

Selecting & Installing Service Entrance SPDs

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Abstract: The art of installing an SPD is to ensure compliance with relevant electrical and safety codes while maintaining optimum performance. This document provides installation examples, "rules of thumb" and discussion of related industry issues.

The first line of defense in protecting a facility from externally created electrical surges is the Surge Protection Device (SPD) installed at the main service entrance. The term SPD is a generic description defined by the IEC. Within the USA "SPDs" are further categorized as:- the Transient Voltage Surge Suppressor (TVSS) and the Secondary Surge Arrester. In accordance with UL 1449 listing requirements, a TVSS device must be installed on the load side of the main over-current protection. *The role of Secondary Surge Arresters, which are intended for installation on the line side of the main over-current protection, are discussed later.*

Factory Standard Electrical Panels

Most TVSS's available on the market are self-contained and designed to be installed next to the electrical panel board via a short direct nipple connection to the panel as shown in Figure 1. "Integrated Panels" where the TVSS is installed inside the panel are becoming more common. The advantages and shortcomings of these specially approved Integrated Panels are discussed later.

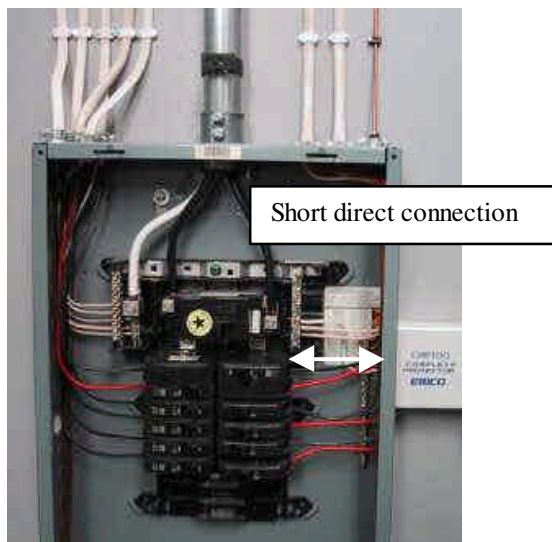


Figure 1. Optimal SPD installation.

UL requires the TVSS to be connected on the load side of the main over-current device. When connecting this external TVSS to a typical compact electrical panel, it is often not possible to access the bus between the main over-current device and the sub-feed/branch circuit breakers. The TVSS is designed to be connected to the "first" sub-feed circuit breaker (i.e. the breaker closest to the main over-current protective device).

Most TVSS's are supplied with flying leads for quick connection to the sub-feed circuit breaker. The TVSS's instructions will list the ampacity requirements of the breaker to which it should be connected. The connection lead length has an important effect on the performance of the protection system and will be discussed more fully later in this document. The optimal installation is to direct nipple mount the TVSS to the outside of the electrical panel next to the circuit breaker to which it is to be connected.

Some larger TVSS's are supplied with internal terminals instead of flying leads, thus allowing the installer to select the interconnecting wire size. Although the wiring to the TVSS carries negligible load current (prior to the presence of a surge), it is normal practice to select the circuit breaker amperage based on the conductor's current carrying ability. If given a choice, utilize the largest wire size as this provides a small improvement in the let-through voltage performance. More importantly, it allows a larger circuit breaker size to be used, potentially increasing the maximum surge current rating that the system can protect against. A large surge may be seen by the circuit breaker as a 50/60Hz short circuit current causing it to trip, taking the TVSS offline. A larger rated circuit breaker is less likely to trip. For example, a 30A breaker will typically trip on a surge current of 15-25kA 8/20 μ s while a 50A breaker will increase this to 20-60kA 8/20 μ s.

Keep in mind that while 50% of all direct lightning strikes are greater than 30kA in peak amplitude, only 2% exceed 120kA. A direct strike to a power line is rare, and in most cases only 25% of this discharge energy reaches the service entrance. Although SPD vendors make devices with surge ratings of hundreds of kA, installing a circuit breaker larger than 50A only offers a very small improvement in the statistical protection provided, while

increasing the risk of not being able to quickly interrupt an electrical short circuit during fault conditions.

The convenience of using a sub-feed circuit breaker to make connection to the TVSS also provides an important advantage. It allows the TVSS unit to be isolated during maintenance, while the primary supply to the facility is still maintained.

It is important to adhere to the manufacturer's recommendations on wiring size and fusing requirements as these are generally based on UL's "conditions of use" for the particular device's Listing.

Larger Custom Designed Panels

For larger custom-designed panels it is often possible to connect the TVSS device between the load side of the main over-current protection and the sub-feed breakers panel. This requires a "T", or tap connection, to be made from the bus to the TVSS.

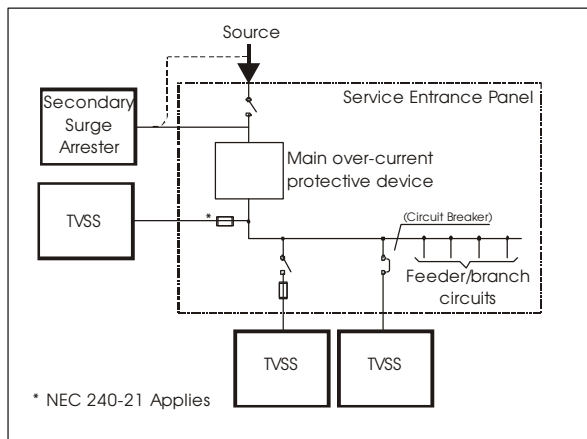


Figure 2. Possible SPD connections

To meet relevant electrical and wiring codes, the TVSS unit is generally installed along side of the electrical panel via a conduit nipple connection. The location of the TVSS unit in relation to its connection to the panel, should be selected to minimize the length of the interconnecting wiring. This will improve performance during a surge condition.

The NEC "tap rule" allows for a smaller "tap wire" to be run from the larger bus to the TVSS. In keeping with the desire to minimize the length of this connection, the "10' tap rule" Article 240-21 generally applies. A tap connection can only be made where the current rating of the tap connection to the TVSS is greater than 1/10 of the upstream over-current device's rating. For example, assume the maximum wire size which a manufacturer specifies can be connected to the terminals of his TVSS device is #3. Reference to Table 310-16 indicates that this can carry a current rating of 80A. Then by applying

the NEC tap rule, we see that the TVSS unit can only be directly connected where the service entrance is limited by an 800A over-current rating. Note: *Although such tap connectors are not generally regarded as load current carrying, it is normal practice to assume that they are when sizing to conform to the upstream over-current protection. It is often easier to do this than to explain to installers/inspectors the apparent mismatch in conductor / over-current protection device ratings.*

When installing a TVSS device on service entrance panels with large current ratings the 1/10 tap requirement may mean that the correct tap conductor size exceeds the capacity of the TVSS's terminals. Under such conditions, a circuit breaker is usually required at the point at which the tap conductor connects to the primary supply. The size of this breaker should be chosen to accommodate the size of the tap conductor rating. While such a measure provides safety and compliance with the tap rule, it also add cost, complexity, and the introduction of extra series components which may increase the let-through voltage, and which may also limit the peak surge rating of the system.

To avoid these performance issues, the user needs to overcome the "1/10" restrictions of Article 240-21 (b.5) "...field installation where the tap conductors leave the enclosure or vault in which the tap is made...":

1. Some TVSS vendors argue that by installing the TVSS on the outside of the enclosure and utilizing a direct nipple connection into the enclosure, the 1/10 requirement does not apply as the wiring "does not leave the enclosure" – rather, the TVSS wires are regarded as entering into the enclosure. Whilst it may be argued that this allows the installer a loop hole which can be exploited, the intent of the NEC tap rule is clear – to limit under-rated tap conductors being connected to large current primary feeds.
2. Some TVSS vendors also argue (and even document) that, as their TVSS's incorporate integral over-current disconnect devices, no additional upstream over-current protection is required and the unit can be installed with small tap conductors on very large services. The author is not aware of any NEC Articles that specifically allow this, unless the TVSS installation is not made as part of a "field installation" – ref. 3.

3. If the installation of a TVSS unit is not carried out as part of a field exercise, as may be the case when switchboard builder incorporates the unit as a component within an electrical panel assembly, Article 240-21 (b.5) is not applicable and Section 2.b allows the tap to be installed on any current rated service, provided that the tap conductors are matched to the rating of the TVSS's internal over-current protection.

Rather than exploiting loose interpretations of the 1/10 rule to avoid upstream over-current protection, it is recommended that upstream over-current protection be provided *at the point the conductors receive their supply*. This safer approach may however introduce another complication. The NEC mandates a maximum of 6 disconnects off any one primary service feed (Article 230-71). A connection of a TVSS device to this feed is included in this count. When this limitation is encountered, the installation of the TVSS device is normally relegated to connection on the load side of one of the existing 6 "disconnects". A proposal to exempt the TVSS connection from this maximum of 6 connection has been submitted for the 2005 edition of the NEC.

Integrated Panels – TVSS's installed within the Panel

A growing trend within the industry is the integration of TVSS devices within the electrical panel itself, usually by the panel OEM. This practice has recently lead to panel manufacturers acquiring TVSS manufacturers in an attempt to increase their competency and market opportunity in this area. The potential advantages to the engineer, installer and owner of such integration, are:

- Simplification of the specification process
- Reduction in the number of vendors for supply and support
- Simplification of installation
- Improved performance

This said, integrated protection panels may also present their own deficiencies. Installing the TVSS within the electrical enclosure should ensure shorter connection lead lengths and an improvement in the let-through voltage performance. However, this is often not the case. The TVSS devices are often mounted at the bottom of the standard can, and connected to feed-through lugs. This can increase the lead length, resulting in a much higher let-through voltage to the equipment connected to the upper circuit breakers. A performance degradation of 300-500V is possible, increasing the net let-through voltage to the point where electronic equipment may be damaged or severely stressed.

- The panel extension kit may block the ability to feed cables through the bottom of the electrical enclosure.

- If the TVSS is connected directly to the bus, the entire panel and its load will need to be shut down to allow replacement of a failed TVSS unit. Conversely, an external TVSS unit connected to a dedicated breaker, will allow only that circuit to be disconnected during service.
- Generally the TVSS technology integrated by panel manufacturers is less advanced than that manufactured by dedicated TVSS manufacturers.

Integrated Protection Panels should be Listed to UL 67 which includes fault current testing of the combination – 10 kAIC, 22 kAIC, 65 kAIC etc. Panelboard extension kits which are available to add TVSS onto the bottom of electrical panels are usually Listed to UL 1449.

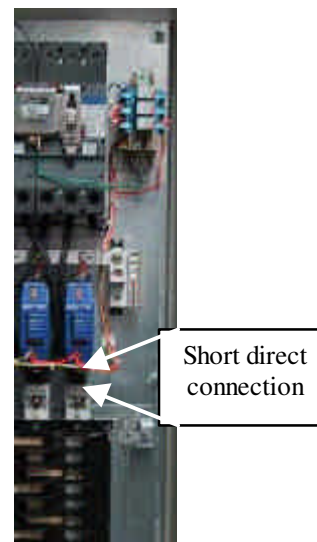


Figure 3. Specialist Integrated panel providing optimum protection

Appropriate Surge Ratings

The question of appropriate surge rating for Service Entrance panel protection has been debated within the scientific community for many years. Unfortunately TVSS manufacturer's seeking to out-market one another, have often started "ratings wars" with ratings up to 600kA 8/20 μ s and even 1,000kA 8/20 μ s being noted. The scientific community through such standards as IEEE C62.41 have sought to provide some guidance to the potential end-user as to appropriate surge ratings by characterizing the electrical environment for the installation. Proposed changes to the existing C62.41 standard will see two scenarios characterized – Scenario 1 will deal with the effects of induced energy onto service entrances from a nearby strike while Scenario 2 deals with the effects of a direct lightning discharge to the facility. Under Scenario 1, currents of 10kA 8/20 μ s can be expected while under Scenario 2, currents of up to 100kA 8/20 μ s or 10kA 10/350 μ s can be expected.

These specifications are intended to provide a much needed “reality check” to those ratings been promulgated by various TVSS manufacturers. A typical rating of 100kA for a service entrance device already includes a safety margin and the only practical reason in requiring a higher rating would be to provide a longer service life. With each doubling of surge rating, for the same number and amplitude of transients, “life” can be increased by a factor of 5-10 times. Value engineering principles point to a rating of between 100 to 200kA 8/20 μ s as being both practical and cost effective. The need for a surge rating of 600kA with the claimed typical life expectancy of 500 years is questionable.

Another problem commonly encountered in the specification of surge ratings for TVSS devices, is the practice of claiming a rating based solely on the aggregate of MOV (or SAD) material contained within the device. In reality, the single shot capacity of the device may be significantly less than this due to the limitations of PCB fuse tracks, thermal of over-current disconnect devices and terminals used. NEMA LS-1 has sought to address this concern by recommending that manufacturers only claim maximum single shot ratings based on actual test results. Ideally, a device should be rated by providing both i) its maximum single shot capacity (tested) and ii) its aggregate surge capacity (surge material). Such dual ratings better define the device’s performance and life characteristics.

Note: Often the failure of a TVSS device is attributed to the number or amplitude of diverted surges, whereas most failures are the result of temporary over-voltages. Even so, some well-known TVSS manufacturers continue to provide TVSS’s with Maximum Continuous Operating Voltages (MCOV) just over 10% of nominal. *10% above nominal is the continuous limit tested by UL; anything above this is allowed to safely fail.* Many TVSS manufacturers provide MCOV rating with a more practical 25% limit, while hybrid technologies are now available that provide even larger MCOVs – without the traditional cost of increased let-through voltage.

TVSS’s and Secondary Surge Arresters

The 1999 edition of the NEC defines the application of Surge Arresters and requires all such devices to be listed. UL differentiates between Transient Voltage Surge Suppressors and Secondary Surge Arresters:

- Transient Voltage Surge Suppressors are tested to UL 1449 and this document limits their scope of use on the load side of the main over-current disconnect. They should not be used on the line side.
- Secondary Surge Arresters are also listed by UL and are intended for use on the line side of the main over-current protection. Note: a loophole currently exists which allows Secondary Surge Arresters to

also be used on the load side of the main over-current disconnect, however the 2002 Edition of the NEC under Article 285 seeks to better address this problem.

It should be noted that it is possible for a manufacturer to complementary list an SPD as both a TVSS device as well as a Secondary Surge Arrester.

Secondary Surge Arresters are tested to less demanding safety standards and are generally lower performance products. These devices were originally intended to protect power system insulation from flash-overs and not to protect load-side sensitive electronic equipment from damaging transient voltages. Unfortunately, some manufacturers have sought to capitalize on this loophole and provide the cheaper Secondary Surge Arresters in locations where the intent is that TVSS devices, with their more stringent test requirements, are intended. . While most installers and inspectors are accustomed to checking installed devices for the presence of an approved Listing logo, few are experienced with the subtleties of SPDs to correctly differentiate between a Secondary Surge Arrester and a TVSS device.

The question regarding the need for both Secondary Surge Arresters and TVSS devices to be installed on a facility, is often raised. Accepted practice often utilizes both of these devices. A secondary Surge Arrester may be installed at the primary service entrance or power pole as the first line of defense and a TVSS device close to the equipment actually being protected. This second device also provides protection against the more common smaller transients that are generated within the facility itself by electrical equipment.

A question often asked is whether a Secondary Surge Arrester installed at the meter socket eliminates the need for TVSS protection at the Service Entrance Panel. Figure 4 illustrates the voltage that is added to a meter socket device’s performance due to its connection method. In practice, the situation will be much worse as the Secondary Surge Arrester used here is generally a poorer performing device than a TVSS installed at the panel. In a typical installation with 8 feet of wiring between the meter socket and the Service Entrance panel, a difference in let-through voltage of between 2,000 and 3,000 volts is possible.

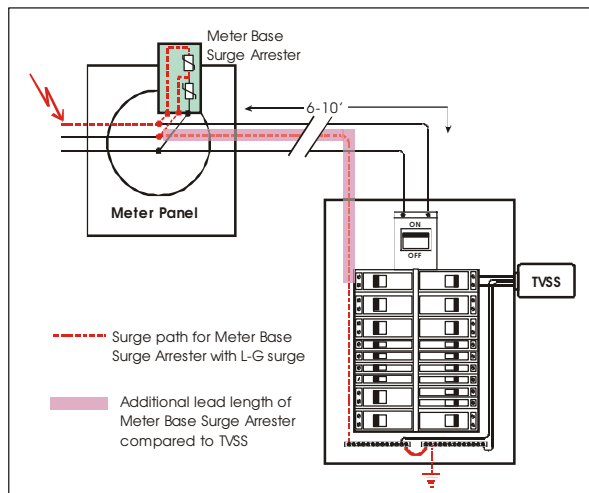


Figure 4. Let-through voltage according to Secondary Surge Arresters installed location

Fault Current Ratings

The 2002 edition of the NEC introduces Article 285, which includes.... **285.6 Short Circuit Current Rating.** *The TVSS shall be marked with a short circuit current rating and shall not be installed at a point on the system where the available fault current is in excess of that rating. This marking shall not apply to receptacles.*

This clears up some confusion in the industry on the applicability of NEC 110-10. It is now clear that TVSS devices must be selected and installed to ensure coordination between the supplies short circuit interrupt capacity and the TVSS's short circuit current rating.

For example, the TVSS shown in Figure 5 requires a short circuit current rating of 56kAIC or greater. An alternative to having to use a TVSS device short circuit current rated to 56 kAIC, is to include a current limiting circuit breaker. If this approach is adopted, it is

important to note that the NEC requires that the TVSS device be tested and Listed in conjunction with the specific breaker at the specified interrupt current rating. Using a different manufacturer's breaker or at different fault levels would void this conditions of use of the TVSS's Listing. Given the large number of combinations that would need to be tested, no manufacturer is likely to support this approach.

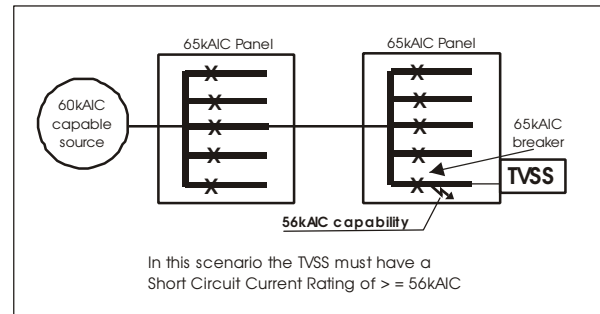


Figure 5. Short Circuit Current Rating

Note: Any circuit breaker installed into the TVSS tap connection would also need to be coordinated with the supply's short circuit current rating.

Connection Lead Length

The performance of a TVSS protected system is dramatically affected by the TVSS installation. The self-inductance of the wire connecting the TVSS device to the panelboard can significantly increase the residual let-through voltage reaching the equipment being protected during a surge condition. Figure 6 shows how the protected circuit experiences the sum of the voltage drop across the surge protector and that due to the connecting leads. While a Kelvin connection eliminates this, it is not practical for most applications. A general rule of thumb is that for each foot of wiring, an additional 165V of let-through voltage can be expected

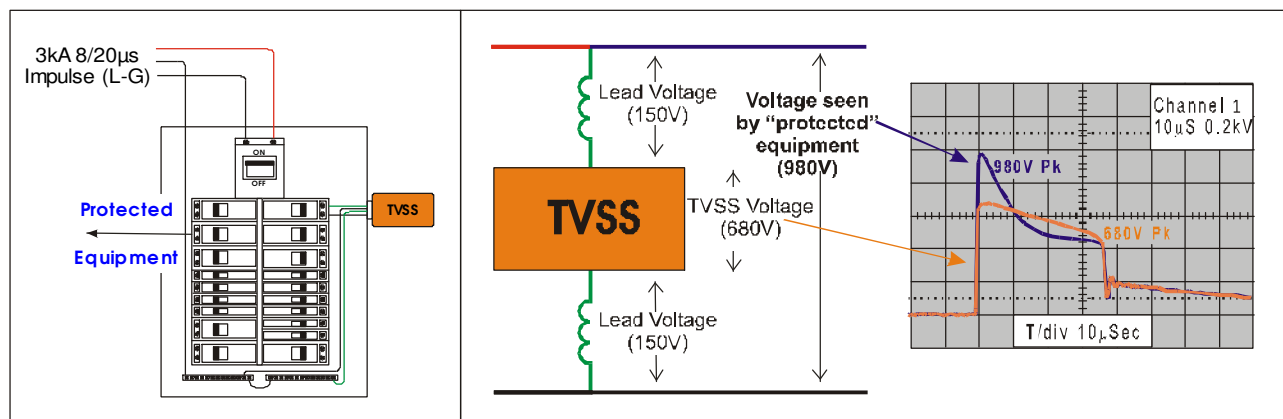


Figure 6. Voltage Drop of the connecting leads

for smaller surges. As shown by Bird & Karmazyn⁽¹⁾, bundling or twisting conductors together improves system performance. Increasing conductor size provides some improvement, but more significantly, can allow for a larger upstream over-current disconnect device to be used. This is important as Bird & Karmazyn also showed that the typical fuse/circuit breaker will have a limiting factor on the peak surge current that can be protected against.

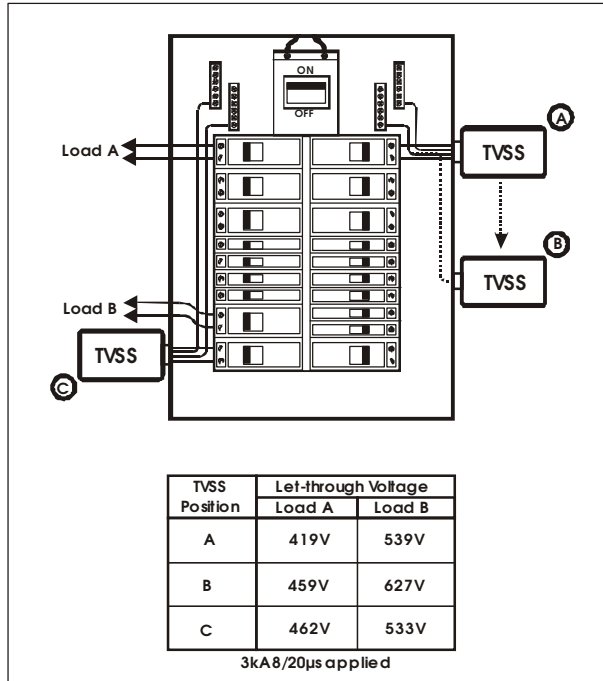


Figure 7. Let-through voltages for different installations choices

To adequately protect "typical" 120V electronic equipment, all surges should be clamped to less than 600Vpk. A good TVSS performance is considered as limiting a 500A 8/20μs impulse to 330Vpk (a UL 1449 330V SVR – measured with 6" wiring). Due to the lead length effect, on a 120V circuit a typical TVSS device with a 330V SVR, would require a wiring length of less than 12" to adequately protect against a 500A 8/20μs impulse. The rule of thumb is each foot of wiring adds an additional 50-200V of let-through voltage. However, 500A 8/20μs is a very small impulse, and with increased surge amplitudes, an increase in the let-through voltage occurs. The 600Vpk threshold is exceeded when the surge amplitude exceeded 3kA on a 6" installed 330V SVR TVSS. According to a 10 year study of service entrance surge amplitudes, this dangerous condition could occur on average 5 times per month.

For effective real world protection:

1. Wiring length needs to be kept to an absolute minimum. Every inch counts!
2. Twist / bundle wires together and avoid creating right-angled bends to lower the self inductance.
3. Protection should be cascaded so that the TVSS closest to the equipment is not seeing the full surge energy, just a small fraction let-through by an optimally installed upstream TVSS.

Branch Panel Protection:

While service entrance TVSS protection has been the main subject of this document, many of the issues dealt with also apply to the selection and installation of TVSS protection on branch distribution panels. Secondary protection at branch panels is generally required when the distance away from the primary service entrance exceeds approximately 30 feet. This "secondary" level of protection also provides protection to the local equipment from the those smaller transient generated within one's own facility by the normal operation of electrical equipment.

References

- (1) 20th International Conference on Lightning Protection, Interlaken September 1990. A.O Bird and H. J. Karmazyn "Specification and installation of effective overvoltage protection.