INTRODUCTION

This reference guide provides a comprehensive background in Power Quality issues. A major focus of this guide is on the causes and effects of transient voltage surges. It covers the strategies available to defend against disruptive and damaging effects of surges using Surge Protective Devices. It describes critical selection criteria for Surge Protective Devices including pertinent standards, performance characteristics, and proper installation techniques. The intention is for the reader to have the information needed to properly implement efficient, cost-effective SPD installations in a broad range of application environments.

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Chapter 1: Power Quality

A Perspective

The power quality problems we’re concerned with today are not new to any facility’s AC powerline environment. Older electro-mechanical equipment, by and large, did not contain microprocessor-based (meaning “computerized”) circuitry. This older equipment easily endured all but the most severe power quality problems without any resultant damage or downtime. However, since the late 1960’s, every aspect of business and manufacturing increasingly depends on some type of microprocessor-based equipment.

Today, the power quality infrastructure has a significant effect on the bottom line in any business. The March, 1993 issue of Electric Light and Power estimated that on average, equipment downtime alone cost each Fortune 1000 company $3.48 million annually. EL&P further estimates that electrical disturbances cost U.S. companies a total of $26 billion.

The bar graph in Figure 1, published in MIS Week, estimated that given the current state of power quality in commercial buildings, data processing downtime attributed to power quality will increase from 27% in 1990 to 47% by the year 2000. Note that downtime due to the electrical environment was only 5% in 1980. The reason for this dramatic increase in downtime is not that the power quality infrastructure is getting markedly worse. Computer chips were much slower in 1980 and operated at relatively high logic levels of 5 volts or greater. In the 1990’s, high speed data transmission is accomplished by computer chips that operate at lower logic levels. These chips are even more sensitive to slight changes in voltage levels or transients that appear on the AC powerline. In other words, accelerated computer technology means an increased vulnerability to the power quality infrastructure.

Power quality problems were first addressed in the 1970’s, when the main goal was to protect sensitive electronic equipment. In the 1980’s, the emphasis went beyond equipment loss to productivity losses. Today in the 1990’s when every aspect of manufacturing, sales, customer service, shipping and finance depends so much on computer-based technology, the loss of revenue is staggering when vital computerized equipment is down.

A study by Infonetics Research on the effects of outages on Local Area Networks or LAN’s illustrates this point. Figure 2 shows that revenue losses in 1989 were a fraction of the productivity losses. Only four years later in 1993, revenue losses begin to overtake productivity losses.

With the 21st century just a few years away, technology may be accelerating at such a pace that there may be a need for a National Power Quality Code. In the meantime, facility managers and design specifiers must be conscious of the serious impact power quality has on keeping vital technology up and running.
AC Power Basics

Any discussion of power quality should begin with a brief refresher on AC power basics. Utilities supply electrical power as ALTERNATING CURRENT, which is usually referred to as AC power. An oscilloscope is an instrument used to create a graphic image of the generated line voltage. Figure 3 represents the image an oscilloscope would show of a single 120 Volt AC cycle. Sixty of these cycles occur every second. However, rather than saying this AC frequency is 60 cycles per second, it is referred to as 60 Hertz, which is usually written in abbreviated form as 60 Hz.

The shape shown in Figure 3 is called a sine wave. Notice that in the first half-cycle above the line, the voltage level rises to 120 Volts. In the second half of the cycle below the line, the voltage is -120 Volts. So the voltage and current alternate polarity each half cycle, hence the term ALTERNATING CURRENT, or AC.

The 120 Volt AC sine waves shown in Figures 3 and 4 represent an ideal condition where perfect, consistent, stable AC power is shown. In the real world, this is seldom the case. AC line power is subjected to all sorts of unwanted disturbances that produce a variety of effects.

Modes of Measurement

Changes or disturbances of the AC power sine wave are generally specified in terms of voltage. Voltage is a potential measured between two specific points. In AC analysis, rather that repeatedly redefining these measurement points, the mode of measurement is identified. For the three-wire, single-phase branch circuit distribution system commonly used in the U.S. and Canada (Black wire = Line or Hot, White wire = Neutral or Common, Green wire = Safety Ground), the power transfer potential, L - N, is called the Normal Mode. Sometimes this mode is also called the Transverse Mode.

Likewise, any voltage measurement taken with respect to Ground, N - G and L - G, represent Common Mode potentials. Common mode potentials are sometimes abbreviated L + N - G, or may be more carefully specified by L - G and N - G. The modes of measurement for a standard NEMA L5-15 receptacle are shown in Figure 5.
FIPS PUB 94

The first official study of the effects of AC powerline disturbances on electronic equipment was published in 1983 by the U.S. Department of Commerce/National Bureau of Standards. Federal Information Processing Standards Publication 94, commonly known as **FIPS PUB 94**, emphasized the importance of the electrical environment for ADP (Automated Data Processing) installations. FIPS PUB 94 included a list of power quality attributes that still serves as practical guide to acceptable limits for computerized equipment.

### FIPS PUB 94

#### 8.2 Some Representative Power Quality Attributes

<table>
<thead>
<tr>
<th>Environmental attribute</th>
<th>Typical environment</th>
<th>Typical acceptable limits for computers and power sources</th>
<th>Units affected and comments</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Normal</td>
<td>Critical</td>
</tr>
<tr>
<td>Line frequency</td>
<td>±0.1%-±3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate of frequency change</td>
<td>0.5-20 x</td>
<td></td>
<td>1.5 Hz/s</td>
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<tr>
<td>Over and undervoltage</td>
<td>±5%-+6,-13.3%</td>
<td></td>
<td>+5%-10%</td>
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<tr>
<td>Phase imbalance</td>
<td>2%-10%</td>
<td></td>
<td>5% max</td>
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<tr>
<td>Power Source:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Tolerance to low</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>power factor</td>
<td>0.85-0.6 lagging</td>
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<td>0.8 lagging</td>
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<tr>
<td>Tolereance to high</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>steady-departures state</td>
<td>1.3-1.6 peak/rms</td>
<td></td>
<td>1.0-2.5 peak/rms</td>
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<tr>
<td>peak current</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Harmonics (Voltage)</td>
<td>0-20% total rms</td>
<td></td>
<td>0-10% total</td>
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<tr>
<td>dc load current</td>
<td>Negligible to 5% or more</td>
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<td>Less than 0.1% w/exceptions</td>
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<td>capability of power source</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage deviation</td>
<td>5-50%</td>
<td></td>
<td>5-10%</td>
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<tr>
<td>from sine wave</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Voltage modulation</td>
<td>Negligible to 10%</td>
<td></td>
<td>3% max</td>
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<tr>
<td>Transients surges/sags</td>
<td>+10%-15%</td>
<td></td>
<td>+20%-30%</td>
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<tr>
<td>Transient impulses</td>
<td>2 to 3 times nominal peak value (0-130% V-s)</td>
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<td>Varies; 1,000-1,500 V typical</td>
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<tr>
<td>RFI/EMI and “tone bursts” normal and common modes</td>
<td>10 V up to 20 kHz; less at higher freq.</td>
<td></td>
<td>Varies widely 3 V typical</td>
</tr>
<tr>
<td>Ground currents</td>
<td>0-10 A rms + impulse noise current</td>
<td></td>
<td>0.001-0.5 A or more</td>
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*FIGURE 6*
IEEE STD-1100 “Emerald Book”

In 1992, The Institute of Electrical and Electronic Engineers (IEEE), issued Standard 1100, known as the “Emerald Book”. Standard 1100 is a “Recommended Practice for Powering and Grounding Sensitive Electronic Equipment”. The Emerald Book is widely respected throughout the electrical industry and addresses power quality issues that every facility needs to consider. Figure 7 is a Selection Guide to Power Conditioning Technologies as suggested in the Emerald Book.

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<td>Surge</td>
<td>Common Mode</td>
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<tr>
<td>Normal Mode</td>
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<td>Noise</td>
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<tr>
<td>Normal Mode</td>
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<tr>
<td>Sag</td>
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<td>✓</td>
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<tr>
<td>Swell</td>
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<tr>
<td>Undervoltage</td>
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<td>✓</td>
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<tr>
<td>Overvoltage</td>
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<td>Momentary Interruption</td>
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<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>Long-Term Interruption</td>
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The level of resolution to power problem will vary from manufacturer to manufacturer.

Power Conditioning

Power Conditioning is a broad and complex industry dealing with the elimination and prevention of power disturbances to the AC power sine wave environment. Though the problems domain may extend from point of generation to load service, the principle focus of the power conditioning industry begins at the facility service entrance.

Disturbances on the AC power line take many forms, each with its own unique symptoms and solutions. However, despite their variety and complexity, power quality problems can be grouped in several distinct categories as represented by the illustration in Figure 9.

The Power Quality Cube is an analogy emphasizing the uniqueness of each power conditioning area. Each face is distinct and separate, yet each adjoins the others at an edge or corner. Likewise, the areas of power conditioning are distinct and require individual, specialized solution technology and methodologies, yet they are related both in terms of environment and result.

The power conditioning areas of REGULATION, ISOLATION and SUPPRESSION are the most often mentioned in the major power quality studies published during the last 20 years. However, these are not the summation of all power quality problem areas. The other faces of the cube represent the areas of GROUNDING, HARMONICS and NOISE.

The electrical professional must have some understanding of the types of disturbances that are likely to occur in the AC powerline environment, as well as the power-conditioning technologies developed to deal with each.
Transient Voltage Surges

Transient voltage surges are sometimes called "spikes", and by general definition, they are short-term deviations or changes from a desired voltage level (or signal in the case of computers and electronic devices). The deviation can cause an electronic device to malfunction, or damage it outright.

Figure 10 shows a transient voltage surge on the 60 Hz AC sine wave. Notice that the transient is very brief in duration, and the surge voltage is much higher than the AC line voltage. In fact, the greater the amplitude of the surge voltage, the greater the risk of it damaging electronic equipment. Furthermore, transient voltage surges originate from a variety of sources, so there is no such thing as a transient-free AC system. Transients are also present on telephone lines, coax conductors and a variety of other electrical environments. Following this chapter, the balance of this reference guide will concentrate on a thorough examination of transients, and the application of surge protective devices to defend against their disruptive and damaging effects.

Regulation

Voltage Regulation problems are familiar to most people because they occur over a relatively long time period electrically speaking, greater than 1 millisecond, and the effects are discernible to the human eye. Voltage surges which qualify in the regulation area are generally defined as having a duration of from one quarter cycle to many cycles.

SWELL is defined by the Institute of Electrical and Electronics Engineers (IEEE) in a publication often referred to as the “Emerald Book”. The IEEE Std. 1100 in this publication describes swells as an increase in the AC voltage, at the power frequency, for durations ranging from a half cycle to a few seconds. Figure 11 shows normal AC line voltage in the left-hand portion of the sine wave. The center portion represents a swell, as can be seen by the increased amplitude of the cycles.

SYMPTOMS: CRT and lights brighten up temporarily, power supply components blown out, burn marks on boards and components.

SAG is defined in IEEE Std. 1100 as a reduction in the AC line voltage, at the power frequency for durations lasting from a half cycle to a few seconds. The right-hand portion of Figure 11 shows a sag, as can be seen by the reduced amplitude of the sine waves.

SYMPTOMS: CPU reboot required, motors and fans lug down or stop, lights and CRT dim or sag in and/or blink off.

Blackouts are power outages, meaning a complete absence of line voltage.

SYMPTOMS: No power, system down.
Uninterruptible Power Supply (UPS)/Standby Power Supply (SPS)

The solution to swells, sags and blackouts is voltage regulation. The fundamental requirement for voltage regulation is that energy is added or subtracted to maintain the integrity of the AC sine wave. This is accomplished by either a Voltage Regulating Transformer, an Uninterruptible Power Supply (UPS), or a Standby Power Supply (SPS). The most popular choices today for solving Regulation problems are microprocessor-controlled UPS and SPS units.

Basically, the UPS or SPS is equipped with a switching mode power supply operating off a battery. The battery is charged while utility power is present. In the event that utility power causes a Regulation problem, an automatic transfer switch allows the battery to deliver power to the load through a DC-to-AC inverter. Note that the UPS or SPS deliver “synthetic” AC power (not a perfect sine wave) to their connected loads.

Figure 12 is a block diagram of the ON-Line or true UPS. Figure 13 similarly shows the SPS, which is sometimes called the BATTERY BACK-UP or OFF-LINE UPS. There are many options available to both the UPS or SPS designer, and as a result there is a wide range of both performance specifications and price. A careful examination of performance parameters is advised, because a UPS or SPS may only function as a sag-blackout power supply, i.e. it may not be capable of any degree of overvoltage regulation, suppression, isolation, or even minor sag regulation.
Standby Emergency Power

In a facility where Standby Emergency Power is utilized, it is important to consider the automatic transfer switch that allows the motor-generator or engine to deliver stored power to the load. The response of this switch may actually generate transients on the AC powerline connection to sensitive microprocessor-based equipment. It is therefore important to evaluate the parameters for the automatic transfer switches incorporated in these power supplies.

Noise Isolation

Sources of noise energy can include motor noise, high-frequency energy placed on the powerline by thermal heating devices, copying machines, ballasts and other equipment. Facilities near broadcast radio and TV towers, or near airport radar sites, can suffer from noise due to high levels of electromagnetic energy radiating from these sources.

Power Conditioning Area: Noise Isolation

Problems:

NORMAL MODE NOISE
SYMPTOMS: CRT data bounce, static chatter, light and LED flicker, data disruption

Description:
“Noise on the line” implies the presence of a low energy, random signal of higher frequency.

Solutions:
Noise attenuation is usually accomplished via filter technology. Hence, line filters and specially shielded “Isolation Transformers” are commonly used. Since noise is low in energy content, noise attenuation technology is not adaptable to high energy applications.

COMMON MODE NOISE
SYMPTOMS: Data disruption, logic problems

Amplitude: Low
Frequency: High
Energy: Low

FIGURE 14
Grounding

Grounds are a necessary element of any power, signal, or data network. All voltages and signal levels are referenced to ground. For example, when voltage measurements are made, they’re most often referenced to ground potential.
Ground Potential Difference

When changes to ground potential take place, they can cause serious damage or disrupt the operation of electronic devices. That's because current flows whenever a difference in potential exists. And this effect can occur in different ground systems within a single facility, or between the ground systems in separate buildings.

It happens that not all ground systems are at zero volts. In fact, the difference in potential between grounds causes current to flow in a so-called ground loop as shown by Figure 15.

These ground loops can adversely affect computer data networks. If one computer is connected to a power line in one building, and joined by a data network to a second computer in a different building, it is very likely that the ground systems of the two buildings are not at the same equipotential point. Consequently, utility current will flow in the data line at a level that is inversely proportional to the resistance of the conductors that join the two computers.

For example, if the two computers are connected via coaxial cable with a shield resistance of .05 Ohms, and the potential difference between the two ground systems is 2 Volts, a current of 2/.05 Amps, meaning 40 Amps, will flow on the shield of the coax. Such a high current flow can easily cause false signals or erroneous data pulses.

Computers rely totally on specific voltage levels to indicate the presence or absence of a data pulse. When ground loop currents occur, the noise they produce causes false logic commands within the computer's logic circuits. This type of anomaly CAN NOT be remedied by the use of surge suppressors. The problem can only be corrected with a solution that reconciles the voltage differences between two ground systems.

Unfortunately, most facilities really don't have very good ground systems. First, they often start out with an underperforming ground grid. Second, the grounding system may be sized to cope only with low-frequency (meaning 60Hz) power grounds rather than the high-frequency currents present within lightning strikes. Third, the grounding system has not been adequately maintained, or it may have degraded or been damaged over the years as a result of changes made to accommodate other building modifications.

There are several fundamental principles that must be taken into account when planning a grounding system.

SOIL CONDUCTIVITY — is perhaps the most important parameter. Soil conductivity is measured in Ohm-meters, and the lower it is, the better the ability of the soil to conduct away unwanted lightning surges and leakage currents.

PHYSICAL GEOMETRY OF THE GROUND GRID — meaning length and width, will determine the overall impedance of the entire grid. The lower the impedance, the better the grid will be for conducting away heavy currents. An overall grid impedance of 5 Ohms or less is desirable for most computer systems.

Other design considerations include inductance of the cable going to the ground system, inductance of the interconnection cabling, and skin effect, which is the tendency of high-frequency currents to flow along the outer surface of a conductor.

Good design practice in designing ground systems seeks to minimize skin effect and inductance, as these parameters are closely related. There are many reference texts that provide very thorough information on all aspects of grounding systems and their design. The topic has been briefly noted in this manual because it's an important consideration in applying a variety of surge-protection strategies.
Harmonics

Harmonics are voltages or currents with frequencies that are integer multiples of the fundamental power frequency. In the case of the AC powerline environment, the fundamental frequency is 60 Hz. The second harmonic would be 120 Hz; the third harmonic 180 Hz, and so on. Harmonics occur on the AC powerline whenever the sine wave shape is distorted. Figure 16 shows the pure AC sine wave, the line voltage with harmonics, and the line current with harmonics as they would appear on an oscilloscope. Harmonics are caused by non-linear loads within an AC power distribution system. Linear loads, such as a resistive heating element, do not cause harmonic distortion and the AC current that flows will be a relatively pure sine wave. However, if the load is non-linear, drawing short bursts of current each cycle, the current wave shape will be non-sinusoidal and harmonic currents will flow. The total resultant current will be a combination of the fundamental frequency plus each of the harmonics.

Switching Power Supplies Generate Harmonics

Power supplies that use semiconductors to switch the line current on and off abruptly during each AC cycle generate harmonic currents. Switching Power Supplies, sometimes called Electronic or Solid State Power Supplies, are used in a wide variety of modern electronic equipment found in every health care, commercial and industrial facility. Solid state ballasts are also used in fluorescent lighting systems. Of particular concern is the fact that all personal computers, printers and microprocessor-based equipment use switching type power supplies.

Problems Caused By Harmonics

Line voltage harmonics can radiate interference into telephone and communication systems. They can cause overloading and malfunctions in circuit breakers, conductors, bus bars, panels, transformers and generators that are designed to primarily handle 60 Hz loads. Standby generators may overheat and/or experience internal control circuit malfunction due to harmonics produced by the very microprocessor loads they’re connected to. Certain motor drives are particularly vulnerable to higher frequency harmonics and must operate in an environment where the Total Harmonic Distortion is less than 5%.

Switching supplies use diode-capacitor circuits to convert AC line voltage to lower voltage DC. These large capacitors charge up with narrow pulses of current that are timed with the peak line voltage. This process generates odd harmonics which are mostly the 3rd and 5th, and to a lesser degree the 7th, 9th, etc. Note that the 3rd and 9th harmonics will algebraically add in the neutral conductor of a 3-phase distribution system, causing conductor overloading and transformer heating.

Reducing Line Voltage Harmonics

Ironically, the ever-increasing quantity of microprocessor-based equipment used in any given facility may generate enough harmonics to create a significant power quality problem. Line Filters are valuable devices for reducing harmonics, and will be discussed in more detail in the next chapter. Another consideration for facility electrical engineers is lowering the power source impedance in the electrical distribution system. Larger transformers, larger and shorter conductors, and better connectors will reduce harmonics. Designing for a good power quality Infrastructure requires that wherever possible, harmonic-generating loads do not share branch circuit wiring with important motor loads. The IEEE Standard 519, “IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems”, is a valuable resource for information on Harmonics.
Chapter 2: Transient Voltage Surges

INTRODUCTION

Transient voltage surges are short-term over voltages, usually measured in milliseconds. They are sometimes called “spikes”, with little or no distinction made between the two terms. However, some reference material may define a Spike as a transient that is less than twice the line voltage, and a Transient Voltage Surge as a transient that is at least twice the line voltage or greater. Regardless of the terminology, they are unwanted bundles of electrical energy in AC power lines or communications lines. The energy content of transients can be enormous, and this unwanted energy can damage equipment or cause it to malfunction. Equipment driven by microprocessors is especially vulnerable to transient voltage surges.

Figure 17 shows just how much of a problem voltage transients present to the Power Quality Infrastructure. This pie chart is based on a 1974 IBM study. The study was revisited by National Power Lab in 1994 and yielded very similar results. The chart shows that 11% of the disturbances are due to under/over voltages, which we’ve also called swells and sags. Spikes account for 39.5% of the disturbances, while transients account for 49%. With transient voltage surges accounting for almost 90% of power line voltage disturbances, it is easy to see why we’re emphasizing surge protection in this reference guide.

Sources Of Transients

Transients occur whenever line current is interrupted. Therefore, transients can originate inside a facility, or come from the outside utility lines. Sources within a facility include loads that are switched, for example, a motor that’s turned on and off. Utility grid switching can cause transients that originate outside. In addition, differential ground potentials can be a source of transients. (See Chapter 1, “GROUNDING” for more information.)

Another frequent though less obvious source of transients is inductive coupling. Whenever electric current flows, a magnetic field is created. Figure 18 shows the magnetic field around a conductor in which current is flowing.

If this magnetic field extends to a second wire, it will induce a voltage in that wire. This is the basic principle by which transformers work, where a magnetic field in the primary induces a voltage in the secondary.

In this same way, wires that run adjacent to one another within a building can magnetically couple transients, as shown in Figure 19.
**Lightning**

But there’s a more dramatic case of magnetic coupling, and it’s **lightning**. As Figure 20 shows, a lightning bolt striking the ground has an enormously powerful magnetic field. This field will produce a spectacular transient voltage surge in nearby power lines by means of magnetic coupling. The lightning bolt doesn’t have to actually strike the utility lines. All that’s required is for the electrical lines to be within the magnetic field.

Lightning’s effect on Power Quality is a much bigger problem in some areas of the country than in others. Figure 21 is an Isokeraunic Map that shows the frequency of lightning storms throughout the United States.

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**Where Transients Occur In The Power Quality Infrastructure**

Figure 22 shows a 1993 study from Florida Power that breaks down the source of power quality problems in the business place. Lightning accounts for 15% of the problems. Utility sub-stations may introduce transients due to grid switching. The important observation here is that 60% of transients are generated by your own office equipment, and 20% of the transients come from equipment in the office next door or equipment common to whole building such as HVAC systems. The Florida Power study is just one of several such studies that show that the main source of power quality problems is inside the building.

Transient can be present on any metallic conductor including utility power lines, telephone, data, and signal lines. Examples of data lines are:

- Local Area Networks, or LAN’s, using formats such as RS-232, RS 422, Ethernet and Token Ring
- Cable and closed-circuit TV
- Fire and surveillance alarm systems
- CNC/machine-tool interfaces, especially non-shielded lines
THE TRANSIENT ENVIRONMENT

The Transient in the AC Environment

Transients may be thought of as “bundles of energy” riding on the AC power sine wave; a potential seeking a pathway to ground. Because they are of short duration with discernible end points, they are usually described in terms of their energy content (Joules) rather than power (energy per unit time, Joules/sec or watts).

Transient overvoltages, which may be positive or negative in potential and be positioned at any phase angle on the wave, originate from a variety of sources, though it is estimated that only 20 percent of all transient activity is generated outside a facility.

Oscillatory or Ringwave Transient

CHARACTERISTICS: Fast rise time with oscillating exponential decay.

SOURCES: Inductive loads such as elevators, copiers, welders, air conditioning equipment, fuse clearing, motors and tools of all types.

The Ringwave transient is generally the result of internal electrical activity. Its amplitude and energy content are determined by its source and environment. The Ringwave may also be the residual product of an externally generated impulse and its resultant interaction with the electrical distribution system.

Impulse or Unidirectional Transient

CHARACTERISTICS: Fast rise time, slower decay, high energy content.

SOURCES: Lightning, utility grid switching, industrial accidents.

Sometimes called a spike, the Impulse transient if often defined by both a voltage and a current waveform. This takes into account the open circuit pre-arc condition (the voltage waveform) and the short circuit or a condition (the current waveform) of impulse behavior. For this reason, the impulse “waveform set” is often called the “Biwave” impulse. The waveform is less common than the Ringwave and is thought to be indicative of externally generated transients.
When Can Transients Strike?

Since transients originate with interruptions in current flow, and also by magnetic coupling, they can occur any time of the day or night. In some cases, it may be necessary to identify the source of transients within a facility. To do this, some sort of power line monitor is generally used. A number of models are available to record the amplitude, duration and frequency of transient activity on the line being checked. If the choice is made to use a power line monitor, sufficient time must be allowed to build an accurate picture of electrical disturbances. Generally, a period of 3 to 6 weeks is needed to establish a useful base of data.

Measuring Transients

As a result of their brief duration, transient pulses can be very high in frequency. That means a typical volt meter won’t measure them properly because of its limited upper-frequency response capability. What’s needed is an oscilloscope or power line monitor with a very fast sampling rate and high upper-frequency response, meaning a minimum of 100-150 MHz bandwidth.

Effects Of Transients

Microprocessor-driven devices can be found in practically every commercial, industrial and residential setting. A brief list of electronic equipment includes computers and their peripherals, computer data networks such as LAN’s, medical diagnostic equipment, CNC production machinery, telecommunications equipment, stereos, televisions, microwave ovens, bar-code scanners, electronic cash registers, copy machines, FAXes, security and alarm sensor equipment, and thousands of others.

All this equipment is especially sensitive to transient voltage surges because of certain characteristics common to integrated circuits and IC chips.

SPACING WITHIN THE INTEGRATED CIRCUIT — Most of the spacing between components of an integrated circuit is substantially less than the thickness of a human hair. The methods for producing power and signal circuit paths (called tracks) in an integrated circuit also produce microscopic self-supporting structures. These structures can become overheated and then sag when hit with surges. Once this happens, tracks which should be isolated can touch, thereby causing internal shorts that render the IC useless.

APPLIED OPERATING VOLTAGE LIMIT — In striving to extend operating time, computer manufacturers are designing machines with lower operating voltages to allow the use of lower-voltage batteries as shown in Figure 23B. Many older computers use approximately 5 Volt DC logic levels. Current designs use 3.3 Volt DC, and future units will use even lower voltages. The result is that any spike above 3.3 Volts that makes its way into the logic IC’s can cause disruption or permanent damage.

INCREASES IN COMPUTER OPERATING SPEED — The internal heart of a computer is called the clock. Faster computers have faster clock speeds so, for example, a 33MHz machine is faster than a 16 MHz unit. At these speeds, electrical noise becomes a threat. When noise enters a computer, it can mimic clock frequencies, and can be mistaken for a valid logic command. When the computer acts on this false logic command, the keyboard can lock up, or some other undesired action occurs. Also noise can cause the computer to miss valid operating commands or clock pulses. If that happens, the computer creates erroneous output, or no output at all.
Harmful Effects: The “3 D’s”

The most common failures produced by transient within electronic devices are disruptive, dissipative, and destructive.

DISRUPTIVE EFFECTS — are usually encountered when a transient enters the equipment by inductive coupling. The energy source for this inductive coupling can act on the data output lines that integrate an electronic installation. The electronic components then try to process the transient as a valid logic command. The result is system lock-up, malfunctions, erroneous output, lost or corrupted files, and a variety of other undesirable effects.

DISSIPATIVE EFFECTS — are associated with repeated stresses to IC components. The materials used to fabricate IC’s can withstand a certain number of repeated energy level surges, but not for long. Long-term degradation begins, and sooner or later, the device fails to operate properly for no apparent reason. Actually, the failure is due to the cumulative build-up of transient-created stresses which have resulted in arc-overs, shorts, open circuits, or semiconductor junction failures within the IC.

DESTRUCTIVE EFFECTS — include all conditions where transients with high levels of energy cause equipment to fail instantaneously. Very often, there is actual physical damage apparent, like burnt PC boards, melting of electronic components, or other obvious faults. Destructive effects can occur when noise pulses are too fast for power-supply regulator circuits to respond by limiting transient energy to acceptable levels. Also, transients on the power line may subject electronic components with overwhelming energy levels. For example, components like rectifier diodes can fail immediately when their Peak Inverse Voltage rating (PIV) is exceeded. PIV diode ratings in a well-designed computer can be in the 1 kV - 1.5 kV range. Transients on AC lines can easily exceed 1,500 Volts, and often by a wide margin.

Basic Operation of Surge Protective Devices ( SPD's )

As described at the beginning of this chapter, a transient voltage surge is a short-term deviation from a desired voltage or signal. Obviously, the higher the transient amplitude, the greater the likelihood of disrupting or damaging electronic equipment. And transients are generated whenever a current is interrupted. For instance, devices like variable-speed drives are constantly switching circuits over very short periods of time. They can produce spikes 1 to 7 times per cycle, or even more often, depending on the drive. That represents over 420 transients per second, at 60 Hz.

Furthermore, transients can occur on any metallic conductor, so they affect not only devices connected to utility power lines, but also telephones, FAX machines, computer data lines, closed circuit and cable feeds, and others.

A Surge Protective Device, or SPD, attenuates the magnitude of these surges to protect equipment against their damaging effects. But a SPD doesn’t necessarily reduce the surge to zero amplitude. It just attenuates it to a level that can safely be passed through to the load. In addition, it's often advisable to apply a network of SPD's to provide a layered defense against transients. Another benefit of Surge Protective Devices is that they can reduce noise energy as well as transient voltage surges. Since the majority of transient voltage surges are generated inside a building, understanding and applying SPD’s is a prime consideration for improving the Power Quality in any facility.
Remember: SPD’s Do Not Solve Every Power Quality Problem

Surge Protective Devices can’t cure sags and swells in the AC power provided by electrical utilities. They also cannot reduce the harmonic conditions produced by non-linear loads like motors and switching-mode power supplies within computers and some fluorescent lighting systems. Harmonics reduction requires devices with very large, specially manufactured capacitors.

Despite some claims that occasionally appear in print, SPD’s cannot provide utility bill savings. There has never been any responsible third party testing that shows SPD’s can cut energy consumption in any way. SPD’s also can’t remedy power outages. If there’s a loss of utility line voltage, a device that can temporarily replace utility power is the Uninterruptible Power Supply, or UPS. Conversely, most UPS systems do not effectively eliminate surges. Although some may have internal components which are protected against spikes, the UPS itself cannot protect any of its loads against spikes and, of course, it can’t have any effect on parts of a facility’s AC lines not connected to the UPS output.

What Are Surge Protective Devices?

These are devices that can attenuate, meaning reduce, transient voltage levels and noise. They’re also called Transient Voltage Surge Suppressors, abbreviated as TVSS. The trend in industry is to call them Surge Protective Devices, or SPD’s. But basically, the terms TVSS and SPD are interchangeable since both refer to the same thing.

Surge protective devices are designed to REDUCE potentially damaging short-duration transients present on utility power lines, data networks, telephone lines, closed circuit and cable TV feeds, and any other power or control lines connected to electronic equipment.

One common misconception is that electronic equipment must have ALL transient voltage surges reduced to zero amplitude on the power or data lines. This is not the case. With computer systems for example, reducing transients to levels of approximately 150% to 300% of line voltage (meaning 400 to 500 V peak) will prevent equipment damage. A feature of higher-quality SPD’s is the ability to eliminate continuous high-frequency noise in addition to attenuating short-lived transients.

How Surge Protective Devices Work

In the simplest terms, SPD’s prevent damaging transient voltage surge levels from reaching the devices they protect. Figure 24 is a graphic representation of how an SPD provides a shunt path for transients before they can enter a computer.

A useful analogy makes this clearer. Consider a water mill protected by a pressure relief valve. The pressure relief valve does nothing until an over-pressure pulse occurs in the water supply. When that happens, the valve opens and shunts the extra pressure aside, so that it won’t reach the water wheel. The general arrangement of this system is shown in Figure 25.

If the relief valve was not present, excessive pressure could damage the water wheel, or perhaps the linkage for the saw. Even though the relief valve is in place and working properly, some remnant of the pressure pulse will still reach the wheel. But pressure will have been reduced enough not to damage the water wheel or disrupt its operation.

This describes the action of surge protective devices. They reduce transients to levels that will not damage or disrupt the operation of sensitive electronic equipment.
Clamping

“Clamping” is the term used for the process whereby SPD’s reduce or attenuate transients and limit the surges reaching the protected load to a specific lower voltage level.

Figure 26 shows graphically how this happens. An incoming transient voltage surge is shown both before passing through the SPD (on the left), and after (on the right). After passing through the SPD, the transient has been attenuated to a lower amplitude. Notice that it has not been attenuated to zero amplitude. There is still a reduced level of transient voltage remaining, and this is called the RESIDUAL, or “let-through” voltage.

In fact, reducing transients excessively below needed levels can do more harm than good. Excessive transient attenuation causes unnecessary strain on the SPD itself. Furthermore, higher externally-generated transient currents are drawn into the facility, where they may couple onto adjacent wires and cause interference in unprotected branch circuits.

Clamping is one of the very important measures by which an SPD is judged. However, the clamping level is not the sole parameter used to evaluate an SPD’s performance. Other factors such as surge current capability, fusing, and filtering may be equally important. These characteristics will be explained in greater detail later in this reference guide.

Metal Oxide Varistors (MOV’s) and Other SPD Components

One type of SPD component is used in so many transient voltage surge suppressors that it deserves particular attention. This component is called a Metal Oxide Varistor, (Variable Resistor) and is almost always referred to as an MOV. An MOV is actually a non-linear resistor with certain semi-conductor properties. The semi-conductor characteristic making an MOV ideal for use in surge suppressors is that it remains in the “OFF,” or non-conducting state until a surge appears on the line to which it’s connected.

A typical MOV response curve is shown in Figure 27. It’s clear that the response curve is not linear (the response characteristics are not graphed in a straight line). As the transient amperage increases (moving from left to right), the clamping voltage also increases (moving bottom to top). The significance is that as the transient CURRENT increases, so does the clamping level. Therefore, constant rates of increasing current produce disproportionately higher clamping voltage levels.

Another important consideration is the Maximum Continuous Operating Voltage (abbreviated as MCOV) of surge suppressors equipped with MOV’s. This is the maximum utility line voltage (or V rms) that may be applied to the suppressor without damaging the MOV.
## The Essential Advantages and Disadvantages of the MOV and Other Commonly Used SPD Components.

<table>
<thead>
<tr>
<th>Component</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Oxide Varistor (MOV)</td>
<td>Readily available, higher energy capability, excellent reliability and consistent performance.</td>
<td>Non-linear clamping curve, rapid fatigue at higher amperage levels, leaky.</td>
</tr>
<tr>
<td>硅二极管/雪崩二极管 (SAD)</td>
<td>Readily available, flatter clamping curve, excellent Avalanche reliability and consistent performance.</td>
<td>Very low energy capability, some capacitive problems, expensive.</td>
</tr>
<tr>
<td>Gas Tubes</td>
<td>Higher energy capability than either diodes or MOV's, non-capacitive or leaky in data line applications.</td>
<td>Unpredictable and unstable repetitive behavior, tendency to “crow-bar” to ground, higher cost than MOV's.</td>
</tr>
<tr>
<td>LCR Filters</td>
<td>Excellent noise attenuation, clamping harmonic elimination and predictable performance at given frequency.</td>
<td>Expensive, frequency dependent, low energy capability, leaky and low amperage capable. (The LCR filter is not a suppressor in and of itself.)</td>
</tr>
<tr>
<td>TVSS Hybrid</td>
<td>If properly designed, the Hybrid incorporates all of the major advantages of many of the available components while collectively overcoming their individual faults.</td>
<td>The hybrid is inherently more expensive than the single component TVSS.</td>
</tr>
</tbody>
</table>

In addition, some less commonly used SPD components include: Selenium, Spark Gaps, Zener Diodes, and “Crowbars” (Zener/SCR combination). These components provide fast response times to transient voltage surges, but vary in cost, clamping performance and energy-handling capability.
Filters
Filters are important for reducing high frequency noise and harmonics on the AC power line. An LCR filter is an inductive, capacitive and resistive circuit designed to respond to a specific range of frequencies. A filter may be low-pass, high-pass, band pass or band eliminate (notch). The LCR filters used in high-quality SPD’s are the low-pass type. They will have no effect on the 60 Hz line voltage, but present a very high impedance to high frequencies that can potentially disrupt microprocessor circuits. Filters have limited energy capabilities and are not intended to suppress transients on their own. They also play an extremely important role in communication line noise suppression, operating with a fixed load and source impedance of 50 - 300 ohms.

How Noise is Measured
Noise can be measured in terms of either power or voltage. On data systems, voltage amplitudes are usually preferred. An oscilloscope is used to provide measurements in Voltspeak. Noise reduction/attenuation parameters are often given in decibels (dB). The formula for noise attenuation is:

$$dB_{(db)} = 10 \log \left( \frac{\text{Power}_{\text{out}}}{\text{Power}_{\text{in}}} \right)$$

$$dB_{(db)} = 20 \log \left( \frac{\text{Voltage}_{\text{out}}}{\text{Voltage}_{\text{in}}} \right)$$

This test procedure is performed with a 50Ω load and is referred to as the MIL-STD 220A insertion loss test.

Characteristics of Surge Protective Devices
The two most frequently used types of SPD are divided into two very general categories based on the type of surge suppression circuitry they feature. One type uses MOV’s as the suppression component for high-energy transients. The other type also uses MOV’s, but has additional components to make the SPD more effective in suppressing high-frequency transients.

Figure 28 shows how a single MOV SPD operates. The top portion shows a potentially damaging transient being transmitted along the AC line conductor directly to the load. The single MOV device solves the problem by shunting the transient current between the line and neutral conductors, preventing the bulk of the energy from reaching the load. Only the residual transient energy travels on to the load.
MOV Clamping

SPD’s using only MOV’s are referred to as an “envelope clamping” devices. That’s because, as Figure 29 shows, they clamp transient surges by limiting their amplitude within a broad band above and below the 60 Hz AC sine wave.

Hybrid SPD’s

Figure 30 shows an SPD with relatively simple combination of suppression components in addition to MOV’s. This is an example of a hybrid suppression circuit. A properly designed hybrid circuit will vastly outperform any single-component SPD.

Hybrid SPD Clamping

Hybrid suppression circuits are often referred to as “sine-wave tracking” devices. As shown in figure 31, their clamping profile follows the contour of the 60 Hz AC sine wave, and tightly attenuates both positive and negative-going spikes.
Types of Surge Protective Devices

There are many types of surge protective devices available. Two broad classifications include those devices used to attenuate transients on low-voltage conductors, meaning data lines, phone lines, coax feeds, and others. Then there are SPD’s intended to suppress transients on AC utility power lines.

The application settings for SPD’s fall into three general categories: First, SPD’s that are wired into the AC or low-voltage lines at some distance from the equipment they protect. An example would be branch-panel mounted suppressors. Second, SPD’s that provide point-of-use protection at the same location as the equipment. Examples include plug-strips, though some point-of-use SPD’s are wired in rather than plugged in. Third, is integral SPD’s that are built-in component of the equipment they protect.

Among SPD’s for AC line applications, there are some units designed to be wired in parallel, and others designed to be wired in series. Figure 32 shows a parallel-wired SPD.

The advantage of parallel-wired suppressors is that they don’t have to handle any of the load current. Theoretically, these units can be placed on any size main current power bus. Of course, mechanical features of these SPD’s must conform to requirements of the National Electrical Code (NEC) and, sometimes, NEMA requirements to meet the demands of various installation specifications.

Series-operated suppressors work in a different way. These devices have one or more series inductors that rely on a principle called Lenz’s law which states that a current cannot instantaneously change through an inductor. Figure 33 shows a typical series-connected SPD.

Series devices have inductors in line with power leads that ultimately supply downstream loads. In addition to the inductors, other elements such as capacitors and high surge-current protection components are employed to reduce incoming transients to very low levels.

A disadvantage of series SPD’s is that they must be able to handle not only high surge currents, but the load current as well. Therefore, the inductors tend to be quite large when designed for high-current levels, particularly for three-phase devices rated over 100 Amps, with at least one coil per phase.
Chapter 3: SPD Performance Standards

The purpose of performance standards for SPD's is two-fold. First, SPD's can be described by literally dozens of technical parameters, and it is usually not simple to make an apples-to-apples comparison. Second, there is a basic need to define certain upper limits for expected transient voltage and current levels in a number of well-defined facility locations.

There are two important sets of standards that are applied to surge protective devices. One is the Underwriters Laboratories UL 1449 collection of standards, and the other is the Institute of Electrical and Electronics Engineers EEE C62.41 standards.

Using the measures of performance provided in UL 1449 and IEEE C62.41 standards, it is possible to make a meaningful comparison of surge protective devices, and objectively judge which devices are most effective in attenuating transient voltage surges of the sort most likely to occur in their intended application environments. The remainder of this chapter will deal with the specifics of the UL and IEEE standards.

Technical Note On Determining Transient Voltage Levels

Before we examine standard measurements of transient voltage waveforms, it's useful to take a quick look at an important formula.

High-energy transients occur whenever a current is interrupted. The higher the current, the greater the amplitude of the transient. The following formula can be used to determine the transient voltage level (represented by V in the equation):

\[ V = -L \frac{di}{dt} \]

L is the circuit's total inductance. di represents the rate of change in the current. dt is the interval of time over which the current changed.

Note that since dt is the denominator in this fraction, the faster the transient (meaning the smaller the number represented by dt), the larger the transient amplitude (represented by V) becomes.

The IEEE C62.41 Standards That Define Transient Voltage Surges

Prior to 1970, very little information regarding the transient environment was available. By the end of the decade, professional committees of IEEE and others had compiled sufficient data to publish a bench-mark waveform guide thought to describe both transient waveforms and their probable locales of occurrence. The guide became known initially as IEEE 587. Later on, after adoption by ANSI, it became IEEE C62.41.
Two Types of Surges

Two basic types of transient voltage surges are defined by the IEEE C62.41 Standards: First, a “combination-wave” transient, and second, a “ring-wave” transient. For purposes of comparison, a combination wave is associated with lightning-induced transients on utility power lines. It has a significantly higher current than ring waves.

A ring wave is an oscillatory surge with relatively high voltage levels at relatively high frequency, but with limited energy content. Ring waves are associated with fuses opening, power factor/capacitor switching action, or load switching of motors, pumps, compressors, and other electrical loads.

Combination Wave

The combination-wave transients that could be expected from lightning were characterized, and these are displayed in Figure 34. One waveform shown comprises the test CURRENT, and is defined by an 8 microsecond (written 8µs) rise time, with a 20µs trail-off. At that point, the wave has diminished to 50% of its peak value.

By way of explanation, the rise time of any wave is the time needed for it to transition from 10% of its maximum amplitude to 90%.

The accompanying VOLTAGE waveform for lightning has a 1.2µs rise time with a 50µs trail-off.

The test parameter just described is called a combination wave because the test source must provide both the current and voltage waveforms simultaneously.

The second waveform, called a ring wave, is important to testing SPD’s higher-frequency response to transients created within a facility by interrupted load currents.

Ring Wave

As shown in Figure 35, the ring wave is characterized as having a fast rise time of only 0.5µs along with a 10µs period, which yields a natural frequency of 100 kHz.
The IEEE C62.41 Standards That Define SPD Operating Environment Categories

In order to properly test SPD’s, it was also necessary to define the operating environment WITHIN a facility. The IEEE C62.41 Standard defines three operating location environments called Category A, Category B, and Category C, as shown in Figure 36.

**Category C** environments are located on the LINE side of the service disconnect.
- Outside and service entrance
- Service drop from pole to building
- Run between meter and panel
- Overhead line to detached building
- Underground line to well pump

**Category B** environments are immediately adjacent on the LOAD side of the service disconnect breaker. Category B environments are characterized as having short branch circuits and feeder lines.
- Distribution panel devices
- Bus and feeder industrial plants
- Heavy appliance outlets with “short” connections to service entrance
- Lighting systems in large buildings

**Category A** environments have long branch circuits and outlets more than 30 feet from a Category B environment, or more than 60 feet from Category C locations.
IEEE Test Standards

With combination waves and ring waves clearly defined, the IEEE has specified test standards using both wave forms as they could occur in Category A, B, and C locations. There are standards for three levels of exposure within the categories. So, for example, in Category C, the C1 test standard represents the least severe combination wave exposure. C2 represents a moderate exposure, and C3 is the most severe. The test values for exposures in each category are shown in the following table:

Notice that Category C environments are subjected only to combination wave transients, while Category B environments are tested using both ring waves and combination waves. Category A environments are tested with ring waves only.

The reason for limiting the test transients to 6 kV (meaning 6,000 Volts) in Category B environments is because of certain characteristics of typical wiring devices used in commercial, industrial and residential Category B application settings. Specifically, the IEEE determined that terminal screw spacing between line, neutral and ground of receptacles and metering pans would cause arcing when voltages in excess of 6 kV were placed on the lines connected to device terminals.

Furthermore, the combination waves associated with lightning-induced transients were limited to 3 kA in Category B. The IEEE concluded that inductance of wiring within a facility would limit the amplitude of conducted lightning currents to no more than 3,000 Amps. Some experts hold a different opinion and believe that currents in Category B locations may actually be capable of reaching 35,000 Amps. Yet even this figure is far short of the unreasonable claim made by some protective device manufacturers who suggest facilities must be capable of absorbing lightning currents from 250 kA to 1 million Amps.

Such claims are dubious because research shows that the statistical probability of any lightning-induced transient is less than 5%. But more important, the largest lightning-current test facilities are equipped with generators that can produce only up to 180 kA reliably with an accurate 8µs x 20µs wave form per phase. Maximum surge current ratings in excess of these values for any surge protective device are meaningless, because there is no way to carry out tests that can confirm performance.

**Note on “Passing or Exceeding” IEEE Standard C62**

Be wary of manufacturers that claim their SPD’s “PASS or EXCEED IEEE Standard C62,” because such claims are meaningless. The C62 Standards cannot be passed or failed, or exceeded. They simply serve as a yardstick for use when testing and documenting the performance of Surge Protective Devices.

<table>
<thead>
<tr>
<th>Location Category</th>
<th>System Exposure</th>
<th>Peak Values</th>
<th>Effective Impedance (Ω)</th>
<th>Location Category</th>
<th>System Exposure</th>
<th>Peak Values</th>
<th>Effective Impedance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage (kV)</td>
<td>Current (kA)</td>
<td></td>
<td></td>
<td>Voltage (kV)</td>
<td>Current (kA)</td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>Low</td>
<td>2</td>
<td>0.07</td>
<td>30</td>
<td>B1</td>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>4</td>
<td>0.13</td>
<td>30</td>
<td>B2</td>
<td>Medium</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>6</td>
<td>0.2</td>
<td>30</td>
<td>B3</td>
<td>High</td>
<td>6</td>
</tr>
<tr>
<td>B1</td>
<td>Low</td>
<td>2</td>
<td>0.07</td>
<td>12</td>
<td>C1</td>
<td>Low</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>4</td>
<td>0.33</td>
<td>12</td>
<td>C2</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>6</td>
<td>0.5</td>
<td>12</td>
<td>C3</td>
<td>High</td>
<td>20</td>
</tr>
</tbody>
</table>

Chart 1  Chart 2

Courtesy of Steven Engineering, Inc. • 230 Ryan Way, South San Francisco, CA 94080-6370 • Main Office: (650) 588-9200 • Outside Local Area: (800) 258-9200 • www.stevenengineering.com
IEEE C62.45 Performance Testing

The ANSI/IEEE C62.45, “Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power”, established a world-wide accepted performance evaluation for Surge Protective Devices. The tests are performed using off-the-shelf hardware and conducted in strict accordance with ANSI/IEEE C62.45 test procedures. The test results should be repeatable in any adequately equipped laboratory in the world.

“Let-through”, residual or clamping voltage of various suppression products is easily measured by using IEEE waveforms to approximate actual on-line transients at A, substituting SPD samples at B, and measuring the residual clamp with a digital storage oscilloscope at C.

Every SPD sample will demonstrate a unique “signature” with each specified waveform input. These signatures can be compared by waveform. Obviously, the lower and cleaner (implying smooth and without significant harmonic content) the signature, the better the performance.

![Diagram](image-url)

**FIGURE 37**

Velonex 587 Surge Generator

**TEST WAVEFORMS**
- Cat A Ring Wave 6KV, 200 A, 100 KHz
- Cat B Impulse 6KV 1.2 x 50 us
- 3KV 8 x 20 us

IEEE Waveforms

NEMA 15-5 plug-in connection to generator

Suppressor Device Under Test

Residual travels on to the load

Single SPD Component

Transient current is shunted L-N by TVSS component

PROTECTED ELECTRICAL SYSTEM

TYPICAL TEST SETUP

Tektronix Digital Storage Oscilloscope

Scope settings constant as shown during test. Readout on screen

**ELECTRICAL ENVIRONMENT**

**PROTECTION**

**MICROPROCESSOR ENVIRONMENT**

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The New UL 1449

An overview of the second edition requirements for transient voltage surge suppression and the impact of the revisions to the standard.

Introduction:
Underwriters Laboratories satisfied a much called for need to the industry at large when the first edition of UL 1449, the Standard for Safety for Transient Voltage Surge Suppresors was published August 25, 1985. The standard adopted select test waveforms from the IEEE C62.41. However, soon after the introduction of the standard it became evident that certain issues needed to be addressed, most notably with regard to the "fail-safe" operation of surge suppression components contained in these devices under abnormal service conditions or "end-of-life" degradation modes specific to metal-oxide varistors.

After a number of years the proposed second edition of UL1449 was published August 25, 1996. The effective date assigned to these new and revised requirements is February 16, 1998. It should be noted however that Hardwired products (panels and receptacles) have been extended to August 17, 1998.

It is the responsibility of manufacturers and specifiers to make available the safest product to the end-user and consumer. The following outlines a comparison of the "old" versus "new" UL1449 and the impact of these Second Edition requirements.

The Scope of UL1449:
A good place to start a review of UL1449 is the scope of the standard. This is where issues can be clearly defined as to what does and does not apply to the Listing of a product bearing the UL – TVSS mark. It should be noted that unlike most other standards bodies including ANSI, IEEE, NEMA and IEC; UL has elected not to use the term Surge Protective Device (SPD). It is generally accepted that the terms TVSS and SPD are one in the same.

The Scope of UL1449 contains the following:
1. The requirements cover transient voltage surge suppressors intended for permanently connected, cord-connected and direct plug-in applications on 50 or 60 Hz power circuits not exceeding 600v ac.
2. These requirements are intended for installation on the load side of the main overcurrent protection.
3. These requirements do not cover the interconnection of multiple field installed TVSS.
4. These requirements cover TVSS employing circuit components specifically intended to function as filters for conducted electromagnetic interference (EMI) or noise, in addition to limiting transient voltage surges.
5. These requirements do not cover Secondary Surge Arresters intended for use on the line side of the main overcurrent protection.
Test Requirements:
UL1449 has basic safety tests no different from most UL standards for safety. These tests include leakage current, dielectric withstand, insulation resistance, temperature rise and mechanical integrity tests such as impact, drop, crush and mold stress relief distortion for plastics among others. For the sake of this discussion only tests specific to surge protectors will be covered here.

Measured Limiting Voltage Test:
Suppressed Voltage Ratings (SVR) are assigned based on subjecting products to the following waveforms. These waveforms are combination impulses described in IEEE C62.41. The rise and decay waveforms are; 1.2 by 50 us for open-circuit voltage and 8 by 20 us for short-circuit current. Ratings are measured from zero ground to the peak of the “clamped” transient level.

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Voltage</th>
<th>Current Impulse</th>
<th>Voltage</th>
<th>Current Impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panels &amp; Receptacles</td>
<td>6 kV</td>
<td>500 A</td>
<td>6 kV</td>
<td>500 A</td>
</tr>
<tr>
<td>Strips &amp; Plug-ins</td>
<td>6 kV</td>
<td>3000 A</td>
<td>6 kV</td>
<td>500 A</td>
</tr>
</tbody>
</table>

It is also important to note that Hardwired products are measured at the end of Six inches of lead length recommended in the manufactures installation instructions. The “old” UL1449 would measure directly at the terminals of hardwired equipment; devices with integral leads were always measured at six inch lead length.

Duty Cycle:
SVR is assigned based on the before and after levels described in the table below. It should be noted that three samples are tested and the before and after duty cycle measurements shall not deviate by more than ten percent. The rating is then assigned based on the average of the total of six before and after measurements.

<table>
<thead>
<tr>
<th>Product Type</th>
<th>The “Old UL1449”</th>
<th>The “New UL1449”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panels &amp; Receptacles</td>
<td>24 Shots</td>
<td>20 Shots</td>
</tr>
<tr>
<td>Strips &amp; Plug-ins</td>
<td>6 kV 750 A</td>
<td>6 kV 3000 A</td>
</tr>
</tbody>
</table>

Maximum Surge Current Test:
This is a new test added to UL1449 with the intent for a device to withstand a relatively high surge current and not be degraded to the point of causing a risk of fire or shock hazard. Panels and receptacles are subject to two shots of a 10 kA / 6kV impulse.

Strips and plug-ins are subjected to a 3 kA / 6 kV impulse.

Abnormal Overvoltage Tests:
These are the most notable of new tests introduced in the standard. There are three:

1. Temporary Over Voltage: The device is connected to 125 percent of the normal system voltage for seven hours and must not result in risk of fire or shock hazard

2. Full-Phase System Overvoltage: This test subjects the device under test to a simulated "Loss of Neutral". For example, a device intended for 120/240v systems will be connected to 240v. Again, after the test the device shall not exhibit evidence of a risk of fire or shock hazard.

3. Limited Current Overvoltage: This test subjects the device under test to increasing levels of "standby current" through each mode where an MOV is connected within the device. The test basically simulates an "end-of-life" degradation, or thermal runaway scenario. Again, at the conclusion of the test there shall be no evidence of a risk of fire or shock hazard. Verify also includes a dielectric withstand (hipot) and leakage current tests.

There may be various approaches in design of a product to pass these tests including several methods of properly fusing MOVs, or just over-rating the maximum continuous operating voltage for the MOVs employed in the device. Obviously the latter design will result in a safe, but high SVR, or clamping level.
Product Markings:
Believe it or not, UL has elected not to require any changes in the "UL – Listed TVSS" marking. In the case of the consumer purchasing a basic surge strip it will be left to honest labeling on packaging to state any claims to compliance to the new, second edition UL1449.

Fortunately for the specification community, compliance to the new UL 1449 can be verified by the actual UL Listing Card. UL has changed the format for the TVSS Listing Card from merely listing catalog numbers of Listed products under the TVSS category to providing a table with suppressed voltage ratings (SVR) for each model by mode.

Suppressed Voltage Ratings are required to be marked on the product by each mode. The measured limiting voltage is rounded up to the following SVR assigned levels:

<table>
<thead>
<tr>
<th>330v pk</th>
<th>600v pk</th>
<th>900v pk</th>
<th>1500v pk</th>
<th>2500v pk</th>
<th>5000v pk</th>
</tr>
</thead>
<tbody>
<tr>
<td>400v pk</td>
<td>700v pk</td>
<td>1000v pk</td>
<td>1800v pk</td>
<td>3000v pk</td>
<td>6000v pk</td>
</tr>
<tr>
<td>500v pk</td>
<td>800v pk</td>
<td>1200v pk</td>
<td>2000v pk</td>
<td>4000v pk</td>
<td></td>
</tr>
</tbody>
</table>

Summary:

**UL1449, the Standard for Safety for Transient Voltage Surge Suppressors—2nd Edition**

- A UL Listed TVSS must be installed on the LOAD side of the main service disconnect. Devices connected LINE side are Secondary Surge Arresters which are Listed by UL under "desk" standard ANSI/IEEE C62.11.
- A UL Listed TVSS may be install OUTDOORS if evaluated to UL50 with appropriate NEMA Type rating assigned to the device.
- A UL Listed Series-operated/connected TVSS must be tested and assigned an Available Fault Current Withstand rating (AIC). Series-operated devices are also known as Two-Port Surge Protectors.
- A UL Listed Parallel-operated/connected TVSS does not require an AIC rating.
- The term SVR denotes Suppressed Voltage Rating. This is the assigned "Clamping" voltage with respect to zero volts (ground) to the peak of the "clamped" voltage.
- Cord-connected and Direct plug-in TVSS are assigned SVR based on 6kV / 500A (Duty Cycle (20 shots)
- Hardwired Panel and Receptacle TVSS are assigned SVR based on 6kV / 500 A at the end of 6 inch leads.

**Hospital Grade Surge Protective Devices**

For Hospital Grade surge protective devices, there is an additional safety test performed to measure leakage current. Figure 38 shows how the test apparatus is arranged.

Devices that are Listed for use in health-care settings are limited to a maximum leakage current level of 300 microamps (written 300 µA) per UL 544, Standard for Safety for Medical and Dental Equipment, third edition. For devices that aren't Listed Hospital Grade and not intended for use in the health care environment, acceptable leakage current levels are somewhat higher at 0.5 milliamps (written 0.5 mA). Devices with leakage currents greater than 0.5 milliamps but less than 3.5 milliamps must carry a WARNING label.
Methodology for Testing Permanently Connected SPD’s

If the device is supplied with wire leads, these are cut back to a six-inch length and connected to the surge generator. Clamping voltage is measured at the end of the leads. If the device is equipped with terminal lugs, the surge generator is still attached with 6 inches of leads from the lugs, and clamping voltage is measured at the ends of the leads.

![FIGURE 39](image-url)
Understanding UL 1449 Ratings

Section 37.1 of the UL 1449 Standard defines the range of clamping levels demonstrated by SPD’s that have been tested by UL. These levels are assigned by taking the ACTUAL clamping level and ROUNDING UP to the nearest UL rating level. The UL rating levels are:

- 330 Volts
- 400 Volts
- 500 Volts
- 600 Volts
- 700 Volts
- 800 Volts
- 900 Volts
- 1000 Volts
- 1200 Volts
- 1500 Volts
- 1800 Volts
- 2000 Volts
- 2500 Volts
- 3000 Volts
- 4000 Volts
- 5000 Volts
- 6000 Volts

Notice that the lowest possible UL assigned clamping level is 330 Volts. Remember that UL rounds UP to the nearest level, so for example, an SPD with an actual clamping level of 290 Volts would still be issued the 330 Volt UL clamping rating. Likewise, a device that actually clamps at, say, 634 Volts would be assigned an 800 Volt UL clamping level.

UL adopted this policy to assure that the clamping levels provided for UL-tested SPD’s would indicate an absolutely reliable minimum level of performance that could be expected by the users of these devices. Furthermore, all UL 1449 Listed surge protective devices MUST be furnished with a label applied directly to the product that plainly shows UL clamping ratings verified by UL testing.

The label plainly indicates “UL Listing – Transient Voltage Surge Suppressor.” It shows the clamping levels of the SPD, and indicates modes of protection. These are the so-called NORMAL MODE, meaning SPD protection is provided from Line to Neutral, and COMMON MODE, meaning there is protection from Line to Ground and Neutral to Ground. The protection modes are important to verify because it is possible for a manufacturer to get UL 1449 Listing on an SPD that doesn’t offer both normal and common-mode protection.

Moreover, real caution on the part of the buyer is needed when choosing plug-in SPD’s. That’s because there are some devices on the market described as surge suppressors by their manufacturers. But they are NOT UL 1449 LISTED AS TRANSIENT VOLTAGE SURGE SUPPRESSORS. Instead, they are often listed under UL 1363 Standard for Safety - Temporary Power Taps. This is actually the set of standards that applies to devices like cube taps or outlet adapters. It DEFINITELY DOES NOT indicate satisfactory clamping performance, and in fact is proof that the device has definitely not been subjected to clamping performance testing by UL. Of course, any product claimed by its manufacturer to be a surge protective device, but without the UL 1449 Listing, should never be used as a surge suppressor, and should be avoided entirely.
IEC 1000-4 Series Standards (Formerly IEC 801)

The International Electrotechnical Commission, known as the IEC, issued the 801 Series Standards for Immunity to Electromagnetic Interference (EMI). IEC 1000-4 addresses EMI that reaches electronic equipment via both conduction and radiation at every point of the equipment. In particular, the IEC addresses the Power Quality problem created by Electrical Fast Transients (EFT) or burst noise. EFT is caused by the showering arcs that accompany heavy power switching, such as in air conditioning compressors, oil burner relays, etc. The IEC 1000-4-4 EFT/Noise test waveform is a repetitive, fast transient wave rather than the single pulse wave selected in earlier ANSI/IEEE Standards. The repetitive wave simulates the phenomena of EFT pulses building up on microchip inputs, eventually causing an incorrect bit or count. The latest ANSI/IEEE C62.41 cites IEC as its EFT requirement.

The Importance of Product Warranties

After reviewing the performance characteristics of SPD’s, the second most important feature of these devices is the manufacturer’s warranty. The warranty should be carefully read, because its fine print often invalidates the very protection features desired by the user.

Generally speaking, the track record and reputation of the device manufacturer is a major consideration. Many manufacturers promise warranty periods that are longer than the time the firm has been in existence.

Some manufacturers claim to offer a “Lifetime Warranty”, but after a short period, the end-user is required to purchase additional insurance to keep the warranty in effect. Also, some SPD’s are sold at grossly inflated prices as a hedge against future warranty claims. Finally, some smaller manufacturers could be bankrupted by warranty claims on major system failures involving their products.

Some manufacturers offer “DOWNSTREAM” warranty provisions. This type of warranty backs not only the SPD itself, but also the electronic equipment being protected by the SPD. Typically, if the electronic equipment is damaged, repairs are made at an authorized shop. After notification of the SPD manufacturer, and a finding that damage was the result of a transient surge event, payment is made to the claimant.

There are many forms of warranty applied to surge protective devices. The one constant is that they must be carefully examined, and viewed in light of the manufacturer’s longevity and reputation.
Chapter 4: Specifying SPD’s

Overview

Because of the volume of data published by the manufacturers of Surge Protective Devices, creating a specification for these devices is vulnerable to omissions or inconsistencies. Recognizing the need for a consistent, reliable specification structure, the National Electrical Manufacturer’s Association, or NEMA, has developed the NEMA LS-1 Specification Format for Surge Protective Devices.

Navigating Through Irrelevant Performance Specifications

It’s also important to understand certain IRRELEVANT characteristics of SPD’s that often muddy the waters, mislead, and confuse the issues when making product comparisons and specifying SPD’s. Perhaps the two characteristics of SPD’s that are most often improperly reported involve Joule energy ratings and response time or turn-on time. Despite the emphasis that these parameters are given by some manufacturers, they can be safely disregarded when evaluating SPD’s, because of the many ambiguous ways these values are reported. Indeed, the NEMA LS-1 format does not include any reference to either Joule energy rating or response time, because NEMA recognizes that these are not critical parameters.

Joule Energy Ratings

To begin with, the “Joule” is a unit of measure applied to the ability to do work, or absorb energy. In the case of SPD’s it relates to the ability for absorbing heat energy. One Joule per second is equal to 1 Watt, a unit of electrical power. Likewise, horsepower is another unit of work. At 100% efficiency, 1 hp is equal to 746 Watts. How is this related to SPD energy absorption?

Well, horsepower is related to British Thermal Units, or BTU’s. One horsepower (746 Watts at 100% efficiency) is equivalent to 2545 BTU’s per hour. A single BTU is the amount of energy needed to raise one pound of water one degree Fahrenheit. This very roundabout path is the basic link of the “Joule” to electrical energy, and the temperature rise within an MOV. To put it in simpler terms, when a transient current passes through an MOV, this component will heat up because of the BTU equivalent energy within that transient current, and because of the resistance value of the MOV itself.

Although this general link exists, it’s often reported in a way that can be misleading. For instance, some manufacturers describe the Joule energy rating of a device as the sum total of the rating for each phase the SPD protects. Obviously, for a three-phase device with neutral-to-ground protection, this figure will be four times higher than any real-world Joule rating available per phase.

Moreover, the Joule ratings are often determined by calculations which depend on waveforms that are very different from the IEEE C62.41 8x20µs standard.

In conclusion, Joule energy ratings of SPD’s are, at best, unimportant and at worst, seriously misleading.
Response Time or “Turn-On” Time

The parameter usually called response time is basically supposed to be the interval of time it takes an SPD to recognize there is a transient present, then react by suppressing the transient. But, at the present time, no standard exists for such a measurement, and it’s also not certain just what such a measurement would mean. That’s because of the basic mathematical relationship first stated in chapter 1 by the formula

\[ \text{Frequency} = \frac{1}{\text{Time}} \]

Many manufacturers state their response times in nanoseconds. (A nanosecond is one thousandth of one millionth of a second.) Using the formula above, a nanosecond represents a transient with a frequency of 1000 megahertz, or 1 GigaHertz. Typical facility wiring just can’t support transmission of these frequencies.

In addition, simply measuring this phenomenon would require an instrument several orders of magnitude more accurate than the thing it measures. As a rule of thumb, 5 to 10 times better, so the frequency bandwidth of an oscilloscope would have to be 5 to 10 GigaHertz. This is not possible with the typical instrumentation available in today’s laboratories.

Worse yet, some manufacturers claim picosecond response times, meaning 1,000,000 MHz, or 1,000 GHz. This is a frequency that’s beyond the radio-frequency spectrum, and it could not be propagated in any solid metallic conductor. Also, the parameter could never be measured because no oscilloscope exists with this performance capability.

Surge Counters

Some SPD manufacturers sell auxiliary devices that claim to “count” the number of surges on the lines being monitored. The surges tallied are supposed to indicate the need for an SPD, or the need to replace an SPD after it has experienced a certain number of transients.

The critical question is what these counters actually count. Counters are basically measuring voltage amplitude, often called voltage threshold levels, as shown by Figure 42.

However, the destructive energy in a transient depends on the voltage and current of the transient. Knowing one without the other is meaningless. For example, there’s a lot of difference in a 600 Volt transient at 5 milliamps compared with a 600 Volt transient at 500 Amps. But the counters don’t distinguish between the two. If any transient simply exceeds a pre-set voltage level, it’s added to the tally. Since a typical threshold for counters is 300-500 Volts, recorded transient events will include noise, and spikes of unknown severity. Some may have truly damaging energy content, some will be harmless. However, if the manufacturer’s suggested replacement schedule is keyed to the counter’s tallies, there’s no way to be sure just how much remaining life may actually be left in the SPD.
Using the NEMA LS-1 Format for Preparing Surge Protective Device Specifications

A brief review of the elements comprising the NEMA LS-1 format will be helpful in defining the information to be shown.

1. **DEVICE NAME AND MODEL NUMBER:** Available from manufacturer’s published literature and specifications.

2. **DEVICE CIRCUIT DESCRIPTION:** This defines the components within the Surge Protective Device that actually suppress transient voltage surges. Examples include single or multiple Metal Oxide Varistors (MOV’s), gas-tube design, hybrid circuit, and others. This also indicates whether the device is series or parallel operated.

3. **NOMINAL LINE VOLTAGE:** Whether the device is panel-mounted, a plug-in unit, or a hard-wired unit, the intended line voltage for its application should be specified.

4. **MAXIMUM CONTINUOUS OPERATING CURRENT:** This rating must be specified for Surge Protection Devices that contain in-line series-connected components in their circuit design to confirm that the device will be operated within the circuit ampacity limits and not be overheated when installed.

5. **MAXIMUM CONTINUOUS OPERATING VOLTAGE (MCOV):** The MCOV is typically dictated by the assigned rating of the MOV’s within the surge protection device. The MOV rating is established by the MOV manufacturer rather than by the maker of the Surge Protective Device. This value provides a ceiling for the device’s vulnerability to being degraded as a result of line-voltage swells.

6. **CONNECTION MEANS:** Depending on the type of device, this could be lug terminals, terminal screws, wire leads, plug-in, or others.

7. **PROTECTION MODES:** For point-of-use devices, three modes of surge protection should be provided: line to neutral, line to ground, and neutral to ground. Of course, clamping data should be furnished for each mode. In the case of panel-mounted units, especially those installed on delta systems or at service entrances where ground and neutral are bonded, the devices may provide adequate protection even though every possible suppression mode is not applicable.

8. **MAXIMUM SURGE CURRENT:** This is a measure of how robust a Surge Protective Device may be in the the face of extremely high peak currents associated with, for example, lightning-induced surges. The standard of measure is a single-pulse 8x20µsec waveform specified in IEEE Standard C62.45. It is important that this information be provided by actual testing of the device, and not only from calculations based on manufacturer’s component specifications.

9. **CLAMPING VOLTAGE:** The clamping rating of a Surge Protective Device is the result of tests conducted using the IEEE C62 Standards Collection waveforms. It’s important for these values to show clamping levels with respect to zero ground level, and with line voltage applied. Also, clamping data should be provided for each protection mode the device offers.

10. **EMI/RFI NOISE REJECTION:** Electromagnetic interference (EMI) and radio frequency interference (RFI) should be attenuated by Surge Protection Devices in the frequency ranges specified. Test methods are based on 50Ω insertion loss procedures outlined in MIL-STD 220A.

11. **SAFETY AGENCY APPROVALS:** Certification organizations like UL, CSA, and NOM, should be specified along with their appropriate test standards, product categories, and reference file numbers. For example, in the case of a plug strip, the UL listing would be based on evaluation under standards UL 1449 TVSS (UXHT) and also UL 1363 Temporary Power Taps (XBYS). In addition, manufacturers are assigned file numbers for their listed devices. UXHT and XBYS are UL product identifiers (CCN Directory Codes).

12. **SAFETY AGENCY RATINGS:** Safety agencies assign suppression (clamping) ratings based on requirements in applicable test standards. For instance, the UL 1449 rating levels that appear in Chart 3 are used to determine clamping ratings for UL listed Surge Protective Devices. It is important to note that CSA and UL both prohibit outdoor installation of these devices unless they’re protected by an additional suitable enclosure like a NEMA-3R box, for example.

13. **PHYSICAL DATA:** Available from manufacturer’s specifications, this entry spells out device dimensions, weights, materials composition and other physical characteristics.
**NEMA LS-1**  
**SPECIFICATION FORMAT**  
**FOR SURGE PROTECTION DEVICES**

| SPD Model: | 
|---|---|
| SPD Circuit Description | 
| Nominal Line Voltage: | 
| Maximum Continuous Line Current: | 
| Maximum Continuous Operating Voltage: | 
| Connection Means: | 
| SPD Protection Modes: | 
| Maximum Surge Current: | *(Single Pulse, 8/20 µs, Mode, Data obtained from actual tests)* |
| Clamping Voltage during Maximum Surge Current *(VPeak measured)*: | 
| Clamping Voltage: | *(Data taken at 90 degrees phase angle of power frequency voltage, positive polarity only, applicable surge current)* |
| EMI-RFI Noise Rejection: | 
| Safety Approvals *(Agency, Standard, File)*: | 
| Safety Ratings *(UL1449, VPeak)*: | 
| Application Environment: | 
| **PHYSICAL DATA:** | 
| Dimensions: | 
| Weight: | 
| Materials: | 
| Wire size and length: | 
| Accessories: |
Surge Protection — Solving Problems Without Creating Them

The threat posed by electrical disturbances, particularly those of an impulse nature, is well known to most computer users. These disturbances go by many names: spikes, surges, transient surge voltages. The effects, however, are universal; disruption, degradation and damage. Of equal importance, especially with the increasing popularity of computer networking, is the effect of transients on communication lines. Communication lines entering a building (underground or aerial) can import high-magnitude transients into a facility. Through complex coupling mechanisms, voltage surges may damage an inner building’s communication interfaces. This complexity makes the “band-aid” approach to surge protection a short-sighted, inappropriate strategy.

The mechanisms by which transient voltages couple into data circuits can be divided into two categories. The first is inductive coupling; so called because the dataline forms part of an “inductive” loop. Surge currents flowing through metallic conductors produce a changing magnetic field, which will induce a voltage in the loop formed by the dataline. The greater the rate of change of surge current, the higher the voltage that will be induced in a given dataline loop.

The second and most destructive mechanism is ground potential difference. A dataline connecting two items of computer equipment will be subjected to any difference in voltage that may exist between the two equipment grounds. The destructive effects of this coupling mode can readily be seen when a dataline interconnects two separate buildings.

During a lightning storm, the ground potential between buildings may differ by many thousands of volts. The resulting physical damage to interface chips is a familiar sight to service engineers.

Avoiding or Minimizing Noise on Data and Communication Systems

Noise on data lines can often be avoided by proper consideration of the data line layouts within a facility. Data lines should not be draped over power line conduits. Metal conduits should not be considered a shield from the noise and transients occurring on power lines. Other areas to avoid when running data lines are ballast transformers, lightning down-conductor areas, and building steel (especially in the vicinity of lightning downconductors).

Ground connections within facilities should only be connected to a single tie point located at the service entrance panel. This single-point connection to earth ground precludes the inadvertent development of multiple ground points. Multiple ground points create differences in utility voltage, causing undesired currents to flow on low voltage data lines. These undesired currents flow in the form of noise which contaminates the transmission of data on Local (LAN) and Wide Area Networks (WAN’s).
Objectives of Implementing Surge Protective Devices (SPD’s)

In an uncontrolled environment, transient voltages can reach significant amplitudes; many times greater than the immunity of the electronic systems. The objective of implementing Surge Protective Devices (SPD’s) is to achieve a controlled transient environment, bridging the gap between the equipment and the environment. The level at which transients are controlled should always be lower than the immunity of the equipment. Ground potential problems may also occur within a building, particularly if equipment is supplied from separate transformers. One solution to mitigate the effects of both coupling mechanisms is to keep high magnitude surge currents out of the building.

![Diagram: The Threat](image)

**THE THREAT**

AC Power Cable

Potential threat to equipment operation

Transient Environment

Equipment Immunity

**FIGURE 45**

Protective Shield — the Systematic Approach

The protective shield approach to Transient Voltage Surge Suppression establishes a series of defined transient environments or zones. The two guiding principles are:

1. Keep the highest surge currents out of inner building wiring.

2. Ensure that at specific interfaces (AC or data) transients are controlled to a level below equipment susceptibility and vulnerability.

![Diagram: The Goal](image)

**THE GOAL**

SPD

AC Power Cable

Slightly separated

Transient Control Level

Equipment Immunity

**FIGURE 46**
Outside the Building (Zone 0)

Cables, lines, etc., outside a building (underground or aerial) may carry very high magnitude surge currents, particularly during lightning.

Uncontrolled surge currents flowing on inner building wiring will produce both inductive dataline transients and ground potential differences – a recipe for disaster.

As these cables enter the building, the first protective shield must be established. Ideally, the AC supply and all communication lines should enter the facility at the same general location. Surge Protective Devices are installed at this point, thereby preventing high-magnitude surge currents from entering. Both AC and communication line surge suppressors should be bonded to the same electrical ground.

On AC systems, it is common practice to install this first line of defense at the service entrance panel. On incoming telephone lines, the telephone company may provide a course level of protection at the main distribution frame.
Within the Building (Inner Zones 1,2,3 etc.)

In large facilities, local control of transients is often mandatory for either specific equipment or for a whole computer room. The installation of SPD's on both AC and communication lines, as shown in Figure 48, creates a second zone with lower transient voltage levels. The surge currents allowed to flow within this area are many orders of magnitude smaller than the currents in an uncontrolled environment. The final protective shield is always the equipment chassis itself, into which some inherent protection has been designed.

Local Ground Window

In some sites where a systematic approach is not practical or economical, a local protective shield can be established for individual equipment. A typical example would be a remote terminal. By using a combined AC and Dataline SPD, a local ground reference (ground window) is established. The maximum transient voltage present between any line and local ground within the protective shield is precisely controlled. Therefore, the problem of potential differences has been eliminated for the equipment within the shield.

“PERCEIVED” Protection

It is important to consider the possible results of the inappropriate application of AC protection products. For example, a small UPS, containing suppression components connected to ground, may cause ground potential differences. This in turn may lead to disruption or damage of dataline ports. There appears to be a simple solution to this problem: Use products that do not employ suppression components connected to ground. Closer inspection, however, shows that the use of such products will generate large neutral to ground voltages which may overstress power supplies. As so often happens with “band-aid” solutions, the problem is moved from one area to another.

In reality, the problem of multiple ground paths already exists in all but the most simple facilities. Each item of electronic equipment contains some filtering and/or suppression components connected to ground. In a large building where we find a wide variety of computerized equipment, a multiplicity of current paths to ground exists.

The correct solution to this problem is to prevent high magnitude surge currents flowing on inner building wiring. In the case of AC, this is achieved by the installation of surge suppression at the service entrance – the systematic approach.

Effective Protection

Correctly applied, the protective shield approach to surge protection represents one of the most powerful cost effective tools for preventing equipment disruption, degradation and damage.
Communication Line Protection for Modems when used with UPS's, Power Conditioners & SPD's

Protection For:
- Modems
- Point of Sale Terminals
- FAX Machines
- Credit Card Readers etc.

Models Available For:
- Dial-Up (Ringing) Lines
- Leased Or Dedicated Lines
- T1 Applications
- DDS Applications

FIGURE 49
Communication Line Protection
for use with
UPS’s, Power Conditioners & SPD’s
in Network Applications

FIGURE 50

Courtesy of Steven Engineering, Inc.
230 Ryan Way, South San Francisco, CA 94080-6370
Main Office: (650) 588-9200
Outside Local Area: (800) 258-9200
www.stevenengineering.com
An Overview of Ethernet LAN Applications...

10 BASE5 BACKBONE
Runs from 1st through 4th floors.

10 BASE2
ThinNet

10 BASES-T UTP

10 BASE2
ThinNet

10 BASE5 ThickNet

UL 497 PRIMARY

Zone 0

SPD
SPD
SPD
SPD
WATER/GAS PIPES
BUILDING GROUND

Zane 1

SPD
Surge Protection Devices

FIGURE 51

Courtesy of Steven Engineering, Inc. • 230 Ryan Way, South San Francisco, CA 94080-6370 • Main Office: (650) 588-9200 • Outside Local Area: (800) 258-9200 • www.stevenengineering.com
## Leviton Communications and Data-Line Surge Protective Devices

### Stand-Alone and Stackable Modules

<table>
<thead>
<tr>
<th>Leviton Part Number</th>
<th>Industry Standard</th>
<th>Protocol or Application</th>
<th>No. of Wires or Pins Protected (Active Pins)</th>
<th>Cable Type</th>
<th>Operating Frequency</th>
<th>Maximum Capacitance</th>
<th>Series Resistance</th>
<th>Clamp Voltage</th>
<th>Maximum Surge Current</th>
<th>Item Description</th>
<th>Operating Line Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>5350-TLL (Stand-Alone)</td>
<td>NEC Art. 800 (UL497A)</td>
<td>Telco Leased Lines</td>
<td>4 RJ11 (2,3,4,5)</td>
<td>UTP</td>
<td>N/A</td>
<td>60pF</td>
<td>22 Ohms</td>
<td>105 Volts (1)</td>
<td>3.8kV/1.9kA</td>
<td>4 Wire Lease Line Connector-RJ11</td>
<td>70V AC</td>
</tr>
<tr>
<td>5350-RS2 (Stand-Alone)</td>
<td>EIA</td>
<td>RS232</td>
<td>8 Wire RJ45 (1 thru 6)</td>
<td>UTP</td>
<td>1MHz Maximum</td>
<td>N/A</td>
<td>4.3 Ohms</td>
<td>27 Volts (1)</td>
<td>4kV/2kA</td>
<td>8 Wire RS232 Connector-RJ45</td>
<td>18V DC</td>
</tr>
<tr>
<td>5350-TBT (Stand-Alone)</td>
<td>IEEE</td>
<td>10 Base T**</td>
<td>4 Wire RJ45 (1,2,3,6)</td>
<td>UTP</td>
<td>130 MHz Maximum</td>
<td>19pF</td>
<td>None</td>
<td>5 Volts (1,2)</td>
<td>2kV/1kA</td>
<td>4 Wire Ethernet Connector-RJ45</td>
<td>4V DC L-L</td>
</tr>
<tr>
<td>5350-BNC (Stand-Alone)</td>
<td>IEEE</td>
<td>Video or IBM 3270</td>
<td>2 (Center + Shield)</td>
<td>Coaxial</td>
<td>70MHz Maximum</td>
<td>45pF</td>
<td>4.3 Ohms</td>
<td>15 Volts (1,3)</td>
<td>5kA</td>
<td>2 Wire Video/3270 Connector-BNC</td>
<td>8V DC</td>
</tr>
<tr>
<td>5350-TTR (Stand-Alone)</td>
<td>IBM</td>
<td>Token Ring</td>
<td>4 Wire RJ45 (3,4,5,6)</td>
<td>UTP</td>
<td>130MHz Maximum</td>
<td>19pF</td>
<td>None</td>
<td>5 Volts (1,2)</td>
<td>2kV/1kA</td>
<td>Token Ring Connector-RJ45 F/F</td>
<td>4.4V DC L-L</td>
</tr>
<tr>
<td>5350-TEB (Stand-Alone)</td>
<td>EIA</td>
<td>RS422</td>
<td>4 Wire Terminal Strip (All)</td>
<td>A/R</td>
<td>70MHz Maximum</td>
<td>45pF</td>
<td>4.3 Ohms</td>
<td>15 Volts</td>
<td>4kV/2kA</td>
<td>4 Wire RS422 Terminal Strip (422)</td>
<td>8V DC</td>
</tr>
<tr>
<td>5350-PC</td>
<td>IEEE</td>
<td>CATV</td>
<td>2 (Center + Shield)</td>
<td>Coaxial</td>
<td>1GHz Maximum</td>
<td>N/A</td>
<td>4.3 Ohms</td>
<td>25 Volts (1,3)</td>
<td>5kA</td>
<td>2 Wire Coax Connector-COAX-F</td>
<td>10V DC</td>
</tr>
<tr>
<td>5350-SAT</td>
<td>IEEE</td>
<td>DSS</td>
<td>2 (Center + Shield)</td>
<td>Coaxial</td>
<td>1.5 GHz Max.</td>
<td>N/A</td>
<td>4.3 Ohms</td>
<td>25 Volts (1,3)</td>
<td>5kA</td>
<td>DSS F-Connector</td>
<td>10V DC</td>
</tr>
<tr>
<td>5350-PT4</td>
<td>IEEE</td>
<td>4-Wire Telco</td>
<td>4 Wire RJ11 (2,3,4,5)</td>
<td>UTP</td>
<td>N/A</td>
<td>60pF</td>
<td>22 Ohms</td>
<td>220 Volts (1)</td>
<td>3.8kV/1.9kA</td>
<td>4 Wire Lease Line Connector-RJ41</td>
<td>90V DC</td>
</tr>
<tr>
<td>5350-PT8</td>
<td>IEEE</td>
<td>8-Wire Telco</td>
<td>8 Wire RJ45</td>
<td>UTP</td>
<td>N/A</td>
<td>60pF</td>
<td>22 Ohms</td>
<td>220 Volts (1)</td>
<td>3.8kV/1.9kA</td>
<td>8 Wire Lease Line Connector-RJ45</td>
<td>90V DC</td>
</tr>
<tr>
<td>5360-DDS (Stackable)</td>
<td>NEC Art. 800 (UL497A)</td>
<td>DDS</td>
<td>4 Wire RJ45 (1,2,7,8)</td>
<td>UTP</td>
<td>5.6 MHz Maximum</td>
<td>60pF</td>
<td>22 Ohms</td>
<td>105 Volts (1)</td>
<td>3.8kV/1.9kA</td>
<td>4 Wire DDS Lines Connector-RJ45</td>
<td>70V DC</td>
</tr>
<tr>
<td>5360-RS2 (Stackable)</td>
<td>EIA</td>
<td>RS232</td>
<td>8 Wire RJ45 (1 thru 8)</td>
<td>UTP</td>
<td>1MHz Maximum</td>
<td>N/A</td>
<td>4.3 Ohms</td>
<td>27 Volts (1)</td>
<td>4kV/2kA</td>
<td>8 Wire RS232 Connector-RJ45</td>
<td>18V DC</td>
</tr>
<tr>
<td>5360-TBT (Stackable)</td>
<td>IEEE</td>
<td>10 Base T**</td>
<td>4 Wire RJ45 (1,2,3,6)</td>
<td>UTP</td>
<td>130MHz Maximum</td>
<td>19pF</td>
<td>None</td>
<td>5 Volts (1,2)</td>
<td>2kV/1kA</td>
<td>4 Wire Ethernet Connector-RJ45</td>
<td>4V DC L-L</td>
</tr>
</tbody>
</table>

### NOTES:
1. Maximum Clamping Voltage measured at 2kV (1.2/50 µs) 1kA (8/20 µs).
2. Maximum Clamping Voltage measured between twisted pair during the common mode application of the test waveform.
3. Maximum Clamping Voltage Line to Shield.

### * Operating Frequency equates to the Maximum Bit Rate by using the Formula:

\[
\text{Max Operating Frequency} = \frac{\text{Maximum Bit Rate}}{5}
\]

### LAN TERMINOLOGY

**Standard Name Convention for IEEE 802.3 & Ethernet**

**10 Base T** explanation

- Frequency in Mbps
- Base = Signal Type (Baseband or Broadband)
- T = Segment Length in hundreds of meters
Telco & Data Line Surge Protection Guide

SYMPTOMS: What to look for —

1. Large Loop Areas (Inductive Coupling)
2. Facility Entrance (Copper!)
3. Different Grounds/Multiple Grounds
4. “Noisy” Electrical Environment (i.e.: Ballasts)
5. Multiple Service Entrances
6. Multiple Lines in One Area
7. Line to Ground AC Protectors (electrically pollute ground references)

Characteristics of EFFECTIVE Surge Protection:

1. Control Transient Voltage.
2. Withstand Electrical Environment.
3. Compatibility.

Reasons for Surge Protector Failures:

1. Poor Transient Control Level — Device clamps above equipment susceptibility level.
2. Length of Protector’s Ground Wire — avoid pigtail leaded devices! Voltage drop across ground pigtail is added to overall clamp level.
3. Different Grounds — loop potential differences.
4. Unprotected Lines — “backdoors”, “cover all bases”.
5. Protector circuitry exhibits high capacitance – results in signal interference.

Approvals compliance for Telco Protectors:
NEC ARTICLE 800 — Communications Circuits
UL 497A — Safety Standard for Secondary Protectors

SYSTEM COMPATIBILITY TABLE: Protocols, Connectors and Operating voltages, frequencies, transmission speeds.
Introduction

Protection of factory automation equipment follows the same guidelines used for any other type of electronic devices, since the mainstay of such systems is comprised of one or more programmable logic controllers (PLC’s) working in conjunction with multiple input/output (I/O) devices. I/O devices are typically controlled by PLC’s. I/O devices perform a variety of tasks including; the application or removal of voltages to control valves, start, stop or control motors or vary motor speed upon demand. Other I/O functions include the control or monitoring of manufacturing based processes such as measurement of product (assembly line) weight (packaged goods products), measurement and control of solution pH levels, or batch fluid levels during manufacturing or packaging operations.

Automation equipment may be located/housed in an instrumentation rack, or independently mounted in small frame enclosures. Today many automation systems are personal computer (PC) based, using an open (data line) architecture or priority data protocol to communicate with I/O devices.

Analogies

Protection of a PLC system can be compared to a castle surrounded by a moat (Fig 1). In order to effectively protect the castle, all input and output access points must be guarded. The same is true for PLC systems. All input and output lines must be protected from transients. “All lines” means both power and signal/data lines. Most often people forget to protect data lines. Transients do not care where they enter a system or if the lines are input, output or power; therefore protection must be applied to each of them. The costs associated with protecting all lines will more than pay for itself if only one damaging transient is eliminated!

Surge Protection and Grounding Systems

The start of any evaluation program leading to an effective surge protection installation is to verify that all electronic equipment has been properly installed and grounded in accordance with manufacturers instructions and recommendations.

All electronic system components must be properly connected to a ground system. This is the point to which all surges are directed in their path away from the electronics being protected. The grounding system must also be connected to a good building grounding system that is only connected to an earth ground rod system, at one point (Fig 2). This one point is usually at the service entrance location. Randomly grounding building framework to an earth ground rod system can be counterproductive, as it could lead to the formation of ground loop currents that can corrupt data line (LAN, WAN) communication within the building.
Relatively speaking, protection of input power lines to PLC or PC based systems is the most straightforward. Placing a strip, plug-in (for PC’s) or wired-in device (for rack mounted PLC’s) in the power line forms a defense against both internal and externally generated facility transients. It is also preferred to have a panel mounted SPD located at branch and/or service entrance locations. The SPD placed at the PLC or PC will act as a downstream networked device that mitigates the effects of any remnant transient that may pass branch or service entrance mounted SPD’s.

Data line or signal line SPD’s must be mounted (and grounded) as close to PLC or I/O cards as possible, and at each end of the line (when such lines exceed 5 ft in length). Having SPD’s grounded near PLC’s or I/O cards is especially important when data or signal inter-connection lines are unshielded, and also when they are required to exit the shielded confines of their grounded rack enclosure.

**Data Line SPD Selection Criteria**

Critical parameters when selected SPD’s for non standard data protocols include:

- Peak Voltage Levels
- Frequency of Operation
- Protection Modes (Line-Line, Line-Ground)
- Capacitance Loading L-L and or L-G
- Type of Fusing
- Underwriters Laboratory (UL) Listing Per UL 497B
- CE Marking (Required for European Operation)
- Clamping Voltage Levels with associated test current and test waveform
Accurate Assessment of Electrical Systems

Precise identification of the electrical system is critical in the proper selection and application of the most effective surge protective device. Since SPD performance is directly related to nominal line-voltage parameters, line voltage measurements should always be taken by a qualified electrician before the SPD’s are specified and installed. Measurements should be taken even when the electrical system configuration is known.

Figure 52 shows some common electrical systems used throughout the USA and Canada. Specific systems present in a given facility should be identified by measuring with a voltage meter across each line to neutral, and line to line. The readings should be written down and referred to when ordering the required SPD’s.

Voltage Measurements Can Be

EXTREMELY DANGEROUS! PLEASE BE VERY CAREFUL!

![Diagram of electrical systems and voltage measurements]

**Common Voltages (VAC)**

<table>
<thead>
<tr>
<th>Voltage Type</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(L-N)</td>
<td>120, 220, 277, 346</td>
</tr>
<tr>
<td>V(L-N)</td>
<td>208, 240, 380, 480, 600</td>
</tr>
<tr>
<td>V(L-L)</td>
<td>120, 240</td>
</tr>
<tr>
<td>V(L-L)</td>
<td>240, 480</td>
</tr>
<tr>
<td>V(L-L)</td>
<td>208, 480, 600</td>
</tr>
<tr>
<td>V(L-N) 1</td>
<td>120</td>
</tr>
<tr>
<td>V(L-N) 2</td>
<td>208</td>
</tr>
<tr>
<td>V(L-N) 3</td>
<td>120</td>
</tr>
</tbody>
</table>

*FIGURE 52*
SPD Networks

PI Filters and SPD Networks

Remarkable improvement can be made in SPD performance through the use of a relatively simple concept: inductive coupling. With this concept, SPD networks can be created within SPD circuit designs or which span entire electrical systems and utilize the existing features and components of the system to great advantage.

This concept is certainly not new and has its roots in electrical engineering circuit design. For example, inductively coupled networks are often used to achieve enhanced levels of performance beyond that possible through multiplication of components in a circuit. In the traditional PI Network, an inductor “couples” the two identical capacitors of value C, yielding better low-pass filter performance than could otherwise be achieved by a single capacitor of size 2C.

If the capacitors of the PI Network filter are replaced by SPD components, the result is a “coupled” SPD Network with better overall performance capability than a single SPD module.

Simply adding and additional SPD module to a single-module circuit without the inductor would result in only slight improvements.

In PI Network Filters or SPD Networks, the inductor serves as the coupling medium and is primarily responsible for the increase in performance capability, though “matching” of the inductor is an engineering challenge.

Component-Based Hybrid Networks

SPD Hybrid circuits which utilize inductors may be regarded as SPD “Component Networks”
Transformer-Based SPD Networks

A convenient way of achieving SPD Network “coupling” is through the use of a transformer. Because of its unique power conditioning and electrical properties, the transformer is an ideal coupling medium.

In the single-phase, progressive action schematic illustration below, a 6800 Volt transient of specified energy content (perhaps the residual of lighting arrestor activity at the service entrance) enters the electrical system through the service panel and is attenuated by an SPD Network consisting of two appropriately sized SPD modules and a shielded, step-down transformer.

Had only one side of the transformer been “protected”, the resulting stress at the load would have been much higher. For example, with the 480V module alone, the resulting 1600V transient would have had access to the load. With the 120V module alone, the resultant or clamping voltage of the module would have been significantly higher than 320 Volts since the module would have had to contend with the entire energy content of the original transient. The attenuating effect of the transformer on clamping harmonics and random noise associated with SPD activity would not have been realized.

An installation schematic for a Three-Phase, Transformer-Based SPD Network is shown below.
Branch Circuit Based SPD Networks

Transformers are not absolutely necessary in achieving optimum SPD Network performance. Since it is inductance which primarily responsible for the “coupling” effect, very effective networks can be developed using the natural inductance of branch circuit wiring.

In the example below, two networks are established. One is between the service entrance lightning arrester and the distribution panel SPD, the other is between each of the two loads and the distribution panel SPD. Of course, the overall effectiveness of these networks depends upon the relative capabilities of the SPD components involved and the actual inductance (or length) of the branch circuit wiring.

Network Zones of Effect

In the above example, a zone called the SPD “Zone of Effect” or “Zone of Effectiveness”, is depicted about the point of application of the secondary or load-side SPD device and next to the specific loads requiring protection.

The zones pictured indicate the area or greatest protection in the network. Typically, networks are derived in order to provide enhanced protection for a specific load. All loads connected to the branch circuit within the network are SPD protected, but the greatest or optimum protection is in the vicinity of the secondary or load-side SPD within the zone. This is why SPD networks are generally constructed from a point where specific protection is needed, backwards through the electrical system, to a panel or a transformer.

How these zones work and their performance (protection) characteristics are illustrated in the example on the next page.
In order to illustrate the properties of a Branch Circuit Network, 50 feet of #14 AWG 3 conductor wire is laid out from points A to B. A surge generator with back-filter is employed to inject IEEE C62.41 type transients onto the sine wave at 90 degrees of phase angle. Simple SPD’s are employed at both A and B as indicated below.

\[ V = L \frac{di}{dt} = 0.6 \, \mu H \times \frac{200 \, A}{600 \, ns} = 200 \, VOLTS \]
Applications for Commercial/Light Industrial Facility

1. **Power Distribution**
   - Load centers
   - Switchgear
   - Distribution equipment

2. **Electrical Loads**
   - Lamps
   - Ballasts
   - Lighting controls

3. **Building Controls**
   - Building management systems
   - Motor controls
   - Drives

4. **Computers & Communications**
   - Voice/data equipment (PBX system, LAN’s, WAN’s)
   - Security system
   - Fire alarm system
   - Patch Panels
   - UPS systems

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Indicates suggested placement of Leviton SPD product. Other solutions may also apply. Attention should be paid to available options with panel mounted SPD.
Applications for Industrial Facility

1. **Power Distribution**
   - Load centers
   - Transformers
   - Generators

2. **Electrical Loads**
   - Motors
   - Industrial fans, heaters and blowers
   - Ballasts

3. **Industrial Controls**
   - Programmable logic controllers
   - Motor controls
   - Motor control centers
   - Variable-frequency drives
   - Proximity sensors
   - Bar coding equipment
   - Machine vision systems

4. **Computers & Communications**
   - LAN’s and WAN’s
   - Voice/data (PBX)
   - Fire alarm systems
   - Intercoms
   - Security systems
   - UPS systems
   - Building management systems
Indicates suggested placement of Leviton SPD product. Other solutions may also apply. Attention should be paid to available options with panel mounted SPD.
Indicates suggested placement of Leviton SPD product. Other solutions may also apply. Attention should be paid to available options with panel mounted SPD.

SPD Network Example: Medical Radiology Environment

480 VOLT 3 PHASE

57480-DM3
(For service up to 100A wired via “feed through” lugs)

480V 3 PHASE

STEP DOWN TRANSFORMER

120/208 3 PHASE

57120-M3

DISTRIBUTION PANEL 120V SINGLE PHASE OUTPUT

57480-DM3

X-RAY GENERATOR / CAT SCAN / MRI

GANTRY

TABLE

DISC DRIVES

SYSTEM CPU

PROCESS DATA LINES
5350 DATA LINE PROTECTION
SPECIFIED FOR APPROPRIATE PROTOCOL

120V 20A

8380 SURGE PROTECTED HOSP. GRADE OUTLET

5300P

EQUIPMENT CART
5300-HPS HOSPITAL GRADE SURGE PROTECTED STRIP

EQUIPMENT CART
5300-HPS HOSPITAL GRADE SURGE PROTECTED STRIP

PROCESS PC

480 VOLT 3 PHASE

480V 3 PHASE

120V 20A
SPD Network Example: Retail Check-Out

Indicates suggested placement of Leviton SPD product. Other solutions may also apply. Attention should be paid to available options with panel mounted SPD.

**STEP-DOWN TRANS.**

277/480
3 PHASE
52277-M3

480V
3 PHASE
52480-DM3

**PANEL 1**

TO PAYROLL CIRCUITS

5300-PS

**PANEL 2**

ISO. TRANS

**PANEL 3**

STORE REGISTER MINI COMPUTER

**PANEL 4**

HEAVY LOADS

EXAMPLE: REFRIGERATION COMPRESSORS

52120-M3

120V DEDICATED LINES

52120-M3

120V

5280

**TELEPHONE KSU**

LIGHTING

**SECURITY SYSTEM**

POINT CONNECTIONS

51020-WM

5350-PT4

MODEM

MAIN STORE CONNECTION

REGISTER CONNECTIONS RS-232

5350 DATA LINE PROTECTORS

REGISTER SYSTEM INCLUDES CARD READER

5350 DATA LINE PROTECTORS

5350 DATA LINE PROTECTORS

5350 DATA LINE PROTECTORS

**CHECK-OUT REGISTER**

INPUT

INPUT

INPUT

5350 DATA LINE PROTECTORS MATCHED TO APPROPRIATE PROTOCOL

5350 DATA LINE PROTECTORS

5350 DATA LINE PROTECTORS

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Indicates suggested placement of Leviton SPD product. Other solutions may also apply. Attention should be paid to available options with panel mounted SPD.
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>CSA</td>
<td>Canadian Standards Association</td>
</tr>
<tr>
<td>EMP</td>
<td>Electromagnetic Pulse</td>
</tr>
<tr>
<td>EMI</td>
<td>Electromagnetic Interference</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>NEMA</td>
<td>National Electrical Manufacturers Association</td>
</tr>
<tr>
<td>RFI</td>
<td>Radio Frequency Interference</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriters Laboratories</td>
</tr>
</tbody>
</table>

## References

**Institute of Electrical and Electronics Engineers (IEEE) Standard 100-1988**

*Standard Dictionary of Electrical and Electronic Terms*

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C62-IEEE</td>
<td>Guides and Standards for Surge Protection</td>
</tr>
<tr>
<td>C62.41-IEEE</td>
<td>Guide for Surge Voltages in Low Voltage AC Power Circuits</td>
</tr>
<tr>
<td>C62.45-IEEE</td>
<td>Guide on Surge Testing for Equipment Connected to Low Voltage AC Power Circuits</td>
</tr>
<tr>
<td>UL 96</td>
<td>Standard for Safety-Installation Requirements for Lightning Protection Systems</td>
</tr>
<tr>
<td>UL 452</td>
<td>Standard for Safety-Antenna Discharge Units</td>
</tr>
<tr>
<td>UL 497A</td>
<td>Standard for Safety-Secondary Protectors for Communication Circuits</td>
</tr>
<tr>
<td>UL 498</td>
<td>Standard for Safety-Receptacle and Receptacle Plugs (Including Direct Plug-In Devices)</td>
</tr>
<tr>
<td>UL 544</td>
<td>Standard for Safety—Medical and Dental Equipment</td>
</tr>
<tr>
<td>UL 1283</td>
<td>Standard for Safety—Electromagnetic Interference Filters</td>
</tr>
<tr>
<td>UL 1363</td>
<td>Standard for Safety—Temporary Power Taps (Power Strips)</td>
</tr>
<tr>
<td>UL 1449</td>
<td>Standard for Safety—Transient Voltage Surge Suppressors</td>
</tr>
<tr>
<td>NEMA LS-1</td>
<td>Low Voltage Surge Protective Devices</td>
</tr>
</tbody>
</table>
Definitions:

(Per IEEE Standard 100 and IEEE 1100)

**Capacitance:** The property of a system of conductors and dielectrics that permits the storage of electrically separated changes when potential differences exist between the conductors.

**Common-Mode Noise:** The noise voltage that appears equally and in phase from each current-carrying conductor to ground.

**Crest Factor:** Ratio between the peak value (crest) and rms value of a periodic waveform.

**Differential-Mode Noise:** See: noise, transverse-mode

**Decibel (dB):** One-tenth of a bel, the number of decibels denoting the ration of the two amounts of power being ten times the logarithm to the base 10 of this ratio.

\[
\text{Power}_{\text{dB}} = 10 \log_{10} \left( \frac{\text{Power}_{\text{out}}}{\text{Power}_{\text{in}}} \right)
\]

\[
\text{Voltage}_{\text{dB}} = 20 \log_{10} \left( \frac{\text{Voltage}_{\text{out}}}{\text{Voltage}_{\text{in}}} \right)
\]

**Equipment Grounding Conductor:** The conductor used to connect the noncurrent carrying parts of conduits, raceways, and equipment enclosures to the grounding electrode at the service equipment (main panel) or secondary of a separately derived system (e.g., isolation transformer). (The term is defined more specifically in the NEC (2), Section 100).

**Impulse—(Surge Arrestors):** A surge of unidirectional wave of current or voltage of very short duration containing no appreciable oscillatory components.

**Inductance:** The property of an electric current by virtue of which a varying current induces a electromotive force in that circuit or in a neighboring circuit.

**Ground/Ground system**

**Ground:** A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth.

**Ground Loop:** A potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential. (4)

**Ground System:** A system in which a least one conductor or point (usually the middle wire of neutral point of transformer or generator windings) is intentionally grounded, either solidly or through an impedance.

**Grounded Conductor:** Another name for the neutral conductor. A conductor which is intentionally grounded, either solidly or through a non-interrupting current limiting device.

**Grounded Conductor—(NEC):** The conductor that is used to connect the equipment or the wiring system with a grounding circuit to a grounding electrode or electrodes.

**Solidly Grounded:** Connected directly through an adequate ground connection in which no impedance has been intentionally inserted.
Harmonic: A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.

Impulse: (Metal Oxide Varistors) A surge of unidirectional polarity.

Input Power Factor (of a system): Specifies the ratio of input kilowatts to input kilovoltamperes at rated or specified voltage and load.

Induced Current: (General)—Current in a conductor due to the application of a time-varying electromagnetic field.

Induced Voltage: (General)—A voltage produced around a closed path or circuit by change in magnetic flux linking that path.

Induced Voltage: (Lightning Strokes)—The voltage induced on a network or electric installation by an indirect stroke.

Inrush: The amount of current that a load draws when it is first turned on.

Isokeraunic Level: (Lightning)—The average annual number of thunderstorm days.

Isolated Equipment Ground: An insulated equipment grounding conductor run in the same conduit or raceway as the supply conductors. This conductor is insulated from the metallic raceway and all ground points throughout its length. It originates at an isolated ground type receptacle or equipment input terminal block and terminates at the point where neutral and ground are bonded at the power source. (This term is defined more specifically in the NEC (2), Section 250-74 and 250-75).

Isolation: Separation of one section of a system from undesired influences of other sections.

Isolation Transformers: Provides a local ground reference point. Attenuates common-mode disturbances on the power supply conductors.

Joule: The work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force. (A newton is that force when applied to body having a mass of one kilogram, gives it an acceleration of one meter per second squared.)

Leakage Current: (Health Care Facilities) This is any current, including capacitively coupled current, not intended to be applied to a patient but which may be conveyed from exposed metal parts of an appliance to ground or to other accessible part of an appliance.

Linear Load: An electrical load device which, in steady state operation presents an essentially constant load impedance to the power source throughout the cycle of applied voltage.

Maximum Continuous Operating Voltage: The maximum designated root mean square (rms) value of power frequency voltage that may be applied continuously between the terminals of an arrester.

Mutual Inductance: The common property of two electric circuits whereby an electromotive force is induced in one circuit by a change of current in the other circuit. The coefficient of mutual inductance M between two windings is given by the following equation:

\[ \text{emf} = -M \frac{dI}{dt} \]

Noise: Electrical noise is unwanted electrical signals that produce undesirable effects in the circuits of the control system in which they occur (4). (For this Recommended Practice, “Control systems” is intended to include sensitive electronic equipment in total or in part.)

Noise, Normal-Mode: See: transverse-mode noise

Nonlinear Load: Electrical load that draws current discontinuously or whose impedance varies during the cycle of the input as voltage waveform.

Residual Voltage: (Arrester) The voltage that appears between the line and ground terminals of an arrester during the passage of discharge current.

Safety Ground: See: equipment grounding conductor
Self-Inductance: (Inductance) The property of an electric circuit whereby an electromotive force is induced in that by a change of current in the circuit. The coefficient of self-inductance "L" of a winding is given by the following expression:

\[ \text{Voltage (e)} = -L \frac{\text{di}}{\text{dt}} \]

Shield: As normally applied to instrumentation cables, a conductive sheath (usually metallic) applied over the insulation of a conductor or conductors, for the purpose of providing means to reduce coupling between the conductors so shielded and other conductors that may be susceptible to, or that may be generating unwanted electrostatic or electromagnetic fields (noise).

Shielding: Shielding is the use of a conducting barrier between a potentially disturbing noise source and sensitive circuitry. Shields are used to protect cables (data and power) and electronic circuits. They may be in the form of metal barriers enclosures, or wrappings around source circuits and receiving circuits.

Spike: (pulse terms) A distortion in the form of a pulse waveform of relatively short duration superimposed on an otherwise regular or desired pulse waveform.

Surge Impedance: The ratio between voltage and current of a wave that travels on a line of infinite length and of the same characteristics as the relevant line.

Transient Overvoltage: The peak voltage during the transient conditions resulting from the operation of a switching device.

Transverse-Mode Noise: (With reference to load device input ac power) Noise signals measurable between or among active circuit conductors feeding the subject load but not between the equipment grounding conductor or associated signal reference structure and the active circuit conductors.

Voltage Regulation: The degree of control or stability of the rms voltage at the load. Often specified in relation to other parameters such as input-voltage changes, load changes, or temperature changes.

Watt: The unit of power in the International System of units (SI). The watt is the power required to do work at the rate of 1 joule per second.

Withstand Current: The crest value attained by a surge of a given wave shape and polarity that does not cause disruptive discharge on the test specimen.

Withstand Voltage: The specified voltage that, under specified conditions, can be applied to insulation without causing flashover or puncture.

Sag: A rms reduction in the AC voltage, at the power frequency, for durations from half-cycle to a few seconds. (Note IEC terminology is dip).

Swell: An increase in the AC voltage, at the power frequency, for durations from a half-cycle to a few seconds.

Transient: A sub cycle disturbance in the AC waveform that is evidenced by a sharp brief discontinuity of the waveform. May be of either polarity and may be additive to or subtractive from the nominal waveform.

General Information:

Clamp Circuit: Circuit which limits the applied voltage amplitude to a desired level, based on the transients intrinsic current.

Failure Mode: The effect by which a failure is observed.

Clamping Voltage: The (peak) voltage occurring on a conductor, measured at the output of a Surge Protection Device (the point connected to the load/device being protected), to either the ground or neutral conductor.

Residual (voltage): The amplitude (level) that remains after a Surge Protective Device has attenuated the initial transient.

Static Charge: The electricity generated when two dissimilar substances come into contact. (Conveyor belts are active producers of static electricity).

Transient Overvoltage: The temporary overvoltage of short duration associated with the operation of a switching device, fault, lighting, or arcing ground faults.