

Chris M. Finen, P.E.
Application Engineer
Eaton Electrical

Understanding TVSS and its Application

EAT•N

Cutler-Hammer

Overview

- Background
- Test waveforms and standards
- TVSS Features
- Application and Mounting Considerations
- NEC Code Compliance
 - Changes in 2005
- TVSS Overcurrent Coordination – Safety
- Upcoming UL1449 Changes
- Industry Myths
- Specification Guidelines

You Can't Afford to Take Risks

**Lightning strikes the earth
6,000 times a minute**

Each year, there are over \$1 billion worth of lightning-related insurance industry losses

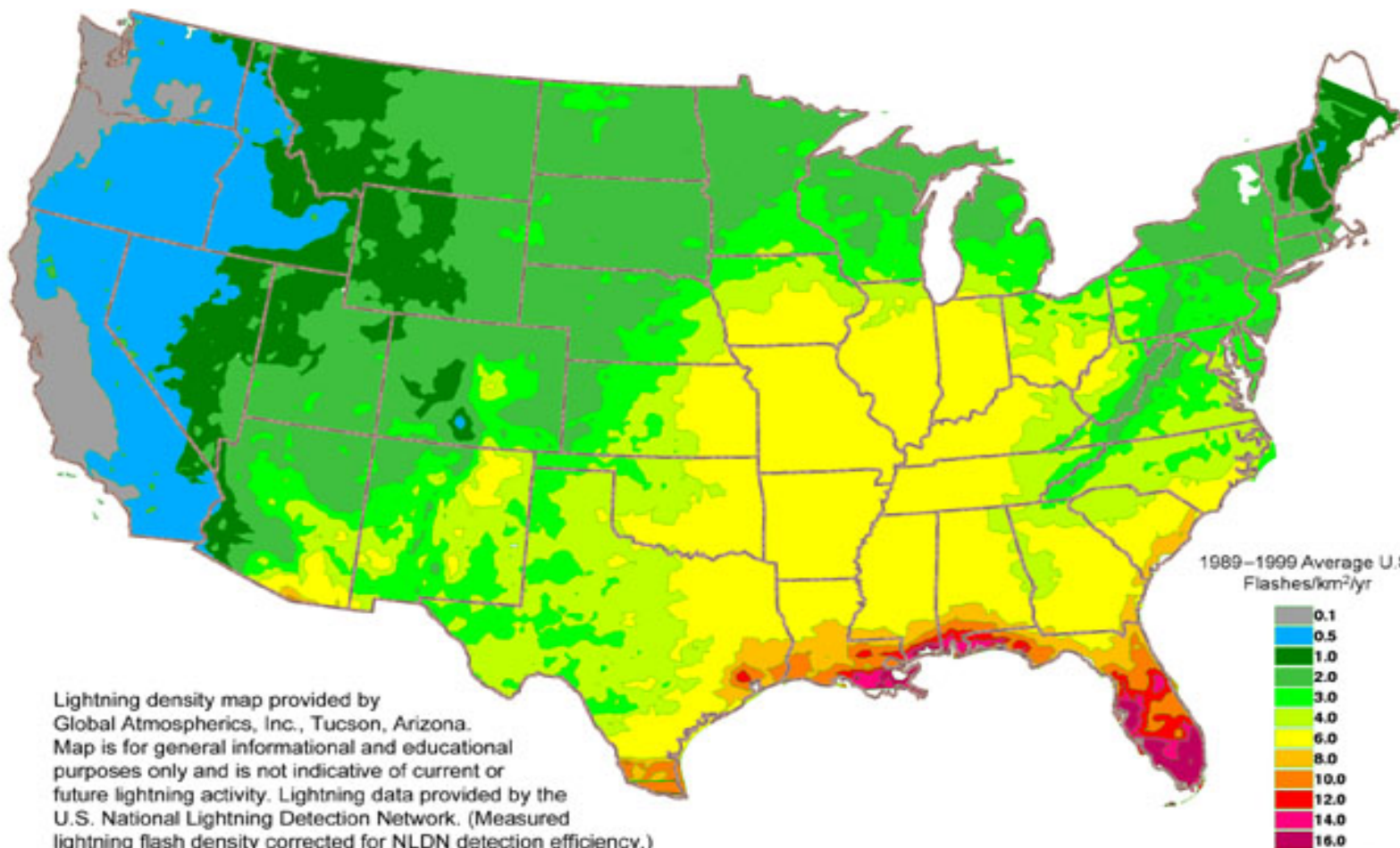
**Nashville Area
averages 6 strikes/km²
per year**

Lightning Activity stats for the US



Global Atmospheric, Inc.

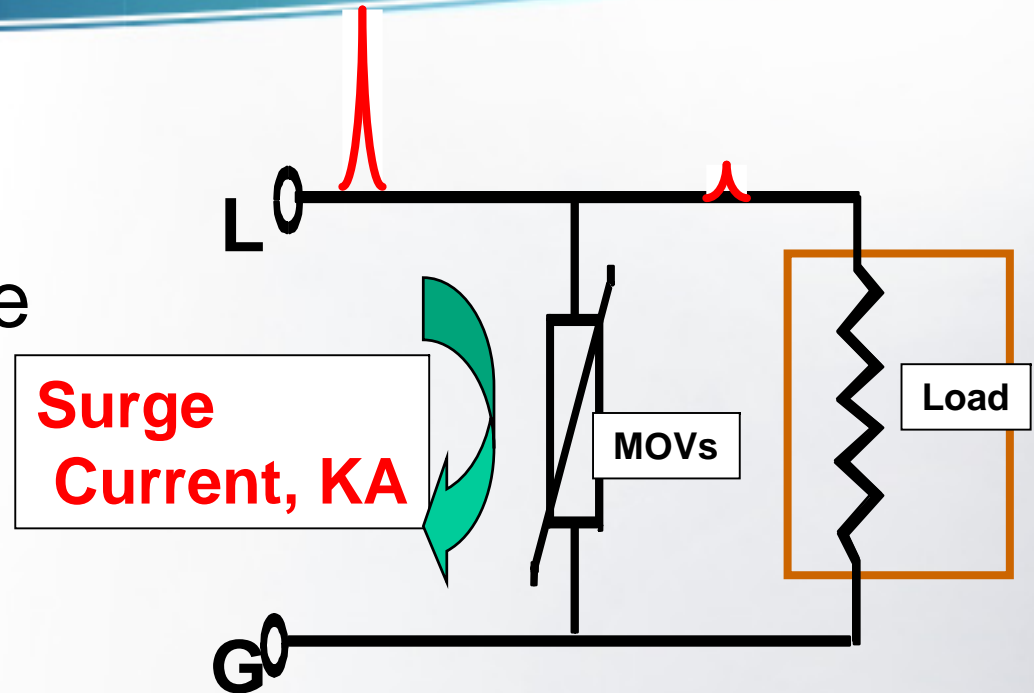
10-year Flash Density Map – U.S.



Lightning density map provided by Global Atmospheric, Inc., Tucson, Arizona. Map is for general informational and educational purposes only and is not indicative of current or future lightning activity. Lightning data provided by the U.S. National Lightning Detection Network. (Measured lightning flash density corrected for NLDN detection efficiency.)

How Does TVSS Work?

- TVSS is a passive, parallel connected device
- Under “normal” circumstances, TVSS has extremely high impedance to ground
- During a surge event, the TVSS instantly changes to a very low impedance
- Surge is shunted to ground



Summary of Applicable Standards

| Standard (current revision date) | Purpose of Standard/Comments |
|---|---|
| UL 1449 (1987) - Transient Voltage Surge Suppressors | <ol style="list-style-type: none"> 1. Safety Test (constructed of approved components in a safe manner). 2. Suppressed Voltage Rating (let-through voltage rating using the IEEE C62.41 C1 test wave). Other IEEE recommended wave forms such as the C3 and B3 Ringwave are not tested by UL. <p>Note: UL 1449 does not require a maximum surge current test.</p> |
| UL 1449 (2 nd Edition 1996) | <ol style="list-style-type: none"> 1. Additional Safety Tests. Test for other standards used to improve safety of products. 2. Surge Test. Let through voltage tested at lower current than 1st Edition 10 kA (IEEE Cat C3) used for the first time, however, it was used only to see if products fail safely. |
| UL 1283 (1996) - Electromagnetic Interference Filters | <p>This safety standard covers EMI filters connected to 600 V or lower circuits.</p> <p>The UL 1283 is a safety standard and does include performance tests such as MIL-STD-220A Insertion Loss or Cat B3 Ringwave Let-Through Voltage tests.</p> |
| UL 497, 497A, 497B | Safety standard for primary telephone line protectors, isolated signal loops and surge protection used on communication/data lines. No performance tests conducted for data/communication lines. |
| IEEE C62.41 (1991) | Recommended Practice on Surge Voltages in Low Voltage AC Power Circuits (ANSI). This document defines the test waves for SPDs. |
| IEEE C62.45 (1992) | Guide on Surge Testing for Low Voltage Equipment (ANSI). This document describes the test methodology for testing SPDs. |
| IEEE Emerald Book | Reference manual for the operation of electronic loads (includes grounding, power requirements, etc.) |
| NEMA LS-1 | NEMA Technical Committee guide for the specification of surge protection devices including physical and operating parameters. |
| NEC | National Electrical Code articles 245, 680 and 800 |
| NFPA 780 | Lightning Protection Code recommendations for the use of surge protection devices at a facility service entrance. |

TVSS IEEE and UL Tests

● IEEE Categories (Emerald Book)

Category A

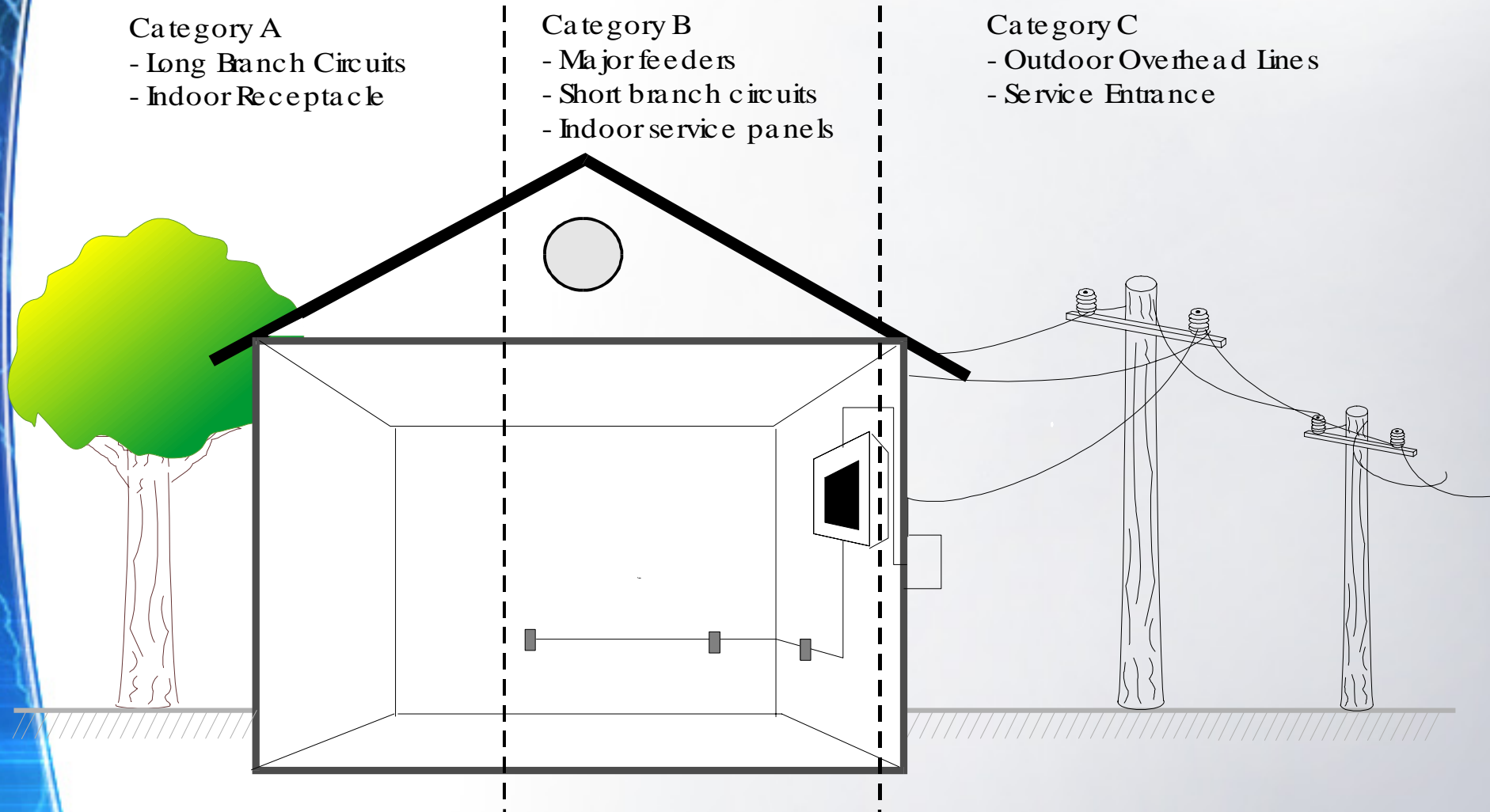
- Long Branch Circuits
- Indoor Receptacle

Category B

- Major feeders
- Short branch circuits
- Indoor service panels

Category C

- Outdoor Overhead Lines
- Service Entrance



TVSS IEEE and UL Tests

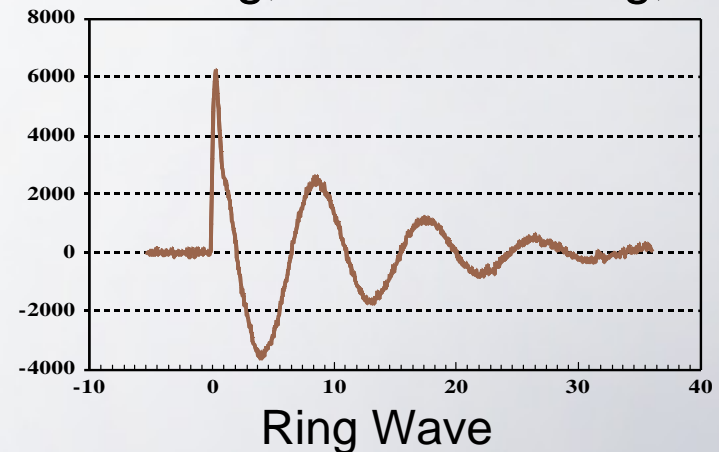
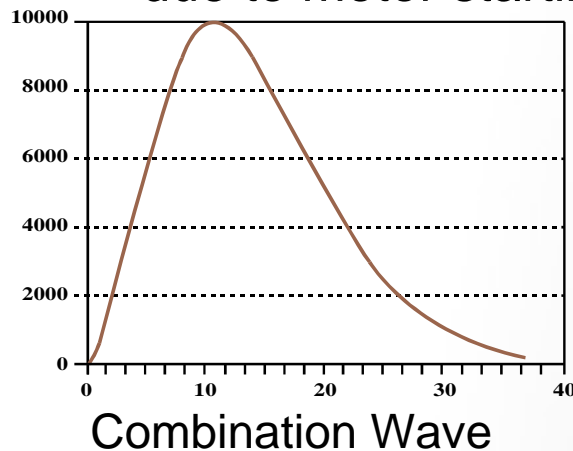
- IEEE Test Waveforms

| Category | Level | Voltage (kV) | 0.5 μ S x 100kHz Ring Wave Current (A) | 1.2 x 50 μ ^S (V) 8 x 20 μ ^S (A) Combination Wave Current (kA) |
|-----------|-------------|--------------|--|---|
| A1 | Low | 2 | 70 | |
| A2 | Medium | 3 | 130 | |
| A3 | High | 6 | 200 | |
| B1 | Low | 2 | 170 | 1 |
| B2 | Medium | 4 | 330 | 2 |
| B3 | High | 6 | 500 | 3 |
| C1 | Low | 6 | | 3 |
| C2 | Medium | 10 | | 5 |
| C3 | High | 20 | | 10 |

TVSS IEEE and UL Tests

IEEE Test Waveforms

- Category C3 (20kV, 10kA)
 - Represents the high level surge imposed on an electrical system service entrance due to a direct lightning striking
- Category C1 (6kV, 3kA)
 - Represents a lower order surge on a service entrance caused by switching events, distance lightning strikes, etc.
- Category B3 (6kV, 500A 100kHz Ringwave)
 - Represents a typical internally generated repetitive surge event due to motor starting, capacitor switching, breaker closing, etc.



TVSS IEEE and UL Tests

- UL1449 2nd Edition Performance Test Procedure
 - **Let Through Voltage Test (Performed with 6” of wire connected to the unit)**
 - Single 6kV, 500A pulse - measure Let Through Voltage
 - 10 positive 6kV, 3kA pulses
 - 10 negative 6kV, 3kA pulses
 - Another single 6kV, 500A pulse - measure Let Through Voltage*
 - Assign Let Through Voltage classification

*Must not vary from original Let Through Voltage by more than 10%

TVSS IEEE and UL Tests

- UL1449 2nd Edition Safety Test Procedure
 - Overvoltage Test
 - 110% of rated voltage applied for 7 hours
 - Unit may not fail unless it automatically resets
 - Abnormal Overvoltage Test
 - L-L voltage is applied to the L-N mode (i.e. 208vac on a 120vac mode)
 - Unit may fail but must do so safely
 - High Current Test
 - Applies fault current of 25kAIC
 - Low Current Test (Slow Cook Test)
 - .125, .5, 2.5, and 5 amps are applied for 7 hours.

TVSS IEEE and UL Tests

- High Energy Impulse Let-Through Test
 - Let Through Voltage Test (Measured at the terminals of the unit)
 - Single Shot of IEEE Category C3 (20kV, 10kA)
 - NEMA LS-1
 - Recognize the UL1449 tests for let through and safety
 - Additional Maximum Surge Current Rating test
 - “Single Shot” test at rated surge current rating*
- *Maximum surge capable of being generated at an independent lab is 250kA.

TVSS IEEE and UL Tests

- REQUIRE INDEPENDENT TEST REPORTS ON ALL TVSS PRODUCTS
 - Units must be tested as a complete unit
 - Some manufacturers will only test a single component and will calculate the affect of paralleling multiple components
 - All reputable TVSS manufacturers have their TVSS units independently tested to verify ratings

Surge Current (kA) Ratings

- Higher surge current (kA) ratings are achieved by paralleling more MOV's
- Gives more paths for the surge to go to ground
- Each individual MOV has to handle less of the total surge
- Increases the life of the TVSS (# of Repetitive Surges)
- **Higher kA ratings do NOT increase performance, only the life of the unit**

Surge Current Ratings

Let Through Voltage

- Higher kA ratings increase the number of repetitive surges a device can take

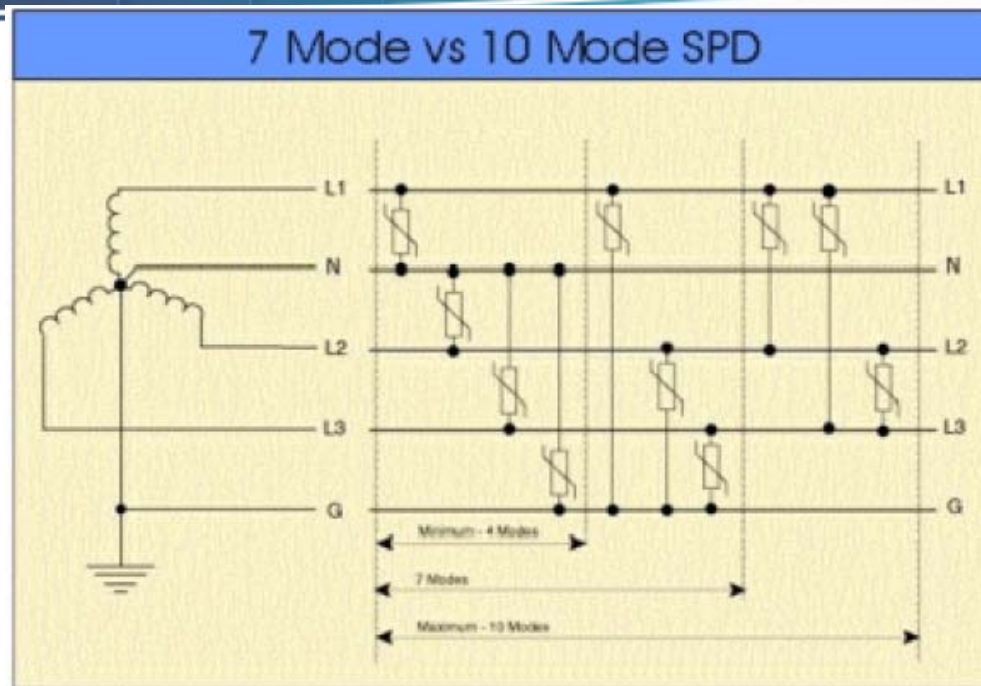
Let though voltage is the same regardless of kA rating

| 208/120v | Modes: | | Repetitive C3 Surges |
|----------|----------|------|----------------------|
| | L-N; L-G | N-G | |
| 100kA | 400v | 330v | 8,000 |
| 120kA | 400v | 330v | 9,000 |
| 160kA | 400v | 330v | 10,000 |
| 200kA | 400v | 330v | 11,000 |
| 250kA | 400v | 330v | 12,000 |
| 300kA | 400v | 330v | 13,000 |
| 400kA | 400v | 330v | 14,000 |
| 500kA | 400v | 330v | 15,000 |

Surge Current Ratings

- Why do are Manufacturers and specifiers pushing higher kA ratings?
 - Has lightning gotten stronger?
 - Have lightning storms become more frequent?
 - Manufacturer “XX” Recommendations
 - 1993250 kA/phase
 - 1995.....350 kA/phase
 - 1997400
 - 1998..... 500
 - 2006..... “To infinity and beyond”
- Recommend ratings for service entrance of **250kA/phase (125kA/Mode)** with minimum Repetitive Surge Rating of 12,000. (~25year life expectancy)

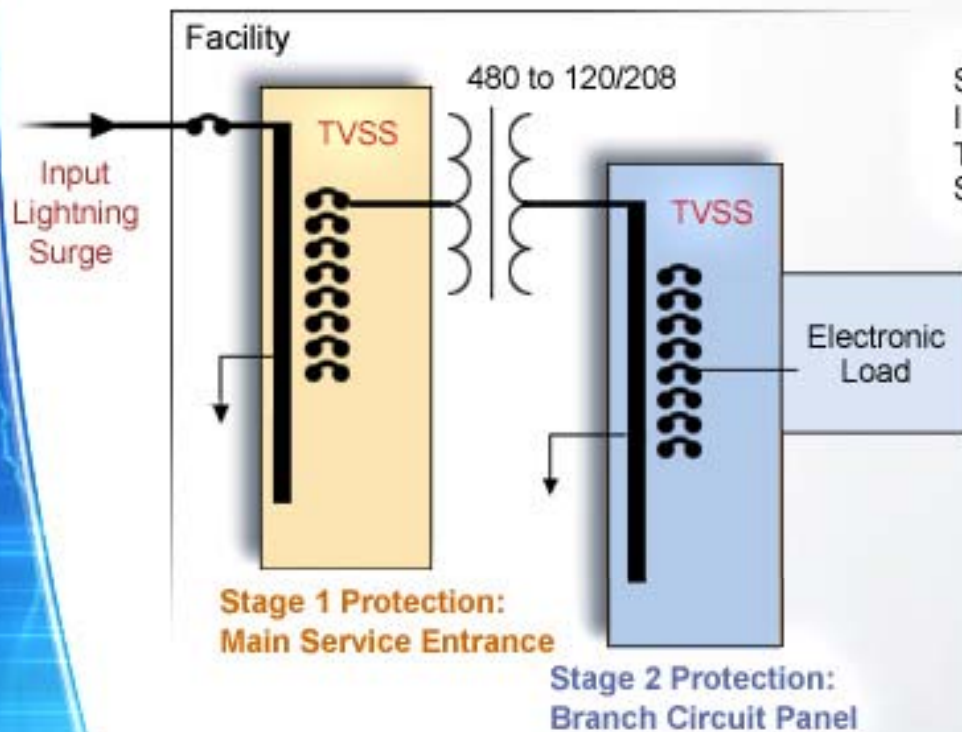
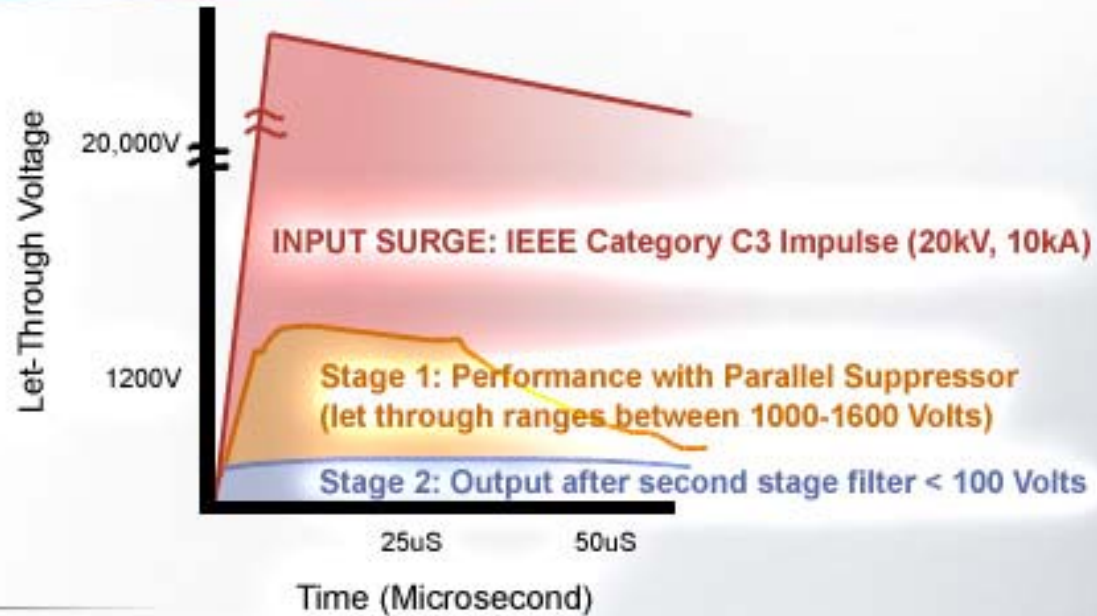
Modes of Protection



- **Each connection is considered a Mode**
 - L-N, L-G, N-G (Wye systems)
 - L-L, L-G (Delta systems)
- **L-L MOV's are not effective on Wye systems**
 - L-L MOV's have higher voltage ratings
 - L-N, L-G MOV's will react much quicker
 - Not impedance matched
 - Don't reduce Let Through Voltage or Life
 - Couple surges to all phases

Surge Current Ratings

“Two Stage” Coordinated Protection Plan



System Test Parameters:
Input Wave: IEEE C62.41 Category C3 Surge (20 kV; 10 kA)
Test procedure: IEEE C62.45
System Voltage 208 Volt (Phase-Neutral)

Surge Current Ratings

Recommendations (maximums)

- Service Entrance (Switchboards, Switchgear, MCC Main Entrance)
 - **250kA/phase (12,000 Repetitive surges)**
- Distribution Panels, High Exposure Roof Top Equipment
 - **160kA/phase (10,000 Repetitive surges)**
- Branch Locations (Panels, MCC, Busway, etc.)
 - **120kA/phase (9,000 Repetitive surges)**
- Series Connected Critical Loads (PLC power supplies, cash registers, etc.)
 - **apply as needed**

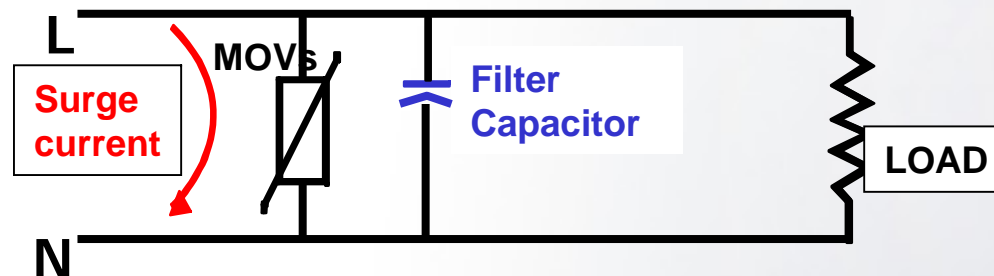
Performance

- What affects TVSS performance (let through voltage)?
 - Filtering (Hybrid TVSS design)
 - Circuit Board Design
 - Circuit Impedance
 - Mounting / Installation

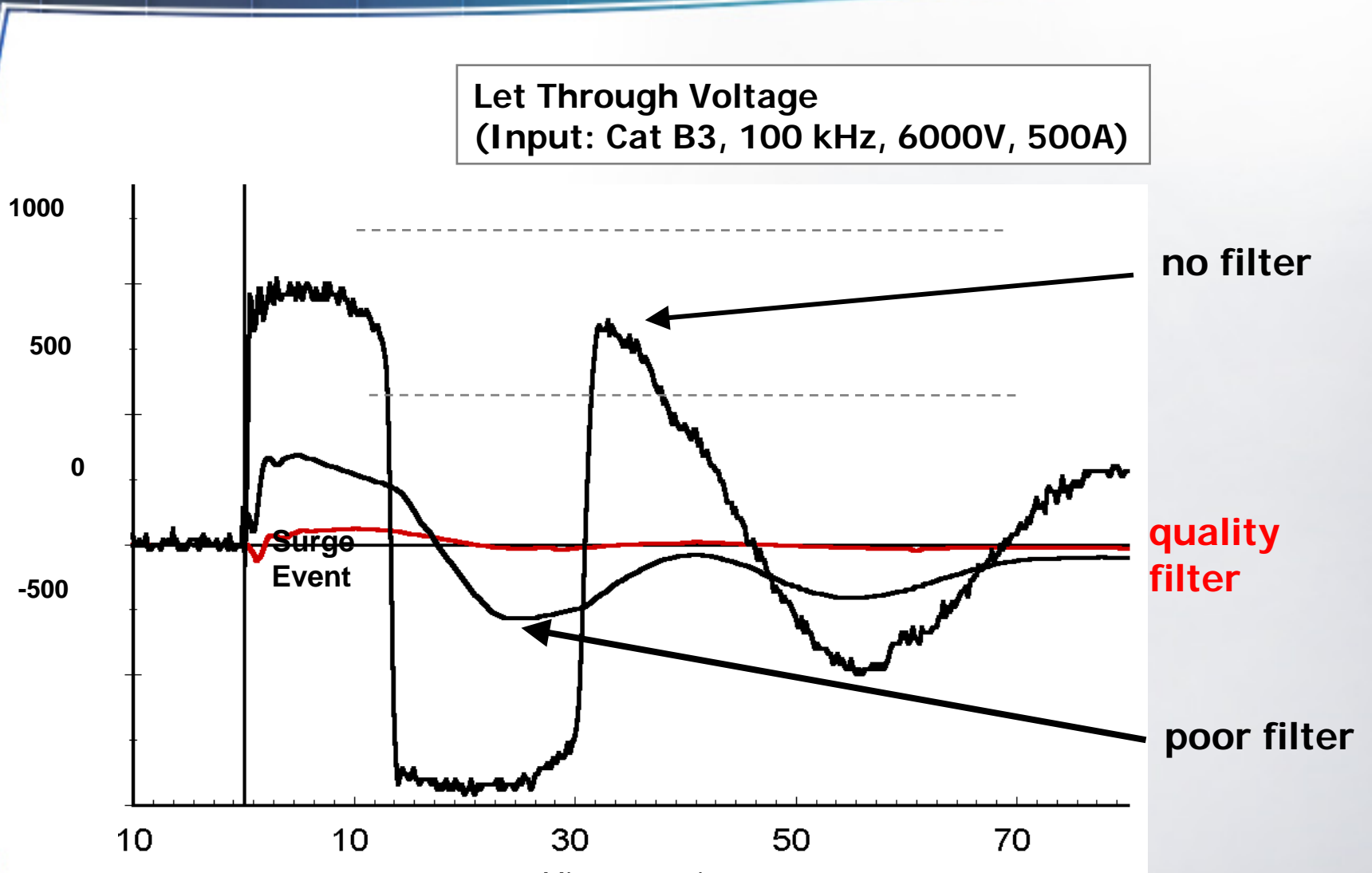
Filtering (aka: Hybrid TVSS, Sinewave tracking)

The benefits realized when combining MOVs and capacitor filtering are:

- **Current Sharing:** Reduces MOV stress and increases life expectancy (better withstand capability)
- **Lower Let-Through Voltage:** Capacitive filters provide an additional low impedance shunt path for both impulse and ringwaves.
- **Noise Attenuation:** Removes low voltage high frequency disturbances at any phase angle (often referred to as “sinewave tracking”).
- **Reliability:** Better performance, longer life and noise attenuation provide more “value” than a “MOV only” device.



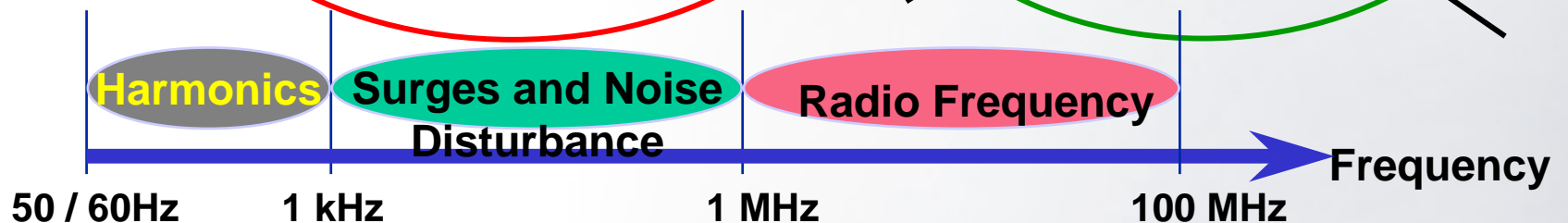
Filtering



Filtering

● Filter Specifications

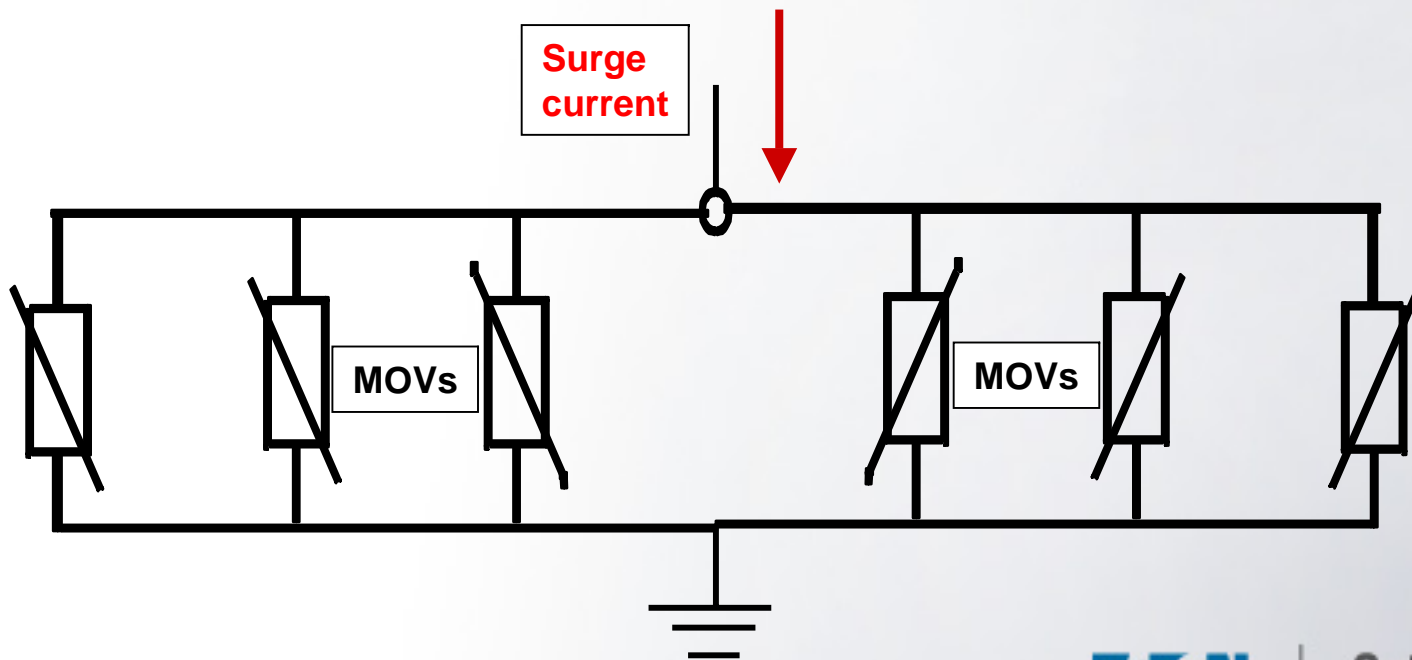
| Attenuation Frequency | 50 kHz | 100 kHz | 500 kHz | 1 MHz | 5 MHz | 10 MHz | 50 MHz | 100 MHz |
|-----------------------|--------|---------|---------|-------|-------|--------|--------|---------|
| | 47 dB | 50 dB | 37 dB | 37 dB | 37 dB | 38 dB | 47 dB | 53 dB |



- EMI/RFI Attenuation: 50dB @ 100kHz
- Filter Bandwidth: 50kHz to 100MHz
- Ringwave Let-Through Voltage < 160v (IEEE Category B3, 208v System L-N)

Circuit Impedance

- Some TVSS manufacturers use a parallel array of MOV's
- This configuration does not equal share surge current. (More impedance to outside MOV's)
- Closer MOV's take more of the surge energy, can fail sooner



Circuit Board Design

- Surge Plane Technology
- Cutler-Hammer is the first to utilize the ground plane concept in the design of a low impedance suppression platform
 - The ground plane provides the lowest possible impedance at high frequencies
 - The plane ensures equal low impedance paths (both resistive and inductive components)
 - Any two points (i.e. A,B,C or D) will be at the same potential

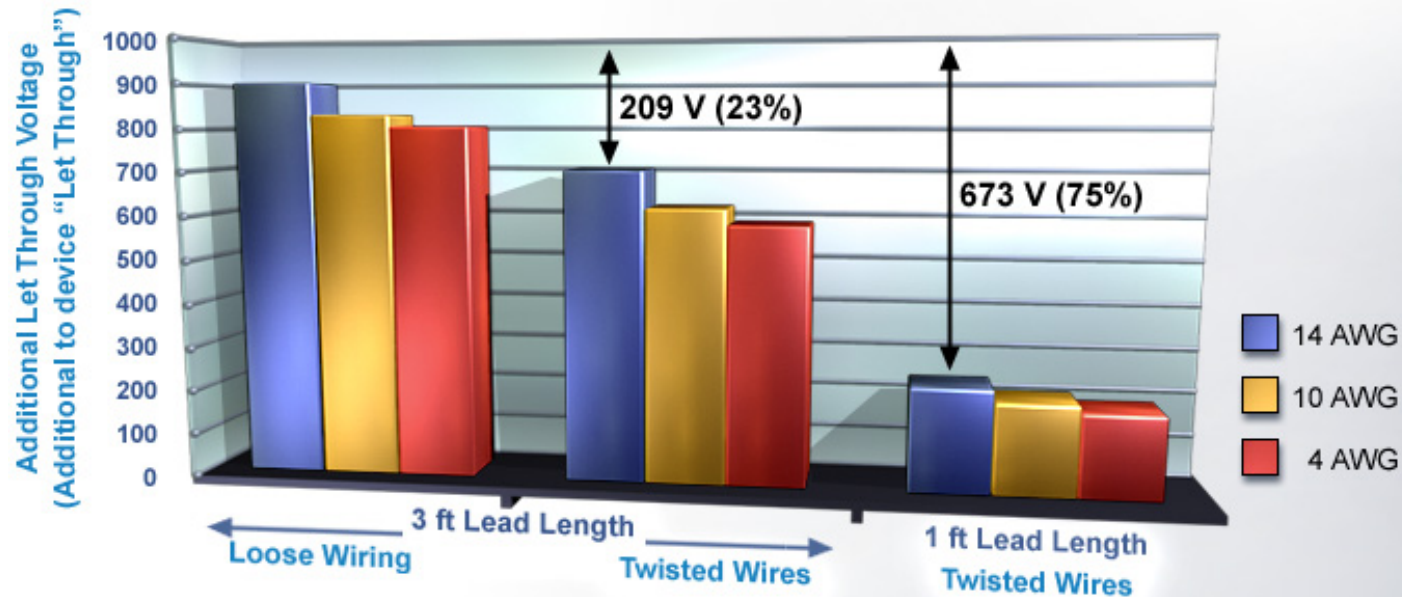


Circuit Impedance

- All MOV's should be matched for impedance in order to equal share surge events
- Most all manufacturers use impedance matched MOV's
- TVSS units with replaceable modules introduce more impedance into the system. (banana clips, etc are not low impedance connections)

Mounting / Installation

Installation Lead Length Can Increase Let-Through Voltage by
15- 25 volts Per Inch



Additional Let-Through Voltage Using IEEE C1 (6000V, 3000A) Waveform (UL1449 Test Wave)

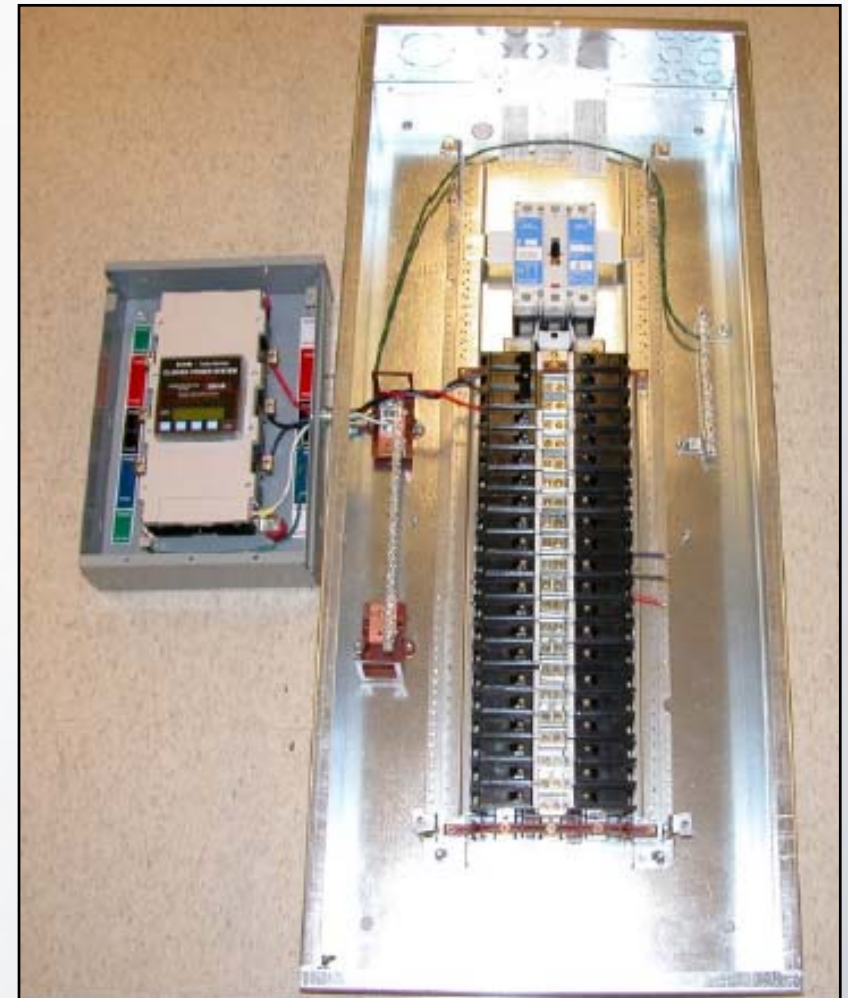
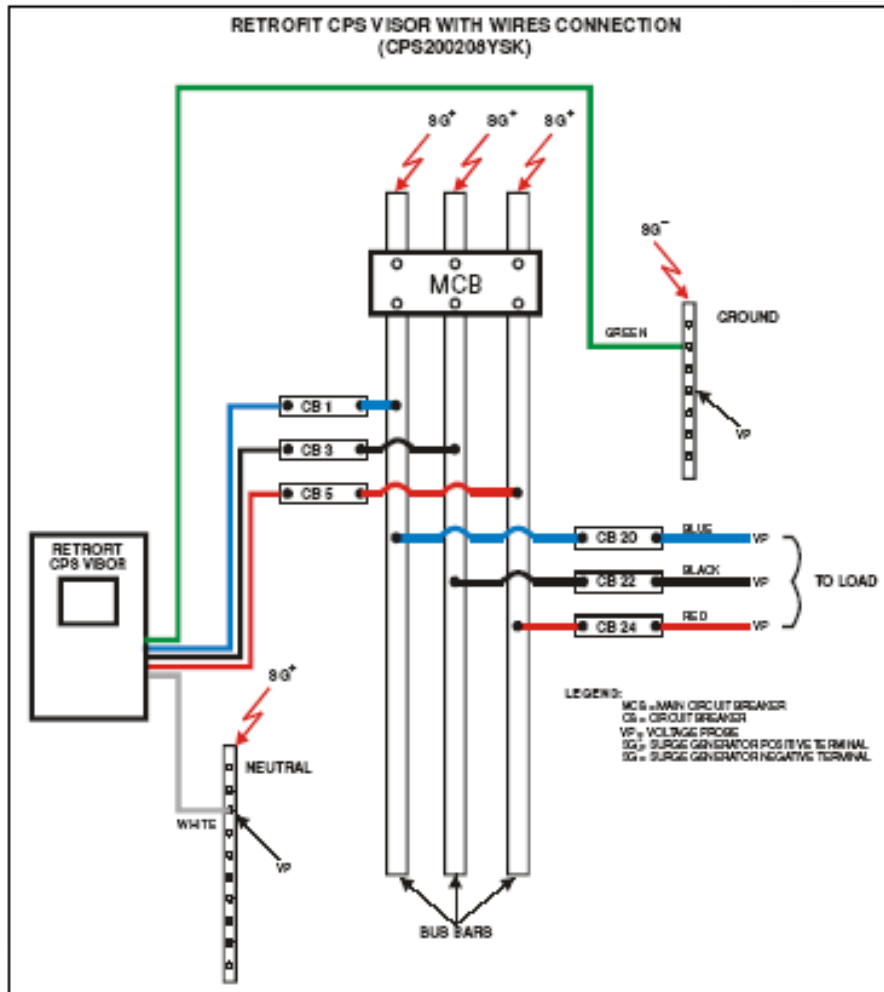
Installation Criteria Order of Importance:

- 1) Lead Length - 75% reduction
- 2) Twisting Wires - 23% reduction
- 3) Larger Wire - minimal reduction

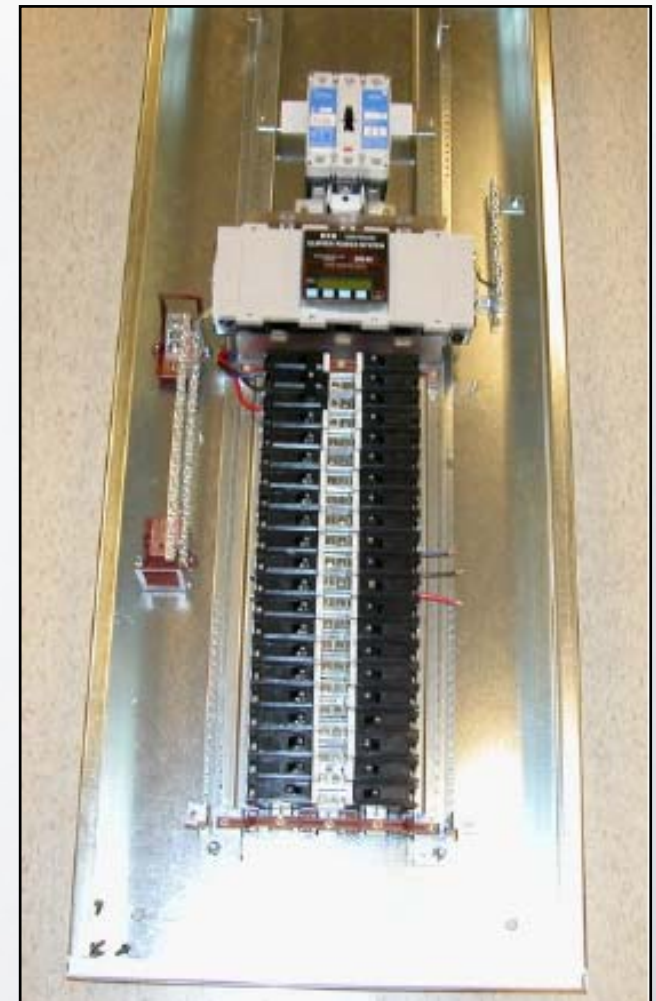
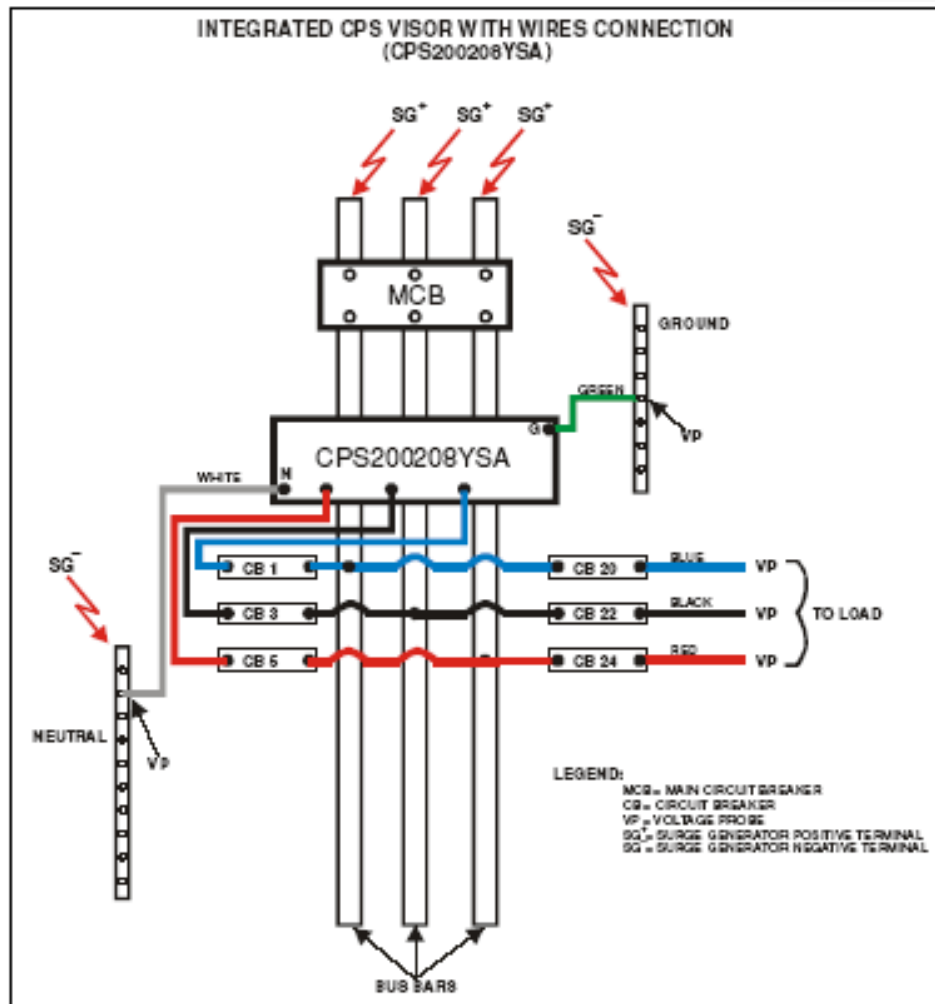
Mounting / Installation

- Three main types of TVSS mounting / installation
 1. Side Mounted
 2. Integrated with cable connection to a breaker
 3. Integrated with direct bus bar mounting
- Eaton Electrical submitted a CPS200 (200kA/phase) unit with each mounting configuration to an independent test lab for Let Through Voltage Testing.
- This independently tests the actual “as installed” performance of the TVSS.

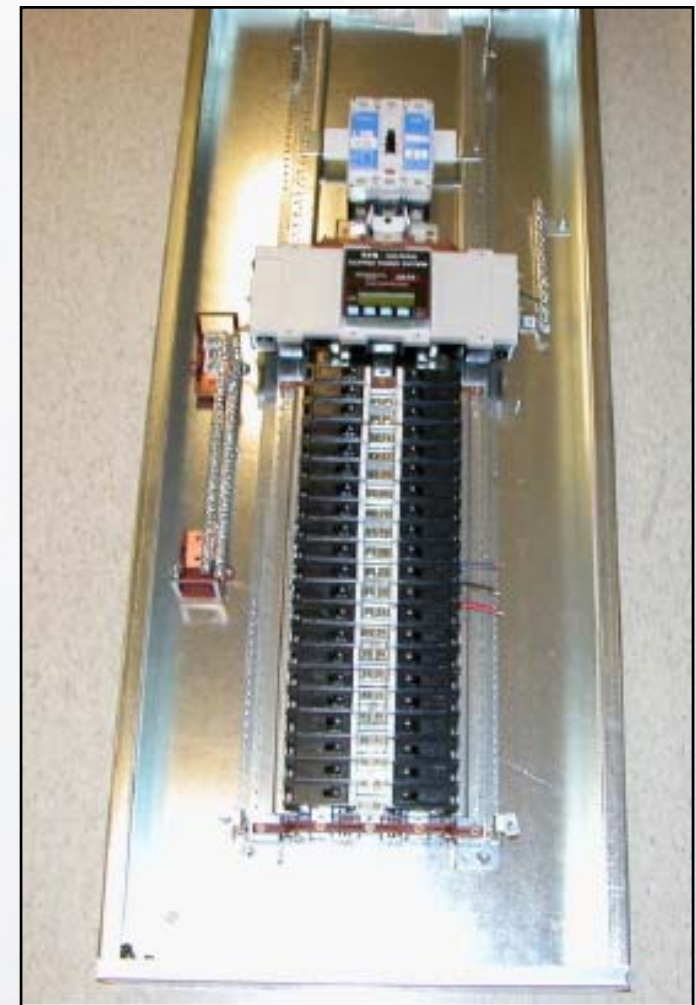
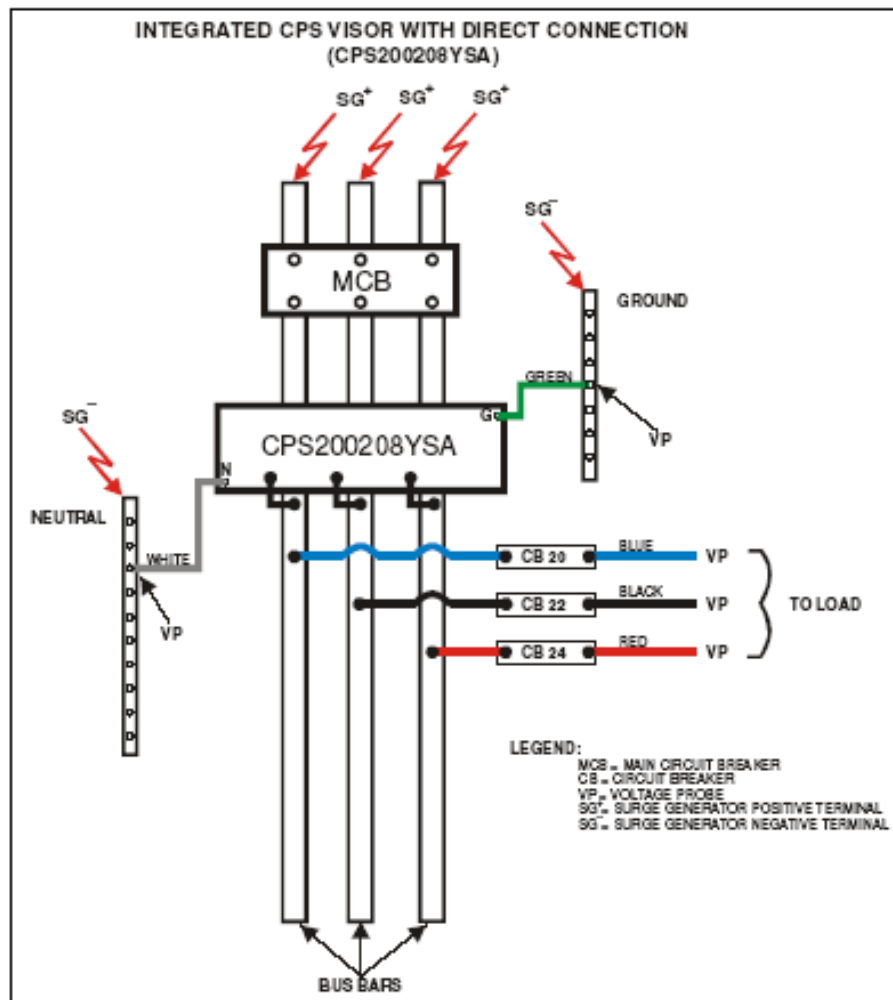
Side Mounted



Integrated – Cabled to breaker



Integrated – Direct Bus Bar Mounting



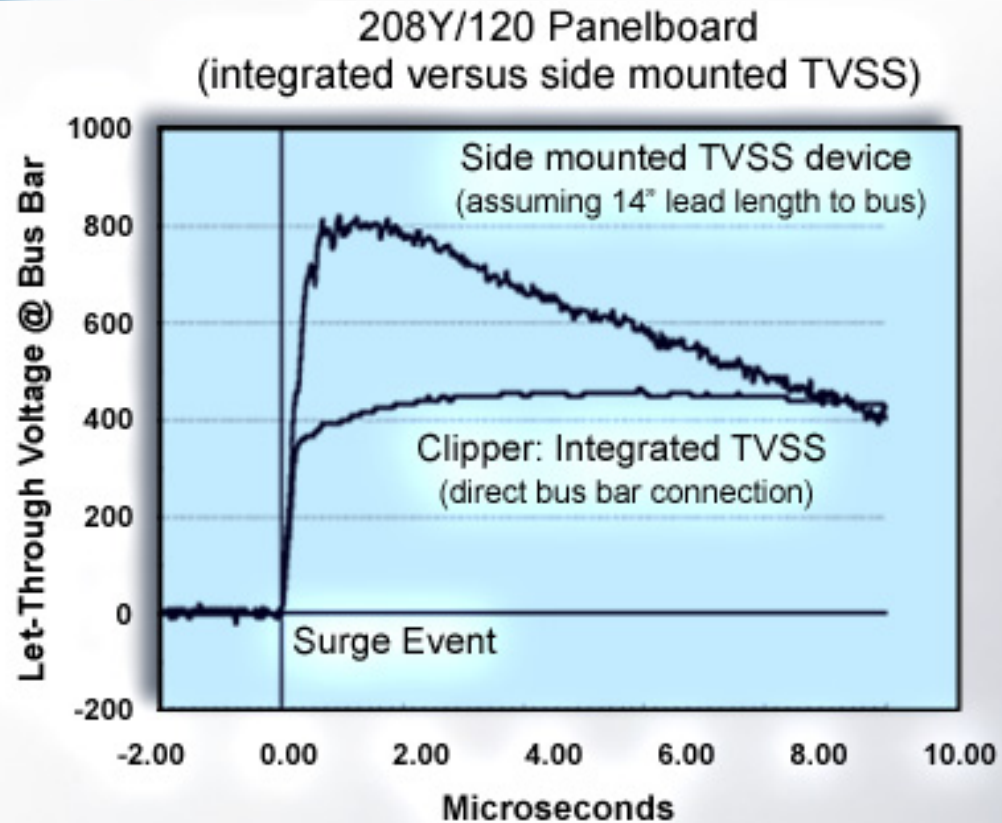
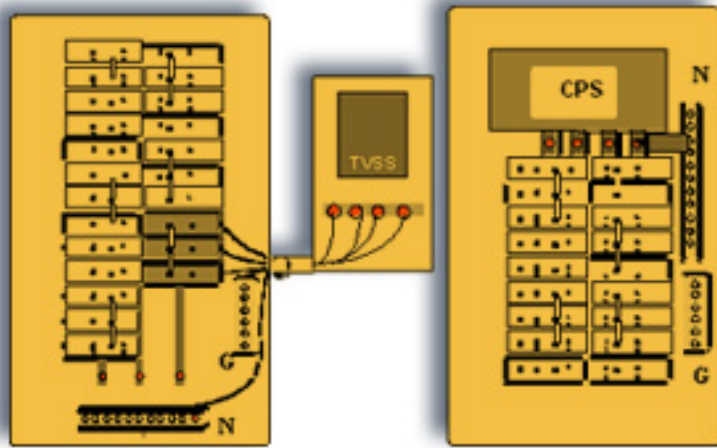
Results

Integrated TVSS with direct bus bar connection is the Best Approach for maximum performance (Lowest Let Through Voltages - LTV)

- Integrated TVSS cabled to breaker allowed **13% - 29%** higher LTV than direct bus bar integrated.
- Side mounted TVSS allowed **28% - 46%** higher LTV than direct bus bar integrated.
- **Conclusion: The identical device can have up to 46% reduction in performance simply by the way it is applied.**
 - New construction should always utilize integrated
 - Side mounted should be used for retrofit applications



Mounting / Installation - Significant Performance Advantages Using Integrated Surge



Less lead length = lower let through voltage

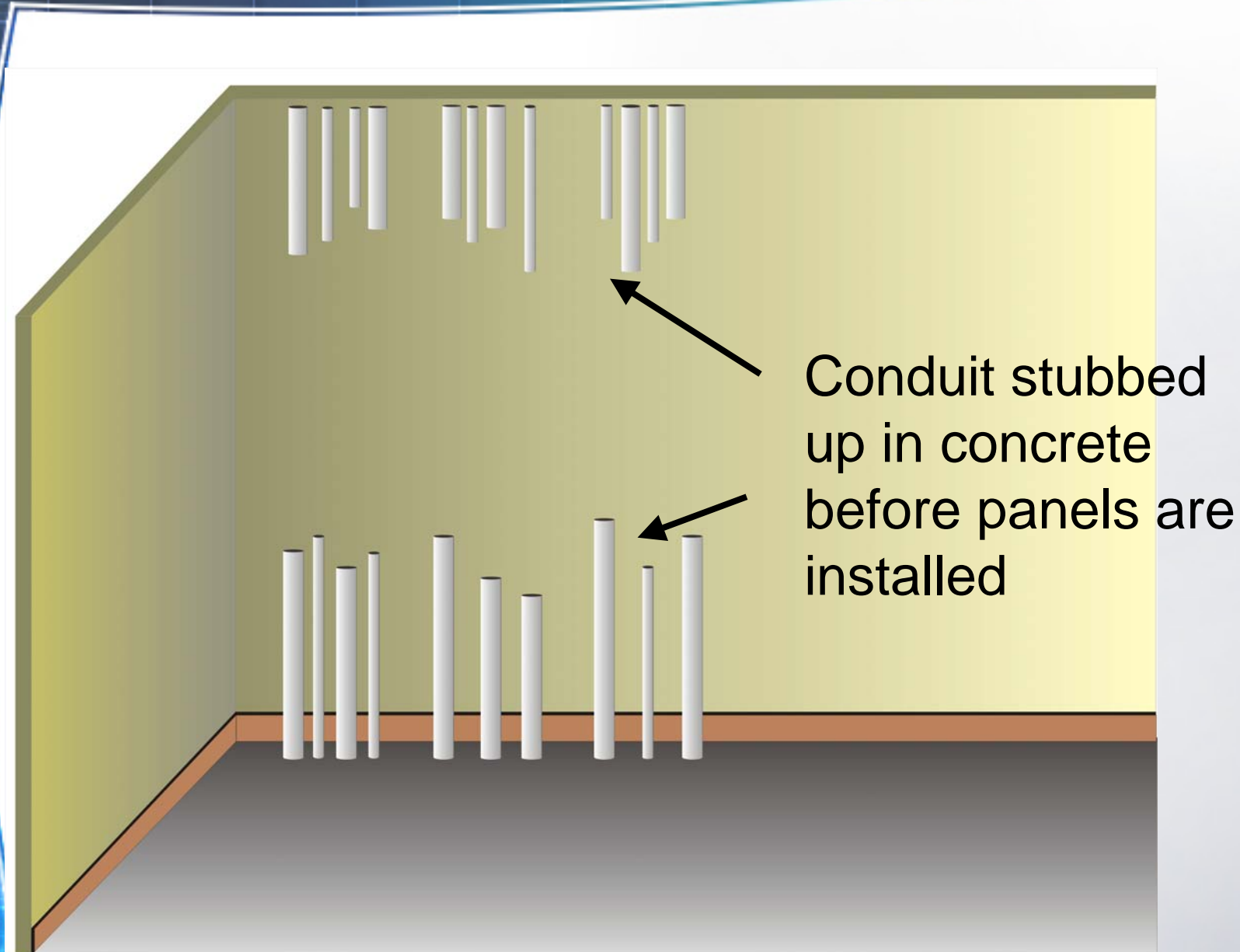
Less components to install in the field

Consistency of installation

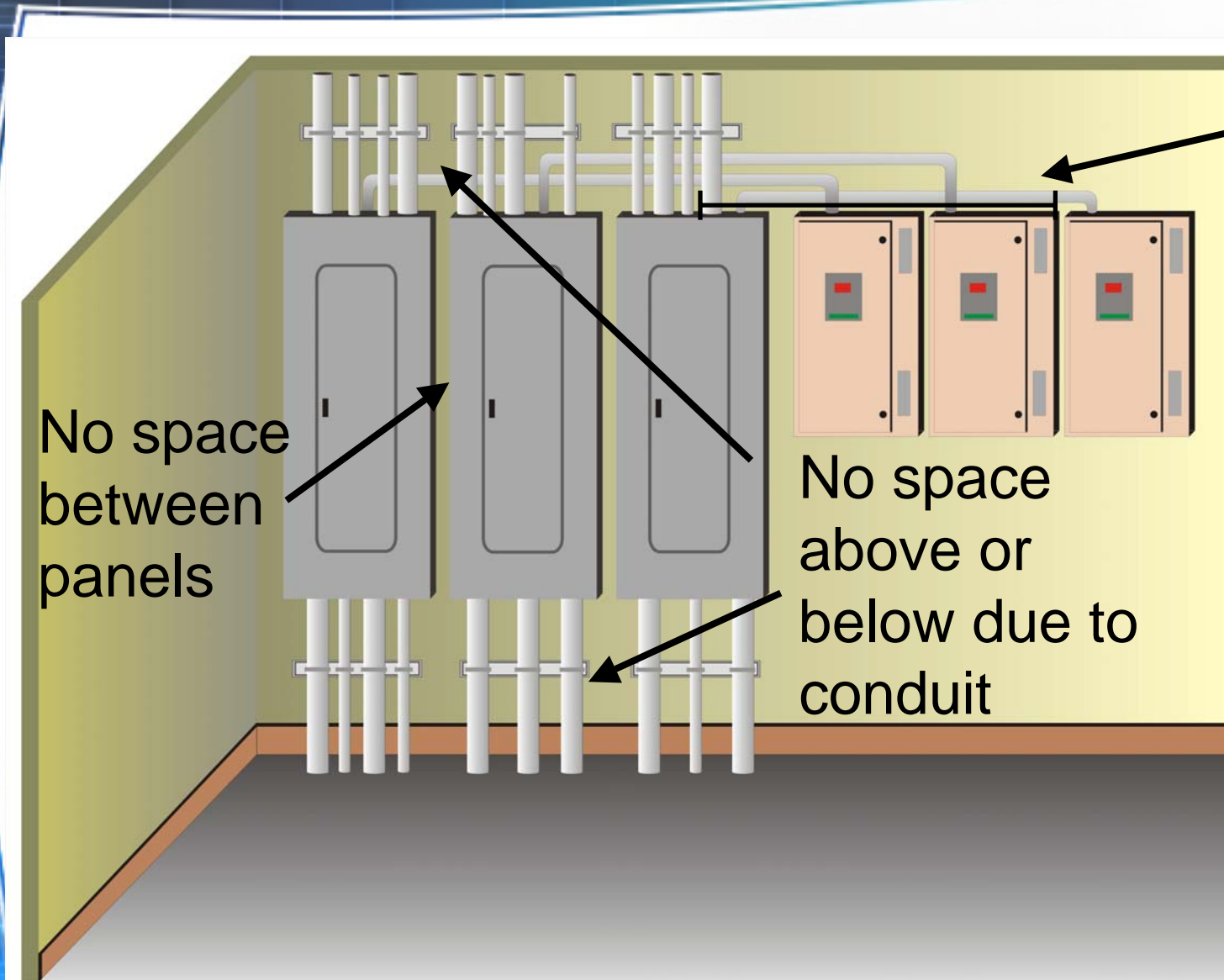
No lost wall space

UL listed as a complete assembly

Advantages to integrated SPDs -Rough In Construction Phase



Side Mounted SPD's Can Not Be Mounted Next To Panel



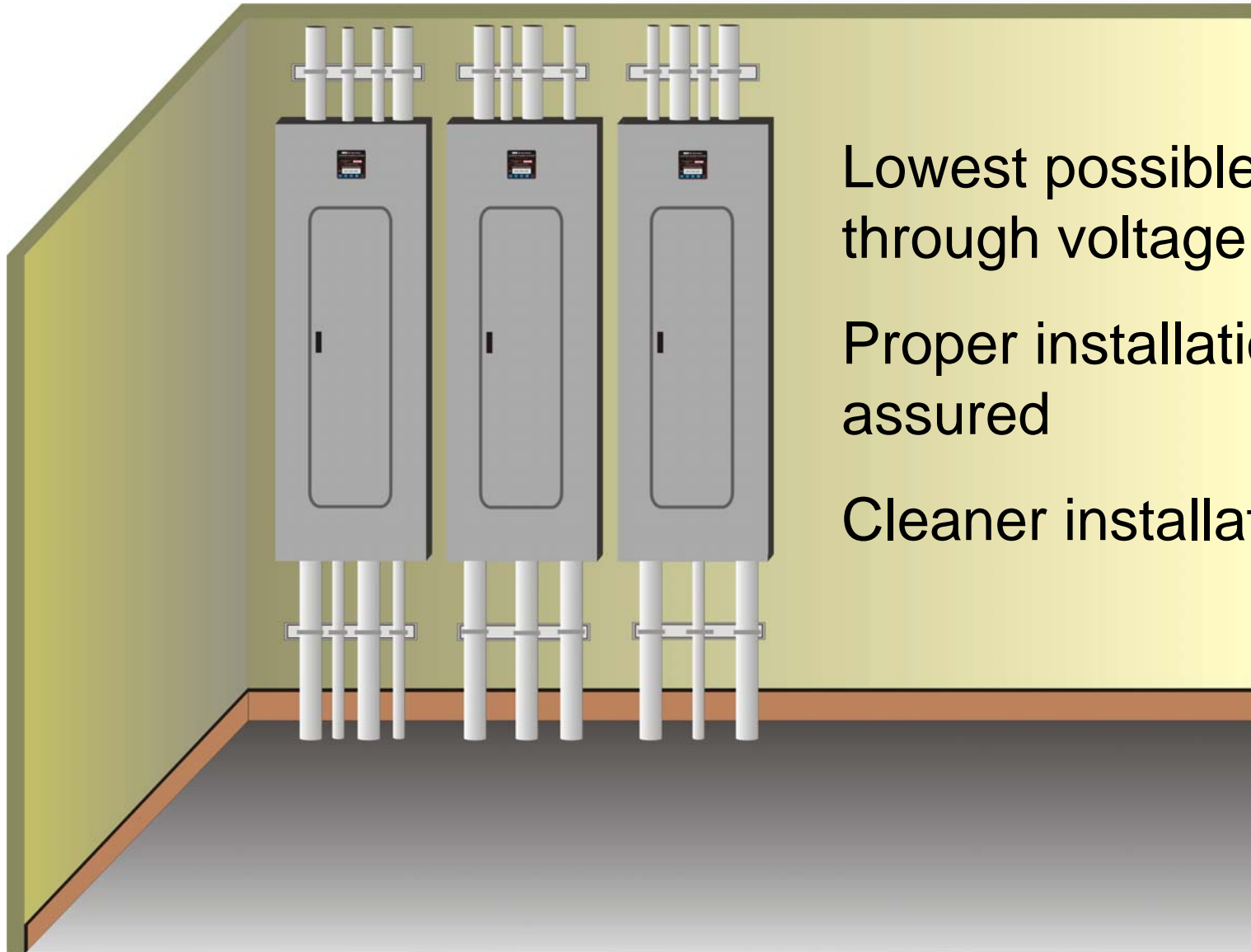
No space
between
panels

No space
above or
below due to
conduit

**Lead length
= 6 - 10 feet**

**Increased
let-through
voltage can
be 100's of
volts!**

Integrated Surge “Guarantees” Correct Installation



Lowest possible let-through voltage

Proper installation is assured

Cleaner installation

Advantages to integrated SPDs - Code Compliance

- 2005 NEC Code changes: (TVSS Article 285)
 - **2002 NEC** TVSS must be mounted downstream of the service disconnecting means.
 - **2005 NEC** (230.82(8)) – TVSS equipment may be permitted on to be connected to the line side of the service disconnecting means if:
 - the TVSS is provided in listed equipment which includes a disconnecting means and overcurrent protection.
 - Side mounted units are only acceptable if they are supplied with a disconnect internal to the TVSS.
(NOTE: This would require the utility to be contacted to disconnect the service in order to remove/replace the TVSS.)

Advantages to integrated SPDs - Code Compliance

- 2005 NEC Code changes: (TVSS Article 285)
 - **2002 NEC** counts the TVSS disconnect as one of the six allowed disconnects on a MLO Service Entrance.
 - **2005 NEC** (230.71(A)) – TVSS disconnect does NOT count as one of the six allowed disconnects if:
 - the TVSS and its disconnect are provided as part of listed equipment
 - Side mounted units are only acceptable if they are supplied with a disconnect internal to the TVSS.
(NOTE: This would require the utility to be contacted to disconnect the service in order to remove/replace the TVSS.)

SPD Overcurrent Protection

How do SPDs fail?

- Most common misconception:
 - SPDs fail from surge events
- This is not the case
- The most common cause of SPD failure (accounting for 90%) is due to temporary over voltage (TOV)
- This condition can be caused from:
 - Loss of neutral on 3ph 4w system
 - Improper installation
 - Elevated system voltage

Example of a Fuse Problem

- Fuses did not work on this over-voltage fault
- MOVs went into thermal run-away, and fuses did not clear fault
- Can result in operation of upstream utility fuse to clear fault, and result in facility shut-down
- Although rare events, these can and do occur



SPD Overcurrent Coordination - Safety

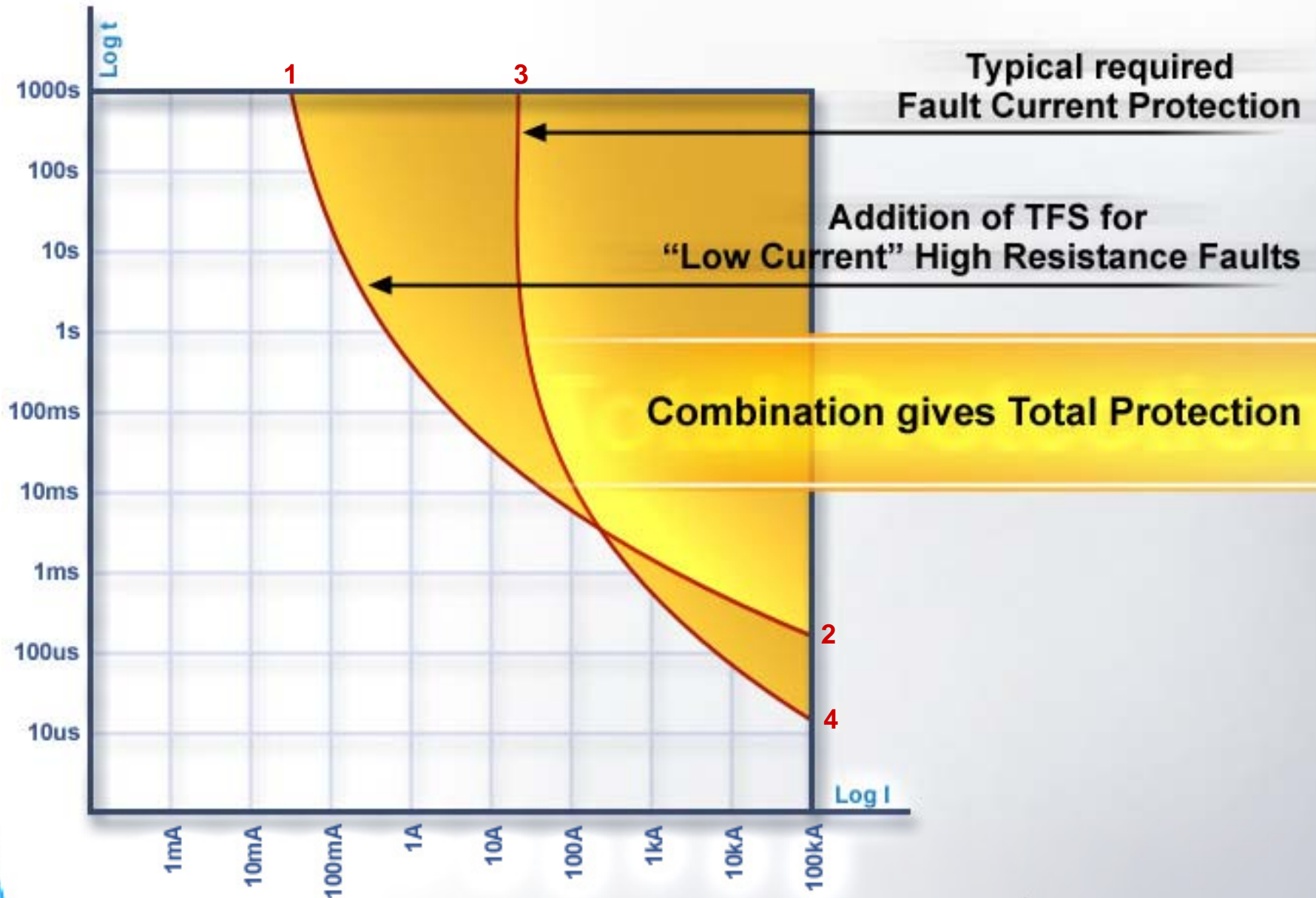
- SPDs should be viewed from a system standpoint – not stand alone devices
 - Coordinated with electrical system
 - Properly connected
- The problem:
 - Need overcurrent protection that can:
 1. Pass large surge currents without opening, but
 2. Must open under low level (high impedance faults)
- This cannot typically be accomplished by a single overcurrent device.
 - Some manufacturers require minimum available fault currents for their TVSS to operate safely.

SPD Overcurrent Coordination - Safety

TVSS Protection must:

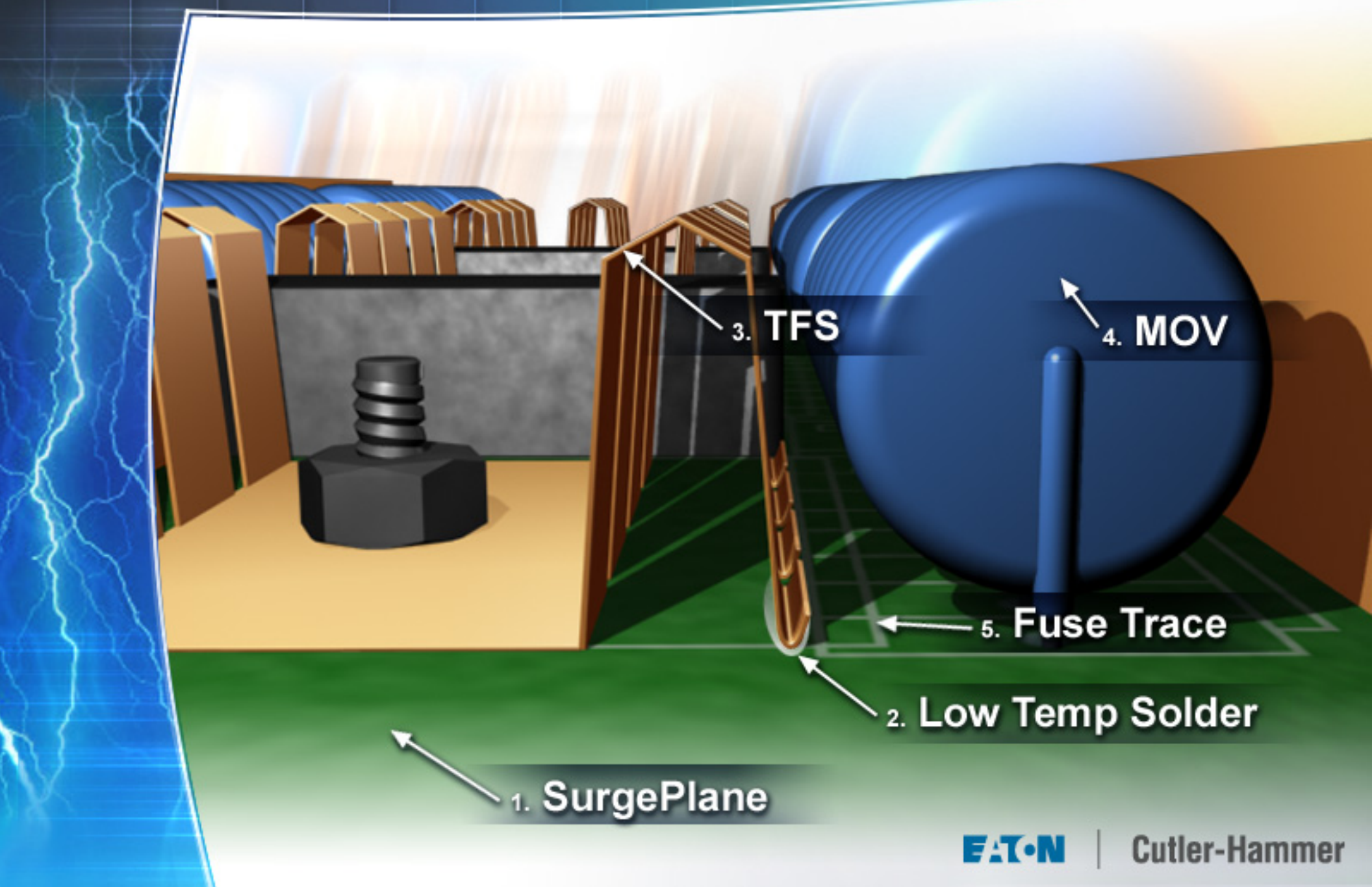
- Eliminate tripping of upstream breaker
- Pass the full rated surge current
 - (100kA - 500kA)
- Safely interrupt fault current ratings for distribution equipment (up to 200kAIC)
- Safely trips under all conditions
 - TOV
 - OV (improper connections)
 - Excessive surge (lifetime)

SPD Overcurrent Coordination - Safety



1-2 Thermal Fuse Spring & Metal Oxide Varistor Combination
3-4 Fuse - Trace as Overcurrent Disconnect

Thermo-Dynamic Fusing™ System



Thermo-Dynamic Fusing™ System



SPD Overcurrent Coordination

How are other SPDs designed?

- Some SPDs attempt to provide high surge current rated fusing (200-300kA)
- And provide low fault current protection from TOV conditions using the same fuse trace
- Physical properties of a fuse means you cannot have it both ways...
- Drawbacks of this approach:
 - The SPD is not disconnected during low current faults (i.e. mis-wiring, open neutral, over-voltage)
 - The upstream circuit breaker trips, resulting in a facility shutdown
 - UL1449 does not test for these low fault current situations (new UL “2.5” Edition safety revision test being added)

Changes to UL1449 Standard

- Currently UL1449 2nd Edition is the recognized industry standard
 - Tests for minimum levels of safety
 - Limited performance (Let Through Voltage) testing
- February 2007 – “2.5th Edition” safety revision
 - Adds a new “Medium” Fault Current test
 - 10, 100, 500, and 1000 amps
 - Voltage is increased until conduction occurs
 - Current level is maintained until failure or protection
 - Must fail safely
 - 2nd Edition only tests 5 amps and below, or 5000 amps and above

Changes to UL1449 Standard

- 3rd Edition (currently released in draft)
 - No major revisions to the “2.5th Edition”
 - Rearranges into Surge Protective Device Types
 - Type 1
 - Surge arrestors
 - Devices can be mounted upstream of main
 - All will have to pass the safety requirements
 - Most surge arrestors as we know them today, will fail
 - Type 2
 - Permanently connected
 - Side mounted
 - Most side mounted TVSS devices as we know them today, will be Type 1 and Type 2 listed

Changes to UL1449 Standard

- 3rd Edition (currently released in draft) (cont'd)
 - Type 3
 - Plug-in devices
 - Surge strips, etc.
 - Type 4
 - Assemblies / UL recognized products
 - Surge products that must be placed inside another assembly
 - Integrated TVSS
 - Series connected filters (AEGIS)
 - Integrated TVSS as we know it today, will be Type 1 and Type 4 listed

TVSS Industry Myths

- Lightning Strokes can produce in upwards of 200,000 amps of surge current. (True or False)
- **TRUE**
- 200,000 amps induced from a lightning strike can flow into the electrical distribution system. (True or False)
- **FALSE**
 - Lightning energy takes various paths to ground (building steel, plumbing, structural components, etc.)
 - IEEE testing says a maximum of 20kV and 10kA gets induced into the distribution system from a lightning event. (Category C3 waveform)

TVSS Industry Myths

(Cont'd)

- Cable insulation would fail and / or arcing would occur at terminals.
- TVSS would never see the surge.
- Circuit breakers and Fuses will open due to surge current:
 - 8kA - 25kA Electronic Trip (Typical on SE)
 - 20kA - 100kA Thermal Magnetic Trip
 - 10kA Class CC Fuse
 - 25kA Class R Fuse
- NEMA LS-1 tests each TVSS to its published surge current rating (up to 250kA)

TVSS Industry Myths

- “Magic” Components

- Selenium Cells

- Metal Rectifiers
- Used since 1920's. Discontinued due to high clamp voltage and superior performance by MOVs, Zeners, etc.
- Not proprietary - Not used by other manufacturers for a reason
- Do not increase surge suppression performance
- Do not provide any appreciable protection from Overvoltages (protection is system impedance dependent)
- Large and heavy



Expanded View of Selenium Cells

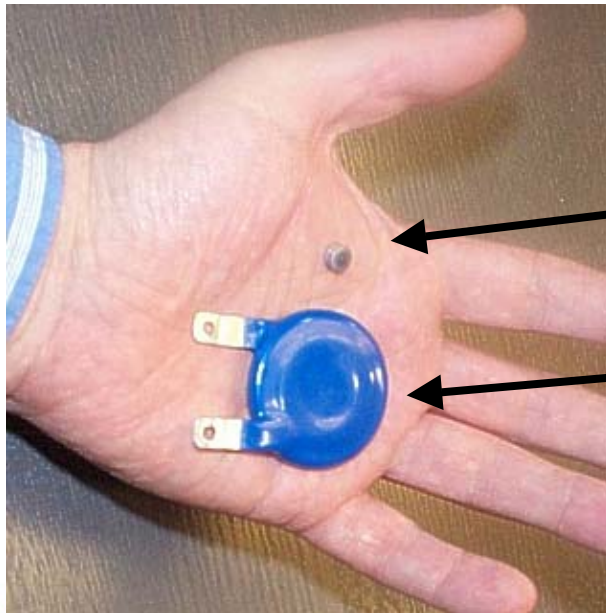
TVSS Industry Myths

- “Magic” Components

- Silicon Avalanche Diodes (SAD’s)

- SADs have faster response time than MOV’s

- Both MOVs & SADs respond 1000 times faster than a surge event. Response time of components is not recognized by IEEE, UL or NEMA.



Silicon Avalanche Diode (SAD):
141Amp (high surge rating)

Metal Oxide Varistor (MOV):
40,000 Amp; 40 mm

Note: SADs have a very low energy content and not recommended for high energy AC surge applications

TVSS Industry Myths

- “Magic” Components
 - Epoxy encapsulated TVSS
 - Epoxy is used purely to keep the TVSS from being dangerous when a failure occurs
 - Epoxy is rigid and cannot vent gases

TVSS Industry Myths

- 3rd Party Integration of TVSS
 - Typically is just a top hat on existing panel
 - TVSS is still wired to a breaker
 - reduced performance
 - Voids Panel / Switchboard UL rating
 - gets replaced with a UL508 panel shop rating
 - Voids manufacturer's warranty
 - any field modifications void the standard manufacturer's warranty
 - Lack of AIC testing and final assembly testing
 - Potential problems with system coordination
 - Lack of field service support

TVSS Industry Myths

- Integral disconnects
 - Disconnect is located inside the TVSS housing
 - Does not provide means for isolating the TVSS
 - Replacement of TVSS still requires a shutdown of the service

Specifying SPD's

- Spec should reflect functional and performance characteristics
 - Avoid specifying “how” the product must be constructed
 - Proprietary components, “space-age” polymers, number of MOV's, size of MOV's, etc.
- Good functional specifications will cover these areas:
 1. Performance
 2. Life
 3. Protection / System Coordination
 4. Warranty
 5. Monitoring

1. Performance

- Specify actual Let Through Voltages from all the test waveforms
 - UL 1449 2nd Edition tests
 - IEEE Category C3 High Energy Impulse
 - IEEE Category B3 Ringwave
- Specify integrated TVSS where possible
 - direct bus bar connection (zero lead length)
 - Make sure entire assembly is tested. Beware of “third party” manufacturers that modify panelboards to integrate by cabling to a breaker.
- Require independent testing from a recognized test lab

2. Life

- Specify life expectancy by number of repetitive IEEE Category C3 (20kV, 10kA) surges

| 208/120v | Modes: | | Repetitive C3 Surges |
|----------|----------|------|----------------------|
| | L-N; L-G | N-G | |
| 100kA | 400v | 330v | 8,000 |
| 120kA | 400v | 330v | 9,000 |
| 160kA | 400v | 330v | 10,000 |
| 200kA | 400v | 330v | 11,000 |
| 250kA | 400v | 330v | 12,000 |
| 300kA | 400v | 330v | 13,000 |
| 400kA | 400v | 330v | 14,000 |
| 500kA | 400v | 330v | 15,000 |

- Repetitive surge rating is more important than kA rating**
- Puts all manufacturers on an even playing field**

3. Protection / System Coordination

- SPDs = Reliability and Uptime
- An SPD by design is a “self sacrificing” device
- Over time and with repeated over-voltage conditions an SPD can fail
- As a result SPDs:
 - Must be designed to “fail safely”
 - Must not trip the upstream breaker and shut down a facility
 - Must provide long term, maintenance free surge protection
 - Current UL1449 2nd Edition does NOT test for Medium fault currents

4. Warranty

- Failure rates on quality TVSS units are very low
- Industry standard is a 10 year full replacement warranty – (Regardless of kA rating)
- Beware of limited, pro-rated, or replacement component warranties
- Interesting note: Some manufacturers that have only been around for 5 years or less are pushing 25 year warranties. Will these companies be around in 25 years to honor their warranties?

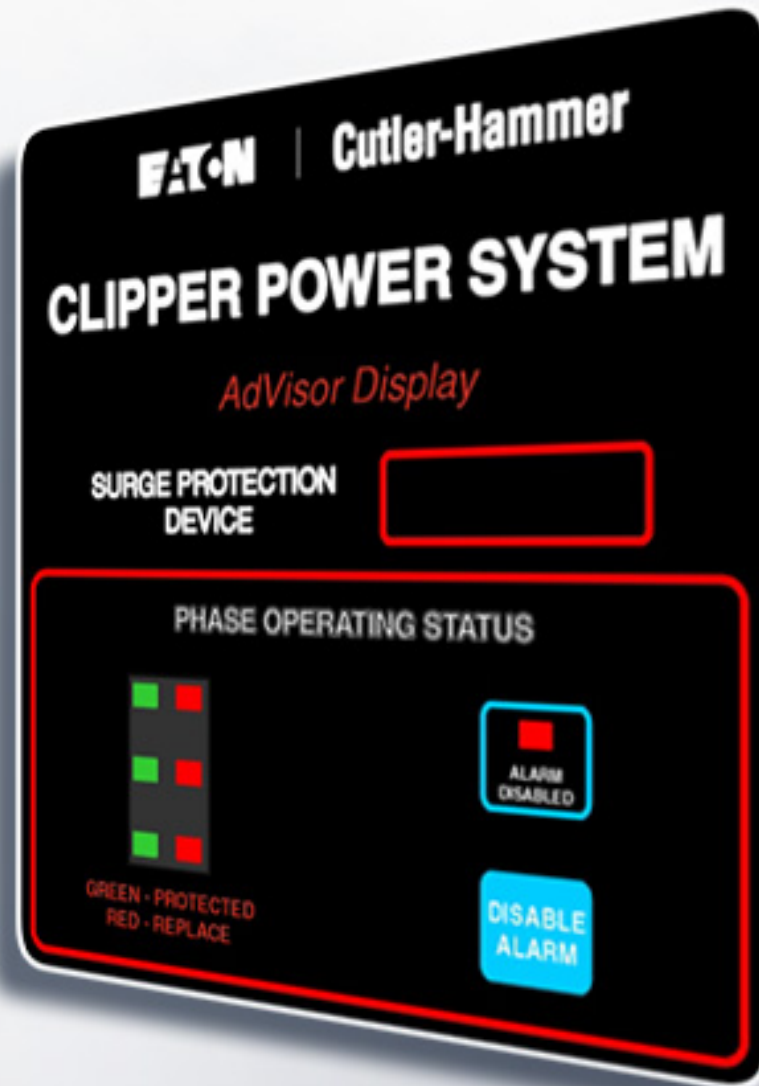
5. Monitoring

**TVSS devices are NOT good power monitors!
(very low accuracy)**

**Use actual equipment designed
for power metering.**

**Typical TVSS monitoring
options:**

- Form C, Audible Alarm
- Red/Green status LED
- Audible Alarm w/ enable/disable
- Surge counter



Questions?
Thank You!

EAT•N

Cutler-Hammer