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SERIES K: PROTECTION AGAINST INTERFERENCE

ITU-T K.20, K.21 and K.44 – Internal DC powering interface surge testing factors

ITU-T K-series Recommendations – Supplement 15

ITU-T
International Telecommunication Union

Supplement 15 to ITU-T K-series Recommendations

ITU-T K.20, K.21 and K.44 – Internal DC powering interface surge testing factors

Summary

Recommendation ITU-T K.44 defines direct current (DC) power interface ports, which are connected by cables that are internal to the building. There are two types of DC powering system considered; floating and earth bonded. Floating DC supplies will inherently develop a common-mode surge on both conductors. Earth bonded DC supplies will inherently develop differential-mode surges on the unbonded polarity connection. Earth bonding can be a single point at either the supply powering source or the powered equipment or multipoint. If the internal cable connecting the power source and the powered load runs for any distance, the series inductance of the cable needs to be considered. Ports with electronic control could have either high or low impedance during a surge, which would produce either a voltage stress test or a current stress test. The interaction of these factors is considered in this Supplement 15 to the ITU-T K-series Recommendations to make ITU-T K.20 and ITU-T K.21 equipment designers and testers aware of the surge stress levels.

History

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1 Scope

Recommendation ITU-T K.44 defines DC power interface ports. Testing the DC powering interface means understanding the following factors:

- DC powering system type
  - floating (no earth bonding)
  - polarity earth bonded
- type of surge test
  - common-mode (port to earth)
  - differential-mode (transverse)
  - mixture of both common-mode and differential-mode
- inductance of the internal cable connecting the power source and the power load
- any surge protection functions present
- port impedance response to surge conditions

This supplement analyses these factors to make ITU-T K.20 and ITU-T K.21 equipment designers and testers aware of the surge stress levels.

2 References

[ITU-T K.44] Recommendation ITU-T K.44 (2018), *Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation*.

[ITU-T K.96] Recommendation ITU-T K.96 (2016), *Surge protective components: Overview of surge mitigation functions and technologies.*

[IEC 60050-195-05] IEC 60050-195-05, *International Electrotechnical Vocabulary – Part 195: Earthing and protection against electric shock – Section 05: Voltages and currents.*

[IEC 61340-1] IEC TR 61340-1 (2012), *Electrostatics - Part 1: Electrostatic phenomena – Principles and measurements.*

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 bonding [IEC 61340-1]: Electrical connection between two or more conducting objects that reduces the potential difference between them to an insignificant level.

3.1.2 common-mode conversion [ITU-T K.96]: Process by which a differential mode electrical signal is produced in response to a common mode electrical signal.

NOTE – This definition is based on the definition provided in [IEC 60050-161].

3.1.3 common-mode surge [ITU-T K.96]: Surge appearing equally on all conductors of a group at a given location.

NOTE 1 – The reference point for common-mode surge voltage measurement can be a chassis terminal, or a local earth/ground point.

NOTE 2 – Also known as longitudinal surge or asymmetrical surge.

3.1.4 DC power interface ports [ITU-T K.44]: The port connects to a cable, e.g., a shielded cable which provides d.c. power, e.g., –48 V.

3.1.5 differential-mode surge [ITU-T K.96]: Surge occurring between any two conductors or two groups of conductors at a given location.

NOTE 1 – The surge source maybe be floating, without a reference point or connected to reference point, such as a chassis terminal, or a local earth/ground point.

NOTE 2 – Also known as metallic surge or transverse surge or symmetrical surge or normal surge.

3.1.6 touch-current [IEC 60050-195-05]: Electric current passing through a human body or through an animal body when it touches one or more accessible parts of an installation or of equipment.

3.2 Terms defined in this Supplement

This supplement defines the following terms:

3.2.1 earth bonded DC powering: DC power system that is connected to earth at one or more points

NOTE – Single polarity DC supplies normally have one voltage polarity bonded to earth. Dual polarity supplies normally have the 0 V bonded to earth e.g., a 140 V dc. dual polarity supply has cable conductors of +70 V d.c. and –70 V d.c. with respect to earth.

3.2.2 floating DC powering: DC power system that is not bonded to earth or is bonded to earth via a high resistance.

NOTE – Floating DC powering having high resistance earth bonding designs are used to limit a powering cable conductor touch current to a level compliant to safety standard requirements.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

CDN Coupling Decoupling Network

DC Direct Current (when used as a suffix or standalone the acronym is written as d.c.)

MOV Metal Oxide Varistor

SPD Surge Protective Device

5 Conventions

None

6 DC powering supply configurations

The supply configuration options are summarized in Table 1.

Table 1 – Port types

DC Source Type	Source earth bonding	Load/feed earth bonding
Single polarity	None (floating)	None (floating)
		Positive polarity
		Negative polarity
	Positive polarity	None
		Positive polarity
	Negative polarity	None
		Negative polarity
Dual polarity (±)	0 V	None
		0 V (three wire system)
	Single polarity supply to be made balanced about earth potential by a high resistance voltage divider (essentially floating)	None

The port earth bonding of the source, or load or both, configures the supply type. By letting the equipment port bonding set the supply type, it is possible to have a generic surge test circuit for all of the above, two wire options.

7 Generic surge test circuit

Inherently, floating DC supplies will develop a common-mode surge on both supply conductors, as illustrated in Figure 1.

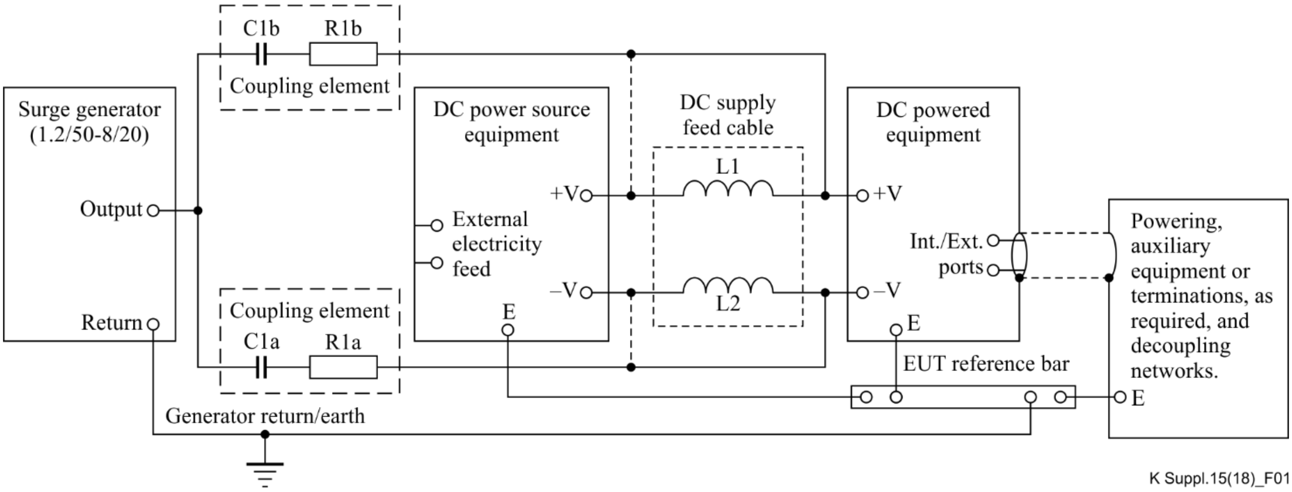

Figure 1 – Example of a common-mode surge test circuit

In Figure 1, the output 1.2/50-8/20 surge generator is split into two outputs and DC is blocked by coupling networks R1a, C1a and R1b, C1b. The common-mode surge is applied to the DC power input port of the powered equipment. Alternatively, the powering source equipment can be surge tested by applying the common-mode surge to its DC power output port, as shown by the dotted connection in Figure 1. The equipment connecting cable inductance is represented by inductors L1 and L2.

If the floating DC supply system is made into an earth bonded DC supply system, by earth bonding a supply terminal, the surge current feed to that terminal is shorted. The short leaves the other feed to apply a differential surge to the unbonded supply terminal. This situation is shown in Figure 2 where the equipment E terminal is internally connected to the −V supply terminal. As a result, the surge from the R1a, C1a coupling network is diverted to the earth bonded E terminal and the surge from the R1b, C1b coupling network is applied as a differential-mode surge to the +V terminal. Such a connection from terminal E can be made to either polarity conductor terminal, at either the power source equipment or the power equipment or at both.

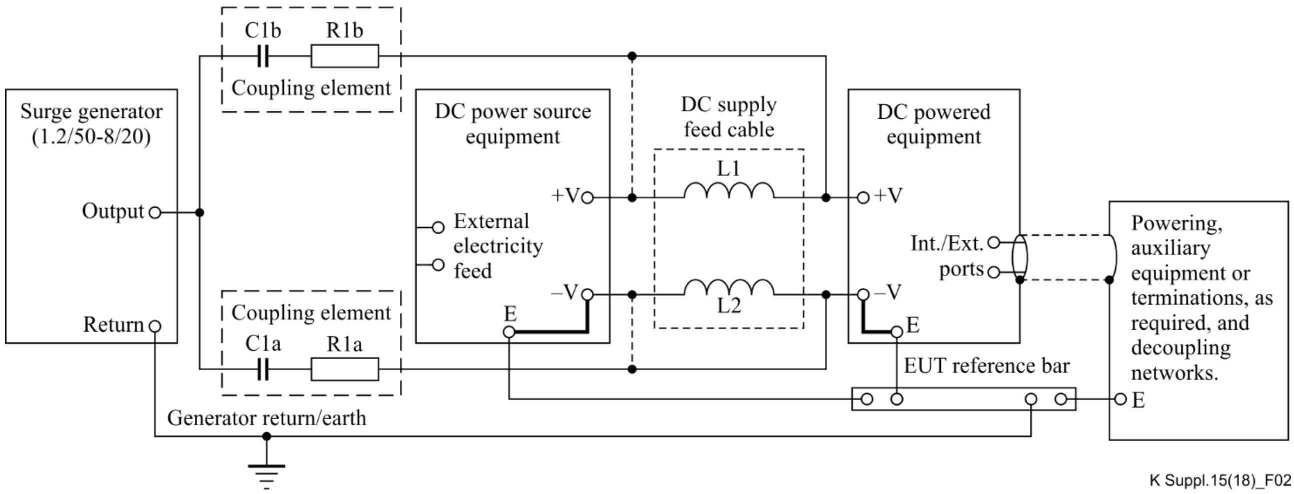

Figure 2 – Example of a test circuit where the applied common-mode surge is converted into a differential surge by equipment earth bonding

The DC power interface port test can have a single generic circuit where the port earth bonding will automatically set if the applied common-mode surge remains common-mode surge or is converted to a differential mode surge. Both the powered load equipment port and the source equipment port need to be surge tested, leading to two variants; one for powered equipment port test circuit and the other for power sourcing equipment port test.

8 Connecting cable inductance

The connecting cable inductance can be approximated as 2.5 µH/m. A 1 m cable would be L1=L2 = 2.5 µH and a 100 m cable would be L1=L2 = 250 µH. Actual cables can be used for the test, as can a surge generator power decoupling network or power coupling decoupling network (CDN), which incorporates both coupling capacitors C1a, C1b and inductors L1, L2. Networks intended for signal lines using common core inductors that form a common-mode choke must not be used as they present a very low series impedance for differential-mode surges, see Figure 3. Power networks that contain shunt surge decoupling capacitors may not give the same equipment interaction as a real cable would give.

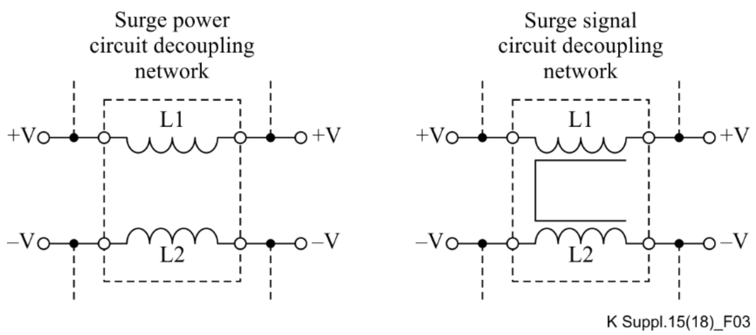

Figure 3 – Examples of commercial power and signal surge decoupling networks

9 Surge protection

A surge protection function may be included in the equipment or be applied externally by using a surge protective device (SPD). The surge protection function may be implemented through using linear components, non-linear components or through combinations of both, see [ITU-T K.96]. Linear surge mitigation is independent of the system current or voltage amplitude and can be regarded as an attenuator of specific spectrum components. Non-linear surge mitigation operates when the system current or voltage amplitude exceeds a given threshold level.

Reverse voltage protection can be simply achieved by using an appropriately connected rectifier diode across the port supply terminals, such that the diode forward conducts current, if the supply polarity reverses. Floating supply insulation can be protected against excessive common-mode voltages by non-linear earth bonded voltage limiters that are connected to the supply terminals.

10 DC power port impedance

Electrical controls in the equipment ports can mean that the port terminal impedance might become very high (blocking) or very low (shorted) during a surge event. Designers should understand the consequences of such impedance changes. This supplement does not cover dynamic port impedance changes under surge conditions; it only covers the linear features of resistance and capacitance.

11 Simulation program with integrated circuit emphasis (SPICE)

SPICE software allows the modelling of electrical circuit behaviour. The results strongly depend on the accuracy of the circuit model used for the simulation. The circuit models used in the appendices of this supplement are relatively simple, but show the expected surge result trends.

The appendices cover:

– Appendix I: SPICE modelling of the equipment DC port with a floating supply
– Appendix II: SPICE modelling of an earth bonded powered equipment DC port
– Appendix III: SPICE modelling of an earth bonded powering source equipment DC port
– Appendix IV: SPICE modelling of the floating supply surge protection

Appendix I shows the main requirement that the equipment insulation withstand voltage must be at least equal to that of the surge generator charge voltage. Cable length does not have a major effect.

The Appendix II configuration results in the surge generator returning currents combining in the powered equipment earth bonding. If the surge is applied to the powered equipment port terminals roughly half (67 A peak) of the (134 A peak) bonding current flows through the port. If the surge is applied to the power source equipment port terminals, the oscillatory waveshape current into the powered equipment terminal is strongly dependent on the connecting cable series inductance. The power source equipment insulation withstand voltage should be at least equal to that of the surge generator charge voltage.

The Appendix III configuration results in the surge generator returning currents combining in the power source equipment earth bonding. This configuration is the same as in Appendix II with the powered equipment interchanged with the powering source equipment. If the surge is applied to the powering source equipment port terminals, then roughly half of the bonding current flows through the port. If the surge is applied to the powered equipment port terminals, the oscillatory waveshape current into the powering source equipment terminal is strongly dependent on the connecting cable series inductance. The powered equipment insulation withstand voltage should be at least equal to that of the surge generator charge voltage.

Appendix IV shows the use of voltage limiters to reduce the insulation voltage withstand need of the equipment. If the powered equipment has a capacitive input (C4), the powering supply voltage holds up during the surge period. If the powered equipment has a resistive input (R9), the powering supply voltage collapses during the surge period.

Appendix I

SPICE modelling of the powered equipment DC port and a floating supply

I.1 General

I.1.1 Component values

Cable lengths of 1 m (appears as L2=L3=2.5 µH) and 100 m (appears as L2=L3=250 µH) are modelled. The power sourcing equipment port is assumed to be a 50 V voltage source (appears as V2) that can accept surge currents in both polarities. Separate elements are used to represent the powered equipment port features of a 100 µF capacitor (appears as C4) or a 10 Ω resistor (appears as R9, which draws a 5 A current from the 50 V source). The 1.2/50-8/20 generator uses the equivalent circuit shown in [ITU-T K.44] Figure A.3-5 with a charge voltage of 1 kV. Generator splitting, coupling and DC blocking network components are R4 = R5 = 10 Ω and C3 = C4 = 10 µF. Bonding of the powered equipment and power sourcing equipment is controlled by the resistance values of R7 and R8, which are connected to the positive polarity line.

Figure I.1-1 shows the SPICE circuit used for the 100 m cable, floating supply condition with the surge applied to the powered equipment port (R9 or C4).

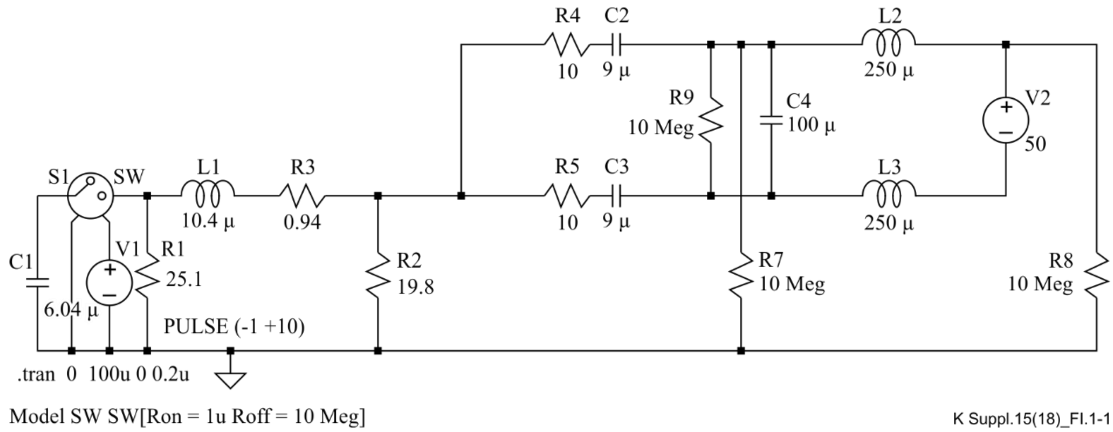

Figure I.1-1 – Example SPICE circuit with a floating supply (R7 = R8 = 10 MΩ) with the powered equipment port represented as a capacitor (C4 = 100 µF)

I.1.2 Surge results

The surge conditions at the equipment ports are recorded for a time period of 100 µs from the start of the surge. The voltage conditions of the +V and −V terminals of the power sourcing and powered equipment terminals are always reported for the 100 µs period. When substantive terminal currents flow these are reported too.

I.2 Floating power supply surge results

I.2.1 Powered equipment DC port surged with a 100 m cable

Figure I.2-1 shows the port terminal voltages where the powered equipment port is represented by a 100 µF capacitor. This result is expected, the supply voltage difference (+V to −V) remains at 50 V for the plot time and the terminal voltages follow the surge generator voltage, reaching a peak voltage of over 900 V. The same waveforms result for the various values of R4, C4, L2 and L3. The design requirement here is for the power source and powered equipment port voltage withstand to be greater than the peak surge generator voltage.

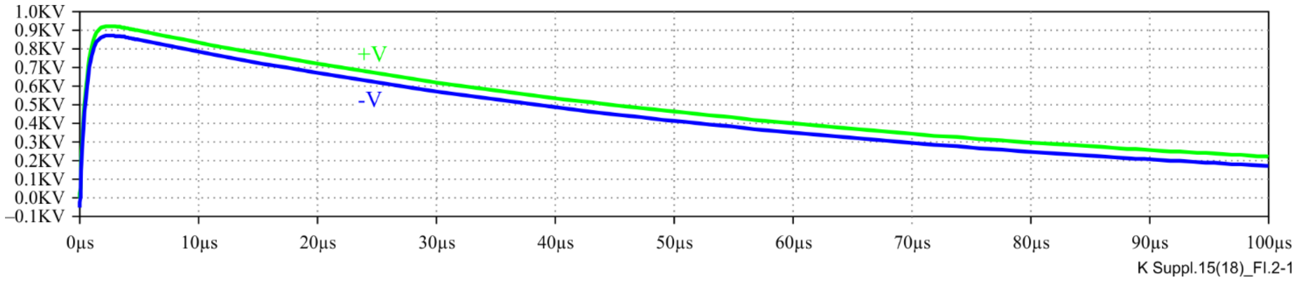

Figure I.2-1 – SPICE circuit waveforms with a floating supply (R7 = R8 = 10 MΩ) with the powered equipment port represented as a capacitor (C4 = 100 µF)

Appendix II

SPICE modelling of an earth bonded powered equipment DC port

II.1 General

II.1.1 Component values

Component values are given in clause I.1.1.

Figure II.1-1 shows the SPICE circuit used for the 100 m cable, earth bonded +V supply condition (R7 = 0) with the surge applied to the powered equipment port. The resulting voltages across the powered equipment (green) and power source (blue) are recorded.

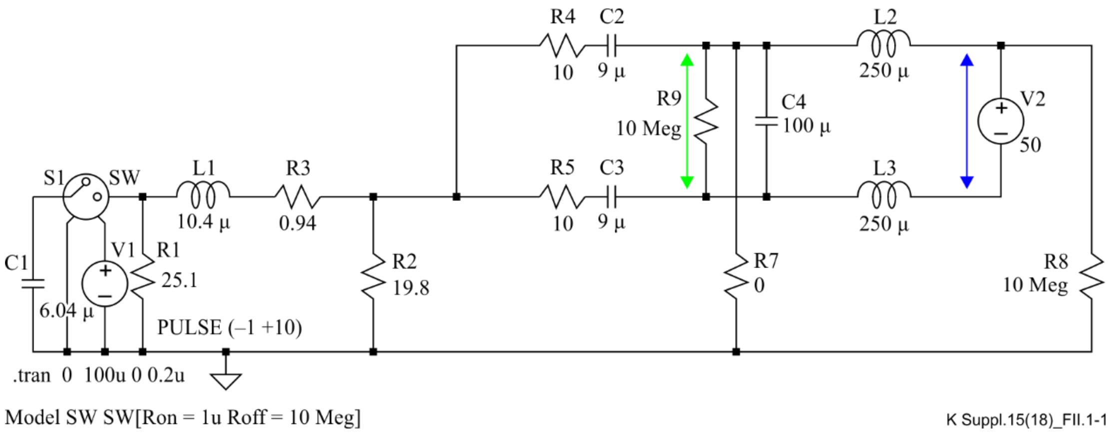

Figure II.1-1 – Example SPICE circuit with an earth bonded supply (R7 = 0 and R8 = 10 MΩ) with the powered equipment port represented as a capacitor (C4 = 100 µF)

II.1.2 Surge results

The result measurement conditions are reported in clause I.1.2.

II.2 Earth bonded power supply surge results

II.2.1 Bonded powered equipment DC port surged with a 100 m cable

The surge current from the generator splits equally between the two coupling networks before recombining in the earth bond link. Figure II.2-1 shows the earth bond current (green trace, 134 A peak) and the currents delivered by capacitor C2 (blue trace, 67 A peak) and capacitor C3 (red trace 67 A peak). The current from C2 flows directly to the earth bond. The current from C3 flows through the powered equipment terminal impedance and partially through the parallel loop containing the powering equipment.

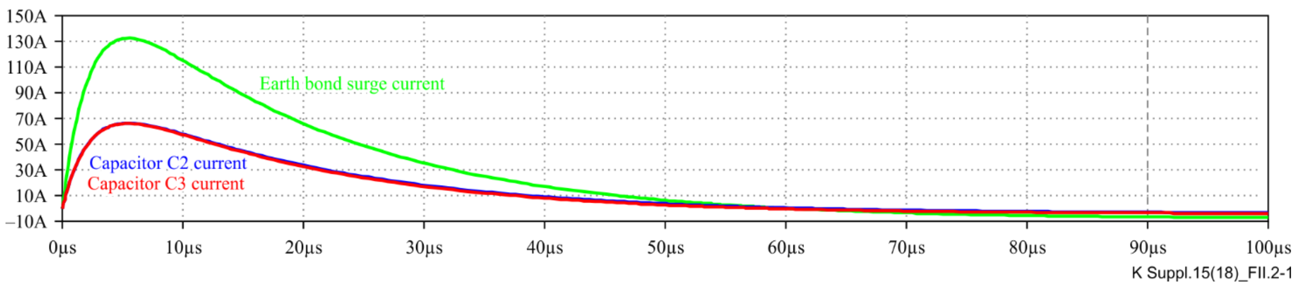

Figure II.2-1 – SPICE surge generator currents

Figure II.2-2 shows the port terminal voltages when the powered equipment port is represented by a 100 µF capacitor.

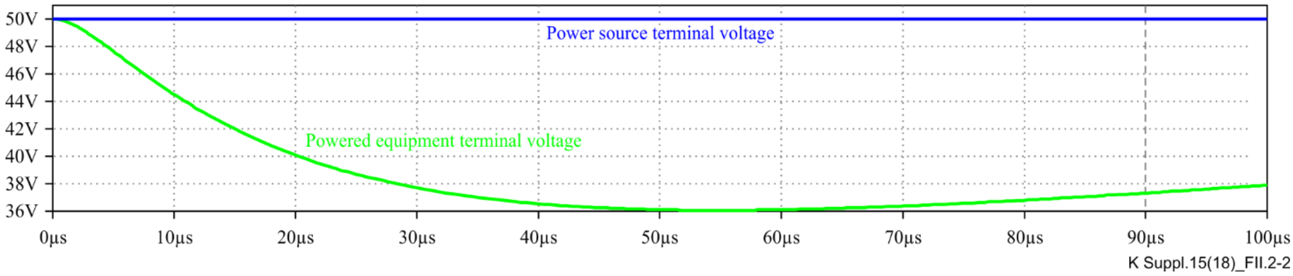

Figure II.2-2 – SPICE circuit voltage waveforms with an earth bonded supply (R7 = 0 and R8 = 10 MΩ), a 100 m connecting cable and the powered equipment port is represented by a capacitor (C4 = 100 µF)

Figure II.2-2 shows that the powered equipment capacitor C4 (100 µF) is discharged from 50 V to 36 V during the surge, while the power source voltage remains at 50 V. Figure II.2-3 shows how a short cable (2.5 µH) allows the power source to reduce the powered equipment capacitor C4 voltage reduction but interacts with the generator resulting in a peak recovery voltage of 62 V. This interaction indicates that studying short and long cable effects is prudent.

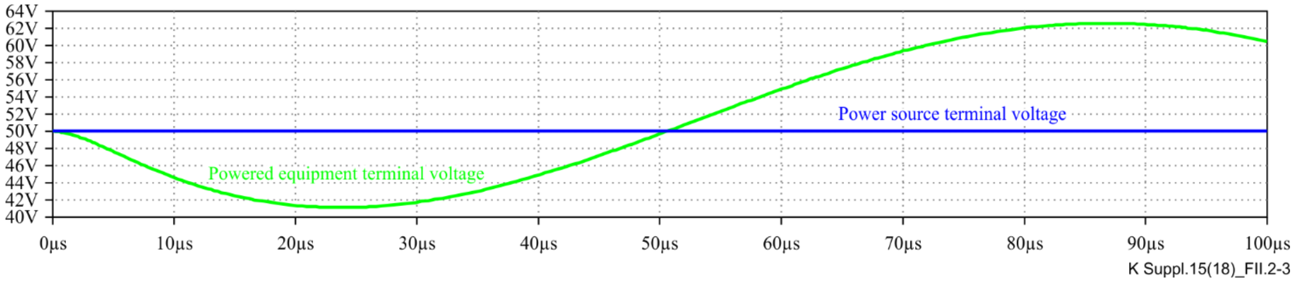

Figure II.2-3 – SPICE circuit voltage waveforms with an earth bonded supply (R7 = 0 and R8 = 10 MΩ), a 1 m connecting cable and the powered equipment port represented by a capacitor (C4 = 100 µF)

Figure II.2-4 shows the currents occurring in Figure II.2-3. The capacitor current (green) ranges from about −67 A to +50 A, while the power source current (blue) ranges from −55 A to +30 A.

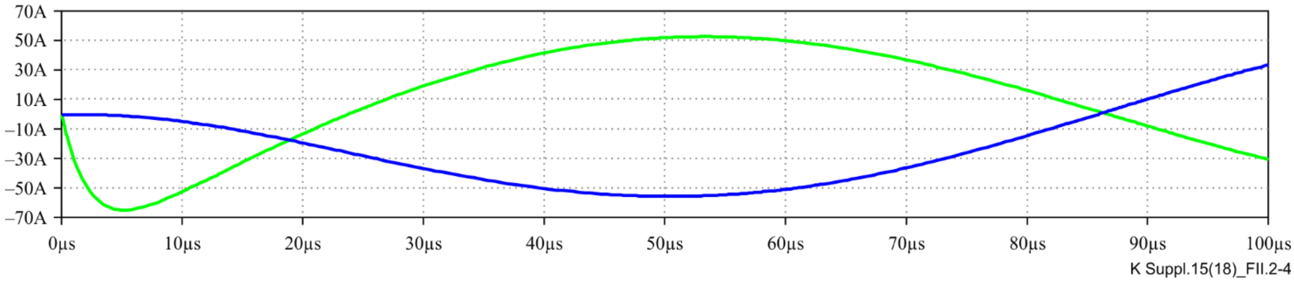

Figure II.2-4 – SPICE circuit port current waveforms with an earth bonded supply (R7 = 0 and R8 = 10 MΩ), a 1 m connecting cable and the powered equipment port represented by a capacitor (C4 = 100 µF)

If the powered equipment port is represented by a resistor R9 (10 Ω), the resulting powered equipment port surge voltage range, as shown in Figure II.2-5, is −300 V to +120 V. However, these are lower currents (−30 A to +12 A) than the capacitive currents of −67 A to +50 A shown in Figure II.2-4.

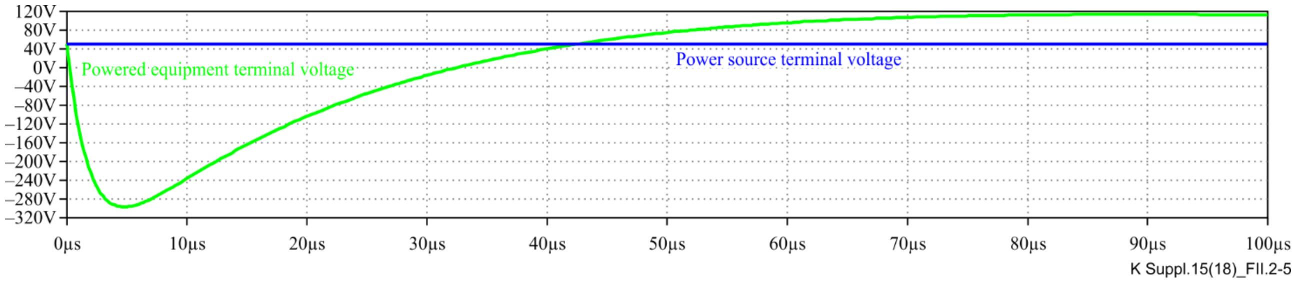

Figure II.2-5 – SPICE circuit port voltage waveforms with an earth bonded supply (R7 = 0 and R8 = 10 MΩ), a 100 m connecting cable and the powered equipment port represented as a resistor (R9 = 10 Ω)

If the powered equipment is bonded and the surge is applied to the powering source terminals, then the insulation withstand voltage of the powering source needs to be about 800 V, see Figure II.2-6.

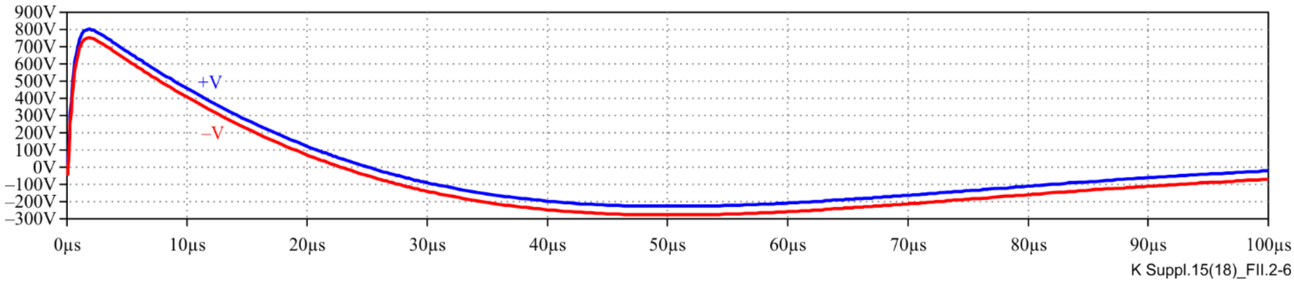

Figure II.2-6 – SPICE circuit voltage waveforms for earth bonding at the powered equipment and the surge applied to the power source DC port supply, cable connection 100 m

The cable inductance interacts with the surge generator to produce an oscillatory current waveform into the powered equipment terminal.

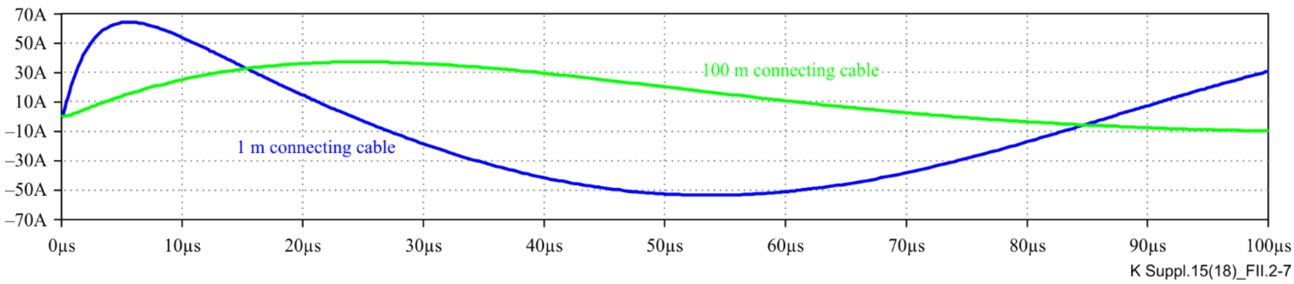

Figure II.2-7 – SPICE circuit connecting cable current waveforms for earth bonding at the powered equipment and the surge applied to the power source DC port with connecting cable lengths of 1 m and 100 m

Appendix III

SPICE modelling of earth bonded powering source equipment DC port

III.1 General

III.1.1 Component values

Component values are given in clause I.1.1.

Figure III.1-1 shows the SPICE circuit used for the 100 m cable, earth bonded +V supply condition (R8 = 0) with the surge applied to the power sourcing equipment port. Because the power sourcing equipment is modelled as a pure voltage source, a surge voltage will not develop across the port terminals and the powered equipment will not be subjected to a surge. A power sourcing equipment with some series resistance or a change of state during a surge would be required to pass on the surge to the powered equipment.

This configuration is the same as in Appendix II with the powered equipment interchanged with the powering source equipment.

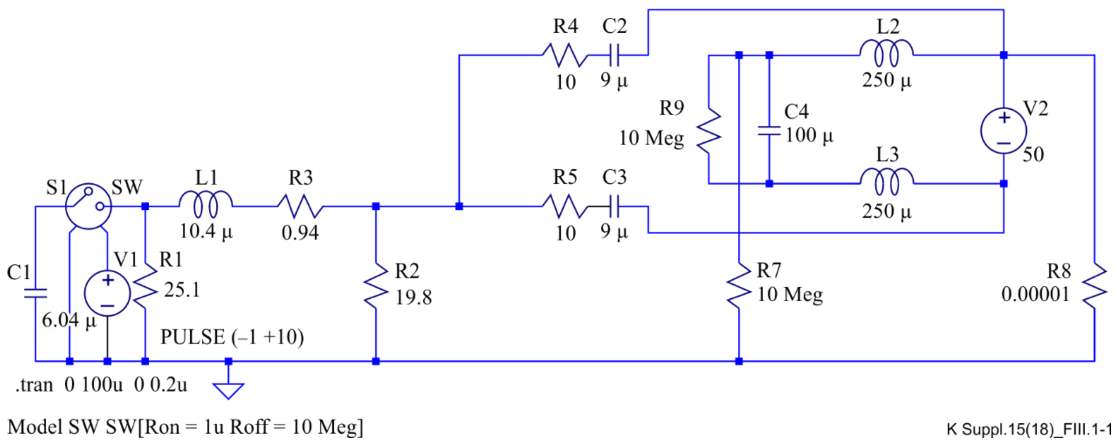

Figure III.1-1 – Example SPICE circuit with an earth bonded supply (R7 = 10 MΩ and R8 = 0) with the powered equipment port represented as a capacitor (C4 = 100 µF)

III.1.2 Surge results

The result measurement conditions are reported in clause I.1.2.

III.2 Earth bonded power sourcing equipment surge results

III.2.1 Powered equipment DC port surged with a 100 m cable

If the powering source equipment is bonded and the surge is applied to the powered equipment terminals, then the insulation withstand voltage of the powering source needs to be about 800 V, see Figure III.2-1.

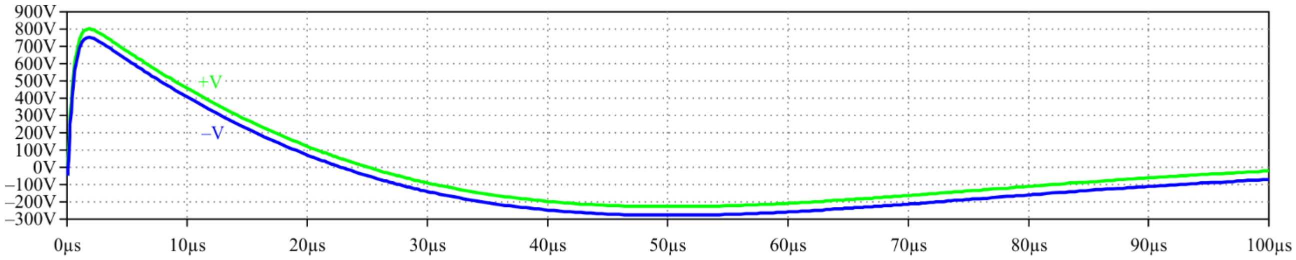

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Figure III.2-1 – SPICE circuit powered equipment terminal voltage waveforms with an earth bonded supply (R7 = 10 MΩ and R8 = 0), a 100 m connecting cable and the powered equipment port represented as a capacitor (C4 = 100 µF)

Figure III.2-2 shows the currents occurring in Figure III.2-1.

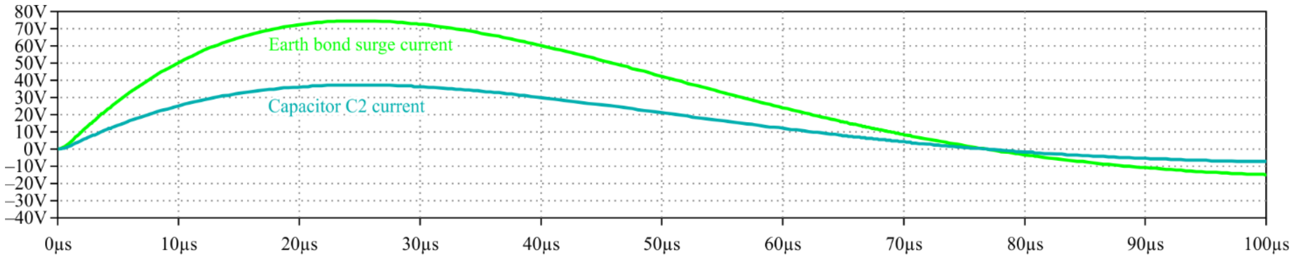

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Figure III.2-2 – SPICE circuit powered equipment current waveforms with an earth bonded power sourcing equipment (R7 = 10 MΩ and R8 = 0), a 100 m connecting cable and the powered equipment port represented as a capacitor (C4 = 100 µF)

Appendix IV

SPICE modelling of the floating supply surge protection

IV.1 General

IV.1.1 Component values

Component values are given in clause I.1.1.

Figure IV.1-1 shows a previously used SPICE circuit with the addition of four metal oxide varistors (MOVs). The MOV functions are A1 to A4 whose 100 V threshold voltage is set by the V3 to V6 sources. When operating in a voltage limiting mode, the MOVs have a clamping slope resistance of 0.5 Ω. The MOVs connected to the −V or +V voltage rails are effectively bonded to earth when resistors R10, R11, R12 or R13 are set to a low resistance value. In the circuit shown, MOVs A1 and A3 are limiting the voltage of the powered equipment +V and −V terminals because resistors R10 and R12 have a low value of resistance.

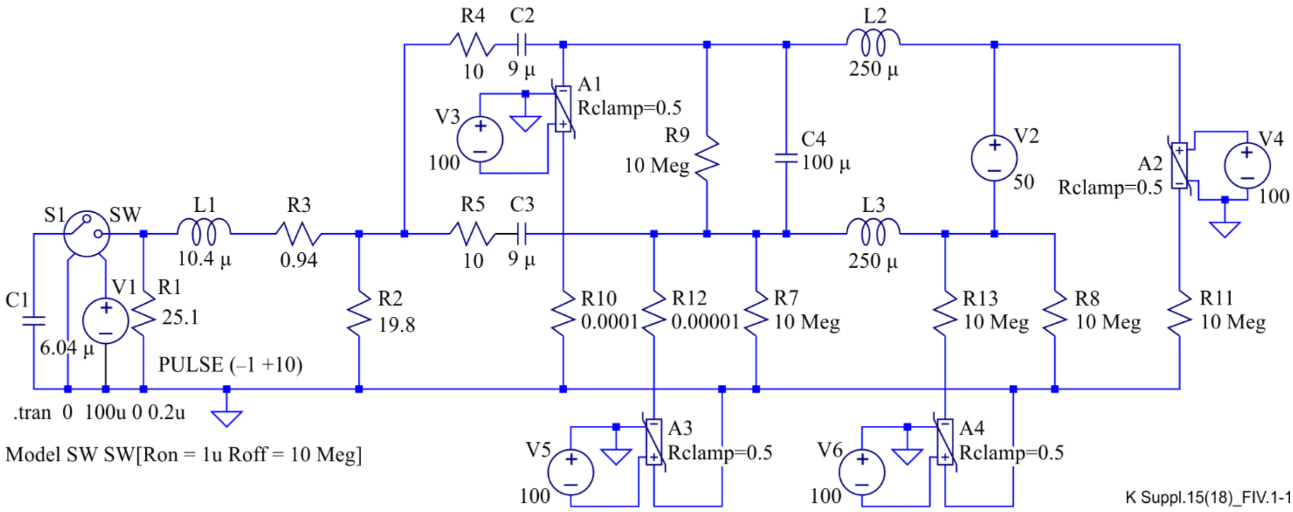

Figure IV.1-1 – Example SPICE DC Interface circuit with four MOV functions added

IV.1.2 Surge results

The result measurement conditions are reported in clause I.1.2.

IV.2 Earth bonded power sourcing equipment surge results

IV.2.1 Powered equipment DC port surged with a 100 m cable

If the powering source equipment is bonded and the surge is applied to the powered equipment terminals, the MOVs A1 and A3 limit the powered equipment terminal voltages to less than 160 V, as shown in Figure IV.2-1. The port current, capacitor C4 current is −50 A peak.

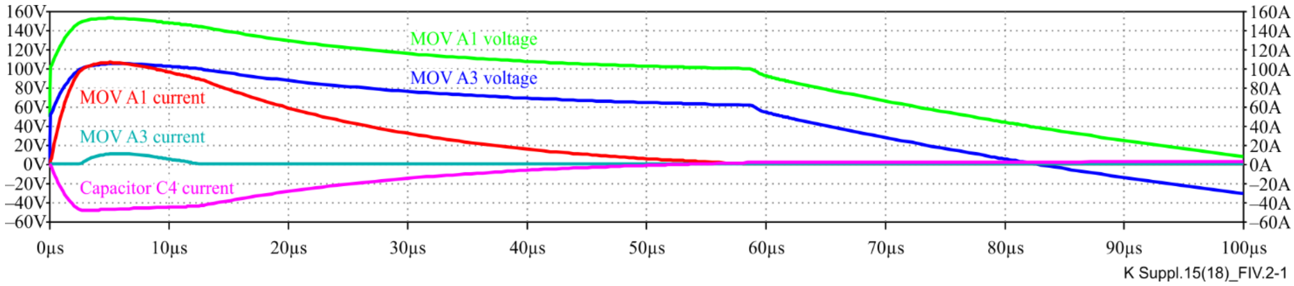

Figure IV.2-1 – SPICE circuit MOV A1 and A3 voltage and current with a floating supply (R7 = 10 MΩ and R8 = 10 MΩ), a 100 m connecting cable and the powered equipment port represented as a capacitor (C4 = 100 µF)

Figure IV.2-2 shows what happens to Figure IV.2-1 waveforms if the terminal impedance of the powered equipment was represented by a 10 Ω resistor (R9). Without a capacitive voltage holdup (C4), the supply voltage to the powered equipment collapses to zero for the conduction period of MOV A3. When MOV A1 stops conduction, the terminal supply voltage of 50 V (difference of green and blue trace vales) is restored. The MOV A1 current is lower in this case as the MOV A3 current is higher.

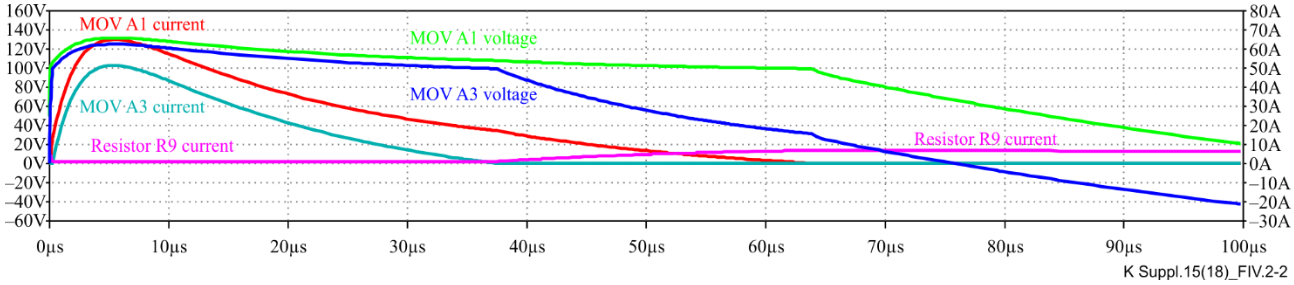

Figure IV.2-2 – SPICE circuit MOV A1 and A3 voltage and current with a floating supply (R7 = 10 MΩ and R8 = 10 MΩ), a 100 m connecting cable and the powered equipment port represented as a resistor (R9 = 10 Ω)

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