TRANSIENT SURGE FILTERING

USE OF LOW PASS FILTERING IN SURGE PROTECTION
AGENDA

• Classification of Impulses & Surges
• Traditional MOV/Crowbar Protection vs. Filtering
• Concepts Behind Surge Filtering
• Summary
Classifications of Surge Impulses

- **Waveshape**
  - $t_{front}, t_{tail}$

- **Magnitude**
  - $i_{pk}$

- **Charge**
  - $Q$

- **$I^2t$**
  - $kJ/\Omega$
Classification of Surge Impulses (cont.)

- Frequency
  - Harmonics
    - Sum of Dirac delta functions
  - Bandwidth
  - Magnitude

\[ \hat{f}(\xi) = \delta(0) + \delta(10E3) + \delta(20E3) + \ldots + \delta(100E3) \]

All transients are signals and can be analyzed by the Fourier Transform.
Traditional Surge Protection Design

- Metal Oxide Varistors (voltage limiting devices)
- Crowbar (GDT/Sparkgap type devices)

Voltage limiting and switching are the main components for protection.
Traditional Surge Protection Design

• Cascading protection
  – SPDs at the service entrance are higher rated (higher let-through)
  – SPDs at the sub-panels are lower rated (lower let-through)

Cascading protection limits the voltage from transients in stages
Cascading Stage Limiting

Stage 1 (2400V)
Type 1 (UL1449)
20kA 8/20µs | 2400V

Stage 2 (1600V)
Type 1/Type 2 (UL 1449)
10kA 8/20µs | 1600V

Stage 3 (330V)
Type 2/Type 4CA (UL 1449)
3kA 8/20µs | 330V

Each stage diverts more energy and keeps the end voltage low
Different Voltages on Parallel Lines

Voltages in parallel are the same, additional voltage drop exists
Voltage Must be Dropped Across the Wiring

Wiring impedance can be used to isolate staged protection
Voltage Drop Across Wiring

- Theoretically: 4mm² (12AWG) wire is ≈ \(4m\Omega/m\) and \(1\mu H/m\)

\[
V = i \cdot R + L \frac{di}{dt}
\]

- Given a 3kA 8/20µs impulse

\[
V = 3000A \cdot 4m\Omega/m + \frac{1\mu H}{m} \cdot \frac{3000A}{8 \cdot 10^{-6}s}
\]

\[
V = 3 + 375
\]

\[
V = 378 V/m
\]

- Gets lower with larger wire

<table>
<thead>
<tr>
<th></th>
<th>6 AWG</th>
<th>4 AWG</th>
<th>2 AWG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(V/ft)</td>
<td>(V/cm)</td>
<td>(V/ft)</td>
</tr>
<tr>
<td>3 kA</td>
<td>152.40</td>
<td>5.00</td>
<td>94.45</td>
</tr>
<tr>
<td>10 kA</td>
<td>441.16</td>
<td>14.47</td>
<td>385.00</td>
</tr>
<tr>
<td>40 kA</td>
<td>?</td>
<td>?</td>
<td>1579.35</td>
</tr>
</tbody>
</table>

Wiring might be sufficient to mitigate this problem
When Wiring is Short with Minimum Losses (1/2)

Smaller SPD clamps first
Since the lower rated MOVs are more sensitive they will begin clamping the voltage first

Larger SPD only when threshold is exceeded
The larger SPD will only turn on if the smaller SPDs clamping voltage goes above the turn-on voltage of the larger SPD

Current initially goes through the smaller SPD until larger turns on
The lower rated device absorbs most of the impulse
What is a Low Pass Filter?

Low-Pass Filter

- **Lower** frequencies **Pass** while higher frequencies are attenuated

Low Frequency Signals Pass!
Low Pass Filters

- Low frequency signals experience no attenuation
- High frequency signals experience large amounts of attenuation

\[ H(s) = \frac{1}{1 + RCs} \]

Where \( s = j\omega \)
Characterizing a Filter

- At higher frequencies, $V_{out}$ is multiplied by something smaller than “1”.
- 3 dB Point – “cutoff frequency” this is the frequency where the filter cuts off of the output power (half-power point)
- 100 kHz Gain – a benchmark frequency used to compare filtering at a high frequency

Higher Frequencies are attenuated!
100kHz Benchmark

\[ \text{Filter input } = 15.8 \text{Vpp} \]

\[ \text{Filter output } = 8.6 \text{mVpp} \]

\[ \begin{align*}
= 20 \log_{10} \left( \frac{V_2}{V_1} \right) \\
= 20 \times \log(0.0086/15.8) \\
= 20 \times \log(0.0005) \\
= -65.28 \text{ dB}
\end{align*} \]
RC Filter

\[ Z_C = \frac{1}{j\omega C} \]

![RC Filter Diagram](image-url)
LC Filter

![Diagram of an LC filter showing high and low frequency regions.](image)

![Graph showing the frequency response of the LC filter with different damping factors.](image)
Comparing: RC vs LC

---

The graph compares the magnitude response of RC and LC circuits across different frequencies. The graph shows the magnitude in dB against frequency in Hz. Key frequencies highlighted are 60Hz, 3000Hz, and 50kHz.
Combining these Functions

Low-Pass between LINE and NEUTRAL

Traditional Surge Protective Device (MOV, GDT...)
Combining these Functions

- Clamps transient voltage
- Slows the rate of voltage rise
- Attenuates small signal RFI/EMI noise problems

Surge Filter reduces let-through voltage!
Value Choices for inductor & capacitor

Filter – Negligible improvement but badly ringing

- 3kA 8/20us
- Green SPD output
  - 378Vpk
- Purple filter output
  - 620Vpk

- No improvement over MOV only
- Harmful ringing of the LC filter actual makes the results worse

Filter ringing worsens results!
Value Choices for inductor & capacitor

Filter – Bad

- 3kA 8/20us
- Green SPD output
  - 370Vpk
- Purple filter output
  - 542Vpk

- Filter starts to improve the dV/dt
- The output voltage is still climbing even after MOV voltage has dropped.
- Once the inductor current reaches zero the output voltage peaks

Voltage continues to rise after MOV drops
Value Choices for inductor & capacitor

Filter – Good not Great

• 3kA 8/20μs
• Green SPD output
  • 378Vpk
• Purple filter output
  • 358Vpk

• Filter starts to improve the dV/dt
• The output voltage is still climbing even after MOV voltage has dropped.
• Once the inductor current reaches zero the output voltage peaks

What is the point?
Value Choices for inductor & capacitor

Filter – Great Filter

- 3kA 8/20µs
- Green SPD output
  - 382Vpk
- Purple filter output
  - 166Vpk

- Filter significantly reduced the dV/dt
- Filter output is less than the MOV alone

Filter reduces the output!
Cascading Stage Testing w/ TSF

Input Impulse

Stage 1
- Type 1CA (UL1449)
- 20kA 8/20µs

Stage 2
- Type 1/Type 2 (UL 1449)
- 10kA 8/20µs | 1600V
Cascading Stage Testing w/ TSF

<table>
<thead>
<tr>
<th>Input Impulse</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1CA (UL 1449)</td>
<td>20kA 8/20µs</td>
<td>Type 1/Type 2 (UL 1449)</td>
</tr>
<tr>
<td>Type 1/Type 2 (UL 1449)</td>
<td>10kA 8/20µs</td>
<td>1600V</td>
</tr>
</tbody>
</table>

Graph showing input current and time.
Cascading Stage Testing w/ TSF

Each stage diverts more energy and keeps the end voltage low
Many industries demand high performance protection

• Process Control
• SCADA and Telemetry
• Panel Shops / SI’s
• OEMs
• Automotive
• Petrochem
• Telecom Power
• Lighting Control
• Water & Wastewater Treatment
• Medical Equipment
• Semiconductor Equipment

Many Applications...
Application: BTS Sites

Mobile Telecom Enclosure

- Standalone type BTS sites
- No shelters – trending upward
  - Small IP66 enclosure where they can fit all electrical switchgear equipment.
Application: Communication System at a LNG Extraction Facility

Telecommunications cabinets (Fiber nodes, telephones, CCTV)

Fiber Optic

Surge Filter (240VAC - 6A)

Example Application: Resource Extraction Telecom Cabinets
Application: Public Transit Pass

Fast Pass Reader for railway / subway stations

Surge Filter (120VAC - 20A)

Example Application: Railway Pass Readers
Application: SCADA

Remote Terminal Unit (RTU) used to take sections of the grid offline

Example Application: RTU

- SCADA control unit
- 120VAC to 24VAC transformer
- Surge Filter (120VAC - 3A)
Application: Lighting Control

Lighting Control Panel

Digital I/O Module

Surge Filter (120VAC to 6A)

PLC

Example Application: Control Panel
Technology is not limited to small current levels

Current Levels Range: 3A - 1000A
What is a Surge Filter?

Relevant Standards for Surge Filters

- UL 1283 – Standard for Electromagnetic Interference Filters
- IEC 61643-11 – Standard for Low-voltage Surge Protective Devices
QUESTIONS?

GREG.MARTINJAK@PENTAIR.COM

CHRISTIAN.BARCEY@PENTAIR.COM