

SURGE PROTECTION IN PANEL DESIGN



SPD Sizes in Panel Design



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Overview

Panel design is an art. Panels that are well-designed strike a balance between form, function, and cost. This can be difficult considering that an attempt to do so is an attempt at achieving the best of three worlds.

However, knowledge, is power. When a panel designer is well-informed, optimizing cost-effective protection into the panel design is easy.

Surge protection sizes can be a confusing subject. When a person uses a surge protection device (SPD) that is the incorrect size for their system, they waste money on an unnecessarily high level of surge protection (which is the best-case scenario), or they waste money on a device that will provide inadequate protection and also have a short lifespan.

This guide is tailored to panel designers who wish to optimize surge protection in panels for industrial power distribution systems and equipment. It will teach panel designers how the correct size of SPD is determined for each of the seven most common types of systems.

Why Surge Protection is Important

Downtime caused by surge events is common. All 75 maintenance and facility managers who were surveyed in 2013 by the National Electrical Manufacturers Association (NEMA) said they have experienced operational downtime caused by a surge event. More than 30 % of the respondents said they had experienced downtime that lasted between 6 and 12 hours, and almost 20 % reported having experienced downtime of more than 2 days [1].

NEMA's survey found that the cost of equipment damage caused by surges was not only expensive, but common. Among the respondents:

- 50 % reported the cost of damage due to surges to be between \$1,000 and \$10,000
- 22 % reported the cost to be between \$10,000 and \$100,000
- 6 % reported the cost to be greater than \$100,000

The most commonly cited (47 %) cause among NEMA's survey respondents for the surge event they had experienced was that it was due to an unexplained process interruption.

SPD Markings

UL requires certain markings on all Listed and Recognized SPDs:

SPD Type: Describes the intended location of the SPD in regard to the main circuit breaker.

- **Type 1:** An SPD used between the secondary of the service transformer and the line side of the main circuit breaker.
- **Type 2:** A permanently connected SPD on the load side of the main circuit breaker.
- **Type 3:** A point of utilization SPD, like a receptacle, must be within 10 meters (30 feet) of the panel.

Nominal System Voltage: This should match the utility system voltage that is being protected.

Maximum Continuous Operating Voltage (MCOV): The maximum voltage the device will allow before it starts to clamp. The MCOV is usually between 15 and 25 % more than the nominal system voltage.

Nominal Discharge Current: The peak value of the current through the SPD having an 8/20 waveform where the device is still functional after 15 surges. The manufacturer chooses which level to test: 3 kA, 5 kA, 10 kA, and 20 kA.

Voltage Protection Rating (VPR): The average limiting voltage of an SPD when subjected to a 6 kV, 3 kA 8/20 combination waveform generator. VPR is a clamping voltage measurement rounded up to one of the standardized table of values. All VPR tests are conducted with 6-inch leads outside of the SPD enclosure.

Short-circuit current rating (SCCR): The amount of fault current to which an SPD can be subjected and still safely disconnect from the power source.

Enclosure Type: NEMA rating for environmental conditions and locations where the SPD can be installed.

SPDs are important. NEMA says their survey's results "underscore the importance of the role that SPDs can fill in preventing damage to and improving the reliability of electrical and safety systems." According to NEMA, "a strong majority" of people report being pleased with SPDs that are permanently connected [1].

Surge Protection Device Overview

SPDs reduce surge voltages to a level that the power distribution system and the equipment that is connected to the system can handle. They protect the programmable logic controller in the equipment that they are building, the power supplies, the step-down transformer, variable-frequency drives, and the input/output devices.

SPDs are primarily rated by how much of a surge current magnitude they can handle, and how well they limit the voltage when conducting that surge current.

SPDs are not one-size-fits-all devices, nor do the size of their kA rating (the surge rating) go hand-in-hand with the size of the panel. In other words, do not select an SPD with a maximum kA rating just because the panel is large.

Surge Protection Device Classifications

UL 1449 [2] defines Type 1, Type 2, and Type 3 SPDs:

- **Type 1:** One port, permanently connected SPDs, except for watt-hour meter socket enclosures, intended for installation between the secondary of the service transformer and the line side of the service equipment overcurrent device, as well as the load side, including watt-hour meter socket enclosures and molded case SPDs intended to be installed without an external overcurrent protective device. Type 1 SPDs for use in PV systems can be connected between the PV array and the main service disconnect.
- **Type 2:** Permanently connected SPDs intended for installation on the load side of the service equipment overcurrent device; including SPDs located at the branch panel and molded case SPDs.
- **Type 3:** Point of utilization SPDs, installed at a minimum conductor length of 10 meters (30 feet) from the electrical service panel to the point of utilization, for example cord connected, direct plug-in, receptacle type and SPDs installed at the utilization equipment

being protected. The distance (10 meters) is exclusive of conductors provided with or used to attach SPDs.

For the purposes of this guide, Type 2 SPDs will be discussed.

Why Are US Panel Designers Abandoning NEMA-Style for DIN-Rail Mountable SPDs?

The transition from NEMA- to DIN-mounted panel protection is great for U.S. panel builders. DIN-mounted panel protection has always been preferred over NEMA-style outside of the U.S. Recently, however, the U.S. finally began to make the switch.

Why? DIN-rail surge protection saves space. It is also less expensive and easier to work with than NEMA-style devices. This is ideal for panel designers because a DIN-rail style makes it easy to integrate surge protection into panel designs.

Advantages of Metal Oxide Varistors

SPDs are built with a surge-protective component, which is responsible for clamping voltage when the voltage surges above a given level. Metal oxide varistors (MOVs)—which are the most common type of component used in SPDs—are generally considered to be the most effective because they only clip surges that are rising above the nominal supply voltage,

Littelfuse SPD2 Series

The most important features of the SPD2 series for panel designers are that they:

- have a high SCCR;
- have DIN-rail locking tabs, which make them easy to install;
- have a remote contact for indication, and can therefore be tied into the programmable logic controller;
- are IEC compliant and UL Recognized in a single part number; and
- will not require any additional fusing or overcurrent protection in U.S. applications.

For more information on the Littelfuse SPD2 series: www.littelfuse.com/SPD

and then instantly turn off after the surge has passed. MOVs have a high surge rating and are available in many different voltage ratings, which means that they provide protection everywhere necessary and for every type of installation. MOVs can also do this without needing additional components to be added into the panel.

The thickness of an MOV determines the clamping ability and its diameter determines its surge capacity.

Modes of Protection

There are four ways to connect MOVs:

- Line to Neutral (L–N)
- Line to Ground (L–G)
- Neutral to Ground (N–G)
- Line to Line (L–L)

L–N and L–L are appropriate for installations that are close to the service entrance. At the service entrance, the neutral and ground are bonded together, so putting an SPD from L–N will cause the connections from L–G and N–G to become redundant.

When far away from the service entrance, the N–G and L–G are more important because the N–G is further from the neutral-ground bond connection. This makes the system susceptible to back door surges and ground potential rises.

Modes can be directly or indirectly connected. By directly connecting two SPDs L–N, you also get an indirect L–L connection.

Single modes give the user flexibility and the ability to design-in sufficient protection without adding an unnecessary cost (which multi-mode SPDs do).

Characteristics of Good Surge Protection

DIN-rail SPDs reduce the number of components, along with their associated costs. An SPD that does not require additional components to be built into the panel's design is a big win in a compact size. This streamlines the facility's inventory and simplifies its allocation of parts. This also helps make the SPD more compact. Compact SPDs enable flexibility in the panel design.

Panel designers should look for SPDs that:

- have a 20-kA nominal interrupting rating, which is the highest nominal interrupting rating per UL testing; and
- have a high SCCR (to comply with NEC 285.6)

Other important features include:

- **Ability to clamp and withstand high-energy transients.** This ensures a low-residual voltage during high-energy surge events and higher nominal discharge current. This is important because it prevents disruption, downtime, and degradation or damage to equipment.
- **UL Recognized and IEC-compliant in a single part number.** When one component can be utilized globally, the inventory size will be reduced and the allocation of parts will be simplified.
- **Interlocking tab mechanism.** This secures the module so that it can withstand vibration.
- **A compact size.** Small SPDs provide flexibility in the panel design.
- **A visual life indicator.** A quick visual is important because it determines the module replacement status, which avoids a loss of protection and saves time.
- **Remote contacts.** The ability to connect the SPD into the programmable logic controller in the cabinet to quickly be alarmed of the health of the SPD.
- **Pluggable.** A pluggable module makes the device's replacement fast and simple. This will minimize the maintenance and downtime, and eliminate the need for tools.
- **Thermal protection.** Thermal protection eliminates catastrophic failure.
- **An IP2+ rating.** When the first number of the IP rating (such as IP20, IP21) is 2, the device will protect against solid objects up to 12 mm (such as a person's fingers). Finger-safe designs are incredibly important because they increase the worker's protection.

How to Select the Correct SPD for Each Type of Electrical System

To determine which SPD should be used for the system, you must know the reference to the ground as well as the type of voltage that is present. Therefore, you will first determine the type of power system in use and then size the SPD to the voltage. This is based on the secondary side of the upstream transformer, not how the load is connected.

If the customer knows their system's reference to ground, then the panel designer can provide them with an SPD that will clamp at the appropriate voltage for their system.

IF THE SYSTEM'S REFERENCE TO GROUND IS UNKNOWN, USE AN SPD WITH AN MCOV THAT IS CLOSEST TO 25 % HIGHER THAN THE L-L VOLTAGE.

However, not everyone shopping for SPDs knows their system's reference to ground. In this situation, err on the side of caution and determine the SPD that will provide protection in worst case scenarios.

An SPD's maximum continuous operating voltage (MCOV) is the maximum voltage that the SPD can withstand before it starts to

clamp. The MCOV must be larger than the reference to ground for it to provide complete protection.

Therefore, if an SPD is to be provided to someone who does not know the reference to ground but wants protection for the worst case scenario, select an SPD with an MCOV that is more than the system's L-L voltage. However, there are repercussions for selecting an SPD that is inappropriately sized for the system:

- An MCOV that is too low for the system will enable the system's susceptibility to temporary overvoltages. It also decreases the SPD's life expectancy by burning out after one overwhelming power surge or by slowly degrading after repeated smaller surges.
- An MCOV that is too high for the system will chop off the surge and cause additional damage to the equipment.

The SPD will still work and provide a level of protection. However, either the SPD's lifespan or its level of protection will not be as good as it could have been had they known their system's reference to ground.

An SPD's clamping voltage should be a minimum of 15 % higher than the circuit's peak working voltage. The Littelfuse SPD2 series begins clamping between 15 % and 25 % of the working voltage, depending on the model.

Determine the Reference to Ground

The reference to ground determines which product is best for the panel. There are seven¹ types of electrical systems that have a reference to ground.

- 3-phase, 3-wire systems
- 3-phase, 4-wire systems
- 3-phase, 3-wire corner-grounded delta systems
- Ungrounded delta systems
- Impedance-grounded wye systems
- Resistance-grounded wye systems
- Single-phase (also known as *split-phase*) systems
- High-leg grounded delta systems

Once you know the type of electrical system, calculate the voltage reference to ground. The formula to determine this will depend on the type of system. Some of these systems share the same method: 3-phase, 3-wire and 3-phase, 4-wire systems; and impedance-grounded wye, resistance-grounded wye and resistance-grounded wye systems.

3-Phase, 4-Wire Systems and 3-Phase, 3-Wire Systems

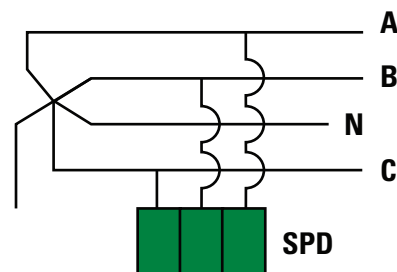


FIGURE 1. A 3-phase, 4-wire wye system.

1 Additional types of systems can be used. These are the seven types that are most commonly used and fall within the scope of this paper.

SPD Sizes in Panel Design

To find the reference to ground in a 3-phase, 4-wire system and in a 3-phase, 3-wire system, divide the line-to-line voltage by the square root of three.

$$\text{reference to ground} = \frac{\text{L-L Voltage}}{\sqrt{3}}$$

A 3-phase, 3-wire system with a 480 L-L voltage has a 277-volt reference to ground. For this system, the best size SPD to use is one with an MCOV of 350 volts (which is the lowest available MCOV above 277 volts²).

3-Phase, 3-Wire Corner-Grounded Delta Systems

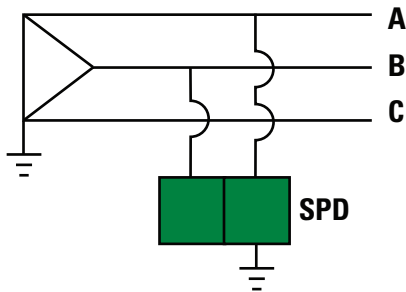


FIGURE 2. If B phase is grounded in a 3-phase, 3-wire corner-grounded delta, use a 2-pole SPD and connect one pole between A and B and the other pole between C and B.

One of the phases is grounded in 3-phase, 3-wire corner-grounded deltas. Therefore, only two of the phases have a voltage potential, so only a 2-pole SPD is necessary.

For example, if B phase is grounded (see **Figure 1**), then put an SPD between phases A and C.

Ungrounded Delta Systems, Impedance-Grounded Wye Systems, and Resistance-Grounded Wye Systems

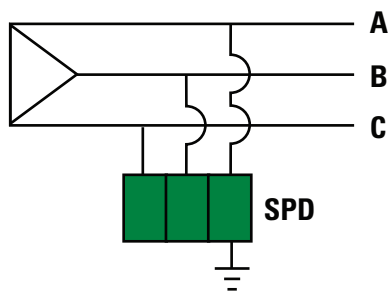


FIGURE 3. An ungrounded delta system.

Ungrounded delta, impedance-grounded wye, and resistance-grounded wye systems use the same principle in SPD selection.

SPDs for these three systems should be rated for L-L voltage.

In resistance- and impedance-grounded wye systems, the neutral can be current carrying if the system is in a fault condition. Although ungrounded deltas do not have a connection to ground, that does not mean that they do not have a reference to ground.

In a fault condition one of the phases is grounded, which must be accounted for. For example, a resistance-grounded system that normally has a 270-volt reference to ground will have a 480-volt reference to ground when it is in a fault condition. Because this 480-volt maximum reference to ground must be accounted for, this system should use an MCOV of 550 volts.

Single Phase (Also Called Split Phase) Systems

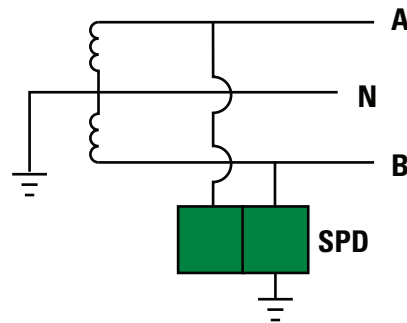


FIGURE 4. A single phase system.

For single phase systems, divide the line-to-line voltage by two.

$$\text{reference to ground} = \frac{\text{L-L Voltage}}{2}$$

For example, if the line-to-line voltage is 240 volts, use an MCOV of at least 120 volts.

2 There are SPDs with MCOVs of 300 volts, however because 300 volts is less than 10 % of the example's reference to ground, an MCOV of 350 volts is better.

High-Leg Grounded Delta Systems

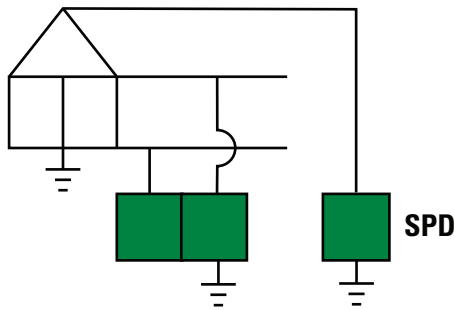


FIGURE 5. The highest phase in a high-leg grounded delta has a different reference to ground than the other phases.

In high-leg grounded deltas, one of the three phases will be higher than the other two. The phase that is the highest is often referred to as *high leg phase*. The high leg phase will have a different reference to ground than the other two. This is unique to other references to ground.

In a high-leg grounded delta, a neutral is tapped halfway between two phases (see **Figure 5**). In **Figure 5**, Phase B (the high leg phase) is the highest voltage potential from ground.

For a high-leg grounded delta system, multiply the system's line-to-line voltage by 0.866.

$$\text{reference to ground} = 0.866 \times (\text{L-L voltage})$$

If the line-to-line voltage is 480 volts, for example, then the SPD's MOV should be closest to a minimum of 415 volts.

Unlike a wye system, the line current in a delta system is not equal to the phase current.

Installation Techniques

Panel designers should select the lowest possible voltage protection rating, which ensures a lower clamping voltage, as well as a short lead length (short wire). A lower clamping voltage indicates better performance.

Wires that have long leads or are bent will decrease the amount of protection that the SPD can provide. When wires are excessively long, bends are more likely to occur.

Large wire sizes slightly improve the let-through voltage performance.

Surge protection should always be installed at the main service entrance. It is best to use cascaded protection for the sub panels and equipment, especially in larger facilities where the critical loads are far away from the main.

Conclusion

Knowledge is power. Theoretically, any size SPD can be used in a system. Panel designers that know the system's reference to ground can provide a level of optimization that will provide systems with long-lasting protection at a cost-effective price point.

References

- [1] R. W. Hotchkiss, "NEMA 5VS survey results on surge protective devices for the protection of safety equipment," in Conference & Exposition, National Harbor, 2014 IEEE PES General Meeting.
- [2] *Standard for Surge Protective Devices*, UL 1449, 2014.

Definitions

Bonded (Bonding): Connected to establish electrical continuity and conductivity.

Bonding Conductor or Jumper: A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.

Clamp Voltage: The peak MOV terminal voltage measured with an applied 8/20 μ s pulse of rated impulse current.

Enclosed: Surrounded by a case, housing, fence, or wall(s) that prevents people from accidentally contacting energized parts.

Fault Current: The current that flows when a phase conductor is faulted to another phase or ground.

Ground: The earth.

Grounded (Grounding): Connected (connecting) to ground or to a conductive body that extends the ground connection.

Grounded, Solidly: Connected to ground without inserting any resistor or impedance device.

Industrial Control Panel: An assembly of two or more components consisting of one of the following: (1) power circuit components only, such as motor controllers, overload relays, fused disconnect switches, and circuit breakers; (2) control circuit components only, such as push buttons, pilot lights, selector switches, timers, switches, and control relays; (3) selector switches, timers, switches, and control relays; (4) a combination of power and control circuit components.

Labeled: Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or material and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Listed: Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic inspection of services and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

Metal Oxide Varistor (MOV): An electronic component that is commonly used to divert excessive current to the ground and neutral lines.

Nominal Discharge Current (In): The peak value of a current, through the SPD having a current waveshape of 8/20 where the SPD remains functional after 15 surges. The peak value is selected by the manufacturer from a predefined level set by UL. I(n) levels include 3 kA, 5 kA, 10 kA and 20 kA, and may also be limited by the type of SPD under test.

Nominal Voltage: A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (such as 120/240 volts, 480Y/277 volts, 600 volts).

Panelboard: A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front.

Short Circuit: A current that is more than the rated current of the equipment or of the circuit and bypasses the normal load that the system can withstand. Current is determined by the system impedance (ac resistance) rather than the load impedance. Short-circuit currents may vary from fractions of an ampere to 200,000 amperes or more. If not removed promptly, large overcurrents associated with a short-circuit can have three profound effects on an electrical system: heating, magnetic stress and arcing.

Short-Circuit Current Rating: The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding defined acceptance criteria.

Surge-Protective Device (SPD): A protective device for limiting transient voltages by diverting or limiting surge current; it also prevents continued flow of follow current while remaining capable of repeating these functions and is designated as follows:

- **Type 1:** Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service disconnect overcurrent device.

- **Type 2:** Permanently connected SPDs intended for installation on the load side of the service disconnect overcurrent device, including SPDs located at the branch panel.
- **Type 3:** Point of utilization SPDs.
- **Type 4:** Component SPDs, including discrete components, as well as assemblies.

Switchgear: An assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) and containing primary power circuit switching, interrupting devices, or both, with buses and connections. The assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors, removable covers, or both.

Ungrounded: Not connected to ground or to a conductive body that extends the ground connection.

Voltage: The greatest root-mean-square difference of potential between any two conductors of the circuit concerned.

Voltage to Ground: For grounded circuits, the voltage between the given conductor and that point or conductor of the circuit that is grounded; for ungrounded circuits, the greatest voltage between the given conductor and any other conductor of the circuit.

Voltage Protection Rating (VPR): A rating indicated from a list of preferred values in Table 63.1 of UL 1449 4th Edition, signifying the rounded-up average measured limiting voltage of an SPD when the SPD is subjected to the surge produced by a 6 kV, 3 kA 8/20 μ s combination waveform generator.

A rating based on the measured limiting voltage performed during testing at a 6 kV/3 kA combination surge wave using 6" of lead length between the SPD and the surge generator. The average value obtained during testing is rounded up to the nearest value provided in Table 63.1 of UL 1449. VPR, which was introduced in the 3rd edition of UL 1449, was previously known as *SVR*.

Voltage Protection Level (Up): Maximum voltage that is to be expected at the SPD terminal when it is subjected to the SPD's nominal discharge current (I_n).

Important Codes and Standards

National Electrical Code

NEC Article 670.6 Surge Protection

NEC 708.20 (d) Surge Protection Devices

NEC Article 695.15 Surge Protection

Canadian Standards

C22.2 NO. 269.2-17 Surge Protective Devices - Type 2 - Permanently Connected

Standards

IEEE C62.72-2016 IEEE Guide for the Application of Surge-Protective Devices for Use on the Load Side of Service Equipment in Low-Voltage Ac Power Circuits

UL 1449 Standard for Surge Protective Devices

UL 1283 EMI/RFI Filtering

IEEE C62.41.1-2002 Guide on Surge Environment

IEEE C62.41.2 Characterization of Surges

IEEE C62.62-2018 IEEE Standard Test Specifications for Surge-Protective Devices for Use on the Load Side of the Service Equipment in Low-Voltage (1000 V and Less) Ac Power Circuits



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