Lightning Surge Considerations for PoE Power Sourcing Equipment Devices

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ABSTRACT

This report considers the implementation of lightning surge protection for Power over Ethernet (PoE) powered sourcing equipment (PSE) applications. The necessity for implementing such protection will normally depend on the environment in which the PSE is intended to operate and the inherent isolation properties of the PSE. There are numerous compliance standards to consider when establishing the surge protection level of the PSE. These standards normally introduce a number of test conditions for various types of products ranging from main's power supplies to legacy telephone equipment. This report examines the various standards in an effort to relate the test conditions that would most likely be applicable to PoE PSE applications and provides suggestions for meeting the associated surge requirements.

This report is based on information that was available in May 2009. The most recent version of the referenced standards should be consulted when applying the information provided in the report.

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1   Relating IEEE 802.3, IEC 60950, and ITU-T K.44 Standards

The IEEE 802.3 standard, which defines the PoE system, specifies that the PSE will provide electrical isolation that withstands at least one of the following electrical strength tests:

(a) 1500 Vrms at 50 Hz to 60 Hz for 60 sec is applied as specified in subclause 5.2.2 of IEC 60950-1:2001.

(b) 2250 Vdc for 60 sec is applied as specified in subclause 5.2.2 of IEC 60950-1:2001.

(c) An impulse test consisting of a 1500-V, 10/700-µs waveform is applied ten times with a 60-sec interval between pulses. The shape of the impulses must be 10/700 µs (10-µs virtual front time, 700-µs virtual time to half value), as defined in IEC 60950-1:2001 Annex N.

The third electrical strength test in the previous list is seen to describe an impulse test in accordance with IEC 60950-1 Annex N. This annex of the IEC 60950-1 standard provides the following definition for the impulse generator. The circuit and component values referred to in the definition are summarized in Figure 1.

N.1 ITU-T Impulse Test Generators

The circuit in Figure N.1, using the component values in references 1 and 2 of Table N.1, is used to generate impulses, the C1 capacitor being charged initially to a voltage Uc.

Circuit reference 1 of Table N.1 generates 10/700 µs impulses (10 µs virtual front time, 700 µs virtual time to half value) as specified in ITU-T Recommendation K.44 to simulate lightning interference in the telecommunication network.
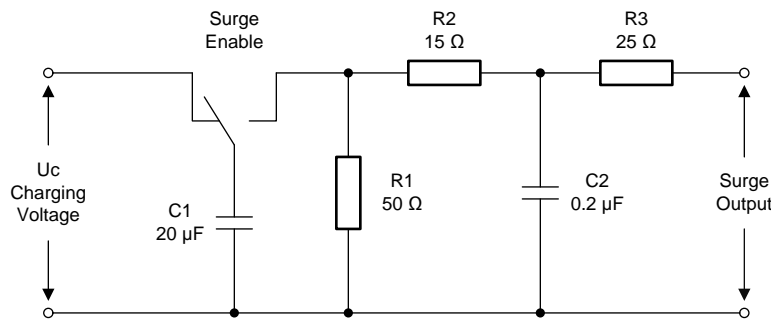

Figure 1. ITU-T K.44 Impulse Generator as Defined in Figure N.1 of IEC 60950-1 Standard

The 10-µs virtual front time and 700-µs virtual time to half value impulse shape refers to the open-circuit voltage waveform of the impulse generator. The 15-Ω resistor (R2) and 25-Ω resistor (R3) shown in Figure 1 combine to provide an effective output impedance of 40 Ω. The peak short-circuit current provided by the impulse generator for various voltage levels based on this effective output impedance is outlined in Table 1. The resulting short-circuit current waveform will have a 5-µs virtual front time and a 320-µs virtual time to half value, so the generator is commonly referred to as a 10/700-µs to 5/320-µs combination wave generator (in accordance with IEC 60060-1).

Table 1. Short-Circuit Current of 10/700-µs Impulse Generator Based on 40-Ω Effective Output Impedance

10/700-µs to 5/320-µs COMBINATION WAVE GENERATOR	
PEAK OPEN-CIRCUIT VOLTAGE	PEAK SHORT-CIRCUIT CURRENT
500 V	12.5 A
1000 V	25 A
1500 V	37.5 A
2000 V	50 A
4000 V	100 A

As stated above, the IEC 60950-1 standard defines an impulse generator to simulate lightning interference in accordance with the ITU-T K.44 standard. Referring to Figure A.3-1 of the ITU-T K44 standard, the 10/700-µs impulse (surge) generator is further defined to use multiple resistors in place of the single 25 Ω resistor (R3 in Figure 1) in order to divide the surge current into multiple conductors simultaneously, while maintaining an overall output impedance of 40 Ω. This is shown in Figure 2 and would imply the use of eight resistors for PoE applications, where an eight-wire (four twisted-pairs) symmetrically balanced cabling system is used (that is, CAT-5 and CAT-6 cable).
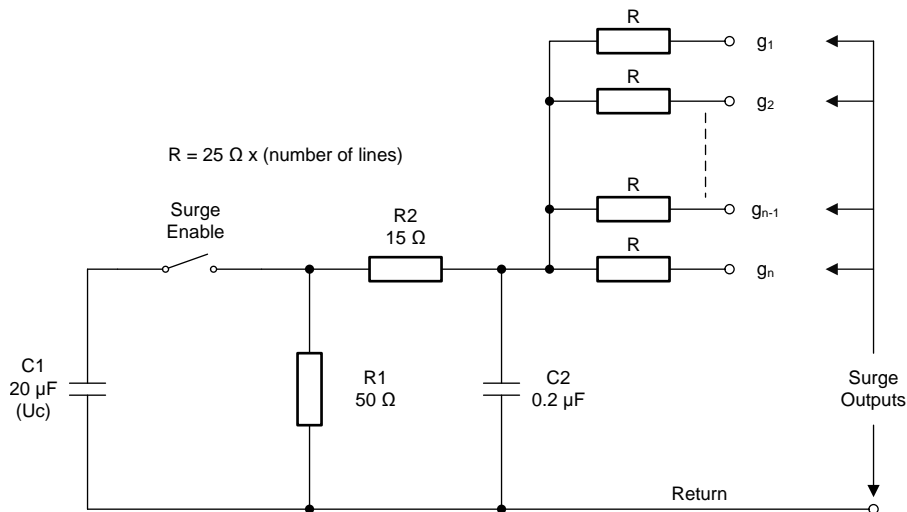

Figure 2. 10/700-µs Surge Generator as Defined in Figure A.3-1 of ITU-T K.44 Standard

2   IEC 61000-4-5:2005 Standard

The IEC 61000-4-5:2005 standard specifies two types of surge generators as follows:

Two types of combination wave generators are specified. Each has its own particular applications, depending on the type of port to be tested. The 10/700 µs combination wave generator is used to test ports intended for connection to symmetrical communication lines. The 1.2/50 µs combination wave generator is used in all other cases, and in particular, for testing ports intended for power lines and short-distance signal connections.

The 10/700-µs surge generator referred to in the IEC 61000-4-5:2005 standard is further described to be in accordance with that defined in the ITU-T K44 standard. Figure 14 of the IEC 61000-4-5:2005 standard includes an example of the setup used for testing unshielded symmetrical lines which would be applicable to the type of cabling system used in a PoE system. Figure 3 expands on this test setup to show the connections required for the eight-wire input associated with the PSE.
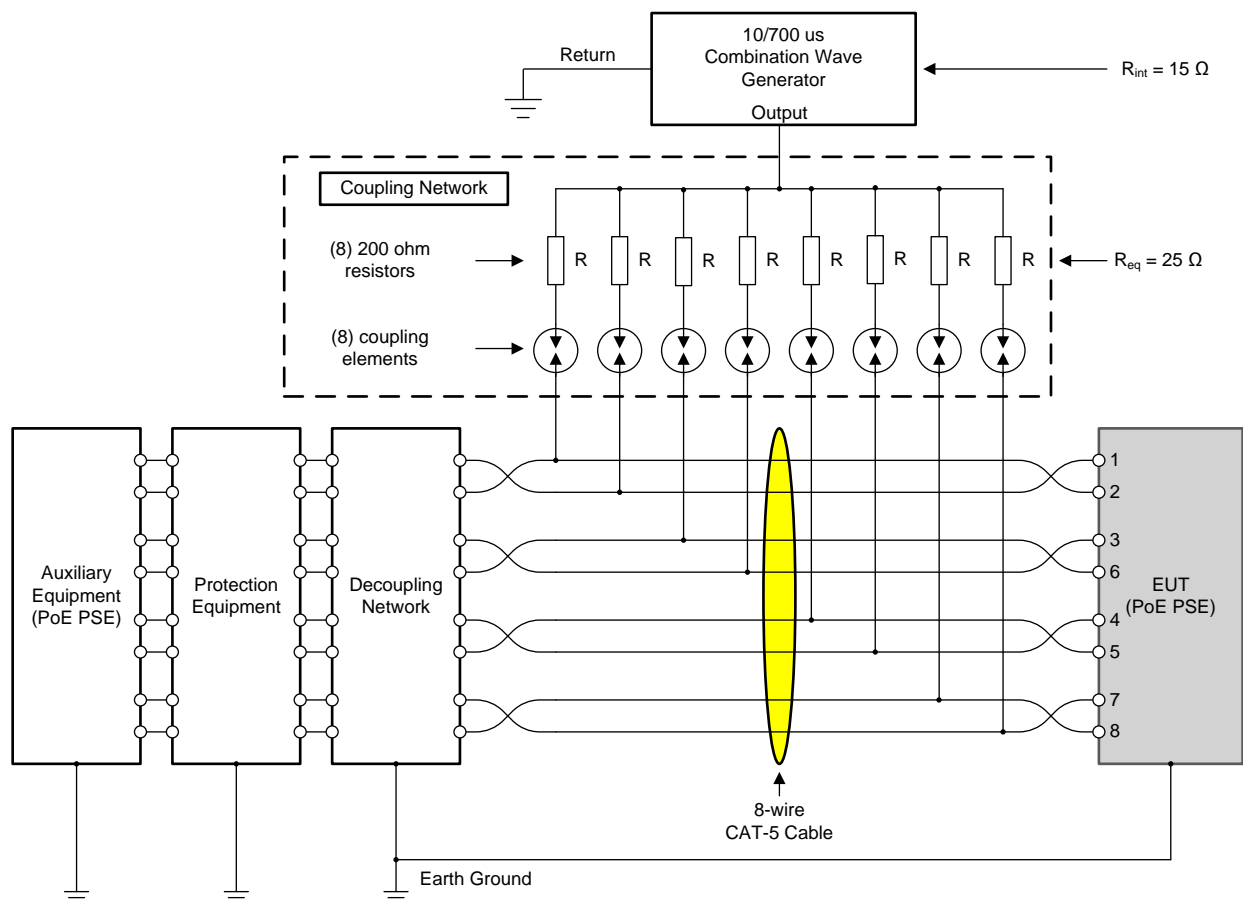
Figure 3. Expanded Eight-Wire PoE PSE Test Setup Based on Figure 14 of IEC 61000-4-5:2005 Standard.

As seen in Figure 3, eight 200-Ω resistors are used along with eight coupling elements, typically gas arrestors, to couple the surge from the generator output to each line of the eight-wire cable simultaneously. The 200-Ω value of the resistors is compliant with the 250-Ω maximum defined in the IEC 61000-4-5:2005 standard. The parallel combination of the eight 200 Ω resistors provides an equivalent resistance of 25 Ω which would be in series with the internal 15 Ω resistance associated with the surge generator. This total resistance satisfies the 40-Ω effective output impedance and peak short-circuit requirements discussed in Section 2.

The IEC 61000-4-5:2005 standard also specifies a 1.2/50-µs generator for use in performing lightning surge tests on power lines and short-distance signal applications. Some PSE applications may fall under the short-distance category where the tests are performed using the 1.2/50-µs generator instead of the 10/700-µs to 5/320-µs combination wave generator. The 1.2/50-µs generator is commonly referred to as a 1.2/50-µs to 8/20-µs combination wave generator, because it is a short-circuit current waveform has an 8-µs virtual front time and a 20-µs virtual time to half value.

Another physical consideration of PoE is discussed on page seven of the *Electrical Transient Immunity for Power-Over-Ethernet* [2] application report:

On a twisted-pairs cable, the two wires of each pair are twisted together, but there is no twisting between pairs at all (in fact, each pair is well separated from its neighbors). Consequently, a differential-mode transient between P and N is likely with that type of cable, and this tandem of pairs can be considered as an unbalanced line as far as the test voltages are concerned.

The implication is that the unbalanced circuit and lines category is also applicable for PoE as is the 1.2/50-µs combination wave generator. Under these assumptions, Table 2 outlines several test scenarios using both an eight-wire and four-wire coupling-decoupling network (CDN).

Table 2. PoE PSE Test Scenarios

TEST CONDITION	EIGHT-LINE CDN	FOUR-LINE CDN
Common mode (line-earth)	8-wires to earth	4-wires to earth
Single wire differential	1-wire shorted to earth with surge applied to 7-wires	1-wire shorted to earth with surge applied to 3-wires
Single pair differential	1-PoE pair shorted to earth with surge applied to other 3-pairs	1-PoE pair shorted to earth with surge applied to other pair

3   Determining the Peak Surge Current

The peak current per line needs to be considered when selecting the surge current rating of components within the PSE, including any surge protection devices (SPDs). The path of the surge must be understood to determine whether the component will see the current associated with one line or an additive current associated with multiple lines. Additionally, there could be other worst case scenarios such as when only one line or one twisted pair is subjected to the surge with the other lines open. It should be noted, that the surge test is not normally performed with some of the lines open; rather the differential surges will be applied as described in Table 2. Other examples include extending the surge voltage to levels above 4kV and testing only four lines instead of eight.

Table 3 and Table 4 show the per-wire currents for both the 10/700-µs and 1.2/50-µs waveforms. The green columns are for four-wire and the orange for eight-wire conditions. Generally speaking, configuration one yields higher per-wire currents than configuration two and the four-wire test generates higher currents than the eight-wire test. In most cases too, the 10/700-µs waveform yields higher peak current with the exception of the eight-wire test in configuration two due to the maximum per-line series resistance of 250 Ω.

Table 3. Configuration One: Surge Applied From Lines to Ground (or Earth) With *Other Lines* Open

10/700 µs V_{POC} (V)	R_{GEN} (Ω)	R_{EQ} (Ω)	5/320 µs I_{PSC} (A)	#Wires	R_{4WIRE} (Ω)	#Wires	R_{8WIRE} (Ω)	All four lines I_{PW-PSC} (A)	Two of four lines I_{PW-PSC} (A)	Two of four lines I_{PW-PSC} (A)	All eight lines I_{PW-PSC} (A)	One of eight lines I_{PW-PSC} (A)	Two of eight lines I_{PW-PSC} (A)
500	15	25	12.50	4	100	8	200	3.13	4.35	3.85	1.56	2.33	2.17
1000			25.00					6.25	8.70	7.69	3.13	4.65	4.35
1500			37.50					9.38	13.04	11.54	4.69	6.98	6.52
2000			50.00					12.50	17.39	15.38	6.25	9.30	8.70
4000			100.00					25.00	34.78	30.77	12.50	18.60	17.39
6000			150.00					37.50	52.17	46.15	18.75	27.91	26.09

1.2/50 µs V_{POC} (V)	R_{GEN} (Ω)	R_{EQ} (Ω)[1]	8/20 µs I_{PSC} (A)[1]	#Wires	R_{4WIRE} (Ω)	#Wires	R_{8WIRE} (Ω)	All four lines I_{PW-PSC} (A)	One of four lines I_{PW-PSC} (A)	Two of four lines I_{PW-PSC} (A)	All eight lines I_{PW-PSC} (A) [1]	One of eight lines I_{PW-PSC} (A)	Two of eight lines I_{PW-PSC} (A)
500	2	40	11.90	4	160	8	250	2.98	3.09	3.05	1.88	1.98	1.97
1000			23.81					5.95	6.17	6.10	3.76	3.97	3.94
1500			35.71					8.93	9.26	9.15	5.64	5.95	5.91
2000			47.62					11.90	12.35	12.20	7.52	7.94	7.87
4000			95.24					23.81	24.69	24.39	15.04	15.87	15.75

[1] For all eight lines, R_{EQ} is 31.3 Ω, which yields larger I_{PSC} due to the maximum per-line series resistance of 250 Ω.

Table 4. Configuration Two: Surge Applied From Lines to Ground (or Earth) With *Other Lines* **Grounded**

10/700 μs V_POC (V)	R_GEN (Ω)	R_EQ (Ω)	5/320 μs I_PSC (A)	#Wires	R_4WIRE (Ω)	#Wires	R_8WIRE (Ω)	All four lines I_PW-PSC (A)	One of four lines I_PW-PSC (A)	Two of four lines I_PW-PSC (A)	All eight lines I_PW-PSC (A)	One of eight lines I_PW-PSC (A)	Two of eight lines I_PW-PSC (A)
500	15	25	12.50	4	100	8	200	3.13	3.13	3.13	1.56	1.56	1.56
1000			25.00					6.25	6.25	6.25	3.13	3.13	3.13
1500			37.50					9.38	9.38	9.38	4.69	4.69	4.69
2000			50.00					12.50	12.50	12.50	6.25	6.25	6.25
4000			100.00					25.00	25.00	25.00	12.50	12.50	12.50
6000			150.00					37.50	37.50	37.50	18.75	18.75	18.75
1.2/50 μs V_POC (V)	R_GEN (Ω)	R_EQ (Ω)[1]	8/20 μs I_PSC (A)[1]	#Wires	R_4WIRE (Ω)	#Wires	R_8WIRE (Ω)	All four lines I_PW-PSC (A)	One of four lines I_PW-PSC (A)	Two of four lines I_PW-PSC (A)	All eight lines I_PW-PSC (A)[1]	One of eight lines I_PW-PSC (A)	Two of eight lines I_PW-PSC (A)
500	2	40	11.90	4	160	8	250	2.98	2.98	2.98	1.88	1.88	1.88
1000			23.81					5.95	5.95	5.95	3.76	3.76	3.76
1500			35.71					8.93	8.93	8.93	5.64	5.64	5.64
2000			47.62					11.90	11.90	11.90	7.52	7.52	7.52
4000			95.24					23.81	23.81	23.81	15.04	15.04	15.04

[1] For all eight lines, R_{EQ} is 31.3 Ω, which yields larger I_{PSC} due to the maximum per-line series resistance of 250 Ω.

For the PoE port front end, the SPDs are placed either across or from each center tap to ground (PSE frame or chassis, which is earth grounded). It should be noted that the capacitance associated with metal oxide varistors (MOVs) generally prevent them from being used on data lines because of their effect on signal integrity. The centertap SPD will shunt twice the per-wire current and Table 5 and Table 6 combine the per-wire currents into PoE center tap currents. Table 5 is a maximization of Table 3 and Table 4 for each waveshape and Table 6 is a maximization of Table 4 only.

Table 5. Maximum Configuration One and Configuration Two Center-Tap Currents: 10/700 and 1.2/50 Waveforms

VPOC (V)	Four-line CM IPCT-PSC (A)	One-line DM IPCT-PSC (A)	Two-line DM IPCT-PSC (A)	Eight-line CM IPCT-PSC (A)	One-line DM IPCT-PSC (A)	Two-line DM IPCT-PSC (A)
500	6.25	4.35	7.69	3.76	2.33	4.35
1000	12.50	8.70	15.38	7.52	4.65	8.70
1500	18.75	13.04	23.08	11.28	6.98	13.04
2000	25.00	17.39	30.77	15.04	9.30	17.39
4000	50.00	34.78	61.54	30.08	18.60	34.78
6000	75.00	52.17	92.31	37.50	27.91	52.17

Table 6. Maximum Configuration Two Center-Tap Currents: 10/700 and 1.2/50 Waveforms

VPOC (V)	Four-line CM IPCT-PSC (A)	One-line DM IPCT-PSC (A)	Two-line DM IPCT-PSC (A)	Eight-line CM IPCT-PSC (A)	One-line DM IPCT-PSC (A)	Two-line DM IPCT-PSC (A)
500	6.25	3.13	6.25	3.76	1.88	3.76
1000	12.50	6.25	12.50	7.52	3.76	7.52
1500	18.75	9.38	18.75	11.28	5.64	11.28
2000	25.00	12.50	25.00	15.04	7.52	15.04
4000	50.00	25.00	50.00	30.08	15.04	30.08
6000	75.00	37.50	75.00	37.50	18.75	37.50

4 PSE Surge Protection Application

Most (if not all) PSE applications will include a dedicated connection to earth ground as shown in Figure 4. Along with acting as a safety ground, this earth-ground connection might serve as a reference ground for internal PSE circuitry, such as Bob Smith cable terminations and the primary-side of an isolated AC-DC converter. These internal earth-ground connections can create paths for common-mode surge currents to flow from the generator, through the PSE, and back to the return of the generator as shown in Figure 4.

Referring to Figure 4, the surge current from the generator, I_S, divides into the eight-wire input of the PSE, as indicated by current paths I_A through I_H. Once entering the PSE, the surge current will seek any paths to earth ground in order to return to the generator. Two possible return paths are $I_{RTN\ 1}$, through the Bob Smith termination circuit block, and $I_{RTN\ 4}$, through the isolated AC-DC converter circuit block. The main conduits for these return paths are seen to be the highlighted CBS capacitor in the Bob Smith termination block and the typically used CCMB common-mode noise capacitor in the AC-DC converter block, each of which crosses the isolation boundary. These two return paths and $I_{RTN\ 2+3}$ are shown to combine as $I_{RTN\ 1+2+3+4}$, which then returns back to the generator.
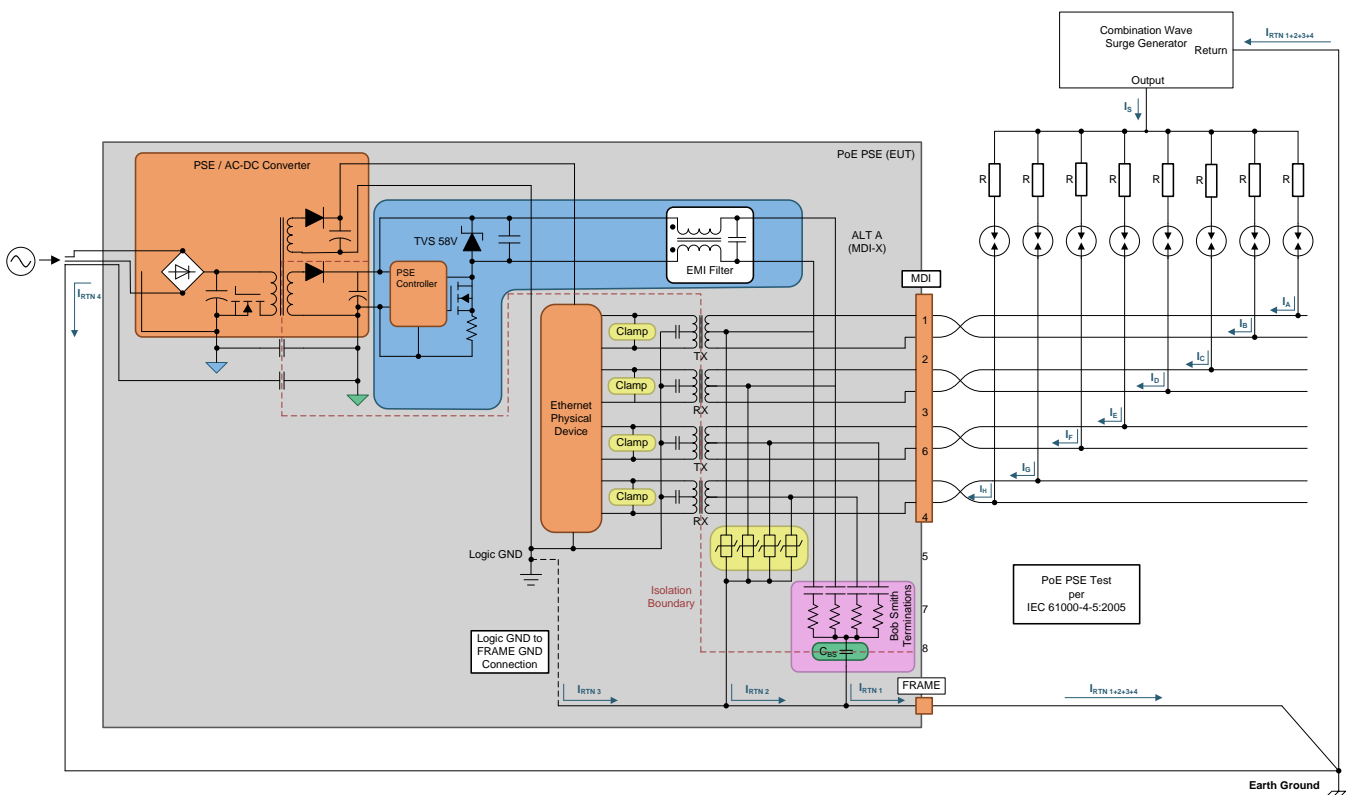
Figure 4. Example of Surge Current Paths Through Earthed-PSE Application

The currents as drawn in Figure 4 indicate a positive surge from the surge generator while, in actuality, the PSE will be subjected to five positive and five negative surges according to the IEC 61000-4-5 test procedure. It should be noted that the surge current paths within each circuit block can vary depending on the surge polarity. For example, during a positive surge some surge current will flow through the port TVS to the positive rail of the 48-V power supply, and during a negative surge some surge current will flow through the body diode of the port MOSFET.

The PSE controller block includes an EMI filter, which is normally required to meet conducted emissions requirements. This filter typically employs ferrite beads or a common-mode choke, which can help to lessen the amount of surge current flowing back to the converter. The PSE controller block is also shown to include a 58-V TVS that is typically placed across the port to protect against hot-plug transients and ESD events. This TVS device will also contribute to the protection of the PSE controller during a lightning surge.

Although this report focuses primarily on lightning surge protection for the front-end and power sections of the PSE, it should be noted that SPDs may require to be placed on the secondary-side data lines as indicated by the clamp blocks highlighted in Figure 4. Several manufacturers, such as Bourns™ and Littlefuse™, offer devices to protect the data lines. In order to maintain signal integrity, the type of device selected will normally depend on the capacitance associated with the device and the data rate of the PoE system. Consult the manufacturer's datasheets for proper selection of these devices.

The requirements for SPDs in the PSE application will normally depend on the required surge test level and the inherent isolation properties of the PSE. As previously described in Section 2, the IEEE 802.3 standard specifies that the PSE must provide electrical isolation that withstands an electrical strength test of 1500 V_{RMS}, 2250 V_{DC}, or the 1500 V_{PK} 10/700-μs impulse test defined in the IEC 60950-1 standard. If the surge test level is below the inherent withstand strength of the PSE then additional SPDs may not be needed. On the other hand, if the PSE will be subjected to surge test levels that exceed the withstand strength of the PSE, then additional SPDs will most likely be required at the front-end of the PSE to either clamp the surge voltage below the withstand rating of the PSE or crowbar the surge to earth ground.

5   Choosing the SPDs for High Voltage Surge PSE Applications

This section expands on the PSE example introduced in Section 4 by relating the actual requirement and selection of SPDs to the various test levels associated with the IEC 61000-4-5:2005 symmetrical lines test.

The SPD block is shown to be MOVs that are used to clamp the surge voltage to earth ground, which creates an added current path, $I_{RTN\,2}$, to return the surge current back to the generator when the MOVs are activated. Each MOV would need to be capable of handling the combined currents of two lines. The actual necessity for the MOVs will depend on the test level requirement and the withstand strength of the PSE.

This section will also discuss a four-port PSE application with each port defined to meet a different surge level. Table 7 shows the high-level requirement summary.

Table 7. Requirements for Four-Port Design Example

PORT	INSTALLATION CLASS	TEST LEVELS				WAVEFORM (OCV-SCC)	
		UNSYMMETRICALLY OPERATED CIRCUITS OR LINES		SYMMETRICALLY OPERATED CIRCUITS OR LINES			
		COUPLING MODE		COUPLING MODE			
		LINE-TO-LINE	ALL LINES TO GROUND	LINE-TO-LINE	ALL LINES TO GROUND		
4	2	NA	1000	NA	1000	10/700 μs to 5/320 μs	1.2/50 μs to 8/20 μs
3	3	NA	2000	NA	2000		
2	4[(1)]	2000	4000	NA	4000		
1	5++	NA	6000	NA	6000		

[(1)]   The line-line can be implemented as a line-GND test for an unbalanced circuit or line.

The MOVs may not be required for test levels up to 1000 V because the IEEE 802.3 standard specifies that the PSE must have a withstand strength of at least 1500 V_{PK} for the 10/700-μs impulse test. This is the case for port 4 above and for this case the guidance provided in *Electrical Transient Immunity for Power-Over-Ethernet*[2] will be used. If the PSE port has been designed with a withstand rating per the 1500 V_{RMS} or 2250 V_{DC} rating specified in the IEEE 802.3 standard then the MOVs may not be required for the 2000-V test level. For this design example, MOVs will be used for port 3. The MOVs would definitely be required to meet test levels that exceed the withstand strength of the PSE, which in most cases would include the 4000-V test level and certainly the 6000-V level. MOVs will be used also for port 1 and port 2 to illustrate the design and selection procedure.

Although the MOVs might not be required to meet some of the lower test levels, implementing them for all conditions can lessen the stress on sensitive components within the AC-DC converter and add to the overall robustness of the PSE. The intended operating environment of the PSE should be considered to assess the potential risk of damage and downtime of the PSE equipment versus the added cost of the protection.

When selecting the proper MOV, its allowable operating voltage, maximum clamping voltage, and surge current ratings need to be considered. Equally important is the repetitive surge capability (lifetime rating) of the MOV, since it will need to survive ten repetitions (five positive and five negative) during the test. In general the package size of the MOV will be directly proportional to its energy handling and surge capability. While MOVs are available in a variety of package styles, this report concentrates on the use of radial-leaded disc-type devices that are available in various diameters ranging from 5 mm to 20 mm.

As will be seen later, the MOVs chosen will provide a significantly higher lifetime rating than ten pulses as this reference design will be subjected to a good deal of surge testing over and above the normal product surge lifetime.

The general safety section of the IEEE 802.3 standard specifies that the PoE equipment shall conform to the safety requirements of the IEC 60950-1 standard. Section 6.1.2 of this IEC standard states the following regarding SPDs that are connected from telecommunications networks to earth:

> *6.1.2 Separation of the telecommunication network to earth*
>
> *6.1.2.1 Requirements*
>
> *Except as specified in 6.1.2.2, there shall be insulation between circuitry intended to be connected to a telecommunications network and any parts or circuitry that will be earthed in some applications, either within the EUT or via other equipment.*
>
> *Surge suppressors that bridge the insulation shall have a minimum rated operating voltage Uop (for example, the sparkover voltage of a gas discharge tube) of*
>
> *Uop = Upeak + ΔUsp + ΔUsa*
>
> *where Upeak is one of the following values:*
>
> *for equipment intended to be installed in an area where the nominal voltage of the AC mains exceeds 130 V: 360 V*
>
> *for all other equipment: 180 V*
>
> *ΔUsp … shall be taken as 10% of the rated operating voltage of the component.*
> *ΔUsa … shall be taken as 10% of the rated operating voltage of the component.*

Therefore, based on the above, the MOV used for the earthed PSE must have an allowable operating voltage of at least 216 V_{RMS} when installed in an area where the nominal AC mains is less than 130 V and at least 432 V_{RMS} when installed in an area where the nominal AC mains is greater than 130 V. This report will assume that the PSE is installed in an area where the nominal AC mains are less than 130 V, which requires an MOV with an allowable operating voltage of at least 230 V_{RMS} (standard value).

It should be noted that the IEC 60950-1 standard allows insulation-bridging surge suppressors to be removed during the steady-state electrical strength test of an SELV circuit. In conjunction with this, the IEEE 802.3 standard specifies that the Power Sourcing Equipment of the PoE system must not introduce non-SELV power into the PoE wiring plant, which would imply that the PSE is considered to be an SELV circuit.

For this example, the current levels for the two-line differential mode (DM), four-wire CDN from Table 6 will be used. The Littlefuse UltraMOV® Varistor Series was chosen based on availability and because of the detailed repetitive surge capability curves within the device datasheet. The standard value for the 230 V_{RMS} rating was chosen (VxxE230P, where xx = disc diameter). The selection process continues by using the repetitive surge curves provided for each MOV size. The repetitive surge curves will indicate the maximum current versus pulse width rating of the MOV based on the number of expected surge pulses. For the IEC 61000-4-5:2005 test, the MOV will need to survive ten surge pulses with each current surge having an equivalent rectangular pulse width of 320 µs, which is based on the 320-µs time to half value associated with the 10/700-µs to 5/320-µs combination wave.

The Littlefuse V14E230P, V10E230P, and V07E230P were selected for port 1 (75 A), port 2 (50 A), and port 3 (25 A), respectively. For port 1 use a 320-µs impulse duration and 75-A surge current as shown in Figure 5 to get approximately 600 repetitions. This provides additional lifetime margin for extended testing and higher current levels such as those in Table 5. If the V10E230P is used at 320-µs impulse duration and 75-A surge current, the number of repetitions drops to approximately 30.
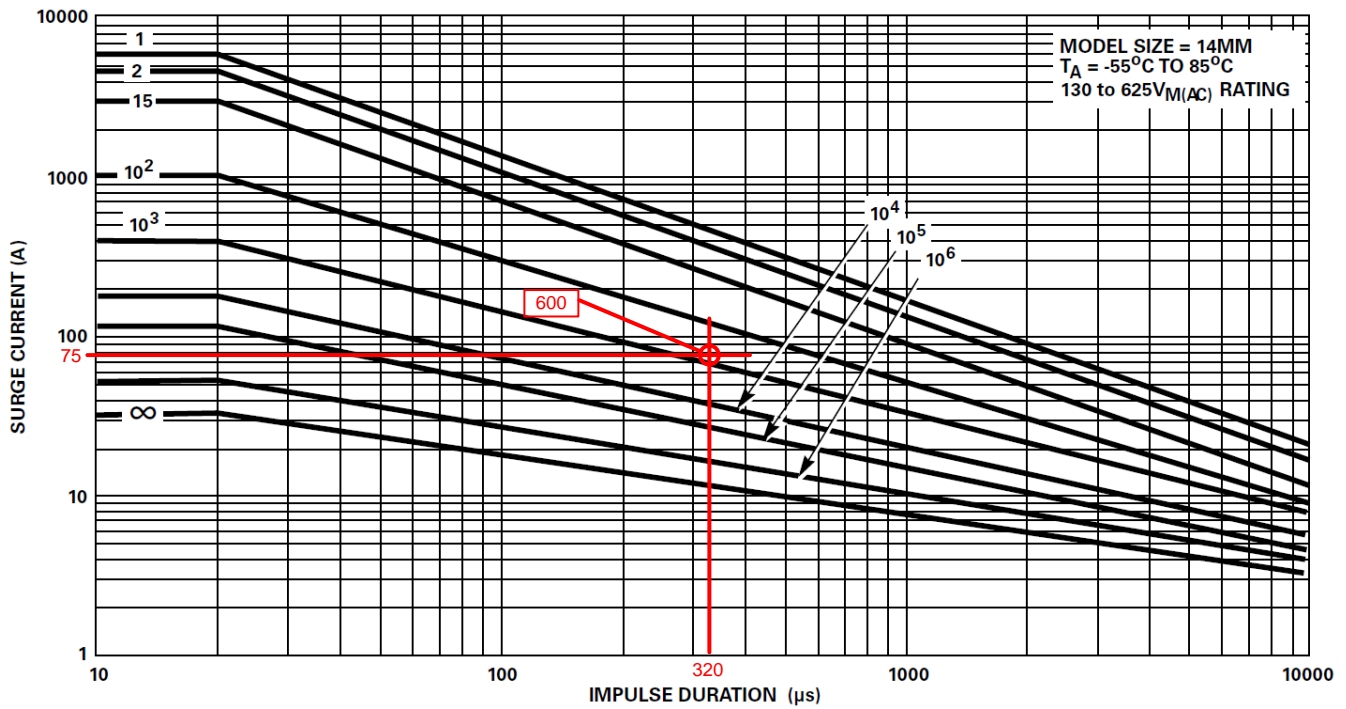
Figure 5. Using MOV Repetitive Surge Capability Curves

Continuing the example using V14E230P, the surge voltage between the center tap and ground during the 75-A surge can be estimated using Figure 6.
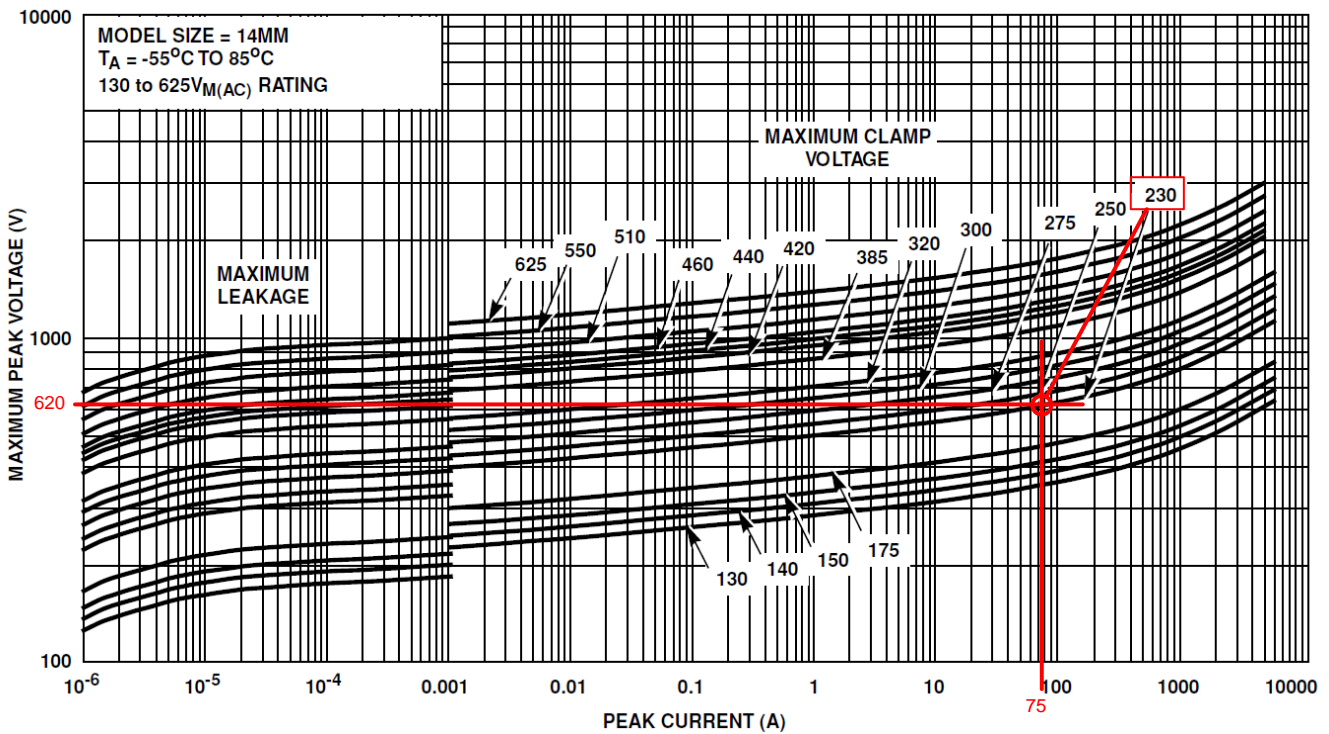

Figure 6. Using the MOV Maximum Clamping Voltage Curves

In order to finish the design for port 2 and port 3, go to the Littlefuse datasheet for V10E230P and V07E230P. For port 2 at 320-µs impulse duration and 50-A surge current, there are approximately 100 repetitions, and for port 3 (25 A), there are 300 repetitions. The surge voltage at port 2 (50 A) and port 3 (25 A) is 640 V and 630 V, respectively.

If the current waveform of the 1.2/50-µs to 8/20-µs combination wave generator sets the PSE surge requirement, the MOV surge current requirement is reduced by approximately ten times. This requirement can reduce the amount of PCB area and cost associated with the larger MOVs.

6   Reference Design

This section covers the details of the four-port lightning surge reference design (PR2189E1). PR2189E1 is designed to meet the requirements of Table 7. Design goals include configuration as a typical customer system including power, logic, and earth grounding, test points for measuring resultant surge voltages, isolated I2C communication, PHY side emulation to facilitate resultant surge voltage measurement, and PHY side protection options. The main design goal is to protect the PSE controller and PHY from damage due to the surges. A stretch goal is to allow the system to ride through these surges without any noticeable malfunctions. Key design features include:

- Grounding
  - System *frame* or earth ground-current shunting path for RJ45 housings
  - PoE or 54 V_{DC} power ground from DC power supply
  - Logic or digital ground-may be connected to earth ground through resistors
- PCB spacings
  - > 80 mils from earth (and logic) ground (>4 kV based on 20 V/mil)
  - > 30 mils from Ethernet cable side nets (> 600 V)
  - > 20 mils from 54 V_{DC} (V_{PWR}) and port DRAINx nets
- SPDs
  - MOV as primary protection
    - One from each PoE port center tap to (depends on surge voltage or current)
    - Two at DC power input feed to earth
  - Per port TVS and clamping diodes-depends on surge voltage or current
  - Data line (PHY side) bidirectional TVS and transient current suppressor (TCS)

A graphical representation of PR2189E1 is shown in Figure 7. Four PoE ports are arranged along the bottom side with the corresponding PHY side ports at the top. The TPS23861 PSE controller is in the middle and is managed over the isolation boundary by the USB-I2C host (if required). PoE 54 V_{DC} input is provided at the right side and provisions, such as MOVs and HV capacitors, bridging the isolation boundary are included to emulate the AC-DC converter in a PSE system.
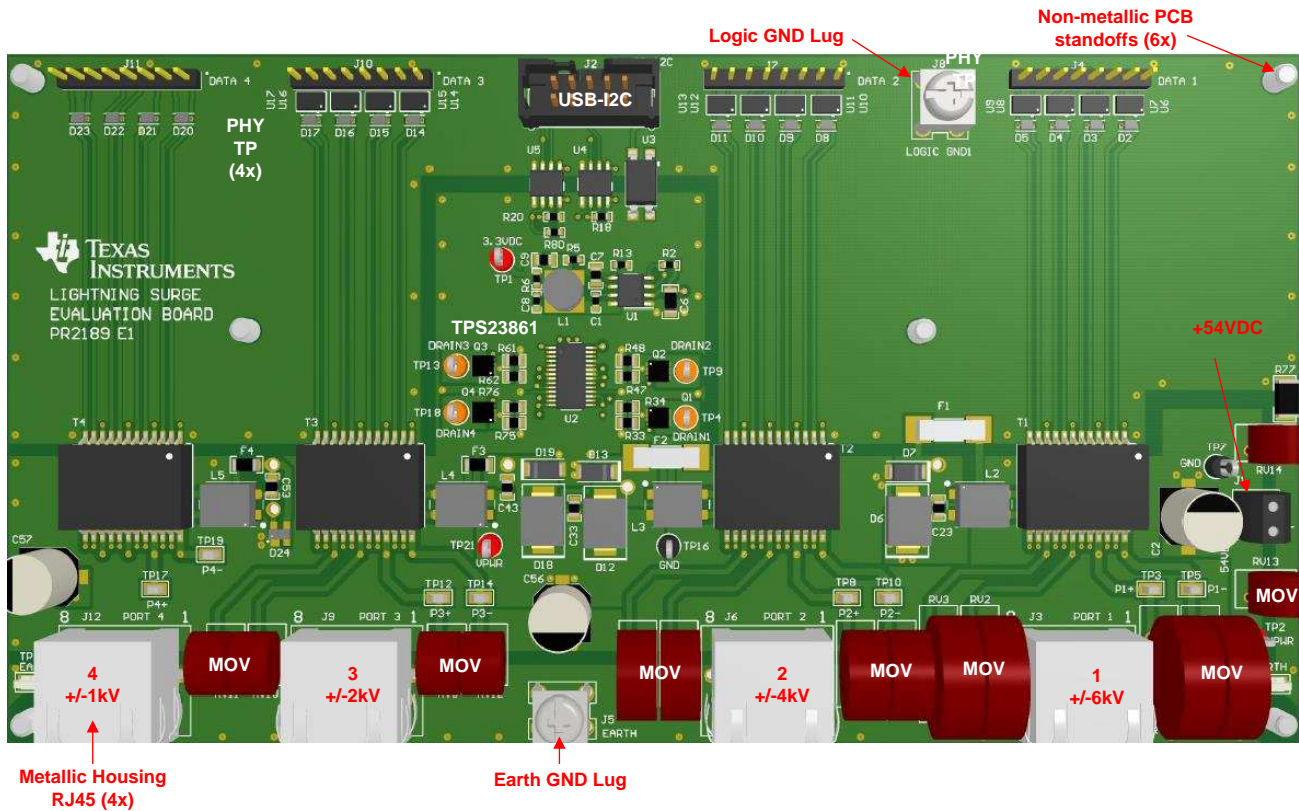
Figure 7. PR2189E1 Reference Design Layout
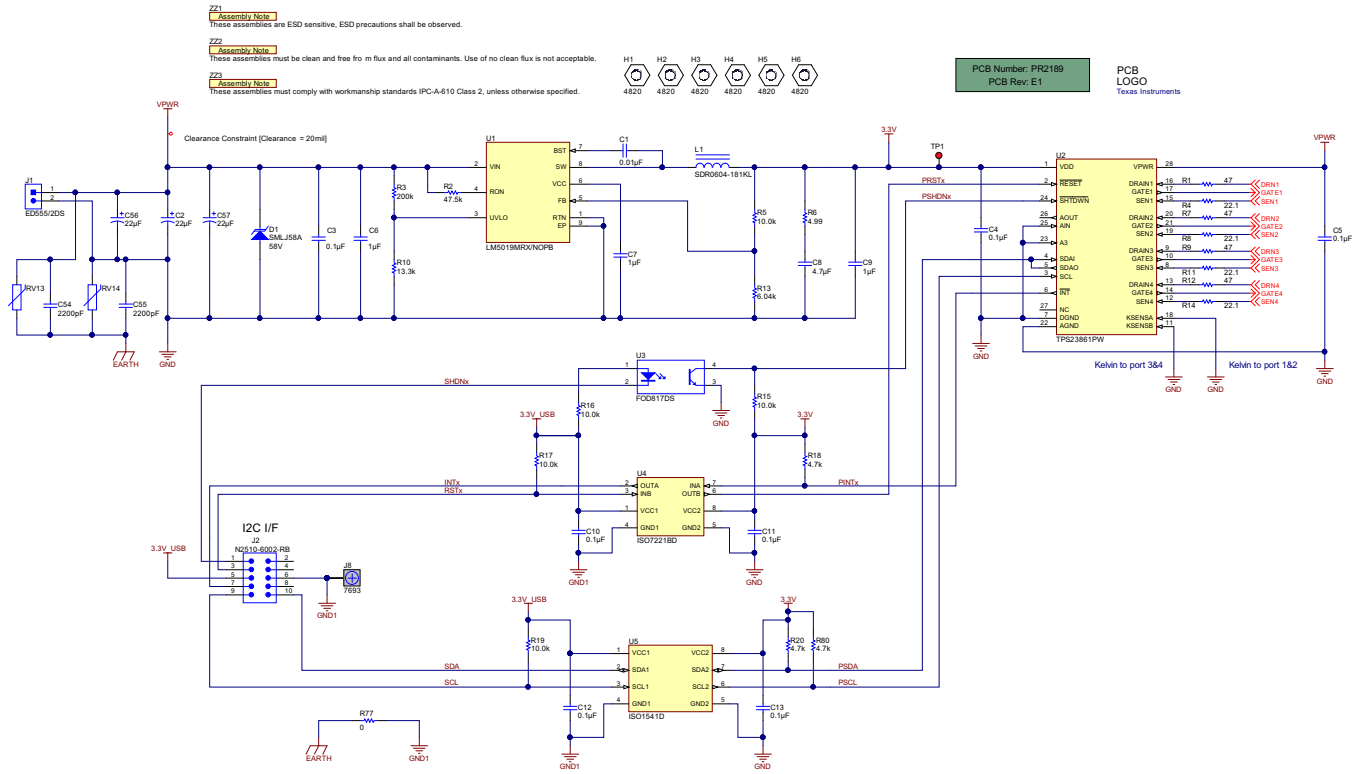
Figure 8. Schematic One
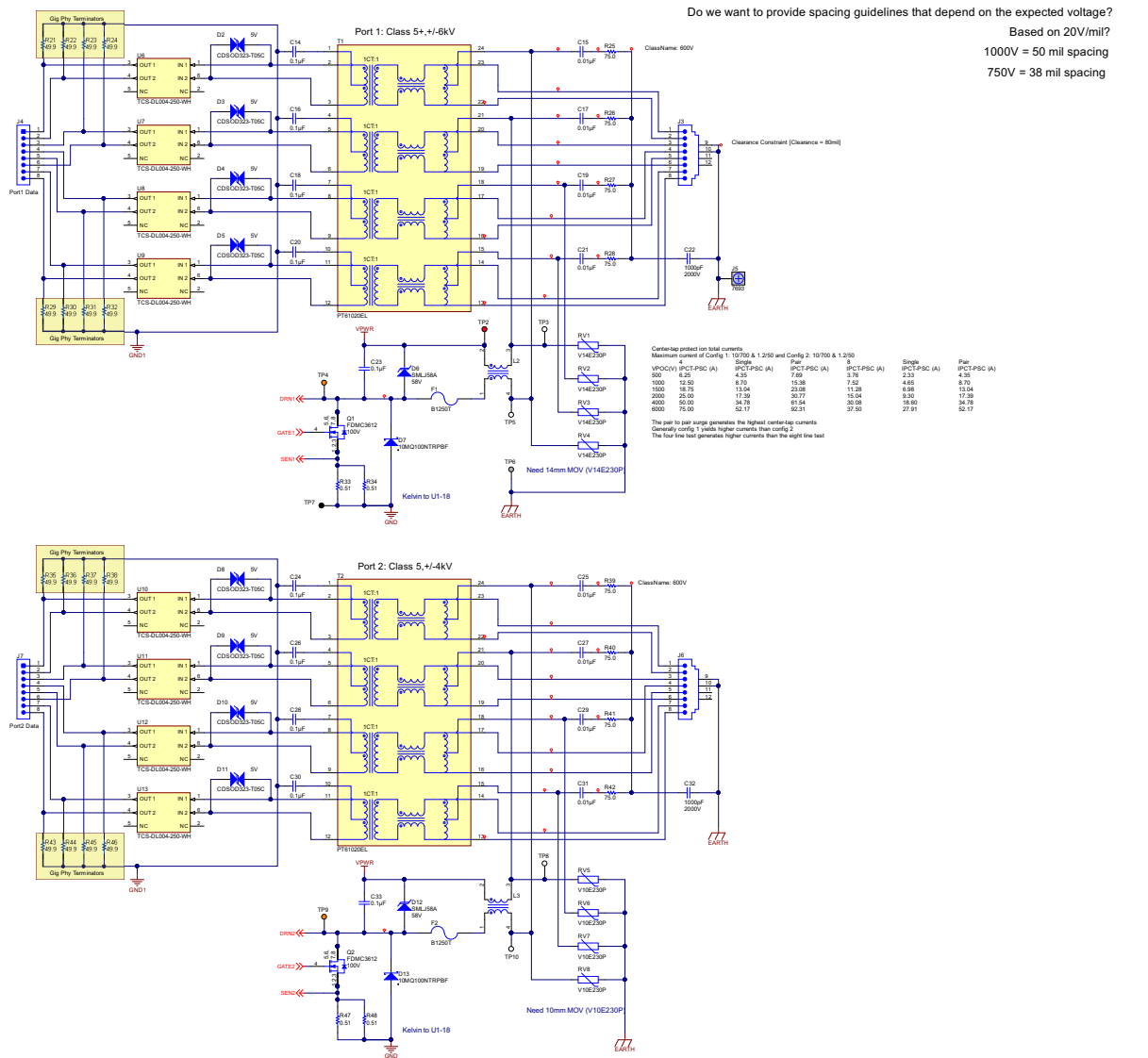
Figure 9. Schematic Two
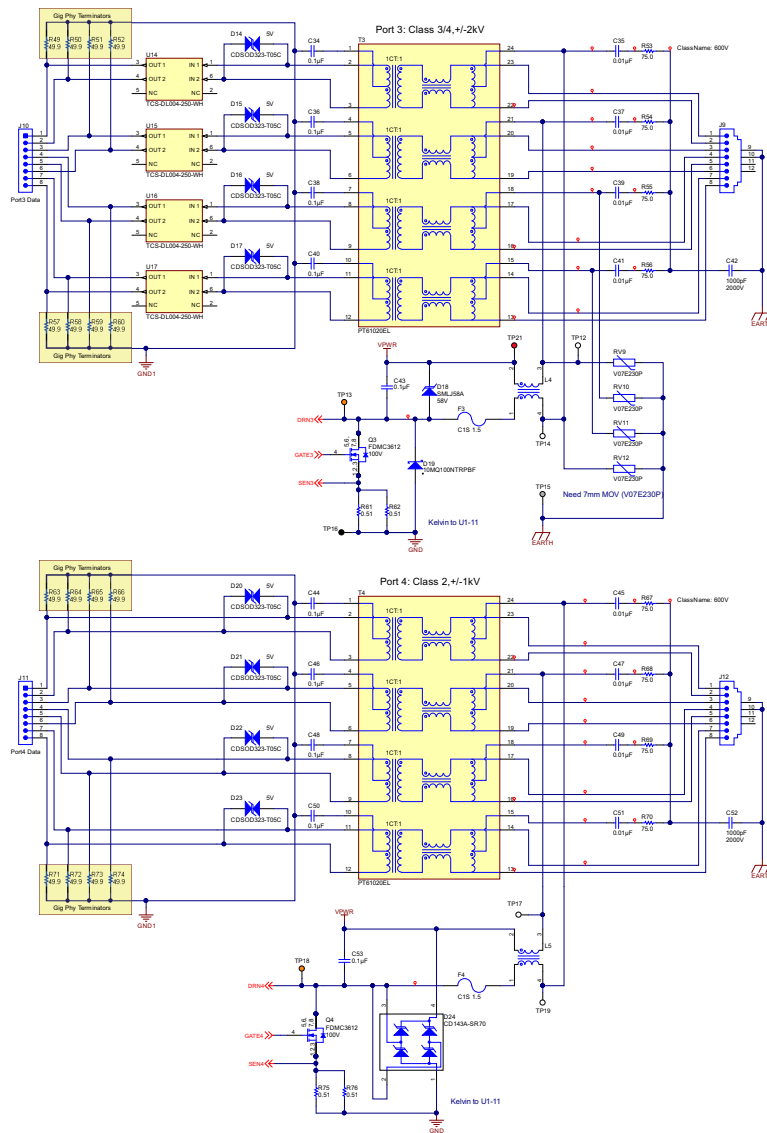
Figure 10. Schematic Three

7 Test Report

Common mode:

Port	Detection status	Class status	Surge waveform	Port on
1[1]	Open circuit	unknown	±6kV 1.2/50µs	Pass
2	Resistance valid	Class 4	±4kV 1.2/50µs	Pass
3	Resistance valid	Class 4	±2kV 1.2/50µs	Pass
4	Resistance valid	Class 4	±1kV 1.2/50µs	Pass

[1] Surges applied to pair 1 and 2 followed by pair 3 and 6 using the surge generator in series with a 42-Ω resistor. Port tested is in forced ON state with DC disconnect disabled.

Common mode:

Port	Detection status	Class status	Surge waveform	Port on
1[1]	Open circuit	unknown	±6 kV 10/700 µs	Pass
2[1]	Open circuit	unknown	±4 kV 10/700 µs	Pass
3[1]	Open circuit	unknown	±2 kV 10/700 µs	Pass
4[1]	Open circuit	unknown	±1 kV 10/700 µs	Pass

[1] Surges applied to pair 1 and 2 followed by pair 3 and 6 using the surge generator in series with a 40-Ω resistor. Port tested is in forced ON state with DC disconnect disabled.

Differential mode (single-wire differential):

Port	Detection status	Class status	Surge waveform	Port on
1[1]	Resistance valid	Class 4	±4 kV 1.2/50 µs	Pass
2	Resistance valid	Class 4	±4 kV 1.2/50 µs	Pass
3	Resistance valid	Class 4	±2 kV 1.2/50 µs	Pass
4	Resistance valid	Class 4	±1 kV 1.2/50 µs	Pass

[1] The surge generator used had ±4kV maximum capability.

Differential mode (single-pair differential):

Port	Detection status	Class status	Surge waveform	Port on
1[1]	Resistance valid	Class 4	±4 kV 1.2/50 µs	Pass
2	Resistance valid	Class 4	±4 kV 1.2/50 µs	Pass
3	Resistance valid	Class 4	±2 kV 1.2/50 µs	Pass
4	Resistance valid	Class 4	±1 kV 1.2/50 µs	Pass

[1] The surge generator used had ±4kV maximum capability.
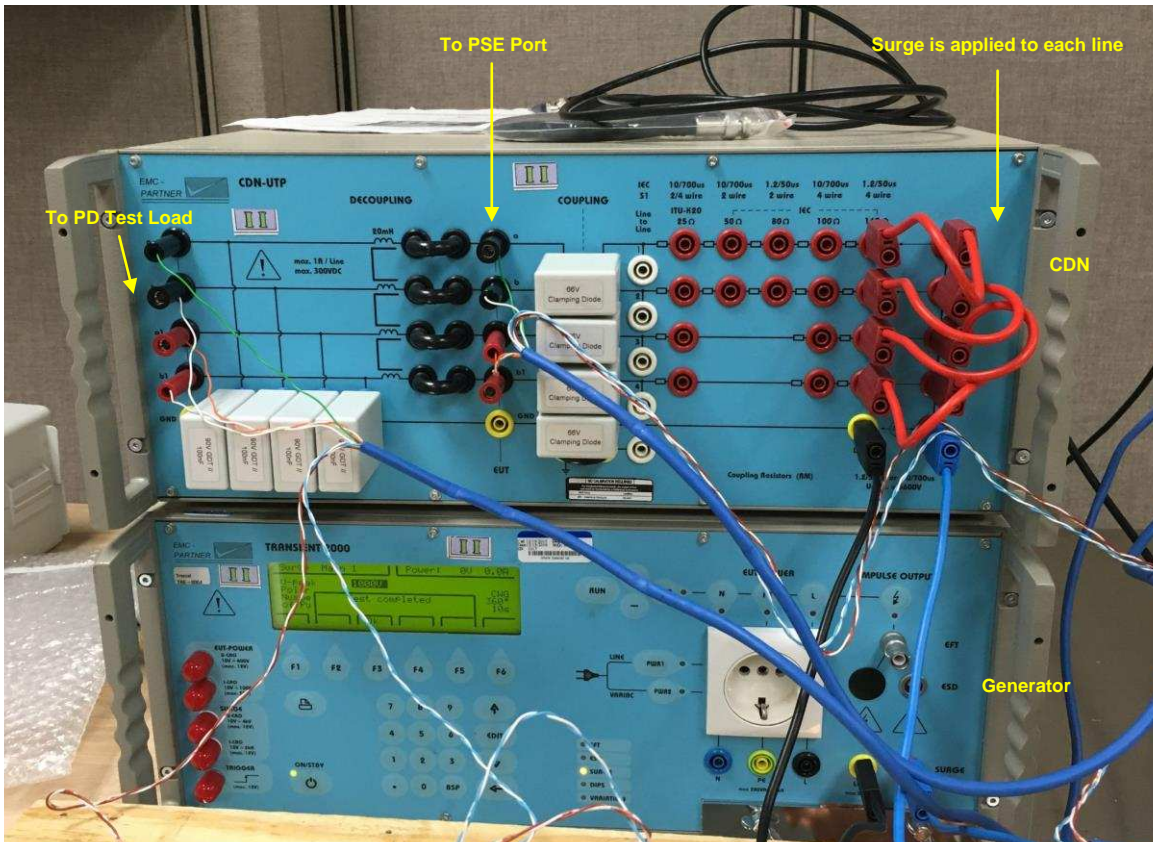
Figure 11. Test Equipment
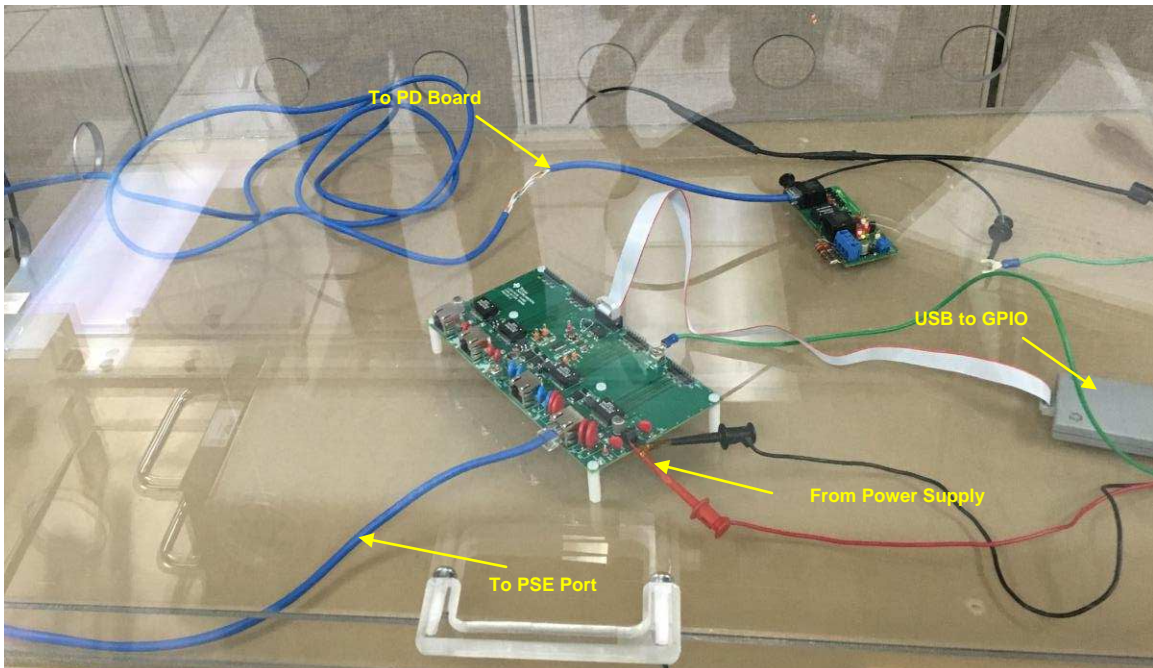
Figure 12. Test Setup

8   Conclusion

This report has concentrated on the lightning surge requirements outlined for unshielded symmetrical lines according to the IEC 61000-4-5:2005 standard. The surge protection suggestions for the PSE have been based on applying a common-mode surge using the 10/700-µs to 5/320-µs combination wave generator in accordance with the IEC standard. It should be noted that the surge protection requirements may be different for PSE applications that require testing against other standards. In particular, attention must be paid to the surge coupling method (common-mode or differential mode) and the equivalent pulse width of the surge current waveform when selecting the proper SPDs to meet a particular standard. In some cases, thyristors or gas discharge tubes may be used along with or instead of MOVs. The device choices might be based on surge handling capability or on acceptable PSE operation during the surge. In some cases the PSE may be expected to seamlessly ride through a surge while in other cases a temporary glitch in operation may be acceptable as long no damage is incurred. This report has adopted the use of MOVs in an effort to provide seamless operation of the PSE during a surge.

Although beyond the scope of this report, it should be understood that any lightning surge protection solution that is ultimately used for the PSE must also be compliant with any governing safety standards. For example, in some applications the PSE may be required to include input fuses to meet certain safety requirements related to power line cross. Aside from relating some of the references that the IEEE 802.3 standard makes to the IEC 60950-1 standard, the suggestions provided in this report have been primarily focused on meeting the surge protection requirements of the PSE. The safety related requirements of the PSE will normally depend on its installation environment and possible user interface.

9   References

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3. IEEE 802.3at -2009
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6. ITU-T Recommendation K.44 (Prepublication), April, 2008
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