Application Report

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Lightning Surge Considerations for PoE Powered Devices

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ABSTRACT

This report considers the implementation of lightning surge protection for Power over Ethernet (PoE) Powered Device (PD) applications. The need for implementing such protection will normally depend on the environment in which the PD is intended to operate and the inherent isolation properties of the PD. There are numerous compliance standards to consider when establishing the surge protection level of the PD. These standards normally introduce a number of test conditions for various types of products ranging from mains power supplies to legacy telephone equipment. This report examines the various standards in an effort to relate the test conditions that are applicable to PoE PD 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 PD shall provide electrical isolation that withstands at least one of the following electrical strength tests:

1. 1500 V_{RMS} at 50 Hz to 60 Hz for 60 s, applied as specified in subclause 5.2.2 of IEC 60950-1:2001
2. 2250 V_{DC} for 60 s, applied as specified in subclause 5.2.2 of IEC 60950-1:2001
3. An impulse test consisting of a 1500 V, 10/700 µs waveform, applied 10 times, with a 60-second interval between pulses. The shape of the impulses shall 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 electrical strength test in item (3) 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.

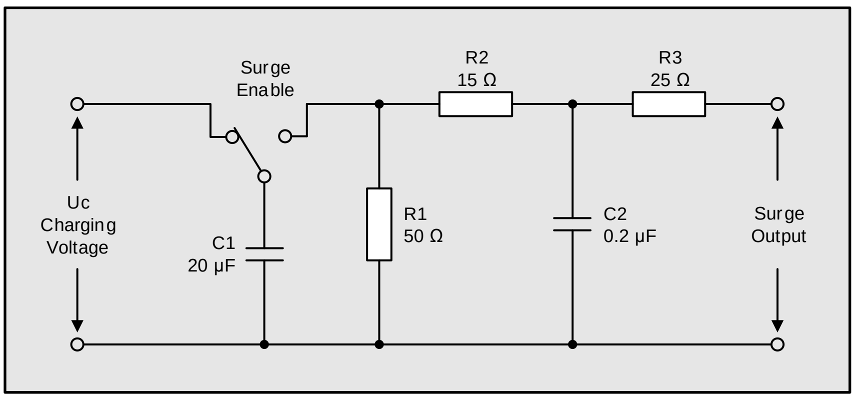


Figure 1. ITU-T K.44 Impulse Generator as Defined in Figure N.1 of IEC 60950-1 Standard

The described 10 µs virtual front time, 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 - 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 - 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 previously stated, 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 implies the use of eight resistors for PoE applications, where an 8-wire (4 twisted-pairs) symmetrically balanced cabling system is used (that is, CAT-5 and CAT-6 cable).

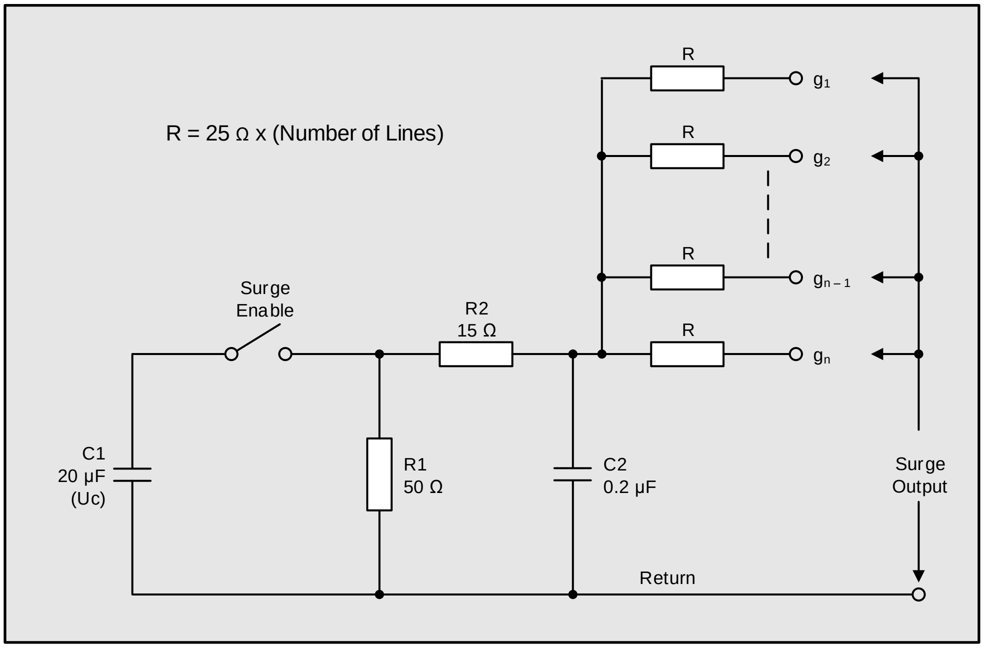


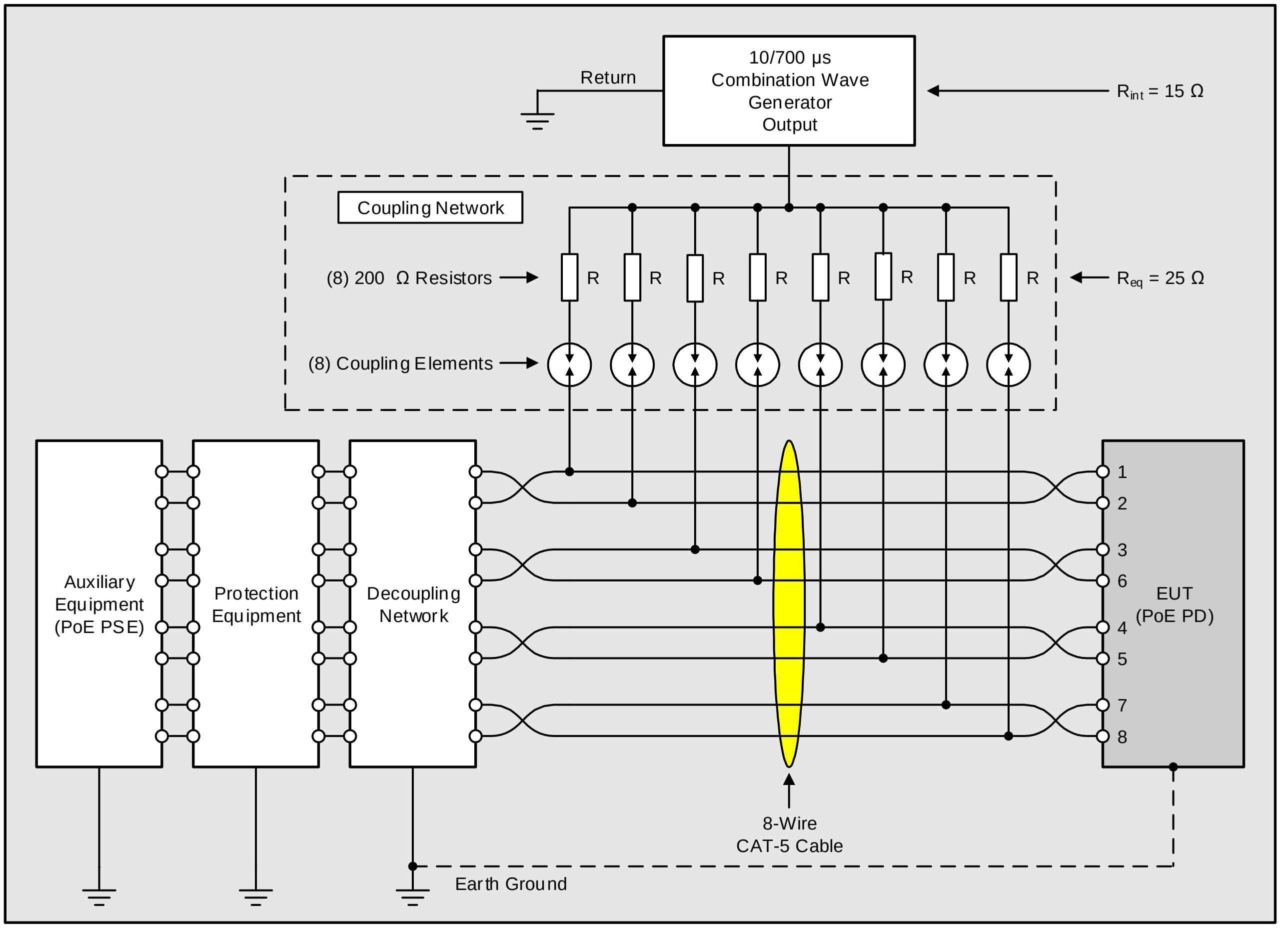
Figure 2. 10/700 µs Surge Generator as Defined in Figure A.3-1 of ITU-T K.44 Standard

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 are 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 8-wire input associated with the PD.



Based on Figure 14 of IEC 61000-4-5:2005 Standard

Figure 3. Expanded 8-Wire PoE PD Test Setup

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 8-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 is 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 1. If all eight lines of the 8-wire cable were shorted to the return of the surge generator simultaneously, the peak current through each line would be one-eighth of the total peak short-circuit current from the surge generator as outlined in Table 2. Table 2 also includes some worst-case scenarios when using this 8-wire setup, indicating the peak current per line when only one line or one twisted pair is shorted with the other lines open.

Table 2. Peak Current Into Each Shorted Line of the 8-Wire Test Setup Shown in Figure 3.

10/700 µs Combination Wave Generator		8-Wire Test Setup Based on IEC 61000-4-5: 2005		
Peak Open-Circuit Voltage	Peak Short-Circuit Voltage	Peak Current per Line		
		All Lines Shorted	One Line Shorted	One Pair Shorted
500 V	12.5 A	1.56 A	2.33 A	2.17 A
1000 V	25 A	3.13 A	4.65 A	4.35 A
1500 V	37.5 A	4.69 A	6.98 A	6.52 A
2000 V	50 A	6.25 A	9.3 A	8.7 A
4000 V	100 A	12.5 A	18.6 A	17.39 A

The peak current per line needs to be considered when selecting the surge current rating of components within the PD, including any surge protection devices (SPDs). The path of the surge needs to be understood to determine whether the component will see the current associated with one line or an additive current associated with multiple lines. This is emphasized in the following definition of the multiple ports test according to the ITU-T K44 standard:

The multiple ports lightning surge test checks that the equipment has the required level of resistibility when an overvoltage surge occurs on n ports simultaneously, which can result in a high current flowing into a common component or part of the equipment.

Referring to the setup in Figure 3, it is evident that the surge is being applied to the eight lines with respect to the return of the surge generator which is referenced to earth ground. This type of test is commonly referred to as an all lines-to-ground or common-mode test. The IEC 61000-4-5:2005 standard specifies this test for unshielded symmetrical lines as is indicated in Figures 14 and 15 and Table A.1 of the standard. It should be noted that unlike the unshielded symmetrical lines setup shown in Figure 12 of the older IEC 61000-4-5:1995 standard, the setup in Figure 14 of the newer IEC 61000-4-5:2005 standard does not include a line-to-line test or an each line-to-ground test.

Table 3 summarizes the test levels and coupling modes used for interconnection and communication lines according to Table A.1 of the IEC 61000-4-5:2005 standard. The highlighted section for symmetrical lines corresponds with the test setup shown in Figure 3. The test level used depends on the intended operating environment of the PD which could range from installation class 0 for well protected environments to installation class 5 for harsh outdoor environments.

Table 3. Test Levels and Coupling Modes According to Table A.1 of IEC 61000-4-5:2005 Standard

Installation Class	Test Levels					
	Unsymmetrical Operated Circuits/Lines		Symmetrical Operated Circuits/Lines		Shielded I/O and Communication Lines	
	Coupling Mode		Coupling Mode		Coupling Mode	
	Line-to-Line	Each Line-to-Ground	Line-to-Line	All Lines-to-Ground	Line-to-Line	Each Line-to-Ground
0	N/A	N/A	N/A	N/A	N/A	N/A
1	N/A	500 V	N/A	500 V	N/A	N/A
2	500 V	1000 V	N/A	1000 V	N/A	500 V
3	1000 V	2000 V	N/A	2000 V	N/A	2000 V
4	2000 V	4000 V	N/A	2000 V	N/A	4000 V
5	2000 V	4000 V	N/A	4000 V	N/A	4000 V

3 Unearthed PD Applications

Referring to the setup in Figure 3, a dotted-line connection is shown from the EUT to earth ground to indicate that such a connection might not be present for particular applications. This would be the case for a PD that is intentionally designed to be floating with no connection (including capacitive coupling) to earth ground. The IEC 61000-4-5:2005 standard states the following regarding the test setup for these unearthed situations:

Connection to a ground reference is only required when the EUT is normally installed with a ground reference connection.

As previously mentioned, the generator applies the common-mode surge with respect to the return of the generator which is referenced to earth ground. If the PD has no connection to earth ground, then there should be no inviting path for the surge current to take through the PD to return to the generator. In these situations, the normally-used input filter and transient voltage suppressor (TVS) devices included at the front-end of a PD for conducted emissions filtering and hot-plug transient protection should also serve to provide adequate lightning surge protection for unearthed PD applications.

Although the following statement from the IEC 61000-4-5:2005 standard is directed particularly toward the testing of power ports, its content appears to be in support of the previous observations:

For double-insulated products without PE or external earth connections, the test shall be done in a similar way as for grounded products but without adding any additional grounded connections. If there are no other possible connections to earth, line-to-ground tests may be omitted.

If the PD has no possible connection to earth ground and its physical proximity to earth ground is such that no arc-over can occur at voltages as high as 4000 V, it would seem that the PD could be subjected to all of the common-mode tests highlighted in Table 3 without failure.

Although beyond the scope of this report, it should be noted that in some applications, the PD might also be powered from an auxiliary power source such as a wall adapter. According to the IEEE 802.3 standard, this auxiliary power source (or any other equipment that can be connected to the PD) must provide isolation between the MDI leads (that is, the RJ-45 input to the PD) and all accessible external conductors, including any frame ground. The PD isolation and withstand requirements, described in Section 1, also apply to the auxiliary power source. For intentionally unearthed PD applications, the actual withstand voltage of the auxiliary power source and any associated capacitive coupling to earth ground needs to be considered when determining if any possible surge paths are created through the PD by way of the auxiliary power source connection.

4 Earthed PD Applications

Some PD applications may include a dedicated connection to earth ground where the dotted-line connection shown in Figure 3 is present. Along with acting as a possible safety ground, this earth ground connection might serve as a reference ground for internal PD circuitry such as Bob Smith cable terminations and the secondary-side of an isolated DC-DC converter. These internal earth ground connections can create paths for common-mode surge currents to flow from the generator, through the PD, 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, is shown to divide into the 8-wire input of the PD, as indicated by current paths I_A through I_H. Once entering the PD, the surge current will seek any paths to earth ground in order to return to the generator. Two possible return paths are shown as being $I_{RTN\ 1}$, through the Bob Smith termination circuit block, and $I_{RTN\ 2}$, through the isolated DC-DC converter circuit block. The main conduits for these return paths are seen to be the highlighted C_{BS} capacitor in the Bob Smith termination block and the typically-used C_{CM} common-mode noise capacitor in the DC-DC converter block, each of which crosses the isolation boundary. These two return paths are shown to combine as $I_{RTN\ 1+2}$, which then returns to the generator.

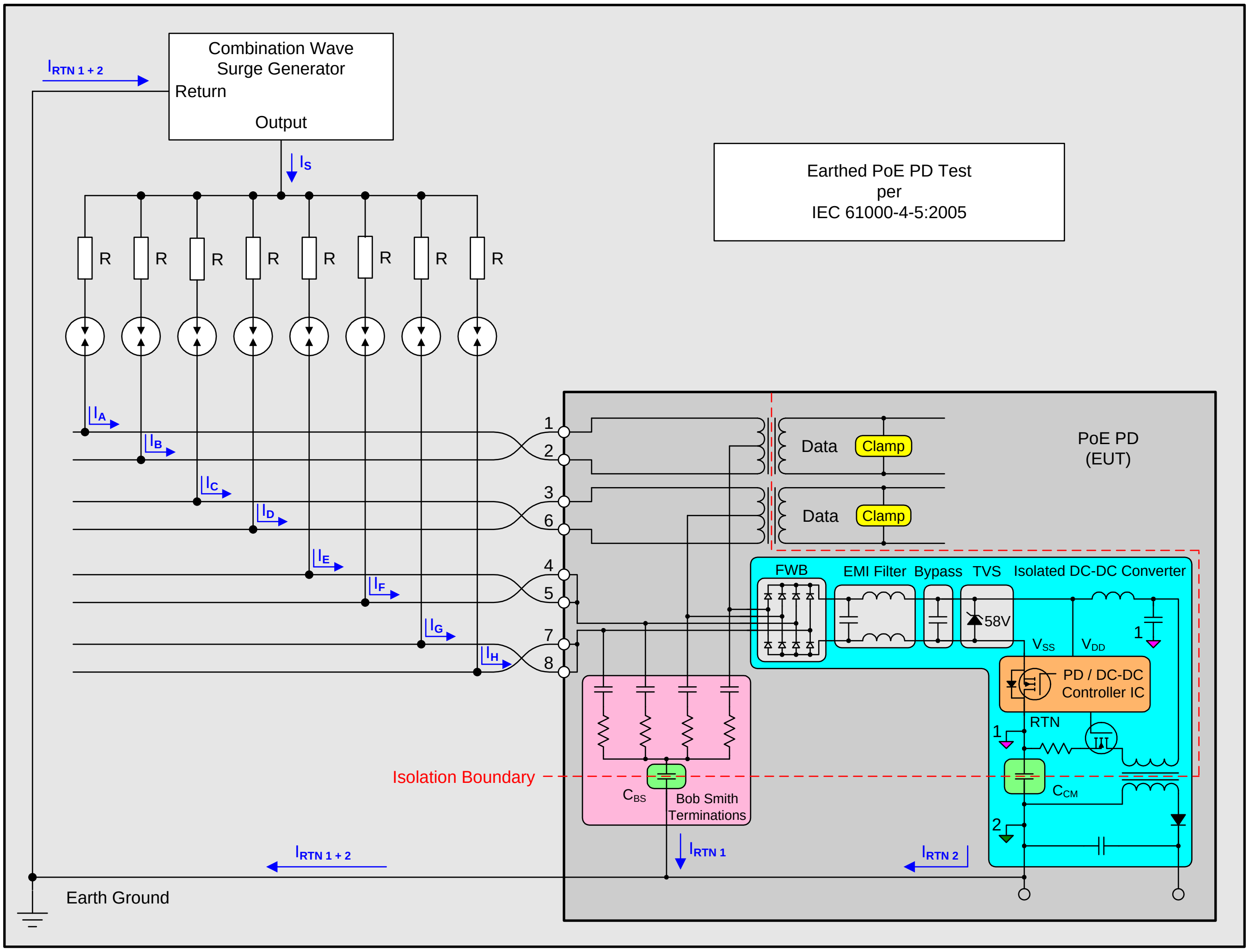


Figure 4. Example of Surge Current Paths Through an Earthed PD Application

The currents, as drawn in Figure 4, indicate a positive surge from the surge generator, while in actuality the PD is subjected to 5 positive and 5 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, particularly for the DC-DC converter block which uses directional components. For example, during a positive surge the surge currents will flow through the upper four diodes shown for the converter's FWB, while during a negative surge, the surge currents will flow through the lower four diodes of the FWB.

The DC-DC converter block is shown to include an EMI filter which is normally required for the earthed PD 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 through the converter. The converter is also shown to include a 58-V TVS that is typically placed across the input rails of the PD/DC-DC controller IC to protect against hot-plug transients and ESD events. This TVS device also contributes to the protection of the controller IC during a lightning surge. The controller IC itself is shown to include a pass-FET that connects the primary-side return of the converter to the return side of the rectified PoE input. While multiple current paths may exist within the DC-DC converter block that can contribute to the overall $I_{RTN\ 2}$ return path, it becomes obvious from the circuit in Figure 4 that an inviting path for the surge current is through the pass-FET of the controller. Providing surge protection for this pass-FET is covered further in Section 5.

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

The need for additional SPDs in the earthed PD application normally depends on the required surge test level and the inherent isolation properties of the PD. As described in Section 1, the IEEE 802.3 standard specifies that the PD must provide electrical isolation that withstands an electrical strength test of 1500 V_{RMS}, 2250 V_{DC}, and/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 PD, then additional SPDs may not be needed. Alternatively, if the PD will be subjected to surge test levels that exceed the withstand strength of the PD, then additional SPDs will most likely be required at the front-end of the PD to either clamp the surge voltage below the withstand rating of the PD or crowbar the surge to earth ground.

5 SPDs for Earthed PD Applications

This section expands on the earthed PD example introduced in Section 4 by relating the actual need and selection of SPDs to the various test levels associated with the IEC 61000-4-5:2005 symmetrical lines test. Figure 5 shows the earthed PD example with proposed locations for added devices SPD1–SPD5.

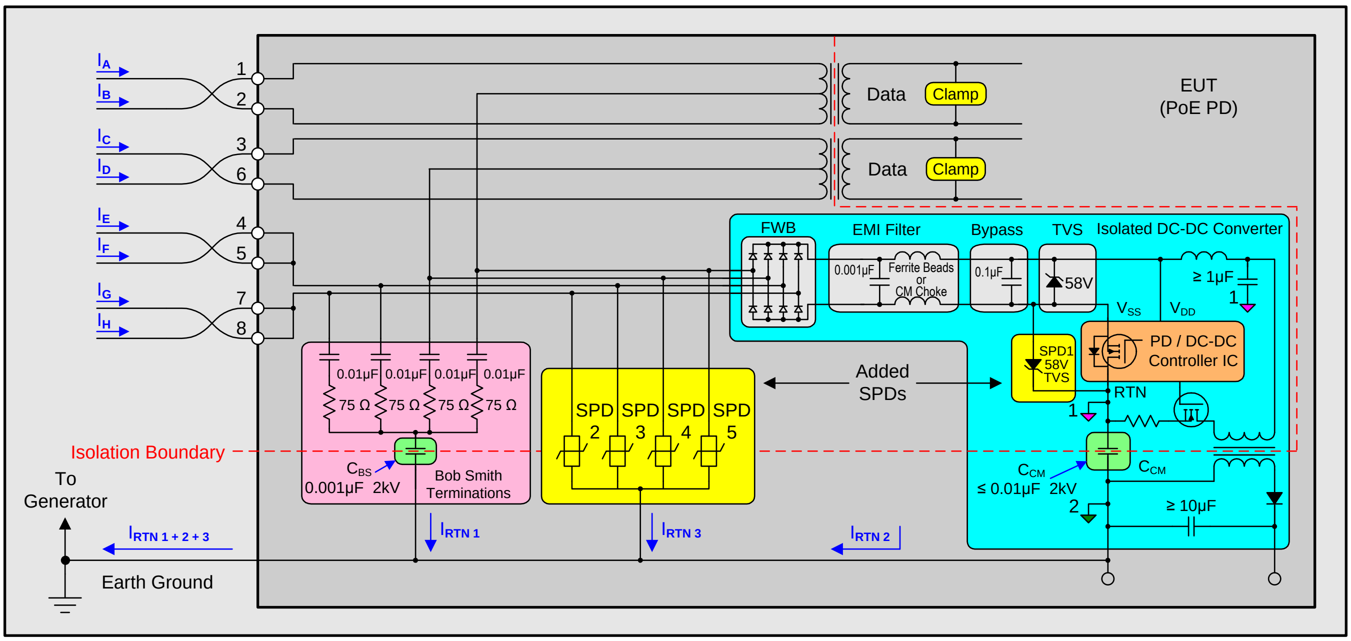


Figure 5. Proposed Addition of SPDs for an Earthed PD Application

SPD1 is a 58-V TVS that is placed across the pass-FET of the PD/DC-DC controller IC to protect the FET during either a positive or negative surge, including conditions when the FET is operated in its off state. SPD1, which is used in conjunction with the normally used 58-V TVS that is placed across the input rails of the PD/DC-DC controller IC, should be included as a minimum requirement for all of the test levels.

SPD2–SPD5 are shown to be metal oxide varistors (MOVs) that are used to clamp the surge voltage to earth ground, creating an added current path, $I_{RTN\ 3}$, to return the surge current to the generator when the MOVs are activated. Each MOV needs to be capable of handling the combined currents of two lines. The actual need for the MOVs depends on the test level requirement and the withstand strength of the PD.

The MOVs may not be required for test levels up to 1000 V, since the IEEE 802.3 standard specifies that the PD must have a withstand strength of at least 1500 V_{PK} for the 10/700 µs impulse test. If the PD has instead 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. The MOVs would definitely be required to meet test levels that exceed the withstand strength of the PD, which in most cases includes the 4000-V test level. 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 DC-DC converter and add to the overall robustness of the PD. The intended operating environment of the PD should be considered to assess the potential risk of damage and downtime of the PD equipment versus the added cost of the protection.

It should be noted that the capacitance associated with MOVs generally prevents them from being used on data lines because of their affect on signal integrity. For this reason, SPD2–SPD5 have purposely been placed on the power-related connections associated with PD. In particular, SPD4 and SPD5 have been placed on the center taps of the data transformers where the added capacitance doesn't present an issue.

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 10 repetitions (5 positive and 5 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.

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*

$$U_{op} = U_{peak} + \Delta U_{sp} + \Delta U_{sa} \quad (1)$$

> *where U_{peak} 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***
>
> *ΔU_{sp} … shall be taken as 10% of the rated operating voltage of the component.*
> *ΔU_{sa} … shall be taken as 10% of the rated operating voltage of the component.*

Therefore, based on the IEC standard, the MOV used for the earthed PD needs to 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 assumes that the PD is installed in an area where the nominal AC mains is less than 130 V, therefore, requiring 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 implies that the PD is considered to be an SELV circuit.

After identifying MOVs that meet the allowable operating voltage requirement, the selection process continues by using the repetitive surge curves that the MOV manufacturer provides for the various sizes of MOVs, narrowing down the selection to a certain MOV family (package 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 needs to survive 10 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 - 5/320 µs combination wave. Since each MOV shown in Figure 5 needs to handle the combined surge current from two lines (one twisted pair), the peak current for each MOV can be estimated by doubling the peak-current-per-line values given for the one shorted-pair condition in Table 2. Unlike when using crowbar-type SPDs such as thyristors or gas discharge tubes, this estimate of the peak current is on the conservative side when using MOVs, since the actual current through the MOV is lessened due to its appreciably higher clamping voltage.

After identifying the MOV family using the repetitive surge curves, the proper MOV is selected by using the manufacturer-supplied V-I characteristic curves associated with the MOV family. These curves indicate the maximum clamping voltage of each MOV within the family versus the expected peak current. Along with meeting the allowable operating voltage previously discussed, the maximum clamping voltage of the selected MOV needs to be below the withstand strength of the PD, which according to the IEEE 802.3 standard, could be 1500 V_{RMS}, 2250 V_{DC}, and/or 1500 V_{PK} for the 10/700 µs impulse test defined in the IEC 60950-1 standard.

Table 4 summarizes the requirements for the SPDs proposed in Figure 5 for the various test levels of the IEC 61000-4-5:2005 symmetrical lines test. Installation class 0 has not been included in the table since no surge test is required for this class of equipment. The MOV suggestions are based on using the smallest diameter disc-type devices available from several manufacturers that meet the individual surge requirements. The MOVs used for installation classes 1 and 2 are generally standard rated devices, while the MOVs for installation classes 3 through 5 are generally high-surge rated devices or larger diameter standard devices. The choice of using a high-surge device as opposed to a larger diameter standard device normally depends on component cost and available board space.

Table 4. Requirements for SPD1-SPD5 for Earthed PD Application Shown in Figure 5

Installation Class	Test Level All Lines-to-ground	SPD1 (TVS) Require-ment	SPD1 (TVS) Suggested Part Number	SPD2–SPD5 (MOVs) Require-ment	Allowable Working Voltage	Maximum Clamping Voltage	10 Pulse Peak Current (320 µs)[(1)]	Suggested Part Number	Manufacturer	Disc Size (mm)
1	500 V	Required	SMAJ58A or equivalent	Optional	230 V_{RMS}	1500 V_{PK}	4.34 A	V360ZA05P	Littelfuse	5
								ERZV05D361	Panasonic	5
								ROV05-361K	Tyco	5
								VDRS05C230xyE	Vishay	5
2	1000 V	Required		Optional			8.7 A	V360ZA05P	Littelfuse	5
								ERZV05D361	Panasonic	5
								ROV05-361K	Tyco	5
								VDRS05C230xyE	Vishay	5
3	2000 V	Required		Contingent[(2)]			17.4 A	V07E230P	Littelfuse	7
								ERZV07D361	Panasonic	7
								ROV05H361K	Tyco	5
								VDRH05E230xyE	Vishay	5
4	2000 V	Required		Contingent[(2)]			17.4 A	V07E230P	Littelfuse	7
								ERZV07D361	Panasonic	7
								ROV05H361K	Tyco	5
								VDRH05E230xyE	Vishay	5
5	4000 V	Required		Required			34.78 A	V07E230P	Littelfuse	7
								ERZV07D361	Panasonic	7
								ROV07H361K	Tyco	7
								VDRH05E230xyE	Vishay	5

(1) Based on MOV pulsed lifetime curves and 320-µs rectangular pulse width.

(2) Required if PD withstand strength is designed for 1500 V_{PK}, 10/700 µs impulse test only. May not be required if PD withstand strength is designed for 1500 V_{RMS} or 2250 V_{DC}.

As mentioned in Section 3, 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 PD 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 - 5/320 µs combination wave generator. The 1.2/50 µs generator is commonly referred to as a 1.2/50 µs - 8/20 µs combination wave generator, since its short-circuit current waveform has an 8 µs virtual front time and a 20 µs virtual time to half value.

Assuming that the current waveform of the 1.2/50 µs - 8/20 µs combination wave generator has an equivalent rectangular pulse width of 20 µs, and upon review of the repetitive surge curves for the MOVs proposed in Table 4, the MOVs are seen to have a 10 pulse current handling capability that is approximately ten times greater than that of the 320-µs pulse-width condition. For applications where the PD is only required to be tested using the 1.2/50 µs generator, the standard rated MOVs listed for installation class 1 in Table 4 should also be sufficient for installing classes 2 through 5. The use of smaller MOVs, such as 3-mm axial-leaded types and surface-mount types, might even be considered for this lower pulse-width condition. The same test setup shown in Figure 3 could be used for testing this condition, except that the internal source resistance of the generator is 2 Ω, and each of the eight coupling resistors is 250 Ω (maximum limit per the IEC standard). Figure 15 of the IEC 61000-4-5:2005 standard specifies an alternate coupling/decoupling network that could also be used with the 1.2/50 µs generator.

6 Considerations

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 PD have been based on applying a common-mode surge using the 10/700 µs - 5/320 µs combination wave generator in accordance with this most recent IEC standard. It should be noted that the surge protection requirements may be different for PD applications that require testing against other standards. In particular, attention needs to 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 and/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 PD operation during the surge. In some cases the PD 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 PD 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 PD must also be compliant with any governing safety standards. For example, in some applications the PD 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 PD. The safety-related requirements of the PD will normally depend on its installation environment and possible user interface.

7 References

1. *IEEE 802.3at Draft 3.3 Standard*, December 1, 2008
2. *UL 60950-1:2007 Standard* (based on IEC 60950-1:2005), March 27, 2007
3. *ITU-T Recommendation K.44*, July, 2003
4. *ITU-T Recommendation K.44 - Prepublication*, April, 2008
5. *IEC 61000-4-5:2005 Standard*, November, 2005
6. *Electrical Transient Immunity for Power-Over-Ethernet*, Jean Picard, Application Report SLVA233A, Texas Instruments, August 2006 Revision

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