BENEFITS OF SUSTAINABLE ELECTRICAL PROTECTION

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ABSTRACT

As today's artificial lift equipment becomes more sophisticated and provides greater rates of return it is more important than ever to strive for 100% reliability. Since the equipment is often deployed in harsh electrical environments it is important to take effective measures to protect this equipment from damaging electrical surges.

This paper will explore various methods that have been used to protect artificial lift equipment in the harsh electrical environments where they are often deployed. It will focus on practical applications, and solutions that are simple to install and have proven effective over multiple years of deployment. The paper will include a case study which demonstrates the economic benefits of using sustainable electrical protection systems to maintain production and protect artificial lift equipment from damaging electrical disturbances.

INTRODUCTION

Artificial lift equipment, by the nature of their purpose, are installed and operated within the harshest electrical environments on the planet. And while they are typically designed to be more robust than industrial equipment intended for deployment in more domesticated operational surroundings, their control circuitry remains vulnerable to damage caused by transient surges. This holds particularly true for those lifts that employ variable speed drives (VSDs) to extend their pumping capabilities. VSDs, generally speaking, draw on very limited defense mechanisms against surge anomalies that attack them via their AC power feeds.

The term "surge" describes a momentary burst of transient energy that is induced on AC power lines by lightning events, utility grid switching activities, power factor correction procedures, and the power cycling of inductive loads; to name just a few. While these energy bursts only last for a few millionths of a second, they can pack a heavy punch during that short time frame. A single lightning induced surge, for example, can induce an overvoltage with the intensity to easily exceed the insulation ratings of a VSD's electrical circuitry; causing degradation and resulting in immediate damage. On the other hand, lower level repeated transient overvoltage activity generated by utility switching operations; for example, can reduce a lift's mean time before failure (MTBF).

In the best case these devices are weakened over time by surge activity until they eventually cease operation. The more dire circumstance regards those catastrophic failure modes resulting from proximity lightning strikes occurring near lifts during electrical storms. While there are obvious costs associated with the repair and/or replacement of surge damaged equipment, the loss of revenue resulting from downed production equipment can easily become the more serious consequence of a surge disabled artificial lift. Therefore, it behooves equipment end users to protect this critical gear from both lightning and non lightning induced surge anomalies. And, the only means to accomplish that task is with the utilization of surge protection devices (SPDs). Quality SPDs, installed on the AC power circuit feeding the VSD employed by artificial lift equipment, for example; will limit the excessive voltage value of the surge to a safe level as it diverts the surge current away from the critical equipment load.

Incorporating surge protection within the VSD controlled pump component of the artificial lift system is a well justified investment. Given the cost – including revenue loss - resulting from equipment downtime, the return on the protection investment dwarfs that of other available profit options.

CASE STUDY

An oil field services company and provider of VSD controlled artificial lift systems, monitored 29 drives operating in an oil field for one year. During that time seven of those drives suffered damage from power surges which resulted in downtime and lost production.

As those drives were repaired, they were successfully retrofitted with effective SPD systems. There were no further damage reports filed throughout the remainder of the trail, and the equipment end user suffered no further downtime or lost production from later surge events. The integrated surge suppression modules provided a total protection solution for those seven VSDs with a 100% success rate. Based on actual data and figures from this installation, Chart 1 at the end of this paper shows the internal rate of return based on crude oil prices.

Following this successful field application and after considering the significant financial benefits, the VSD supplier initiated a worldwide program offering retrofit services for the VSDs already installed at their customers' sites. At the same time all new VSD supplied were redesigned to include integrated SPD modules.

SPD REQUIREMENTS

The SPD of choice to protect artificial lift equipment must meet five key requirements:

1. They must be safe. They cannot fail catastrophically, catch fire, or explode under any circumstance.

   In North America the safety issues related to the use of SPD products are addressed by Underwriters Laboratories (UL), an independent safety organization. The current standard related to SPD products is UL 1449 2nd Edition. However, it will be superseded by UL 1449 3rd Edition in September 2009. The UL 1449 standard recommends testing procedures for both the mechanical and the electrical characteristics of the SPD. Every surge protection device is required to comply with this standard. One of the key tests required by UL 1449 regards its limited current, abnormal overvoltage test. The SPD's end-of-life condition is examined by this trial. The RMS supply voltage that is applied upon the SPD terminals, under test, is regulated so that a constant value of current is passes through the device. The test requires that the SPD withstand the heat generated within it for seven hours as it is called upon to conduct up to 1000 amperes of steady state current without catching fire or emitting smoke.

   The majority of SPDs manufactured today employ thermal disconnects to isolate the SPD from the power supply before it is damaged. They protect themselves from failing catastrophically. However, there are SPDs that utilize fuseless design parameters that offer the better approach with regard to passing this test. They are designed to conduct the full 1000 amperes of current for the full seven hour time period without removing themselves from the test circuit. The end users of these SPDs can be assured that their suppressor will be ultimately safe under any adverse circumstance.

   In any event, it is an absolute requirement for any SPD to bear the UL Mark that assures its users that it has met UL's safety requirements.

   Ideally, the SPD should be certified as a Class 1 protector per the more stringent international safety and performance standard IEC 61643:1 2005. They should be labeled accordingly and certified by a recognized test facility.

2. SPDs must demonstrate the ability to withstand very high surge energy values. Their power handling capabilities must be verifiable by actual testing to accepted industry standards; as conducted by legitimate test laboratories operating independently of the SPD manufacturer.

3. They must exhibit very stable and low voltage protection levels as they are called upon to conduct surge currents in excess of 100,000 amperes.

4. They must be reliable. Their performance characteristics should not degrade with use or over time in a way that would require frequent maintenance.

5. They must employ a mechanical/electrical design that provides a high Short Circuit Current Rating (SCCR) – a necessity in typical VSD installations in oilfields. The SPD should be a non-fused product that can be connected directly to and in-line with the AC power lines feeding the lift equipment. It should not require an auxiliary circuit breaker or other disconnecting means. This design parameter extends the SPD's functionality so that it not only protects equipment from transient surges; it becomes the first line of defense as it protects against

temporary steady state overvoltage events (TOVs), as well. While a TOV is a far less common anomaly, as compared to the likelihood of encountering a transient surge, it can be far more threatening.

Conventional SPDs employ fuses because their typical SCCR is far lower than the SCCR of the VSD service entrance, where the SPD should be typically installed. Fused SPDs become useless when called upon to protect equipment loads in these situations when their fuses clear for any reason. And, they too, will likely fail in a shorted state when subjected to a TOV event. But, in this situation the fused SPD will protect itself by clearing its own fuse and removing itself from the circuit – leaving its equipment loads unprotected. The disturbing end result regards the fact that its equipment loads will now be exposed to whatever the overvoltage condition was that was so intense that it destroyed the surge suppressor. And, the so-called protected loads will likely be destroyed, as well.

SPD TECHNOLOGIES AND TOPOLOGIES

There are several types of SPDs available, each utilizing different overvoltage protection technologies and topologies. These devices employ three basic types of suppression components: Gas Discharge Tubes (GDTs), Silicon Avalanche Diodes (SADs) and/or Metal Oxide Varistors (MOVs). These components differ dramatically from each other with regard to their operational characteristics and with their performance capabilities. Each technology has advantages and disadvantages that make them application specific.

In this section the primary advantages and disadvantages of each suppression technology will be presented with particular focus targeting their suitability to protect the VSDs and other control circuits employed in artificial lift equipment.

1. Gas Tubes (GDTs)

   The gas discharge tube utilizes specially designed electrodes that are fitted inside a tube and filled with one or more compressed gasses. They are rugged, relatively inexpensive and exhibit low shunt capacitance. Therefore, they won't limit the bandwidth of high-frequency circuits as much as other nonlinear suppression components. That better suits them to protect some types of data circuits. However, there are three major drawbacks that preclude their use on AC power lines.

   a. They are slow to conduct. In many cases the GDT won't be activated until after the most damaging content of the transient surge passes through it and on to the protected equipment load. For that reason alone, they cannot adequately protect VSDs or other types of sensitive electronic systems.

   b. Gas tubes are difficult to turn off after they activate and after the transient event has passed. Referred to as "follow current", this phenomenon will temporarily disconnect the SPD from the AC power input to the lift for as long as the effect lasts, disrupting the lift's operation.

   c. The spark which is developed between the electrodes during a GDT operation is a violent effect. When the gas tube switches from its idle state and into conduction, its activation and deactivation sequences can generate a secondary transient surge with enough energy content to damage the equipment that it is supposed to be protecting.

2. Silicon Avalanche Diodes (SADs)

   SADs are semiconductor devices that respond rapidly to transient overvoltages. They clamp the transient overvoltage at a reasonably low voltage value. But, they are plagued with low energy withstand capabilities. Individually, they cannot dissipate much transient energy. Therefore, SPD manufacturers utilizing SADs in their products attempt to overcome this deficiency by combining multiple SAD components in parallel arrays in an effort to equally share the energy associated with a surge event. The SAD based SPD is also suited well to protect on many types of data circuits. It can be generally relied upon to protect at electrical wall outlets within a home or office surrounding, as well. However, SAD based SPDs have proven to be unreliable when called upon to protect upon AC power services where frequent and intense transient activity are common events. They can be anticipated to fail, and they can do so catastrophically when deployed in this manner.

3. Metal Oxide Varistors (MOVs)

MOV based surge suppressors are ideally suited to protect upon AC power circuits. They are capable of withstanding high energy surges while maintaining the sufficiently low voltage clamping characteristics that are required to protect sensitive electronic equipment. For this reason MOV based SPD systems are the preferred protection technology to utilize to protect artificial lifts.

Commercially available MOV based SPDs significantly differ from each other in terms of their surge handling capabilities and with the levels of protection they provide. Field experiences have revealed serious safety issues plaguing older and poorly designed SPDs, particularly during their end-of-life operations. The calls for effective and safe SPDs are of paramount importance to manufacturers and users of all varieties of industrial electronic equipment.

As with the SAD based surge suppressor, it has been a common practice for surge protection manufacturers to build MOV based suppression modules consisting of a printed circuit board that is populated by multiple MOV components. In this example the MOVs are configured in parallel arrays. The goal is to achieve a higher current handling capacity as opposed to that of individual component based suppressor product. A typical example of a conventional SPD using parallel MOV technology is shown in Fig 1 at the end of this paper. Even though it is commonly accepted that a SPD's surge performance will be linearly enhanced by this design parameter, it is important to emphasize that that is not the case; either electrically or mechanically. There will be minor defects and /or impurities in each MOV wafer that will preclude their operational characteristics from being identical to each other. They cannot be relied upon to activate simultaneously, nor can they be anticipated to equally share their surge current diversion responsibilities. That, along with differences in mechanical design, will lead to one individual MOV always having to handle more current than its neighbors.

Almost all manufacturers of industrial type SPDs use MOVs in their designs. MOVs are composed of a thin disk wafer of material (metal oxide) that has a known voltage breakdown characteristic. At low voltages, the MOV conducts very little current (micro-amperes). As the voltage applied to the MOV increases in value and approaches the component's breakdown threshold, it begins to conduct current. At voltages slightly above the breakdown point, large currents flow, effectively clamping the output voltage. This feature allows the current associated with surge to be shunted to ground while maintaining a low level residual voltage drop across the MOV as it prevents the surge from disrupting or damaging equipment loads.

Most SPDs, regardless of their manufacturer, are essentially the same. They typically employ commercial grade, small 20mm diameter MOVs that are mounted on printed circuit boards (PCBs). Each MOV is individually coated with resin to prevent moisture ingress that would cause its performance characteristics to deteriorate and shorten its life expectancy. The applications of these devices calling for them to protect equipment in harsh electrical environments have revealed numerous problems that adversely affect their performance and safety considerations.

On the other hand, the preferred SPD will demonstrate a monolithic design and be constructed with a single large diameter MOV component. These SPDs will outlast and outperform their multiple component counterparts in virtually any application, and in any type of electrical environment. The properly designed single component SPD will utilize a higher quality industrial grade MOV that will exhibit more stable operational characteristics and allow for more even current conduction across its full surface area. It should be built with electrodes that cover the component's entire conductive surface. And, it should be housed inside a strong environmentally sealed conductive casing, i.e. aluminum, for example. This design parameter precludes the need to coat the MOV with resin to protect it from the outside environment. So, where the conventional resin coated MOV based SPD contains the heat that it generates as it is called into service, the single element SPD dissipates it through its housing. The heat sinking advantage realized by this design consideration eliminates the degradation cycles and intensive wear factors that plague conventional surge suppressors. And, it removes all combustible materials that compromise the conventional SPD safety considerations.

APPLICATION

Due to its robust construction and the absence of flammable materials in its housing, the fore mentioned SPD design suits itself ideally for its integration within the VSDs utilized by artificial lifts - shown in figure 2 at the end of this paper. The absence of fusing enables the “in-line” installation of the SPDs. They are connected directly on the load side of the main circuit breaker, eliminating the need for long lead wires. A general diagram of the “in-line” connection is illustrated in figure 3 at the end of this paper.

The key advantage of this innovative method of protection regards the SPD’s ability to protect lift equipment under any surge condition. When encountering a TOV event; the non-fused in-line connected SPD will activate and initially attempt to regulate the overvoltage. But, since long term regulation will fall outside its operating parameters, it will protect its load by entering into a direct shorted state. At such time it will demand the full available fault current from the AC power source to clear the AC power circuit’s main disconnect ahead of it. The equipment loads, in turn, now benefit ultimate protection levels as they are now connected to an open power circuit. Therefore, the SPD must demonstrate very a very high short circuit current rating (SCCR) that is determined by UL 1449 3-cycle testing parameters.

While the lift will be down until the SPD is replaced and its power source is restored, it is a far more preferable circumstance having to simply replace an inexpensive SPD over having to replace the artificial lift that would likely have otherwise been destroyed.

SPD TEST SCENARIOS

Laboratory tests have proven the ability of the single component SPD to handle extremely large levels of thermal energy. The amount of energy that some of these SPDs can handle, as described by their I^2t parameter, measure in excess of 500 MA^2s.

Single component MOV based SPDs have been thoroughly tested in both field trials and in laboratory environments. The results obtained from this testing demonstrate the fundamental performance differences between the different surge protection devices available in today’s marketplace.

FIELD TRIALS

For example, and for the purposes of this paper, a single MOV based SPD module was compared to a conventional surge suppressor. Two installation sites employing the same type of VSD, each with a rich history of severe power surge problems, were selected for a field trial.

The VSD at the first site (Site A) was protected with the single component MOV based SPD.

The VSD at the second site was (Site B) was protected with a conventional parallel connected multiple component MOV based surge suppressor.

The intent of this field experiment was to monitor and record the level and the number of surges that the VSDs were subjected to during a 24 hour time period. VSD operation was monitored without protection and again with surge protection installed. Since the observation period was limited; two sites in a plant where numerous equipment failures had been previously documented were carefully chosen. This selection consideration maximized the likelihood of recording a significant number of surge events.

It is important to point out that most of those surges recorded were induced by switching operations within the facility, and not related to lightning activity.

In both sites the electrical configurations were identically configured 3-wire 240/415V 3-phase services. With regard to the first site, three single component MOV modules were installed between each of the three power lines and ground. The SPD modules were directly installed in-line on the load side of the VSD’s circuit breaker. With the second site a parallel connected multiple MOV based SPD was installed externally to the drive cabinet due to space restrictions inside the drive.
A power line monitor (Powertronics, PQR-2020) was installed prior to the installation of the SPD modules. The device was set to record every transient overvoltage lasting longer than 5µs, and with peak voltage amplitudes extending beyond 50V of the nominal 240Vrms line to ground voltage level. The number and intensity of the recorded overvoltages at both sites are summarized in figure 3 at the end of this paper.

The results of this field trial indicate that the multiple-component, parallel connected MOV based surge suppressor failed to provide sufficient equipment protection. The average peak amplitude of the surges that it encountered were reduced by only **18.5%**. Moreover, the conventional SPD allowed eight surge events whose peak amplitudes exceeded 500V to bypass it and propagate to its equipment load. On the other hand, the single MOV based SPD reduced the total number of surges encountered by the equipment by **84%**.

LABORATORY TESTS

Besides the field trial, a series of surge tests were conducted within a laboratory environment. Using different surge waveforms, the objective of these tests was to attempt to simulate an aging effect on different technology based SPD's.

The following tests were premeditated to verify that conventional multiple component MOV based SPDs would demonstrate an inconsistent level of protection capabilities over time. The intent was to illustrate that the performance characteristics of the conventional surge suppressor would degrade with use, and as it was subjected to as few as ten consecutive surges.

In the first test sequence a conventional SPD was exposed to a series of surge events. Its residual voltage values and its true current conduction levels were monitored during every impulse. Ten surges; each capable of supplying approximately **9kA** of surge current, were applied to the SPD. The waveform employed was the 8/20µs current waveform that is referenced in IEEE C62.41 documentation. The SPD, under test, was allowed to rest for one full minute after each impulse to allow it to cool down.

The test results demonstrated a significant change in the values of the residual voltage and the let-through current as a function of time. The initial residual voltage recorded during the first hit was **1,484V**. After being subjected to the 10^{th} test impulse, however, the residual voltage increased to **3,335V**. This represents a variation of **125%** with regard to the product's voltage protection capabilities. It was apparent that the SPD was incapable of adequately protecting its equipment loads when subjected to intense levels of surge activity.

In a similar test setup a single component MOV based surge suppressor was subjected to a series of **2,000** consecutive surge events; each capable of supplying **20kA** of 8/20µs surge current. This device was also allowed to rest at one minute intervals between test impulses. In contrast with the unimpressive performance measurements obtained from the conventional SPD, the residual voltage of this SPD was recorded at just **810V** after the first surge event. More impressive, perhaps, regards the fact that the residual voltage measured after the **2000^{th}** test impulse increased by only **12** volts to **822V**. The variance associated with this device's performance characteristics from the first to last surge event was a mere **1.5%**, even though it was stressed with more than **twice** the surge current and with **200** times the number of surges that were used to test its multiple MOV based counterpart.

It is important to point out that not all surges occurring in the oil fields will follow the typical 8/20µs model which relate to short term, high intensity surge events that are generally attributed to lightning. In reality, and in most industrial environments - particularity in geographic areas where lightning is not a major concern; surges are mainly caused by switching activities. These surges exhibit significantly lower intensities, but are simultaneously characterized by significantly longer durations. IEEE C62.11defines a test waveform that can be utilized to simulate these types of surge events. It is a rectangular (square) two millisecond long waveform whose current capacity is in the magnitude of **500** to **1,000** amperes.

While intensities of these surges are not high enough to cause an immediate SPD failure, they do carry significant amounts of energy due to their longer durations. These types of surge events, too, will cause the conventional SPD to deteriorate over time. And, it can be anticipated that the conventional SPD will eventually fail as it is called upon to protect against these types of surges over the long run.

For example, in another test, a conventional SPD was exposed to **three** of the fore mentioned square waves. And, as before, it was allowed to rest for one minute intervals between each subsequent test pulse. As it was subjected to the first impulse, its current conduction was measured at **913A**. As it was subjected to the second two millisecond impulse, it was observed to conduct **931A**. However, it was witnessed to emit heavy smoke as it conducted that current. During the third surge the SPD caught fire, with some of its MOV components disintegrating in the process.

The residual voltage measured during the first surge was **700V**. It measured at **1,890V** during the second. And, during the third surge it was measured at **3,360V**. This represents a **380%** degradation factor from the first to third test impulses.

That is unacceptable.

Conversely, in a similar test procedure, a single component MOV based surge suppressor was subjected to a series of **250** of the fore mentioned square wave form test impulses. The SPD's residual voltage measured at 335V during the first surge as it conducted more than **1,000** amperes of surge current. During the **250th** test pulse the residual voltage was measured to be just **339V** as it conducted like current values. No visible damage, smoke emissions, or fire was observed during the test.

The comparison of slope resistance for a single component MOV based SPD versus a conventional surge suppressor is plotted in figure 5, at the end of this paper. This diagram illustrates the measured residual voltages of the two different types of SPDs to be a function of the surge current passing through them. The graph shows that single component MOV based suppressors demonstrate lower slope resistances, resulting with lower residual voltages at intermediate and high surge currents, as compared to the residual voltage characteristics associated with its conventional multiple MOV based counterpart.

CONCLUSION

There are many different types of surge protection devices that can be employed to protect artificial lift equipment. However, only one type of SPD meets all of the requirements necessary to adequately protect this type of equipment. Only the single component MOV based surge suppressors described in the preceding paragraphs are proven to be ultimately safe under any circumstance. They are the only SPDs that are truly maintenance free, have proven performance, are highly reliable and can be installed without an auxiliary disconnect to provide maximum protection for electrical equipment.

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Chart 1

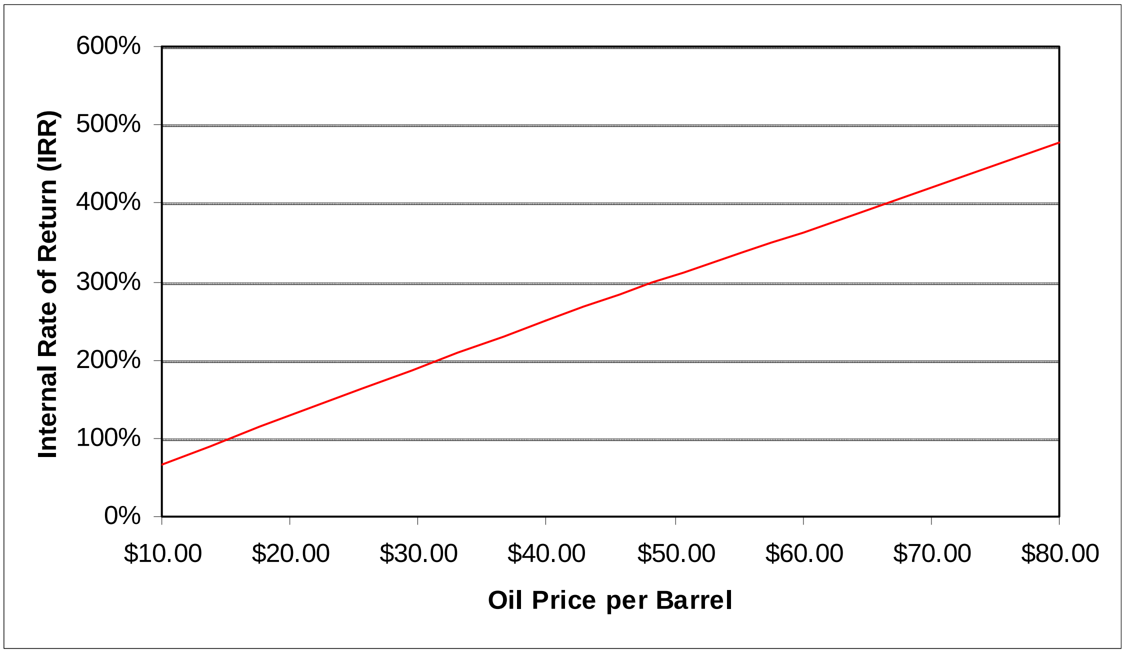

Figure 1

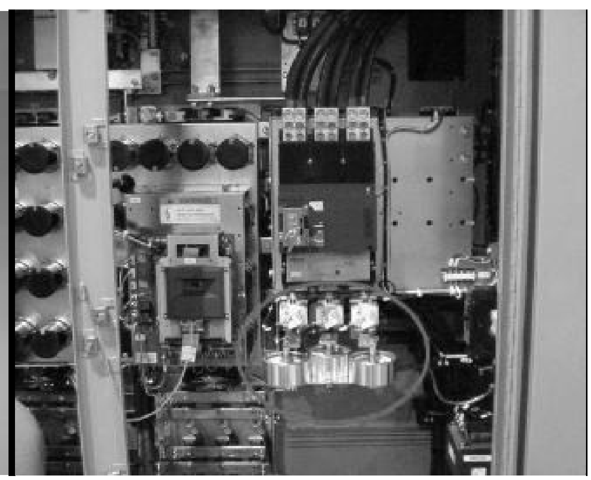

Figure 2

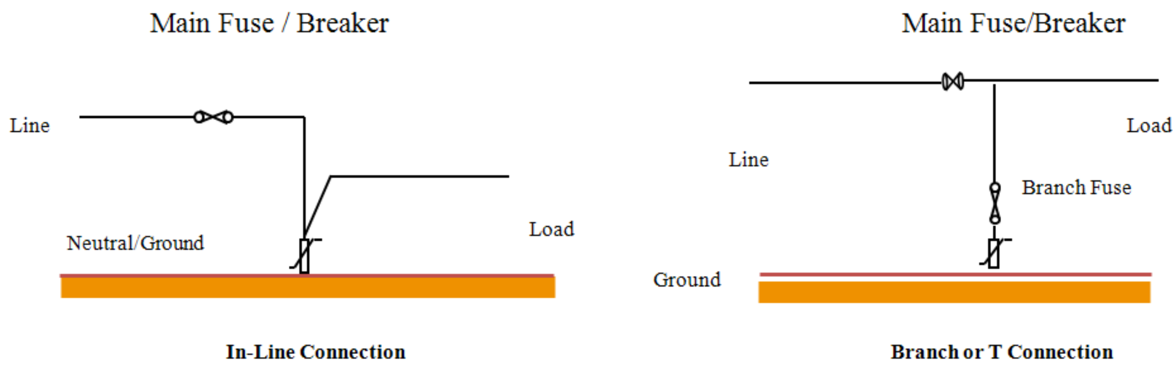

Figure 3

When high frequency surge current flows through a conductor a voltage drop develops across it. The intensity of the voltage drop is dependent upon the inductance of the conductor.

With "T" type connection the voltage imposed on the load is equal to the SPD's residual voltage rating (clamp point) plus the voltage drop realized along the connecting cable, plus the voltage drop across the branch disconnect
In the case of in-line connection the voltage imposed on the load is limited solely to the SPD's residual voltage, as the connecting leads lengths are practically eliminated.

Note that if the branch fuse blows, the load is no longer protected.

While most competitive TVSS are designed for the "T" type connection, the in-line configuration is the preferred installation method.

The in-line configuration provides protection for the load during TOV events whereas that is not possible with the T-Type installation option.

SURGE STATISTICS IN 24 HOUR PERIODS

	Case	Phase	Total number of surges	Maximum Surge amplitude (V)	Number of surges >500V
Site A	Without SPD	A	66	642	2
		B	79	652	5
		C	97	647	12
	single MOV-based SPDs	A	10	215	0
		B	13	187	0
		C	16	209	0
Site B	Without SPD	A	61	580	1
		B	70	715	2
		C	88	604	6
	parallel MOV-based TVSS	A	40	510	1
		B	51	515	2
		C	59	517	5

Figure 4

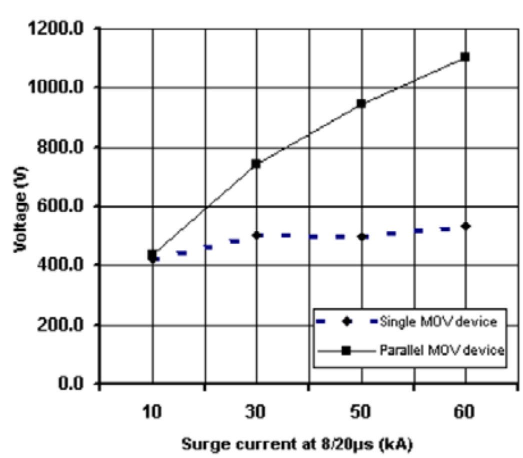

Figure 5