Approach of the IEEE to the Application of Low-Voltage SPDs

by Ronald W. Hotchkiss

Introduction

- IEEE Standards available to:
  - Define the electrical surge environment
  - Provide representative waveforms and amplitudes
  - Supply direction on how to properly and safely test SPDs
  - Provide guidance on the application of SPDs to electrical systems

The Surge Environment

- **IEEE Std C62.41.1™-2002**
  - *IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits*
- **IEEE Std C62.42™-2005**
  - *IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to or Less than 1000 V (ac) or 1200 V (dc)] Circuits*

Sources of Electrical Surges

- Lightning
  - environmental causations
- Switching within the power system (switching surges)
  - system or component causations

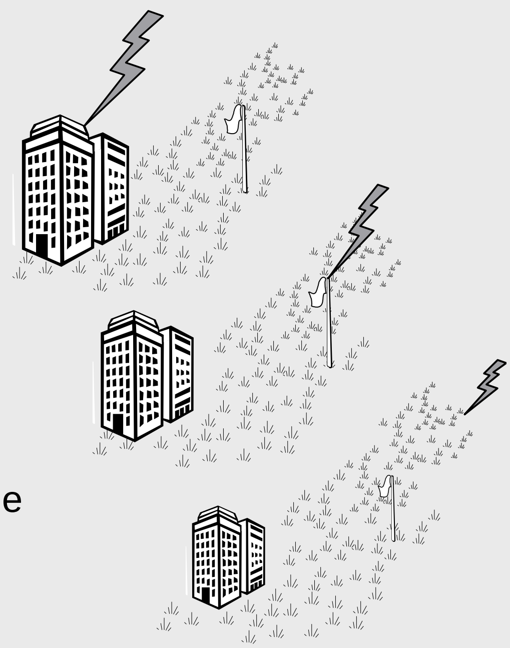
Lightning

- Physical, recognizable
- Most often associated with surges
- Effects can be prominent and devastating

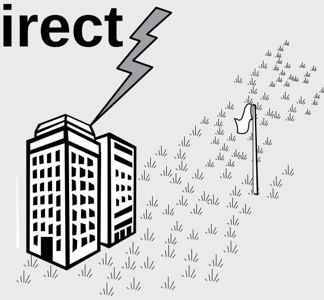
- Occurs much less frequently than switching surges

Lightning

- Direct strike
- Near strike
- Far strike
- Atmospheric charge redistribution

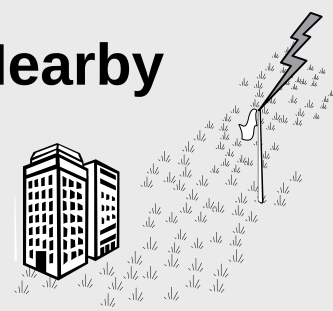


Lightning - Direct



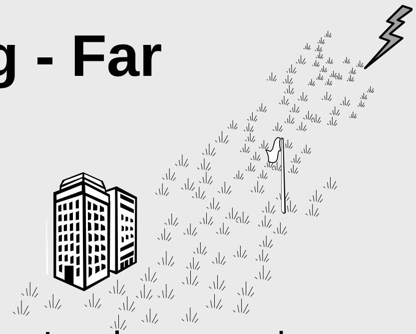
- Most severe, high stress
- Immediately damaging to unprotected electronic components and electrical systems
- Mechanical failure
- Thermal overstress
- Permanent damage
- Intervention required (repairs)
- Involves near-by systems
- Multi-service interaction (communication systems, control circuits, etc.)

Lightning – Nearby



- A fraction of current from a direct strike due to coupling
- Medium to moderate stress
- Typically damaging to unprotected electronic components
- Possibly damaging to electrical systems
- Involves near-by systems
- Multi-service interaction (communication systems, control circuits, etc.)

Lightning - Far



- Less induced voltage and current
- Lesser stress than near or direct
- Typically upsetting to unprotected electronic components
- Repeated events can cause deterioration
- Involves near-by systems
- Multi-service interaction (communication systems, control circuits, etc.)

Atmospheric Charge Redistribution

- Not truly lightning
- No arc to ground (or vice-versa) or to another cloud
- Rapid movement of charge across a cloud
- Often occurs during or just after a lightning strike
- Can occur without a lightning strike
- Electromagnetic field like a cloud-to-cloud strike

Atmospheric Charge Redistribution

- Effects are similar to a far strike
- Induced voltages and currents on power, signal, communications and grounding conductors
- May be the cause of many failures that occur without the presence of a lightning event

Switching Surges

- Less notable (not visible)
- Not always immediately recognized as being damaging or disruptive
- Occur as part of everyday intended operations
- Occur as part of abnormal or unintentional operations or conditions

Switching Surges

- Sources from Normal or Intentional Operations
  - Contactors, relays or breakers
  - Switching of capacitor banks
  - Stored energy systems
  - Discharge of inductive devices
  - Starting and stopping of loads
  - Fault or arc initiation
  - Pulsed power loads

Switching Surges

- Sources from Abnormal or Unintentional Operations
  - Arcing faults or arcing ground faults
  - Fault clearing
  - Power system recovery
  - Loose connections
  - Lightning induced oscillatory surges

Switching Surges

- Frequency 350 Hz to 1000 kHz
- Often represented by 100 kHz
- Amplitudes typically range from a 2-3 times the operating voltage to 6,000 volts or higher
- Occur regularly and frequently – in some cases multiple times per cycle

Switching Surges

- Author’s experience: When monitoring a manufacturing facility using a device intended to record the number of ringing transients occurring over time, over 1,000 surges where recorded within one ten minute interval.
- Source of the surges: The operation of an arc welder in a neighboring facility.

Coupling of Electrical Surges

- Occurs when energy from lightning or switching surges is transferred (coupled) to another system
- Impacts control, communication, data and other systems
- Inductive and capacitive coupling

Coupling of Electrical Surges

- Through multi-service/multi-port loads or even some SPDs
- Often damaging to cabling, connectors or interface of low voltage systems
- From power systems to low voltage systems
- From low voltage systems to power systems

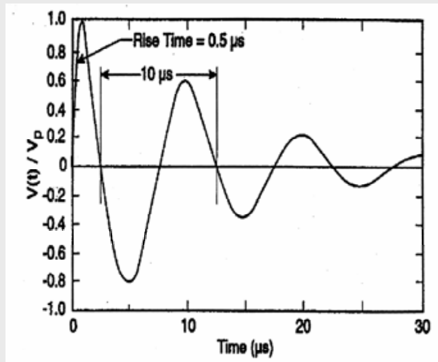
Coupling of Electrical Surges

- Due to coupling, failures of components because of surges can be misinterpreted
- A failed component on the communications side does not necessarily mean the surge originated from that point
- The failed component may have simply provided a low impedance path for the surge when coupled to that system

Surge Testing, Waveforms and Amplitudes

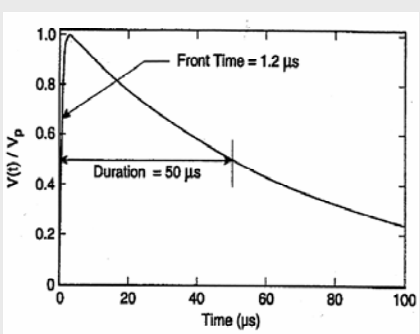
- **IEEE Std C62.41.2™-2002**
  - *IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits*
- **IEEE Std C62.45™-2002**
  - *IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits*
- **IEEE Std C62.62-2000**
  - *IEEE Standard Test Specifications for Surge-Protective Devices for Low-Voltage AC Power Circuits*

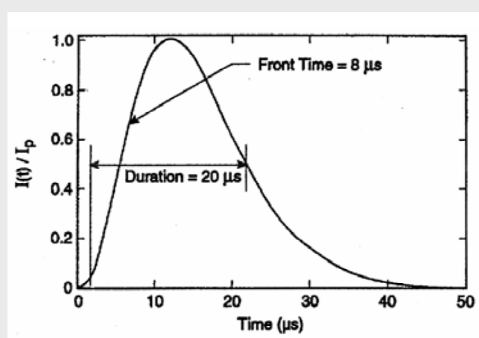
Switching Surges – Ringing/Oscillatory Transients



Represented by a voltage waveform

Lightning Surges – Impulse Transients





Represented by a combination of voltage and current waveforms (combination wave)

Amplitudes

Category C Location			
Exposure Level	**Waveform**	**Voltage**	**Current**
High	8/20 us Current	10 kV (minimum)	10 kA (driven through the SPD)
Low	Combination Wave	6 kV (open circuit voltage)	3 kA (short circuit current)
Category B Location			
High	Combination Wave	6 kV (open circuit voltage)	3 kA (short circuit current)
Low	100 kHz Ring Wave	6 kV (open circuit voltage)	0.5 kA (short circuit current)
Category A Location			
Low	Combination Wave	6 kV (open circuit voltage)	0.5 kA (short circuit current)
Low	100 kHz Ring Wave	6 kV (open circuit voltage)	0.2 kA (short circuit current)

SPD Application

- **IEEE C62.72™-2007**
  - *IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage (1000 V or Less) AC Power Circuits*
- **IEEE C62.43™-1999**
  - *IEEE Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 Vrms or 1200 Vdc) Data, Communications, and Signaling Circuits*
- **IEEE 1100™-2005**
  - *IEEE Recommended Practice for Powering and Grounding Electronic Equipment*
- **IEEE C62.48™-2005**
  - *IEEE Guide on Interactions Between Power System Disturbances and Surge-Protective Devices*

SPD Application

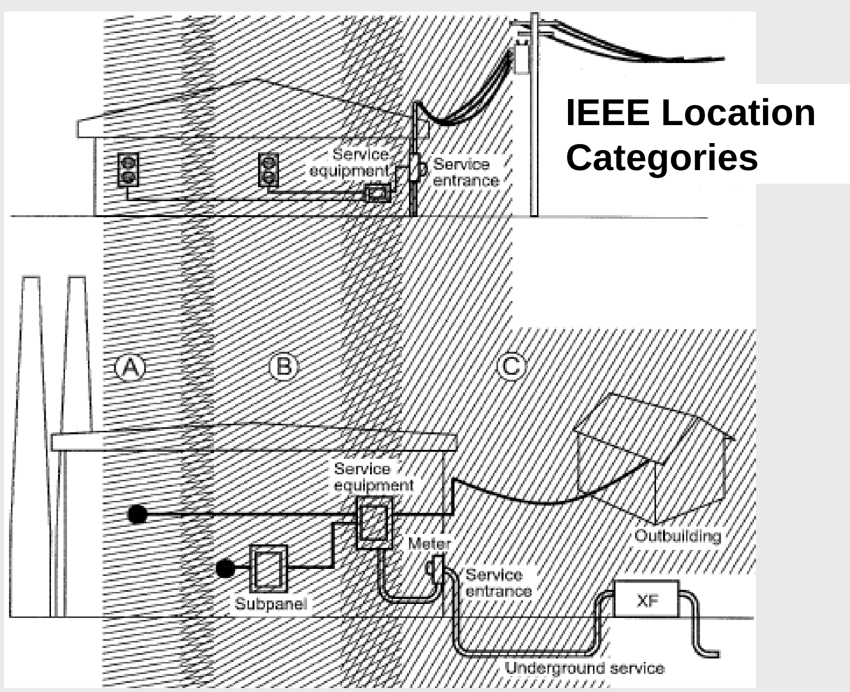
- Location Categories (C, B, A)…
  - Category C
    - Outside and including the service entrance equipment.
    - Service drop from pole or transformer to a building.
    - Conductors between the utility's revenue meter and service entrance equipment.
    - Overhead line to detached buildings.
    - Underground line to a well pump or other outdoor electrical equipment.

SPD Application

- Location Categories (C, B, A)…
  - Category B
    - Service entrance equipment located inside a facility, feeder circuits, and short branch circuits.
    - Distribution panelboards and devices.
    - Busways and feeders in industrial plants.
    - Heavy appliance outlets with short connections to the service entrance equipment.
    - Lighting systems in large buildings or facilities.

SPD Application

- Location Categories (C, B, A)…
  - Category A
    - All outlets at more than about 10 m from Category B.
    - All outlets at more than about 20 m from Category C.



Amplitudes

Category C Location			
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Category B Location			
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Category A Location			
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Available Short-Circuit Current and SPDs

- SPDs are tested to failure at various levels of available short-circuit current
- The highest current used is the SPD’s short-circuit current rating (SCCR)
- SCCR’s typically range from about 5,000 to 200,000 Amps – determined during the listing of the SPD
- The SCCR of an SPD must be higher than the available short-circuit current at the location of installation within the electrical system

Available Short-Circuit Current and SPDs

- If the available short-circuit current of the system at the point of installation is higher than the SCCR of the SPD, a different SPD must be selected or provisions made to limit the available short-circuit current at the point of application
- **This is an NEC requirement**

Coordination of an SPD with a Fuse or Breaker

- Many SPDs require an external fuse or breaker as part of their listing
- This requirement is required to appear on the SPD or in the installation instructions with the SPD
- Installation without the specified fuse or breaker violates the listing of the SPD

Coordination of an SPD with a Fuse or Breaker

- Installation of an SPD without the specified fuse or breaker could create a potentially hazardous situation
- The required fuse or breaker was utilized during the failure testing during the listing of the SPD
- Failure to use the specified fuse or breaker creates an NEC violation

Installation Lead Length of SPDs

- Most SPDs are connected in parallel to the electrical system
- Prevents the load current of the system from having to pass through the conductors of the SPD
- With parallel connection, lead length influences the performance of the SPD

Installation Lead Length of SPDs

- Parallel connection
  - Voltage drop is about 1 kV/m of lead length for 1 kA/us waveform
  - The longer the connecting leads – the higher the let-through voltage
  - Most SPDs are tested with 15 cm (6”) of lead length

Installation Lead Length of SPDs

- Parallel connection
  - Make leads as short as possible
  - Shape to minimize open-loop geometry
  - Twist leads together – avoid sharp bends

Specifying SPDs

- **IEEE C62.72^{TM}-2007**
  - *IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage (1000 V or Less) AC Power Circuits*
- Clause 9
  - Specification and Application questions

Surge Mitigation and SPDs

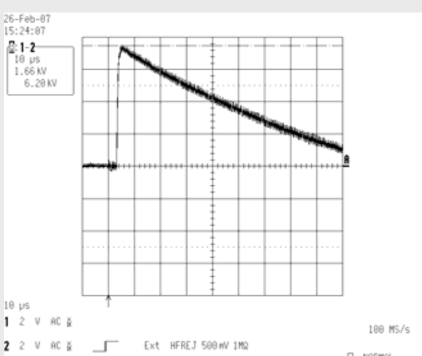
- Surge Protective Devices (SPDs)
  - For both power and low voltage systems (communication, data, control, transducers, coaxial connections, etc.)
  - Paramount to providing reliability and quality power
  - Decrease opportunity for systems failure due to surges

Surge Mitigation and SPDs

- Essential to promote survivability
- Reduce equipment loss, repairs, restarts and downtime
- Aids in providing uninterrupted service

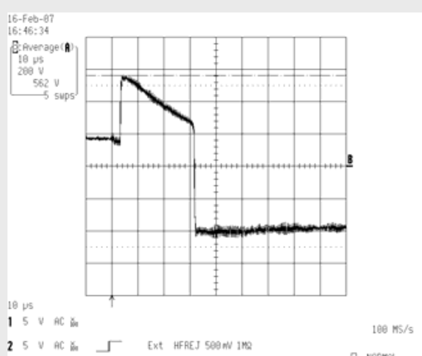
SPDs Action - Impulse

Before



6,200 Vpk

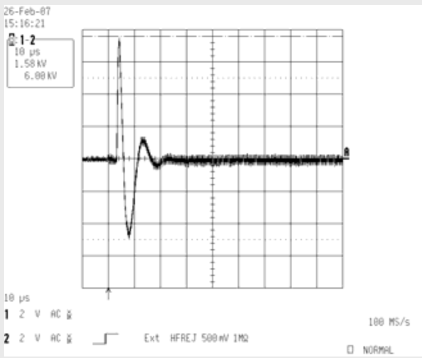
After



562 Vpk

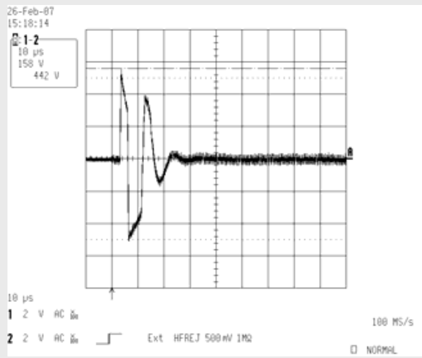
SPDs Action – Ringing Surge (SPD with no filter circuitry)

Before



6,000 Vpk

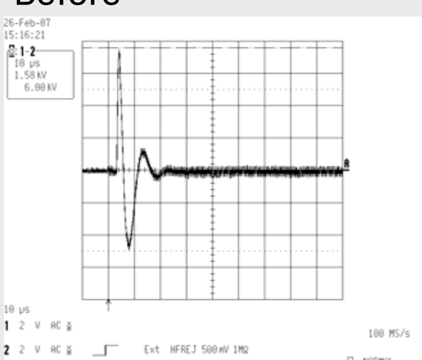
After



442 Vpk

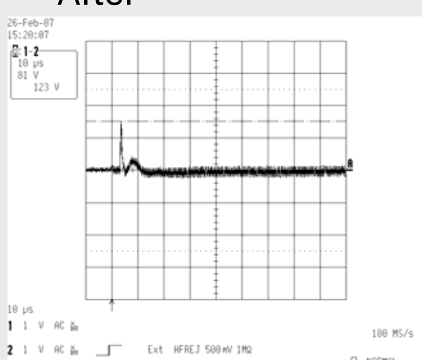
SPDs Action – Ringing Surge (SPD with filter circuitry)

Before



6,000 Vpk

After

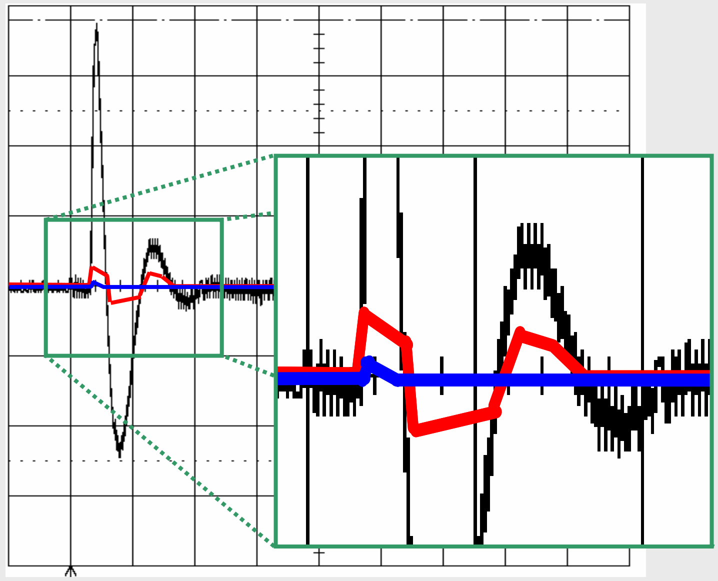


123 Vpk

SPD Action

- Open Circuit 6 kV, 500 A Ring Wave
- Clamping device only
- w/ Filter

All on the same scale.



Application Photos

(Typical Panel Installation – TV Broadcast Location)

Application Photos

(Generator Protection)

Application Photos

(Transfer Switch Protection)

Application Photos

(Digital Sign Controller Circuit)

Application Photos

(Service Disconnect and Sub-Panels)

Application Photos

(Drive Protection)

Summary

- Surge environment – surges from a wide variety of sources
- Surges will propagate along and couple across systems
- Surges are harmful to key components and systems relied upon for operation

Summary

- SPDs help to mitigate the effects of surges
- SPDs promote:
  - Power quality
  - Uptime
  - System performance
  - Reliability

References

- IEEE Recommended Practice for Powering and Grounding Electronic Equipment, IEEE Standard 1100-2005
- IEEE Guide on Interactions Between Power System Disturbances and Surge-Protective Devices, IEEE Standard C62.48™-2005
- IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to or Less than 1000 V (ac) or 1200 V (dc)] Circuits, IEEE Std C62.42™-2005
- IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Standard C62.41.1™-2002
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- F. Martzloff, "The propagation and attenuation of surge voltages and surge currents in low-voltage ac circuits", IEEE Summer Meeting, July 1982
- B. R. Cole, K. Brown, P. S. McCurdy, T. Phipps, R. Hotchkiss, "The short circuit current ratings of surge protective devices (SPDs)", IEEE Power Engineering Society General Meeting, June 2006
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- F. Martzloff, K. Phipps, "Lingering lead length legacies in surge-protective devices applications", IEEE Trans. On Power Delivery, V19-I1, 2004

Thank You!