The Use of Surge Protection Devices in the Petroleum/Petrochemical Industry

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Abstract: Without clean power, petroleum and petrochemical equipment is subject to possible upset or catastrophic failure. To cost-effectively eliminate power disturbances due to lightning, fast ringing transients and electrical noise, the use of surge protection devices at building entrance feeders, key branch panels, critical loads and communication lines is recommended. Their use improves the operating reliability of electronic equipment.

Index Terms: surge protection, clean power, electrical power distribution.

Introduction

“Dirty Power” is preventing facility operators from realizing the increased efficiencies expected from investments in automation and process control equipment.

Surge Protection Devices (SPD), also known as Transient Voltage Surge Suppressors (TVSS), are one technology that improves electronic equipment productivity and up-time. Their effectiveness to protect against transients and electrical noise has made SPDs the fastest growing new technology in the electrical industry (see Figure 1: Growing Demand for Pure Power).

In applications where external data/phone/cable lines enter a facility or ground loop problems exist, surge protection devices can prevent damaging power disturbances.

Protecting a facility against transients and electrical noise requires the installation of SPD devices at building entrance feeders and branch panels or next to “critical loads”. This “cascaded protection” approach reduces high and low energy disturbances to levels where component damage and degradation and process disruption are minimized.

In applications where external data/phone/cable lines enter a facility or ground loop problems exist, surge protection devices can prevent damaging power disturbances.

The Sensitivity of Electronic Equipment Is Increasing

In 1993 power related problems cost U.S. companies an estimated $26 billion [4] a year in lost time and revenue. The cost continues to grow because microprocessor based devices are becoming more sensitive and their use is increasing as forecast by the Electric Power Research Institute (EPRI). EPRI projects that by the year 2000, 60 to 70 percent of total utility power generated within the U.S.A. will be controlled by power electronics. This compares with 30 percent in 1995 [5].

Disturbances such as electrical noise or transients, with magnitude equal to two times the rated operating voltage, can threaten the operation of microprocessor-based equipment, create downtime and reduce productivity (see Table II: Effect of Electrical Noise and Transient Disturbances).

Disturbances less than two times operating voltage also create problems. An example is electrical noise: the logic voltage signal of an electronic circuit can be “swamped” and cause operation errors and equipment downtime (see Figure 2: Effect of Electrical Noise on Microprocessor Operation).

TABLE I
Definitions (1,2)
<table>
<thead>
<tr>
<th>Definitions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surges; Spikes; Transients</strong></td>
<td>• An over voltage (or under voltage) condition with a duration of less than half cycle of the normal voltage wave form of either polarity. Detectable only by sophisticated power analyzers, these disturbances result in direct component damage or deterioration. Due to lightning, switching/cycling loads.</td>
</tr>
<tr>
<td><strong>Noise</strong></td>
<td>• Unwanted electrical signals which produce undesirable effects in the circuits of sensitive electronic equipment. More commonly known as low magnitude, high frequency disturbances; affect equipment operation. Created by motor generators, variable frequency drives, and other electronic equipment.</td>
</tr>
<tr>
<td><strong>Swell</strong></td>
<td>• An “increase” in the RMS nominal voltage (120VAC) at the normal power frequency (60Hz) for duration of a half cycle to a few seconds. Usually due to large loads shutting down or utility faults (e.g. Large motors coming off line). Often a noticeable increase in light brightness.</td>
</tr>
<tr>
<td><strong>Sag</strong></td>
<td>• A “decrease” in the RMS nominal voltage (120VAC) at the normal power frequency (60Hz) for duration of a half cycle to a few seconds. Due to large loads coming on line and utility faults (e.g.: motors, welders, power factor capacitors). Often a noticeable dimming of lights.</td>
</tr>
<tr>
<td><strong>Over Voltage</strong></td>
<td>• Sustained swell; duration of more than a few seconds. Noticeable in lights. Due to large loads, utility faults, improper wiring.</td>
</tr>
<tr>
<td><strong>Under Voltage</strong></td>
<td>• Sustained Sag; duration of more than a few seconds. Noticeable in lights. Due to large load startup, poor distribution wiring, utility faults.</td>
</tr>
<tr>
<td><strong>Interruptions</strong></td>
<td>• The complete loss of voltage for a period of time. No specific time frame is specified.</td>
</tr>
</tbody>
</table>

**TABLE II**  
Effect of Electrical Noise and Transient Disturbances [6]
<table>
<thead>
<tr>
<th>Impact to Electronic Loads</th>
<th>Pulse 4x Normal</th>
<th>Pulse 2x Normal</th>
<th>Repetitive Disturbance (noise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit Board Failure</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Data Transmission Errors</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Memory Scramble</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hard Disk Crash</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCR Failure</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Interrupt Failure</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Power Supply Failure</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program Lock Up</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Advances in microprocessor technology have resulted in sub-micron features and more “densely packed” integrated chips with lower signal voltages to increase operating speed. The decreased signal voltage allows for increasing circuit density; however, the downside is that electronics are more prone to damage or failure.

Application and facility engineers responsible for ensuring maximum up-time and productivity cannot count on past experience when designing modern day process control environments. The greater susceptibility of electronic loads makes past practices and experience only partially relevant.

Maximizing the productivity of modern day facilities requires the use of cost effective surge protection. Based on field operating experience, manufacturers of electronic equipment recommend the use of surge protection devices (see Table III: Manufacturer SPD Recommendations).

**Elements of a Quality Surge Suppression Device**

The SPD design and performance criteria that ensure high levels of protection and reliability include surge current rating, filter performance, the Underwriters Laboratories (UL) assigned Suppression Voltage Rating (SVR), internal fusing, monitoring and the quality of internal construction.

Two types of surge protection devices are commonly used: parallel and series surge protectors. Series SPDs utilize inductors that enhance their ability to reduce power disturbances to levels lower than those achieved by parallel design SPDs.

Series filters are not cost effective for large load applications. At higher current ratings, the inductors used in Pi filter networks become large and costly. In contrast, parallel SPDs are not sized to a given current or load and...
FIGURE 3. Typical Petrochemical Application
### TABLE IV  
**Key Elements of a Quality Surge Protector**

<table>
<thead>
<tr>
<th>Key Elements</th>
<th>Recommended Specification Target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Surge Current Per Phase</strong></td>
<td>• Appropriate sizing for long term protection</td>
</tr>
<tr>
<td>• 250 kA/phase (building entrance feeder);</td>
<td></td>
</tr>
<tr>
<td>120 kA/phase (panelboards)</td>
<td></td>
</tr>
<tr>
<td><strong>2. Integrated Installation</strong></td>
<td>• Lowest possible let through voltage; no contractor/installation problems; eliminates horizontal</td>
</tr>
<tr>
<td>• TVSS supplied by gear manufacturers</td>
<td>wall space</td>
</tr>
<tr>
<td>• TVSS mounted inside low voltage distribution equipment (direct bus bar connection):</td>
<td></td>
</tr>
<tr>
<td>Switchgear, Switchboards, Panelboards, MCCs, Busway</td>
<td></td>
</tr>
<tr>
<td><strong>3. Effective Filter</strong></td>
<td>• Dampens internal ringing transients/noise the most common transient</td>
</tr>
<tr>
<td>• Noise attenuation (exceed 45 dB @ 100 kHz)</td>
<td></td>
</tr>
<tr>
<td>• Let through voltage result using Cat B3 ringwave (6kV, 100 kHz) less than 300V @ 208V, 450V @ 480V</td>
<td></td>
</tr>
<tr>
<td><strong>4. Low “Let Through Voltage”</strong></td>
<td>• Key performance measurement</td>
</tr>
<tr>
<td>• Let through voltage using C1 (6kV, 3kA) equal to 400V (208V system); 800 V (480V system)</td>
<td></td>
</tr>
<tr>
<td><strong>5. Internal Fusing System</strong></td>
<td>• Safety and overcurrent protection</td>
</tr>
<tr>
<td>• 200 kAIC internal fusing system</td>
<td></td>
</tr>
<tr>
<td><strong>6. Reliable Monitor and Diagnostics System</strong></td>
<td>• Comprehensive monitoring system that does not depend on only the monitoring of fuses or circuit</td>
</tr>
<tr>
<td>• Foolproof status indication</td>
<td>breaker</td>
</tr>
<tr>
<td><strong>7. Quality Construction</strong></td>
<td>• Ability to achieve quoted performance</td>
</tr>
<tr>
<td>• All suppression components mounted directly to solid copper surge plane</td>
<td></td>
</tr>
<tr>
<td>• 3rd party independent test results verifying quoted surge current ratings</td>
<td></td>
</tr>
</tbody>
</table>
Effective power quality solutions start with grounding. IEEE recommends the use of TVSS in a facility-wide design. Cost-effective protection for all solid state loads [2]. Voltage Regulation has limited applications (analog power supplies; site specific problems). UPS employed at critical locations (highest $/kVA). IEEE recommends TVSS devices upstream of a UPS [2].

**FIGURE 4. Power Quality Pyramid**

The Power Quality Pyramid also recommends the use of SPDs. Transients and noise can be shunted by surge devices to ground when installed at strategic main and sub-panels, near critical loads and disturbance generating equipment.

A Cascaded Network Is Required to Limit High Energy Disturbances: Building entrance feeder surge protection is mandated as per NFPA 780: “Devices suitable for the protection of the structure shall be installed on electric and telephone service entrances and on radio and television antenna lead-ins. Electrical systems and utilization equipment within the structure may require further surge suppression.” [4].

The concept of “a two-stage” protection approach is recommended in IEEE’s Emerald Book: “For large surge currents, diversion is best accomplished in two stages: the first diversion should be performed at the service entrance to the building. Then, any residual voltage resulting from the action can be dealt with by a second protective device at the power panel of the computer room (or other critical loads).” [2].

**FIGURE 5. Cascaded Network Protection**

The benefit of implementing cascaded network protection is shown in Figure 5: Cascaded Network Protection. Combined, the two stages of protection at the service entrance and branch panel locations reduce the IEEE 62.41 recommended test wave (C3 - 20kV, 3kA) to less than 200V voltage, a harmless disturbance level for 120V rated sensitive loads.

If only building entrance feeder protection were provided, the let-through voltage will be approximately 950V in a 277/480V system exposed to induced lightning surges. This level of let-through voltage can cause degradation or physical damage of most electronic loads.

Framework For Applying SPDs for Facility Wide Protection: The system approach views the electrical distribution layout as one system and attempts to maximize equipment reliability and productivity. By identifying the critical, non-critical and disturbance generating loads within a facility, and reviewing the internal power distribution network, a determination of where to install mitigating equipment can be made.

The most effective and economic solution for protecting a large number of loads is to install parallel SPDs at the building entrance feeder and panelboard locations. This reduces the cost of protection for multiple sensitive loads can be protected with one device.

The recommended methodology is summarized in Figure 6: System Approach for Installing SPDs.

**FIGURE 6. System Approach for Installing SPDs**

There may be critical loads within a facility that require a higher level of protection. Such loads are essential for the health and safety of personnel or responsible for critical
operations within a facility. An example is a computer that controls a processing line/operation. A series SPD is best suited for protecting such loads.

Advantages of the System Approach are:

- the lowest possible investment in mitigating equipment to protect a facility;
- building entrance SPDs protect the facility against large external transients, including lightning;
- SPDs are bi-directional and prevent transient and noise disturbances from feeding back within a system when installed at distribution or branch panels; and
- two levels of protection safeguard sensitive loads from physical damage or operational upset.

**Integrated SPD Devices Offer Significant Performance Improvements**

Historically, surge suppression devices were purchased as stand-alone devices and installed next to a panelboard, switchboard or motor control center by an electrical contractor. In 1995 gear manufacturers began integrating SPD devices into electrical distribution equipment to increase the level of protection provided against surge and noise disturbances.

Directly connecting the surge suppressor to the bus bar of electrical distribution equipment results in the best possible level of protection. Compared to side mounted devices, connecting the SPD unit to the bus bar eliminates the need for lead wires and reduces the let-through voltage up to 50 percent (see Figure 7: Integrated SPDs Offer Significant Performance Improvements).

Given surges are high frequency disturbances, the inductance of the installation wiring increases the let-through voltage of the protective device. Figure 8: The Effect of Installation Lead Length on Let-Through Voltage, shows that for every inch of lead length, the let-through voltage is increased by an additional 15V to 25V above the manufacturers stated suppression performance.

Lead length has the greatest effect on the actual level of protection realized. Twisting of the installation wires is the second most important installation consideration. By twisting the installation wires, the area between wires is reduced and the mutual inductance affect minimized.

![FIGURE 8. The Effect of Installation Lead Length on Let-Through Voltage](image)

Increasing the diameter of the installation wires is of negligible benefit. Inductance is a “skin effect” phenomenon and a function of wire circumference. Since only a marginal reduction in inductance is achieved when the diameter of the installation conductors is increased, the use of large diameter wire results in only minimal improvement.

![FIGURE 7. Integrated SPDs Offer Significant Performance Improvements](image)
Further benefits provided by integrated surge suppression designs are the elimination of field installation costs and the amount of expensive “outboard” wall space taken up by sidemounted SPD devices.

**Building Entrance Feeder Installation Considerations**

Installing a SPD device immediately after the switch gear or switch board main breaker is the optimal location for protecting against external disturbances such as lightning. When placed in this location, the disturbance is “intercepted” by the SPD and reduced to a minimum before reaching the distribution and/or branch panel(s).

The use of a disconnect switch eliminates the need to de-energize the building entrance feeder equipment should the SPD fail or require isolation for Megger testing.

The size or capacity of a suppressor is measured in surge current per phase. Larger suppressors rated at approximately 250kA per phase should be installed at the service entrance to survive high energy surges associated with lightning.

A 250kA per phase surge rating allows for over a 25 year life expectancy assuming an IEEE defined high exposure environment [10]. Lower surge rating devices may be utilized; however, device reliability and long term performance may be compromised.

For aerial structures, the 99.8 percentile recorded lightning stroke current is less than 220kA. The magnitude of surges conducted or induced into a facility electrical distribution system is considerably lower given the presence of multiple paths for the surge to travel along [10]. It is for this reason that IEEE C62.41 recommends the C3 (20kV,10kA) test wave for testing SPDs installed at building entrance feeders.

SPDs with surge ratings greater than 250kA are not required. The incremental benefit is minimal and the additional cost difficult to justify.

**Installing Panelboard Surge Protection Devices**

Wherever possible, consultants, specifiers and application engineers should ensure similar loads are fed from the same source. In this way, disturbance generating loads are separated from electronic circuits affected by power disturbances. For example; motor loads, HVAC systems and other linear loads should be separated from the sensitive process control equipment employed within petroleum and petrochemical facilities.

Smaller surge capacity SPDs (120kA per phase) are installed at branch panelboards where power disturbances are of lower energy but occur much more frequently. This level of surge current rating should result in a greater than 25 year life expectancy.

When isolated ground systems are used, the SPD should be installed such that any common mode surges are shunted to the safety ground.

The use of a disconnect switch is optional. The additional let-through voltage resulting from the increased inductance caused by the disconnect switch is about 50V to 60V. This increase in disturbance voltage can result in process disruption and downtime.

**Motor Control Center and Bus Way Installation Considerations**

Increasingly, motor control centers (MCC) power VFDs, solid state overload relays, electronic soft starters, electronic metering and relaying equipment require protection from power disturbances.

When utilized in building entrance feeder applications, MCC SPDs provide the first stage of protection against external high energy power disturbances. To reduce incoming power disturbances to the lowest level possible, the surge protector should be installed onto the bus bar in the main incoming structure.

If there is no room in the main structure, the SPD should be installed in a cell located at the top of the first or second structure. In this fashion, external disturbances are “intercepted” before entering the facility electrical distribution system.

A common convention in the past has been to install lightning arrestors within MCCs used in building entrance applications. The level of protection offered by these devices is inadequate for today’s sensitive loads.

The typical let-through voltage of a surge arrester using the IEEE C62.41 C1 test wave form (6000V, 3000A) is between 1500V and 2000V. This is a far lower level of protection compared to the 800V let-through voltage for a 480V WYE SPD.

Downstream MCCs may include a panelboard feeding electronic loads. In such applications, the SPD can be integrated into the panelboard or between the transformer and panelboard lugs. This prevents power disturbances from affecting the electronic loads connected to the panelboard.

In all cases, whether at the building entrance feeder, sub-feed or branch locations, the SPD units installed in MCCs should be mounted in a wrapper with stabs to minimize installation lead length, time and cost.

In facilities with busway systems, the first stage of protection is typically integrated into the building entrance switch gear. The second stage of protection is a SPD installed in a bus plug with stabs allowing for easy, minimal lead length installation.

Surge protection should be placed ahead of any critical loads to prevent the primary stage let-through voltage from disrupting operations.
Installing Dataline Surge Protection

Most petroleum and petrochemical facilities utilize communication lines for process monitoring and control. As identified by the Power Quality Pyramid, proper grounding of communication lines is essential for dependable operation. This concept is seconded by NEC Article 800 which states that all data, power and cable lines be grounded and bonded [11].

Power disturbances such as lightning can elevate the ground potential between two communicating pieces of electronic equipment with different ground references. The result is current flowing through the data cable causing component failure, terminal lock-up, data corruption and interference.

NFPA 780 D - 4.8 warns that “surge suppression devices should be installed on all wiring entering or leaving electronic equipment, usually power, data or communication wiring” [9].

Surge suppressers should be installed at both ends of a data or communication cable. In those situations where one end of the cable is not connected into an electronic circuit (e.g. contactor coil), protection on the electronic end only is acceptable.

To prevent the coupling or inducing of power disturbances into communication lines, the following should be avoided:

- data cables should not be run over fluorescent lighting fixtures;
- data cables should not be in the vicinity of electric motors;
- the right category cable should be used to ensure transmission performance; and,
- data cables must be grounded at both ends when communicating between buildings.

Summary

Electronic loads are critical to achieving competitive levels of production within today’s petroleum and petrochemical industry. Their increasing susceptibility makes it necessary to protect them against power disturbances. The Power Quality Pyramid is a framework for implementing facility wide power protection designs. Proper grounding, the use of SPDs at building entrance feeders and branch panel locations using a cascaded network, a facility wide approach and dataline protection to safeguard communication devices, ensures cost effective protection against power disturbances. The level of protection realized is greatest when SPDs are integrated into a facility’s electrical distribution equipment. Compared to conventional side mounted SPD installations, integration eliminates the inductance associated with installation wires and results in 50% lower let-through voltages.

References

[1] EC&M Reader Survey (1995): New Technology Products that have been bought, specified or installed in the previous two years by engineers/contractors (n=1443 responses)
[8] Siemens AG Automation Group EWA 811 6130-02