Integrating SPDs in Switchgear & Switchboards Causes More Problems than it Solves

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Integrating surge protective devices (SPD) into distribution equipment (i.e. switchgear, switchboards, and panelboards) started in the late 1990's as a new method to market and as a way to reduce the overall installation costs associated with SPDs. However, during the initial roll out of this application, incomplete engineering analyses were performed to address the safety and performance attributes of integrating SPDs into the distribution equipment.

There are many characteristics that affect the performance of an SPD (e.g. technology, components, topology, quality, etc.). While the individual SPD is an integral part of overall protection, the connection of the SPD to the electrical system can have the most dramatic effect. Choosing conductors that are too long, have sharp bends, or utilize small conductors can significantly increase the let-through voltage of the installed SPD, which reduces the ability of the SPD to protect the electrical system and the installed electronic equipment (Table I). As a system, integrated SPDs have consistently demonstrated that their ability to limit the amplitude of overvoltage transients is inferior to SPDs installed external to distribution equipment.

TABLE I
LET-THROUGH VOLTAGE OF SPDS BASED ON CONDUCTOR SIZE [1]

Peak Amplitude of 8/20 µs Surge Current (Amperes)	Voltage Drop of Conductor (12 inches)	Voltage Drop of Conductor (36 inches)
500	22	66
1,000	44	132
3,000	132	395
10,000	439	1316
15,000	658	1974
25,000	1097	3290

The safety of SPDs has been rocky at best. Some manufacturers have an excellent record of producing SPDs with minimal catastrophic failures, while others do not. SPDs integrated into distribution equipment pose a dual problem: SPD safety and safety of the distribution equipment. There are documented cases of SPDs failing violently in distribution equipment (Figure 1).
Catastrophic failures have been known to create great volumes of ionized gases that contribute to distribution equipment failure. To increase SPD safety Underwriters Laboratories (UL) *Standard for Safety, Surge Protective Devices*, 1449 third edition, has ***much*** higher safety requirements than the first edition.

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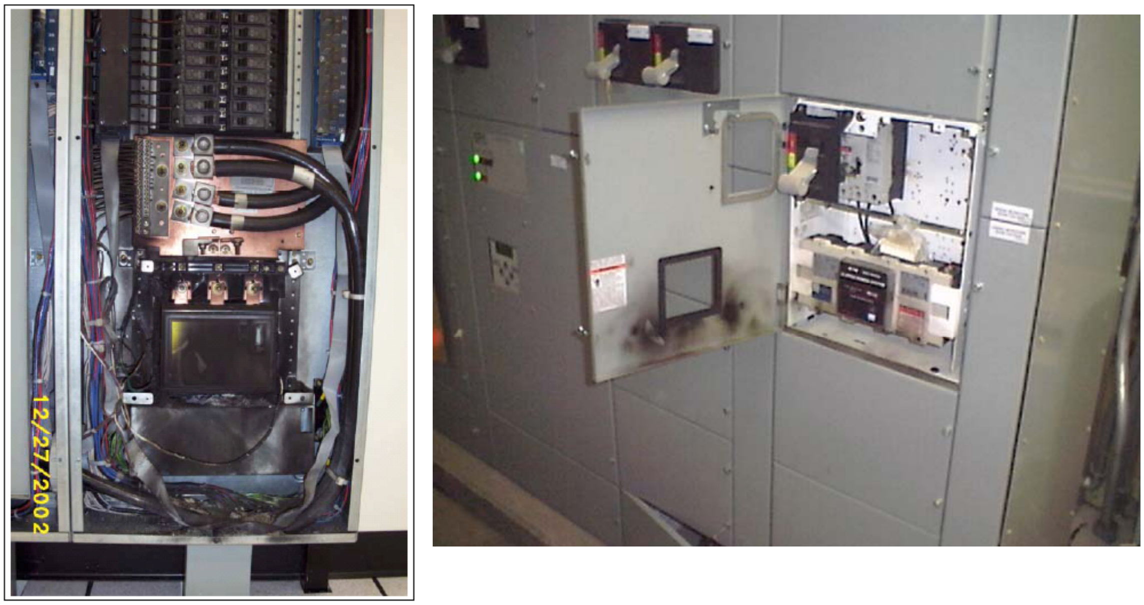
FIGURE 1
INTEGRATED SPDS FAILURES



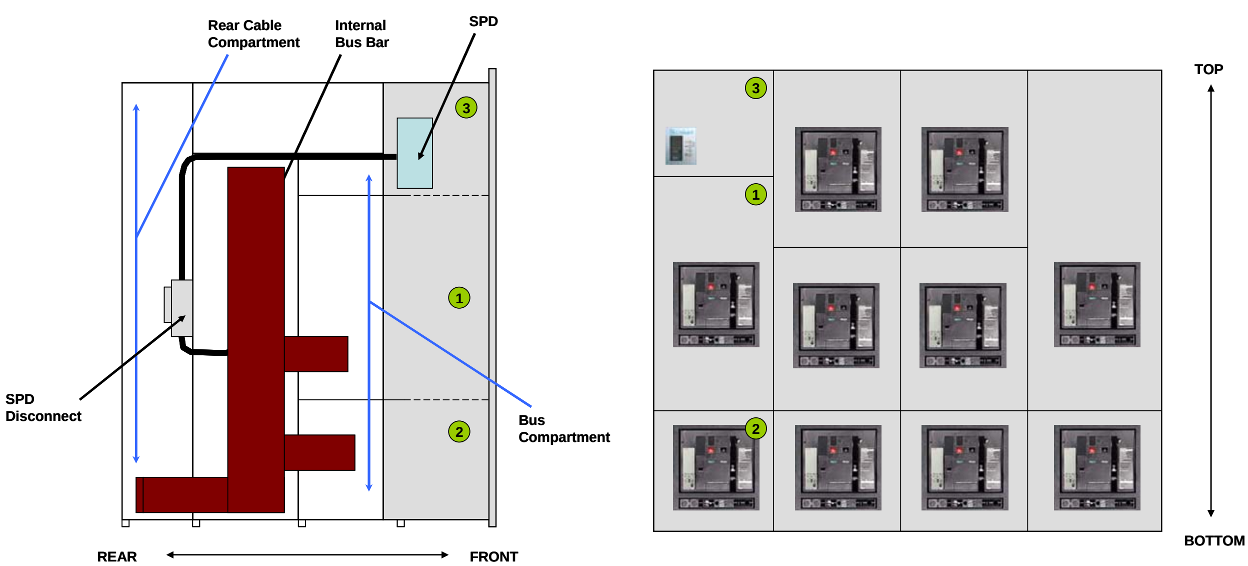
In addition to product safety standards, there are standards guiding SPDs installation. The Institute of Electrical and Electronic Engineers (IEEE) states in *IEEE Guide for the Application for Surge-Protective Devices (SPDs) for Low-Voltage (1000 V or less) AC Power Circuits*, that SPDs integrated into distribution equipment can damage the distribution equipment during failure conditions.

APPLICATION EXAMPLE

Integrating SPDs into distribution equipment can have numerous perils. To reduce the risk of collateral damage to the distribution equipment, those integrating SPDs need to locate the SPDs in separate and isolated compartments within the distribution equipment. Figure 2 shows an illustration of how an SPD is typically installed internal to a switchgear assembly. The design and construction of switchgear and switchboard have many similarities, differing only in the some components and the application.

In Figure 2, the switchgear assembly has a main disconnect (item 1) that feeds the internal bus bars. Item 2 consists of mechanical, rack-type, circuit breakers with adjustable trip mechanisms, and they are located in the remainder of the switchgear compartments. Additionally, there is a separate cable compartment. Separate cable compartments are not always available. In those configurations, conductors are routed in the same area as the internal bus bars.

FIGURE 2
LEFT & FRONTAL ILLUSTRATION OF TYPICAL SPD SWITCHGEAR INSTALLATION



The SPD is located in a separate bucket within the switchgear (item 3). Utilizing the separate compartment limits any collateral damage to the distribution equipment during a catastrophic failure. A limited number of SPDs utilize internal overcurrent protective devices (i.e. fuses), while others rely on external overcurrent protective devices (i.e. fuses, circuit breakers) to provide short circuit current protection. Regardless of the location of the overcurrent protective device, SPDs are typically installed with a disconnect located upstream of the SPD. The external circuit breaker provides short circuit current protection to the SPD and any conductors upstream of the SPD, and as a means to disconnect the SPD.

PERFORMANCE & SAFETY REVIEW OF SPD INSTALLATION

UL standards require that the circuit breaker used in a switchgear or switchboard application be a Listed device [2, 3]. The choices are between an AC Power Circuit Breaker, Listed to UL 1066; and a Molded Case Circuit Breaker (MCCB), Listed to UL 489. In switchgear and switchboards utilizing AC Power Circuit Breakers that are energized and de-energized through a rack mechanism, the rack type of circuit breaker to protect an SPD is impractical. With only a specific number of compartments available, front mounted and accessible circuit breakers are reserved to other primary or branch circuits. Therefore, when SPDs are integrated into this type of equipment, a MCCB is used.

PERFORMANCE

Locating the circuit breaker internal to the switchgear raises both performance and safety concerns. To connect the SPD to the electrical distribution, the conductor starts at the internal bus bars, connects to the internal MCCB, and ends at the SPD. Connection of the SPD to the phase bus bars is determined by the placement of the circuit breaker and the SPD, resulting in the shortest lead length possible. However, in a typical integrated installation (see Figure 2), the length of the conductor for each phase can exceed forty-eight (48) inches.

While connection to the phase bus bars seems long, the connection to a neutral or ground bus can be longer. Connection of the SPD to neutral and ground is accomplished at the main neutral or ground bus bar within the switchgear or switchboard. While there is no circuit breaker to interface with, these conductors can exceed forty-eight (48) inches.

As described earlier, conductor length can affect the performance of an SPD; the longer the lead length connecting the SPD to the electrical distribution, the higher the let-through voltage. This results in less protection of the electrical distribution system and all connected loads. Table II shows the let-through voltage at the internal bus connection of an SPD with a voltage protection rating (VPR) of 400 V, and a conducted lead length of forty-eight (48) inches.

As the amplitude of the transient current increases from 500 A to 10,000 A, the let-through voltage of the connected SPD increases from 488 V to 2,156 V even when the voltage protection rating of the SPD remains at 400 V. If the transient current increases to 25,000 A, then the let-through voltage of the connected SPD increases to 4,788 V.

TABLE II
LET-THROUGH VOLTAGE OF CONNECTED SPD

Peak Amplitude of 8/20 µs Surge Current (Amperes)	Voltage Protection Rating of SPD (VPR)	Voltage Drop of Conductor (48 inches) (Volts)	Let-through Voltage of SPD Connected to Internal Bus (Volts peak)
500	400	88	488
1,000	400	176	576
3,000	400	528	928
10,000	400	1756	2156
15,000	400	2632	3032
25,000	400	4388	4788

But, what amplitude will cause damage to the electrical distribution system of the facility and its connected equipment? Many components have parameters associated with transient conditions (e.g. BIL, PIV, dielectric withstand, surge immunity, etc). Design parameters such as basic impulse level (BIL), peak inverse voltage (PIV) and surge immunity are good parameters to determine the maximum transient voltage capability, but they are relevant to only specific components and are not or cannot be used universally.

The most widely known parameter for overvoltage immunity of equipment is dielectric withstand. The dielectric withstand of equipment is detail in UL Standards, regardless of the products listing status (i.e. Listed or Recognized) is 1000 vac plus two-times the rated voltage from any phase (line or neutral) to ground. For equipment designed for a 120, single-phase, two-wire plus ground system, the dielectric withstand is 1240 vac or 1750 volts peak. An SPD with a VPR of 400 V, connected to the electrical distribution with forty-eight (48) inch conductors, and exposed to a 10,000 A 8/20 ì s current results in a peak voltage as seen by the equipment and connected loads of 2,156 volts, which will not provide adequate protection to the connected equipment. Inadequate transient protection will lead to damage of the connected loads.

SAFETY

The effect of an SPD failure on electrical distribution equipment will be minimized through the placement of the SPD in a separate compartment within the switchgear or switchboard. However, all equipment requires periodic maintenance and testing. Circuit breakers need to be serviced at least every two (2) years. Electrical connections should be tightened yearly. SPDs also need to be serviced as surge components will need to be replaced as a result of attenuating transients, or resulting from random component failure.

When working on electrical equipment, the National Fire Protection Association's (NFPA) *Standard for Electrical Safety in the Workplace*, NFPA 70E, has imposed specific personal protection equipment (PPE) on personnel working on electrical and mechanical equipment. The amount or type of PPE required is dependent on the arc flash hazard and voltage at the service location.

TABLE III
PERSONAL PROTECTIVE EQUIPMENT (PPE) LEVELS [4]

Category	Requirements
0	Long sleeve shirt and long pants (natural fibers), safety glasses
1	Flame retardant (FR) long sleeve shirt and long pants, hard hat, safety glasses, leather shoes
2	FR long sleeve shirt and long pants, hard hat, safety glasses, leather shoes, arc flash shield
3	Cotton underwear, FR long sleeve shirt and long pants, FR coveralls, hard hat, safety glasses, leather shoes, arc flash suit hood, hearing protection
4	Cotton Underwear, FR long sleeve shirt and long pants, hard hat, safety glasses, leather shoes, hearing protection, multi-layer arc flash suit

When an integrated SPD requires servicing or maintenance, the technician has two methods in which to perform this work: energized or de-energized. Most work on an SPD will be conducted when the SPD is de-energized. However, to de-energize the SPD requires that the circuit breaker installed in the switchgear or switchboard be de-energized.

When working on energized equipment which includes opening circuit breakers located internal to switchgear or switchboard assemblies (Figure 2), NFPA 70E requires a justification and analysis be completed. Specifically, NFPA 70E Article 130.1 states "Energized electrical conductors and circuit parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works within the Limited Approach Boundary of those conductors or parts."

Because heat, ventilating, air conditioning (HVAC) equipment, lighting, legally required loads (e.g. pollution abatement equipment) and critical process equipment are commonly interconnected on the electrical distribution system within the facility, most facility or process managers are not able to de-energize a complete switchgear or switchboard assembly to perform maintenance or servicing of an SPD. After a system analysis is conducted detailing the hazards associated with removing electrical power from the switchgear or switchboard assembly, it is possible to open the circuit breaker associated with the SPD as long as proper personal protective equipment (PPE) is used. While many systems can be worked on live, proper processes must be followed (e.g. obtaining a "hot work" permit, wearing rated PPE) to ensure employee and equipment safety.

Switchgear and switchboard assemblies are located at the service entrance where high amplitudes of short circuit current exist. Short circuit current is one of the components incorporated into the arc flash hazard analysis. If switchgear and switchboard assemblies can be accessed when energized, it typically requires Category 3 or higher PPE (Table III and Figure 3). In addition to PPE, performing maintenance or servicing energized equipment requires a "hot work" permit, which requires investigation into the arc flash hazards, voltage hazards, mechanical hazards, and management sign-off. Some organizations also require that a potential problem analysis be conducted to ensure that any potential adverse actions are identified and preventative measures are accounted for to ensure the safety of personnel and minimization of process downtime.

An integrated SPD applied as shown in Figure 2, the facility manager is required to sign a "hot work" permit, and the technician is required to wear the appropriate PPE to remove the panels of the switchgear or switchboard to disconnect the SPD from the electrical distribution. Additional safety personnel are also required on-site while the technician performs the required servicing or maintenance on the integrated SPD.

FIGURE 3
ARC FLASH & PPE

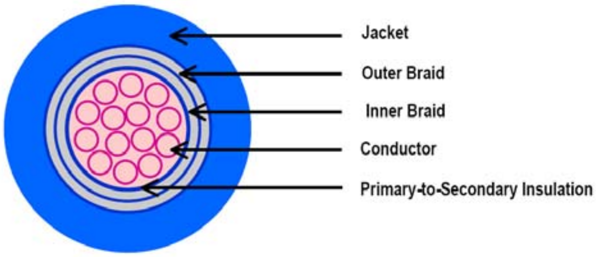
CHANGING DISTRIBUTION EQUIPMENT FOR SPDs

Electrical distribution manufacturers have adapted how they apply SPDs. However, there is still more work to be done to ensure that integrated SPDs provide protection to the electrical distribution equipment and the connected loads. In addition, further design changes are required to ensure personnel safety during the maintenance or servicing of the SPD.

To enhance the performance of the SPD and provide adequate protection, the impedance of the conductors connecting the SPD and its overcurrent protective device to the internal bus bars must be significantly reduced. Simply rerouting conductors may not remove enough conductor impedance to ensure that the SPD can provide the transient protection needed. To achieve sufficiently lower conductor impedance, the geometry of the conductors must change. The utilization of conductors arranged in a coaxial configuration provides significantly lower conductor impedance during a transient conduction (Figure 4) [1].

To prevent people from working near live circuits, the overcurrent protective device for the SPD needs to be moved to a location outside of the switchgear or switchboard deadfront. Having the SPD's overcurrent protective device outside of the deadfront will eliminate the need to wear PPE to de-energize the circuit.

FIGURE 4
ILLUSTRATION OF COAXIAL CONDUCTOR



CONCLUSION

Surge protective devices (SPDs) are an important component to ensure quality electrical power is available to critical processes. Product safety standards from UL and IEEE application guides have provided manufacturers and end-users with requirements and guidelines to properly design and install SPDs. One of the significant changes has been the realization that applying SPDs into switchgear and switchboards needs to be done with care. If an integrated SPD is the preferred option, then the following items need to be accomplished to ensure that an SPD failure will not damage the switchgear or switchboard assembly:

- The SPD needs to be placed in a separate compartment
- The conductor lengths connecting the SPD to the bus bars must be kept short – less than 24 inches for each conductor or use coaxial conductors with a length of less than 100 inches
- The SPD's overcurrent protective device or disconnect device must be accessible without requiring the switchgear or switchboard assembly to be de-energized
- The SPD's overcurrent protective device or disconnect device must be accessible without requiring the technicians to obtain "hot work" permits or wear PPE to disconnect the SPD for service or maintenance

Integrating an SPD into switchgear or switchboard assemblies can be accomplished if design engineers are aware of the performance and safety needs of the SPD and the distribution equipment. If the guidelines listed above are not followed, an SPD integrated into switchgear or switchboard assemblies can damage equipment and endanger personnel.

The best method of applying an SPD is to place the SPD external to all distribution equipment. Externally connected SPDs have the following advantages:

- Flexible mounting locations of the SPD overcurrent protective device
- Optional overcurrent protective device (i.e. fuse, circuit breaker) type and manufacturer
- Flexible mounting locations of the SPD
- Optional SPD type and manufacturer
- Shorter conductor length to the SPD
- SPDs can be serviced without wearing PPE

REFERENCES

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