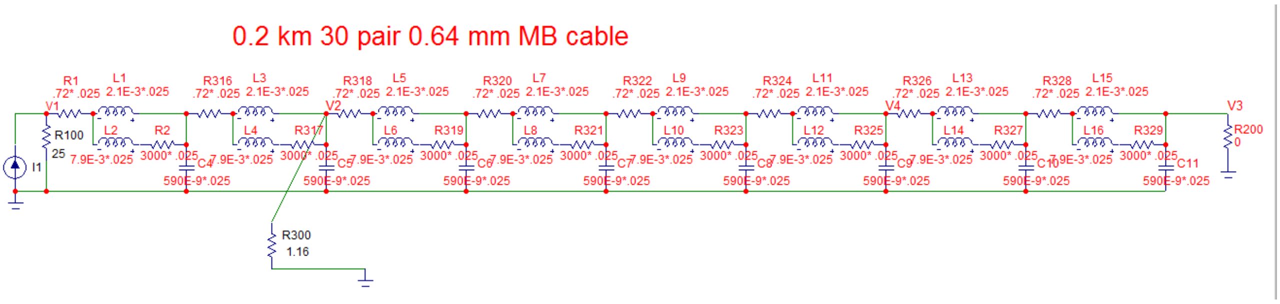
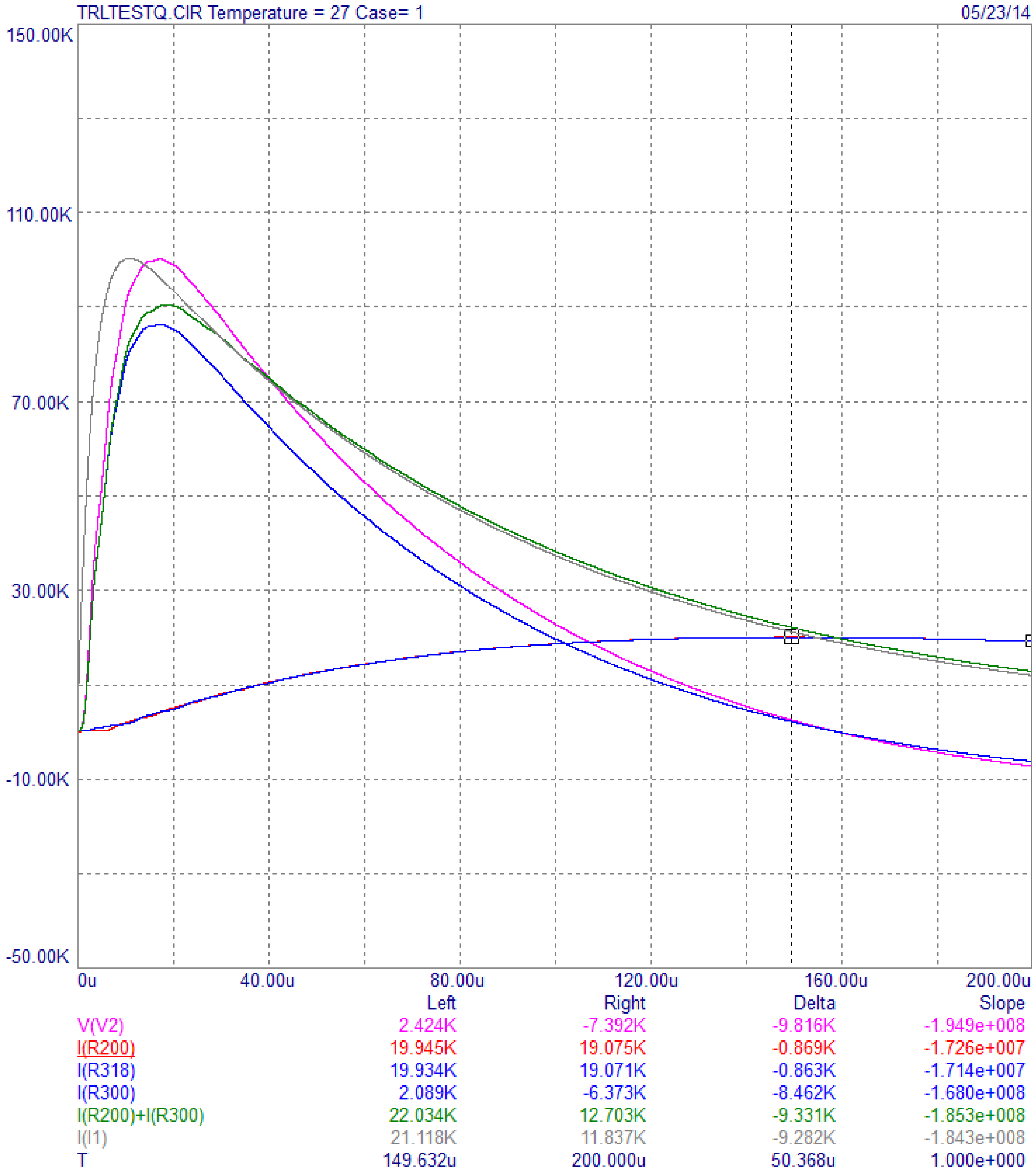


Figure I.9 – Simulation model for a 200 m length of 30 pair 0.64 mm MB cable for a 30 kA lightning strike (short circuit at customer end)

The simulation, see Figure I.10, shows that the current immediately after the shunt resistor and the current at the customer end are similar (i.e., I(R318) and I(R200)). At this shunt to earth point, the current can be defined and a simple surge model can be developed. The current at the customer end has a peak current of 20 kA, a risetime of 92 µs and a falltime of 424 µs. To develop a simpler model at the 100 kV point, one can consider the sum of currents I(R300) and I(R200). The peak current is 90.4 kA, the risetime is 8 µs and the falltime is 85 µs.



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                                  Left        Right        Delta        Slope
V(V2)                           2.424K      -7.392K      -9.816K   -1.949e+008
I(R200)                        19.945K      19.075K      -0.869K   -1.726e+007
I(R318)                        19.934K      19.071K      -0.863K   -1.714e+007
I(R300)                         2.089K      -6.373K      -8.462K   -1.680e+008
I(R200)+I(R300)                22.034K      12.703K      -9.331K   -1.853e+008
I(I1)                          21.118K      11.837K      -9.282K   -1.843e+008
T                             149.632u     200.000u      50.368u    1.000e+000
```

Figure I.10 – Simulation result for a 200 m length of 30 pair 0.64 mm MB cable for a 100 kA strike taking into account cable and joint breakdowns (short circuit at customer end)

A simple surge model for a 200 m length of 30 pair 0.64 mm MB cables is shown in Figure I.11. Resistor R1 is a single pair, R2 is 29 pairs in parallel and R3 is the MB screen. The current generator has a peak current of 90.4 kA, a risetime of 8 µs and a falltime of 85 µs.

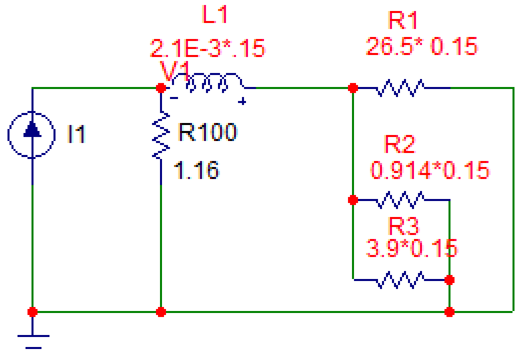
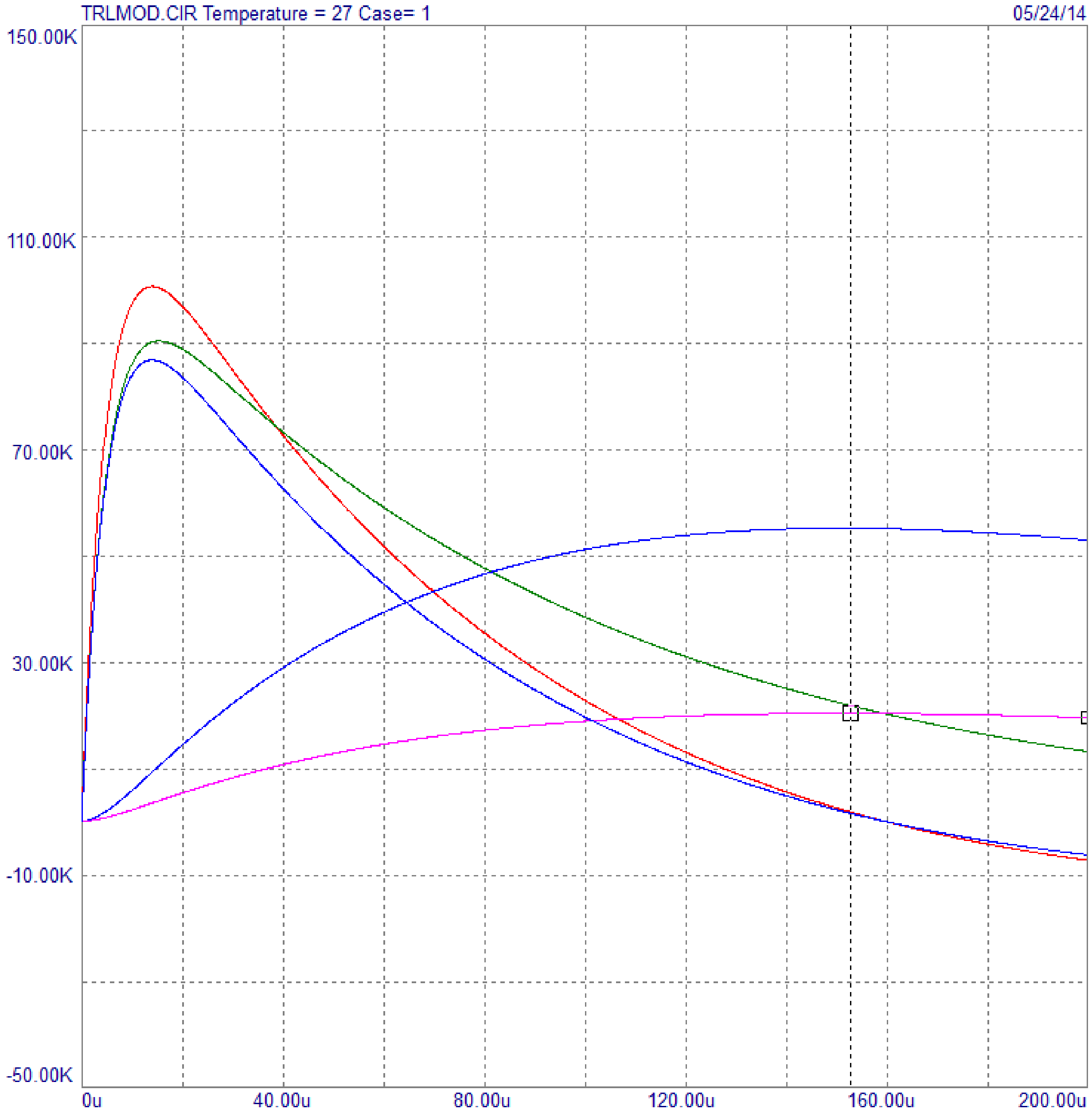


Figure I.11 – Simple surge model

The waveform of the surge current at the customer end, for a short circuit to earth at the end, is shown in Figure I.12. It can be seen that the cable current at the customer end is 20.3 kA and that the single pair current is 552 A. This model is providing a good result for a short circuit at the customer end. However, it may not be suitable for an open circuit, including an open circuit screen, at the customer end.



	Left	Right	Delta	Slope
v(V1)	1.681K	-7.349K	-9.030K	-1.926e+008
I(I1)	21.743K	13.134K	-8.609K	-1.836e+008
I(R1)*100	55.164K	52.922K	-2.241K	-4.781e+007
I(R1)+I(R2)+I(R3)	20.294K	19.469K	-0.825K	-1.759e+007
I(R100)	1.449K	-6.336K	-7.785K	-1.660e+008
T	153.117u	200.000u	46.883u	1.000e+000

Figure I.12 – Simulation result for simple surge model

Appendix II

Impact of local environment

(This appendix does not form an integral part of this Recommendation.)

In general, there is a path to earth at the building (plant) structure either by design or as a result of other needs. To ensure the safety of persons and to prevent damage to plant due to the flashovers resulting from excessive potential differences, it is necessary to provide equipotentialization by earthing and bonding. Earthing is the connection of the earth bar to earth, usually via an installed earth electrode. Bonding is the interconnection of earth electrodes and interconnection of metallic parts to minimise potential differences.

To prevent dangerous voltages occurring between conductive parts, they are bonded to the MET. To provide equipotentialization with respect to the local earth, it is also necessary to provide a local path to earth. The purpose of this clause is to determine how effective this earthing is.

Consider a single vertical rod earth electrode is connected to the MET. The voltage between the MET and the earth surrounding the electrode can be calculated. The maximum voltage with respect to remote earth is $V = I * R$. A single earth electrode is likely to have a resistance in the order of 100 Ω.

The voltage drop off around the electrode can be calculated by the formula given in Appendix I and repeated below.

$$V_{EPR} = \frac{\rho * I_{earth}}{2 * \pi * x}$$

For a current of 80 A and a 100 Ω electrode, the maximum voltage is 80 kV and this voltage drops off as shown in the Figure II.1.

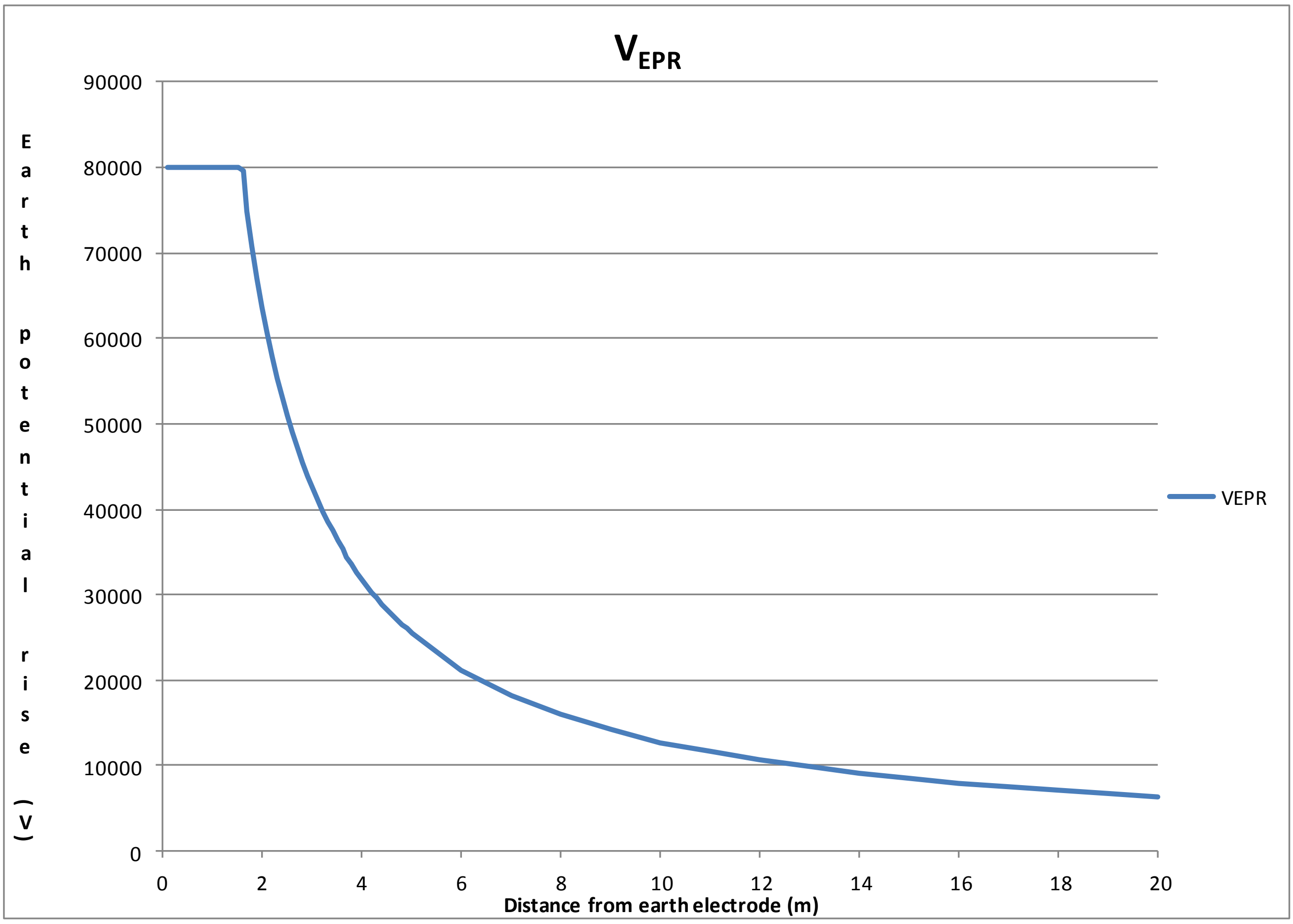


Figure II.1 – Earth potential rise around the earth electrode

It can be seen that 20 m from the electrode, this voltage is less than 10 kV. Thus, there can be a voltage of 70 kV between a cable bonded to the MET and a point 20 m from the electrode which can result in a hazardous situation for the people and the property. This shows the necessity for a ring earth for structures without a bonded reinforced concrete floor. See Figure 9.2-4 of [ITU-T K.66] and Appendix II of [b-ITU-T K.89]. It should be noted that a ring earth will not provide absolute equipotentialization within the ring, but it is significantly superior to a vertical rod electrode.

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[b-Mansoor] A. Mansoor; F. Martzloff (1998), *The effect of Neutral Earthing Practices on Lightning current Dispersion in a Low-Voltage Installation*, IEEE Transactions on Power Delivery, Vol 13, No. 3, July, pp. 783-792.

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