Transient Voltages & Surge Protection Devices

Andy Angrick – P3
P3 is the industry’s trusted and respected advisor for critical power, cooling and energy solutions.
DATA CENTERS

Providing industry knowledge, product expertise, & technological innovation over a broad portfolio of products and services to our customers across a wide range of industries and applications.

To achieve zero downtime, scale the data center to meet ever changing requirements, and reduce energy costs, you need the most reliable and efficient power and cooling infrastructure available.

**Modular & Scalable Data Center Equipment**
Systems that grow and change with your modern Data Center.

**Traditional Data Center Equipment**
Systems built around existing older equipment.

We can provide both Modular / Scalable and Traditional Data Center Equipment
INDUSTRIAL POWER SOLUTIONS

Power Quality Specialists with expertise in your Power Quality needs.

Industrial Power Quality, doesn’t just happen. It takes technical expertise, investment in products and facility coordination to achieve the desired levels of Power Quality. With experience in both new construction and retrofit installations, P3 can help you select and install the correct products.
Power Quality Monitoring

System analysis and evaluation of power quality issues to provide solution recommendations for the best possible performance from your existing power system.

The ability to quickly identify and remedy power quality problems will lengthen the life of electrical equipment and improve power system availability.

Our engineering technicians will help you understand your unique facility power system.
Service Plans & Support Services

Service plans and support services that provide maintenance, parts, & service necessary to ensure the best possible performance from your existing power system.

We offer customized, flexible, full-service packages that offer hassle-free system maintenance to improve uptime at predictable cost which include technical support, preventive maintenance, quick on-site response, and remote monitoring.

- Service Plans
- Energy Management Services
- Power & Cooling Analysis
- Data Center Assessments
- Project Management
- Battery Replacement

We provide top quality maintenance service & support.
Recognized as the American National Standard (ANS)

IEEE Recommended Practice for Powering and Grounding Electronic Equipment

Sponsor
Power Systems Engineering Committee of the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society

IEEE-SA Standards Board

American National Standards Institute
ANSI/IEEE 1100 tells us the following:

- What is a Transient?
- How do I measure a Transient?
- What damage is caused by a Transient?
- What equipment eliminates Transients?
- Where do I locate this equipment in my facility?
- How do I install this equipment correctly?

And if you still don’t get it they include pictures!!!
Voltage Spikes & Surges are known as: Voltage Transients, or just Transients.

Normal 120 Volt 60Hz AC Voltage Sine Wave

120 Volt 60Hz AC Voltage Sine Wave With Transients
Power Quality Events

- Outage
- Transient
- Swell
- Sag
- Harmonics

SPD’s only address transients and noise not, over-voltages, under-voltages, sags and swells
Proper Design will limit voltages to ANSI/IEEE 3.4.3 Levels

No standard for limiting Voltages

UL 1449 3rd ed.
Addressed by ANSI/IEEE 1100

Not addressed by UL
Not addressed by ANSI/IEEE 1100
What causes these Transients?

Motors

Fluorescent Lights & Ballasts

Copiers & other office equipment

Welders & other industrial equipment

Motors
Transients come from two sources:

- **Internal to the facility:** Motors, Ballasts, Office and Industrial equipment (80%)
- **External to the facility:** Lightning, Power Grid problems (20%)
Transients

Generated by Switching 2x4, 4 bulb fixture
IEEE Example of Transients

Generated by Capacitor Switching

Figure 3-12—Sample capacitor-switching oscillatory transient

Reprinted with permission from Dorr [B3].
IEEE Example of Transients

Generated by energizing a transformer
Caused by Harmonics
IEEE Example of Transients
Caused by Motor Switching
Transients

Oscillatory Transient
(Ring Wave)

Impulse Transient
Types of Transients

Impulse or Unidirectional Transient

Conventional Industry Standard
Types of Transients

Ring Wave Transient

0.5 µs, 100 kHz Ring Wave

90% of peak

10% of peak

0.5 µs

T = 10 µs

(f = 100 kHz)

60% of V_{peak}
Some problems caused by Transients:

• Premature Equipment failure
• Long term cumulative equipment damage
• Power loss
• Data losses & system resets
• Catastrophic equipment failure
• Immediate operation shutdown
• Expensive equipment repair & replacement costs
Problems with Equipment

- Motor Windings
- Premature or complete motor failure
Problems with Equipment

Contact Failure from lightning strike
Problems with Equipment
Transients – Malfunctions

Multiple zero crossings
Power disturbances create physical damage and affect logic signals in electronic equipment. Noise disturbances can be interpreted as legitimate ON/OFF signals, resulting in operating errors & equipment downtime.

A. Signal Voltage Levels 1975

20 - 30V logic signal

B. Modern Voltage Levels

.5 – 2.5V logic signal

Transients

Source: EC&M Magazine
Surge Protection
Electron Microscopic Photos

Catastrophic
Cross cut view

Cumulative
Top view

From AD Inc
The Protection Circuit

480V Incoming Power

6000V Voltage Spike

600V Maximum Clamp by SPD

Neutral

Ground

Switchgear

Motor Control Centers

Lights
Phones
Computers Etc.
The SPD unit is designed to:

• Protect equipment from damage

Therefore, the SPD unit must:

• Sense transients quickly- <1 nanosecond
• Limit the let-through voltage- IEEE 3.4.3
• Inform user if not functioning- Alarms
• Not interrupt Normal Service- while doing its job
Common Components

MOV

Strengths

- High energy-handling capability
- Readily available
- Sub-nanosecond response time
- Consistent clamping levels

Weaknesses

- Clamp voltage goes up with current
- Degradation
MOV Degradation

New MOV Fully Functional
Operates at Peak Performance
High Energy – Consistent Voltage Clamping

Slightly Used MOV over time
Less Performance Capabilities
Lower Energy Handling

High Transient Environment
Very Low Performance Capabilities
Lowest Energy Handling, Low Life Span

The relationship between ambient temperature and the life of an MOV can be expressed by Arrhenius rate equation: \( t = t_0 \exp\left[\frac{E_a-f(V)}{RT}\right] \)

Solution
Requires
Multiple MOV’s
Surge Protection Design

Built for Endurance & Peak Surge Capacity

<table>
<thead>
<tr>
<th>Phase</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>N</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line to Ground</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Neutral to Ground</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line to Neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Many SPD’s DO NOT include **ALL MODE PROTECTION**
What if the SPD unit needs replaced?

Replace Modules?

Replace Entire SPD

YES
Surge Protection

The current
UL 1449 3\textsuperscript{rd} Edition Specification
How To Specify

• Numerous changes to a number of surge protection documents have been made:
  – UL 1449 3rd edition – mandatory compliance 9/29/09
  – ANSI/IEEE 1100
  – IEEE C62.41
  – NEC
• Many terms used in the past are now obsolete
The Current UL1449

3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required)
- Short circuit current rating
- Nominal Discharge Current Rating
- System voltages
- System frequency
- Voltage Protection Rating

Model #: XYZ-400-208Y
SCCR: 100kA
Nominal Discharge Current Rating (In): 20kA
MCOV Rating: 150V L-N, NG, L-G; 300V L-L
Sys.V: 100V/174V; 120/208V; 127V/220V
Sys. Frequency: 50/60Hz
VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007

Suitable For Use on a Circuit Capable of Delivering Not More Than 100,000 rms Symmetrical Amperes.
The Current UL1449
3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required)
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Date of Manufacture: 11/21/2007

Suitable For Use on a Circuit Capable of Delivering Not More Than 100,000 rms Symmetrical Amperes.
The SPD type refers to the location where the SPD can be used

- Type 1 – before the service disconnect overcurrent device
- Type 2 – after service disconnect overcurrent device
- Type 3 – at least 10m (30 ft) of conductor between service disconnect overcurrent device and SPD
- Type 4 – component SPD (must be tested to the appropriate installation location where it will be installed)
Locations for SPD Types

**Type 1**
Before service disconnect

**Type 2 (Type 1 permitted)**
After service disconnect

**Type 2 or Type 3**
(Type 1 permitted)
30 feet of conductor between service disconnect and SPD

**Type 3 or Type 4**
Component Level
The Current UL 1449

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- NRTL listing mark
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- System voltages
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Sys.V: 100V/174V; 120/208V; 127V/220V
Sys. Frequency: 50/60Hz
VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007
Suitable for use on a circuit capable of delivering not more than 100,000 rms symmetrical amperes.

No Change
Nationally Recognized Testing

Laboratory Mark - NRTL

- Other laboratories besides Underwriters Laboratories can test and list devices to be compliant with any standard, including UL 1449

- An SPD tested by another NRTL can be “Compliant to UL 1449” but will be “Listed” by the NRTL – e.g. “ETL Listed”, “CSA Listed”
The Current UL1449

3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required by NRTL)
- Short circuit current rating
- Nominal Discharge Current Rating
- System voltages
- System frequency
- Voltage Protection Rating

Model #: XYZ-400-208Y
SCCR: 100kA
Nominal Discharge Current Rating (In): 20kA
MCOV Rating: 150V L-N, NG, L-G; 300V L-L
Sys.V: 100V/174V; 120/208V; 127V/220V
Sys. Frequency: 50/60Hz
VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007

Suitable For Use on a Circuit Capable of Delivering Not More Than 100,000 rms Symmetrical Amperes.

No Change
kA per mode or per phase?

Surge Current splits evenly between L-N and L-G MOV’s due to MOV matching and same MCOV.

100kA per mode = 200kA per phase
The Current UL1449

3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required)
- **Short circuit current rating**
- Nominal Discharge Current Rating
- System voltages
- System frequency
- Voltage Protection Rating

Model #: XYZ-400-208Y
SCCR: 100kA
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Sys. Frequency: 50/60Hz
VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007

Suitable for use on a circuit capable of delivering not more than 100,000 rms symmetrical amperes.

No Change
Short circuit current rating SCCR

• Measure of how much current the electrical utility can supply during a fault condition
The Current UL1449

3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required)
- Short circuit current rating
- Nominal Discharge Current Rating
- System voltages
- System frequency
- Voltage Protection Rating

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Sys. V: 100V/174V; 120/208V; 127V/220V
Sys. Frequency: 50/60Hz
VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007
Suitable for use on a circuit capable of delivering not more than 100,000 ms Symmetrical Amperes.

New
Nominal Discharge Current - $I_n$

- Rating introduced with UL 1449 3rd Edition
- Measure of the “ruggedness” or “robustness” of an SPD
- Measure of how the SPD performs when installed and subjected to operating scenarios closer to real life situations
- “Stress test” – SPD is subjected to 15 surges, one minute apart, with rated voltage applied between surges
• Manufacturer chooses a current they want to test with:
  – Type 1 – 10kA or 20kA
  – Type 2 – 3kA, 5kA, 10kA or 20kA
• Complete SPD is tested along with any required overcurrent devices (fuse or breaker)
• Measured let through voltage for a 6000V 3000A surge is recorded
• SPD is subjected to 15 surges at chosen current one minute apart with rated voltage applied between surges
• Measured let through voltage for a 6000V and 3000A surge is recorded again – let through voltage must not deviate more than 10% from original voltage (this is brand new!)
• The top tier manufactures will test their Type 1 and 2 units at 20kA

• All things being equal, customers and specifiers should choose $I_n$ of 20kA on units larger than 120 kA

• Energy = $I^2R$
  – 10kA SPD can only take 25% of the energy of 20kA
  – 5kA SPD can only take 6.25% of the energy of 20kA
  – 3kA SPD can only take 2.25% of the energy of 20kA

• Unless there is a **significant** difference in cost between a 20kA $I_n$ SPD and a lower $I_n$ SPD, our recommendation is to choose the 20kA SPD on units larger than 120 kA
The Current UL1449

3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required)
- Short circuit current rating
- Nominal Discharge Current Rating
- System voltages
- System frequency
- Voltage Protection Rating

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VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007
Suitable For Use on a Circuit Capable of Delivering Not More Than 100,000 rms Symmetrical Amperes.

No change
The Current UL1449

3rd Edition Specification

- SPD Type
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Date of Manufacture: 11/21/2007
Suitable For Use on a Circuit Capable of Delivering Not More Than 100,000 rms Symmetrical Amperes.

No change
The Current UL1449

3rd Edition Specification

- SPD Type
- NRTL listing mark
- Peak surge current per phase (not required)
- Short circuit current rating
- Nominal Discharge Current Rating
- System voltages
- System frequency
- **Voltage Protection Rating**

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VPR: 700V L-N; 700V L-G; 700V N-G
Date of Manufacture: 11/21/2007

Suitable For Use on a Circuit Capable of Delivering Not More Than 100,000 rms Symmetrical Amperes.

New
Voltage Protection Rating

“VPR”

- Voltage Protection Rating is assigned to an SPD model by the NRTL from a table based on the average of the measured limiting voltage from 3 impulses of a 6000V/3000A Transient

<table>
<thead>
<tr>
<th>Measured Limiting Voltage</th>
<th>Voltage Protection Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>330 or less</td>
<td>330</td>
</tr>
<tr>
<td>331 - 400</td>
<td>400</td>
</tr>
<tr>
<td>401 - 500</td>
<td>500</td>
</tr>
<tr>
<td>501 - 600</td>
<td>600</td>
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<td>601 - 700</td>
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<td>701 - 800</td>
<td>800</td>
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<td>801 - 900</td>
<td>900</td>
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<td>901 - 1000</td>
<td>1000</td>
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<tr>
<td>1001 - 1200</td>
<td>1200</td>
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<td>1201 - 1500</td>
<td>1500</td>
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<tr>
<td>1501 - 1800</td>
<td>1800</td>
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<td>1801 - 2000</td>
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<td>4001 - 5000</td>
<td>5000</td>
</tr>
<tr>
<td>5001 - 6000</td>
<td>6000</td>
</tr>
</tbody>
</table>
Voltage Protection Rating

“VPR”

• VPR gives an indication of the quality of construction and expected performance

• VPR replaces the old “SVR” surge voltage rating which only tested with 6000V 500A.

• VPR ratings will be higher than the old SVR ratings because VPR uses 6000V 3000A
# Summary

<table>
<thead>
<tr>
<th>Out</th>
<th>In</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TVSS</strong></td>
<td><strong>SPD</strong></td>
</tr>
<tr>
<td>Transient Voltage Surge Suppressor</td>
<td>Surge Protection Device</td>
</tr>
<tr>
<td><strong>SVR</strong></td>
<td><strong>VPR</strong></td>
</tr>
<tr>
<td>Surge Voltage Rating</td>
<td>Voltage Protection Rating</td>
</tr>
<tr>
<td><strong>Category A,B,C</strong></td>
<td><strong>Type 1,2,3,4</strong></td>
</tr>
<tr>
<td>Location A-1,2,3/B-1,2,3/C-1,2,3</td>
<td>Locations</td>
</tr>
</tbody>
</table>
NEC Code and SPD

2014 and 2017 NFPA 70 NEC REQUIREMENTS for SPD’s

695.15
700.8
708.20
670.6
620.51(E)
645.18
694.7(D)
700.8 Surge Protection. A listed SPD **shall** be installed in or on all emergency systems switchboards and panelboards.

700.2 Emergency Systems are: Those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, ... illumination is required for safe exiting... such as hotels, theaters, sports arenas, health care facilities, and similar institutions... ventilation, fire detection and alarm systems, elevators, fire pumps, public safety communications systems, industrial processes where current interruption would produce serious life safety or health hazards, and similar functions.
620.51 (E) Surge Protection. Where any of the disconnecting means in 620.51 has been designated as supplying an emergency system load, surge protection shall be provided.

620.51 Loads are: 1. Elevators Without Generator Field Control. 2. Elevators with Generator Field Control. 3. Escalators and Moving Walks. 4. Platform Lifts and Stairway Chairlifts.
670.6 Surge Protection. Industrial machinery with safety interlock circuits **shall** have surge protection installed.

Note: it says “shall have”, not “should have” surge protection installed. "Industrial machinery with safety interlock circuits shall have surge protection installed". The concern is failure of safety interlocks on machinery poising safety risk to operators that may not be aware of disabled safety mechanisms.
695.15 Surge Protection. A listed surge protection device shall be installed in or on the fire pump controller.
708.20 Surge Protection Devices. Surge protection devices **shall** be provided at all facility distribution voltage levels... in Critical Operations Power Systems (COPS)

708.2 Critical Operations Power Systems (COPS). Power systems for facilities or parts of facilities that require continuous operation for the reasons of public safety, emergency management, national security, or business continuity.
645.18 Surge Protection for Critical Operations Data Systems. Surge protection **shall** be provided for critical operations data Systems.

645.2 Critical Operations Data System. An information technology equipment system that requires continuous operation for reasons of public safety, emergency management, national security, or business continuity.
**694.7(D) Surge Protective Devices (SPD).** A surge protective device **shall** be installed between a wind electric system and any loads served by the premises electrical system.
Proper Installation of SPD’s
Surge Protection

What’s Wrong With This Picture?
Surge Protection

And This?
Connector Lead Length

• Absolutely Critical!
• Transients occur quickly-<.000028 sec.
• Each foot of conductor adds
  \(\approx\) 100V to 200V on the
  let through voltage
• Need short, straight, lead lengths
Typical Installations
Typical Installations
8.6.4 Premise electrical system surge protection

In addition to surge protective devices installed in the service entrance equipment, it is recommended that additional surge protective devices of listed Category “b” or Category “A,” as specified in IEEE Std C62.41-1991, be applied to downstream electrical switchboards and panelboards, and panelboards on the secondary of separately derived systems if they support communications, information technology equipment, signaling, television, or other form of electronic load equipment (see Figure 8-25).

Figure 8-25 – Typical locations of power distribution surge protective devices

From ANSI/IEEE 1100
Power Quality Pyramid

Custom Solution

Uninterruptible Power Supply System

Power Conditioning

Harmonic Cancellation

Grounding and Surge Protection Devices
IEEE 1100 6.1 States:

The site survey is the primary tool utilized in locating the source of the (Power Quality) disturbance.
IEEE 1100 6.4 Tells us how to conduct a site survey

**Level 1 survey.**
Visual inspection and analysis of ac distribution and grounding system supplying the equipment.

**Level 2 survey.**
Level 1 plus monitoring of applied ac voltage and load current for the equipment.
END

Thank you for attending