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

- **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 were 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

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

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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

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

• IEEE C62.72™-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

After

6,200 Vpk

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

Before | After
--- | ---
6,000 Vpk | 442 Vpk

SPDs Action – Ringing Surge (SPD with filter circuitry)

Before | After
--- | ---
6,000 Vpk | 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)
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 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 Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits, IEEE Standard C62.41.2™-2002
• F. Martzloff, “The propagation and attenuation of surge voltages and surge currents in low-voltage ac circuits”, IEEE Summer Meeting, July 1982
• IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Std C62.45™-2002
Thank You!