Minnesota Power Systems Conference
Insulation Coordination Tutorial
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Presented By:
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Traveling Wave Theory/Overvoltage Protection

- Current divides and then propagates
- $V = I \times R$
- $R = \text{Surge Impedance of Line}$
Surge Arresters - Concept

- Surge causes traveling voltage wave
- Voltage would be enough to flash-over insulation
- Surge arrester high resistance at L-G voltage
- Surge arrester low resistance at surge voltage
- Surge is diverted to ground
- Surge arrester high resistance again after surge
- Conduction time is too short for breakers to react
Typical Arrester V-I Curve
General Application Issues
Summary - Arrester Selection

- Select MCOV
- Select Type
- Insulation coordination
Arrester - Selection of Size

- MCOV > system line to ground voltage
- Type of system
  - Grounded - minimum size
  - Ungrounded / resistance ground
    > Consult catalog
    > Apply TOV Curve
  - Delta
    > Phase to phase voltage
Arrester - Selection of Size
Coefficient of Grounding

Line-to-ground Sustained Voltage for Grounded Systems*

*Region of small Xo/X1 & Ro/X1

1.73(1.00 L.L.)
1.6
1.5
1.4(0.8 L.L.)
1.25

*Region of small Xo/X1 & Ro/X1
Catalog 31 Recommendations

Selection Considerations

<table>
<thead>
<tr>
<th>System L-L Voltage kV</th>
<th>Arrester MCOV-kV</th>
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<tbody>
<tr>
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Selection of arrester size is based upon the maximum continuous operating voltage (MCOV) that is applied across the arrester in service (line-to-ground). For arresters on effectively grounded systems, this is normally the maximum line-to-ground voltage — e.g., 7.65 kV on a 12.47 kV multi-grounded system. For ungrounded or impedance-grounded systems, the MCOV should be at least 90 percent of maximum phase-to-phase voltage. Smaller arresters than shown may be used, contact your Ohio Brass representative for details.

For convenience, the data shown in this catalog includes the traditional duty-cycle voltage rating associated with the MCOV of each arrester.

The selection of the actual type will be primarily governed by the insulation being protected.
Typical Arrester TOV Withstand

ANSI No Prior Duty TOV Curves for PDV100-Optima Arresters

Voltage per unit MCOV vs. Time (Seconds)

- 3, 6 kV Rated
- 9, 10 kV Rated
- 12, 15 kV Rated
- 18, 21 kV Rated
- 24, 27, 30, 36 kV Rated
- No Bracket
Arrester Types / Differences

- Protection level
- Energy capability
- Pressure relief rating
- Housing Material
ANSI Standard Types

• Distribution
  – Normal Duty
  – Heavy Duty
  – Deadfront
  – Liquid Immersed

• Intermediate

• Station
Ohio Brass MOV Arrester Disc Sizes
### Block Sizes/Arrester Types

- **29 - PDV-65 (Dist.)**
- **32 - PDE (Elbow arresters)**
- **36 - PDV 100 (Heavy duty)**
- **40 - PVR (Riser)**
- **48 - PVI-LP (Intermediate)**
- **56 - EVP (Station)**
- **60 - VL (Porcelain station)**
- **75 - MVN (Porcelain station) and SVN (Polymer station)**
- **2X75 - VNX (EHV porcelain > 345 kV systems)**
- **4X75 - Series capacitor applications**
Advantages of Larger Diameter Blocks

• Spreads surge current over larger cross sectional area
  – Lower current density results in lower discharge voltage
  – Greater energy capacity

• More paths in parallel lowers total resistance
Insulation Coordination
Protective Levels

• Lower is better
• Similar to blood pressure
• Transformer insulated wire are like arteries
• Surges would cause a “stroke”
• Arrester lowers voltage pressure
# Protective Levels

## Heavy Duty

### PDV100-Optima

<table>
<thead>
<tr>
<th>Rated Voltage kV</th>
<th>MCOV kV</th>
<th>Unit Catalog Number</th>
<th>0.5 μsec 10kA Maximum IR-kV (1)</th>
<th>500 A Switching Surge Maximum IR-kV(2)</th>
<th>8/20 Maximum Discharge Voltage - kV</th>
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### Table 4

**Dielectric Insulation Levels for Distribution Transformers and Class I Power Transformers**

<table>
<thead>
<tr>
<th>Application</th>
<th>Basic Lightning Impulse Insulation Level (BIL) (kV crest)</th>
<th>Chopped-Wave Impulse Levels</th>
<th>Front-of-Wave Impulse Levels</th>
<th>Low-Frequency Test Level (kV rms)</th>
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*See 6.10 for a description of Class I power transformers.*
Insulation Coordination

- Arrester .5 μsec IR $\Rightarrow$ CW Insulation
- Arrester 8/20 IR $\Rightarrow$ BIL Insulation
- Arrester S/S IR $\Rightarrow$ BSL Insulation
- Lead length voltage drop adds to IR levels
- % PM = $\left(\frac{\text{Insulation}}{\text{Arrester}+\text{Lead}}\right) - 1 \times 100$
Metal-Oxide Arrester Insulation Coordination

![Diagram](image-url)

- Crest Voltage in kV
- Front-of-Wave Strength
- Chopped Wave Test
- 0.5 μs Discharge Voltage Margin
- BIL
- SIL
- Switching Surge Margin
- Switching Surge Discharge Voltage
- ARRESTER MCOV
- Full Wave Margin (IR Discharge Voltages)
- % @ kA

Time to Voltage Crest in Microseconds
Lead Length - 1

- Adds to stress on equipment if
  - Carries surge current and
  - Is in parallel with protected equipment
• **AB + DE + EG**
  Arrester to connection from conductor + Arrester ground to pole ground connection + Pole ground connection to transformer ground connection

• **IMPROVEMENT**
  Connect from conductor to arrester and arrester to bushing on transformer
  Reduce distance to ground transformer and arrester together by placing arrester closer to transformer.
Transformer Mount Application
URD Installation
Lead Length - 2

- \( V = L \times \frac{di}{dt} \)
- \( L = 0.4 \) microhenry per foot
- 8/20 Wave @ 10 kA = 500 V per ft.
- 0.5 Wave @ 10 kA = 8,000 V per ft.
Overhead Distribution – Transformer Protection

- Base Case – Develop Fundamentals
- Voltage Class vs. BIL vs. Arrester Protective Level
- Explore Impact of Lead Wire Length
- Explore Impact Arrester Type (Heavy, Normal, and Riser)
- 12.47 kV – 9 or 10 kV Rated
- Summary Tables (15, 25 and 35 kV) – Bang for the Buck
Base Case – 13.8 kV System
8.4 kV MCOV/10 kV Rated Heavy Duty
95 kV BIL No Lead Length

Diagram:
- Front-of-Wave Strength
- Chopped Wave Test 109.25 kV
- BIL 95 kV
- SIL 79 kV
- Switching Surge Margin 223 %
- Switching Surge Discharge Voltage 32 kV
- Full Wave Margin (IR Discharge Voltages) 201 % @ 10 kA
- 0.5 μs Discharge Voltage Margin 221 %
- Arrester MCOV 8.4 kV

Time to Voltage Crest in Microseconds
- DynaVar metal-oxide arrester 8.4 kV maximum Continuous operating voltage
- Protection for equipment of 95 kV basic impulse insulation level
Voltage Class vs. BIL vs. Arrester Protective Level

15 kV Class

8.4 kV MCOV/10 kV Rated Heavy Duty
95 kV BIL – No Lead Length
Voltage Class vs. BIL vs. Arrester Protective Level

25 kV Class

15.3 kV MCOV/18 kV Rated Heavy Duty

125 kV BIL – No Lead Length
Voltage Class vs. BIL vs. Arrester Protective Level

35 kV Class

22 kV MCOV/27 kV Rated Heavy Duty

150 kV BIL – No Lead Length
Voltage Class vs. BIL vs. Arrester Protective Level

<table>
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<tr>
<th>System Voltage</th>
<th>BIL</th>
<th>Type</th>
<th>MCOV</th>
<th>Lead Length</th>
<th>FOW Margin %</th>
<th>BIL Margin %</th>
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Impact of Lead Length on Protective Level
15 kV Class
8.4 kV MCOV/10 kV Rated Heavy Duty
95 kV BIL – 2 Foot Lead Length
Impact of Lead Length on Protective Level

15 kV Class

8.4 kV MCOV/10 kV Rated Heavy Duty

95 kV BIL – 4 Foot Lead Length
Impact of Lead Length on Protective Level
15 kV Class
8.4 kV MCOV/10 kV Rated Heavy Duty
95 kV BIL – 8 Foot Lead Length
Impact of Lead Length on Protective Level
25 kV Class
15.3 kV MCOV/18 kV Rated Heavy Duty
125 kV BIL – 2 Foot Lead Length
Impact of Lead Length on Protective Level
25 kV Class
15.3 kV MCOV/18 kV Rated Heavy Duty
125 kV BIL – 4 Foot Lead Length
Impact of Lead Length on Protective Level
25 kV Class
15.3 kV MCOV/18 kV Rated Heavy Duty
125 kV BIL – 8 Foot Lead Length
Impact of Lead Length on Protective Level
35 kV Class
22 kV MCOV/27 kV Rated Heavy Duty
150 kV BIL – 2 Foot Lead Length

Diagram with labels:
- Crest Voltage in kV
- Time to Voltage Crest in Microseconds
- DynaVar metal-oxide arrester: 22 kV maximum continuous operating voltage
- Protection for equipment: 150 kV basic impulse insulation level
Impact of Lead Length on Protective Level
35 kV Class
22 kV MCOV/27 kV Rated Heavy Duty
150 kV BIL – 4 Foot Lead Length

Time to Voltage Crest in Microseconds

0.1 1 10 100 1000 10000

Crest Voltage in kV

Front-of-Wave Strength

Chopped Wave Test 172.5 kV

0.5 µs Discharge Voltage Margin 39 %

Arrestor MCOV 22 kV

Switching Surge Discharge Voltage 66 kV

Full Wave Margin (IR Discharge Voltages) 71 %

Switching Surge Margin 89 %

20 kA

10 kA

5 kA

DynaVar metal-oxide arrester 22 kV maximum continuous operating voltage

Protection for equipment of 150 kV basic impulse insulation level
Impact of Lead Length on Protective Level
35 kV Class
22 kV MCOV/27 kV Rated Heavy Duty
150 kV BIL – 8 Foot Lead Length

Diagram showing various electrical parameters such as crest voltage, time to voltage crest, and protection levels.

- Crest Voltage in kV
- Time to Voltage Crest in Microseconds
- Protection for equipment of 150 kV basic impulse insulation level

Legend:
- Front of Wave Strength
- Chopped Wave Test
- 0.5 µs Discharge Voltage Margin
- Arrester MCOV
- Full Wave Margin (IR Discharge Voltages)
- Switching Surge Margin
- BIL
- SIL
- Switching Surge Discharge Voltage

Key Values:
- 172.5 kV
- 150 kV
- 125 kV
- 90 kV
- 68%
- 89%
- 5 kA
- 10 kA
- 10 kA

Note: Diagram includes additional details and annotations related to electrical parameters and testing.
## Impact of Lead Length on Protective Level

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<tr>
<th>System Voltage</th>
<th>BIL</th>
<th>Type</th>
<th>MCOV</th>
<th>Lead Length</th>
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<th>BIL Margin %</th>
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Arrester Type vs. Protective Level

15 kV Class

8.4 kV MCOV/10 kV Rated Normal Duty

95 kV BIL – No Lead Length

DynoVar metal-oxide arrester

Protection for equipment of 95 kV basic impulse insulation level

8.4 kV maximum continuous operating voltage
Arrester Type vs. Protective Level
15 kV Class
8.4 kV MCOV/10 kV Rated Heavy Duty
95 kV BIL – No Lead Length

Diagram showing front-of-wave strength, chopped wave test, BIL, Switching Surge Margin, and Switching Surge Discharge Voltage.
Arrester Type vs. Protective Level
15 kV Class
8.4 kV MCOV/10 kV Rated Riser Pole
95 kV BIL – No Lead Length

Diagram showing the relationship between crest voltage margin, chopped wave test, front-of-wave strength, switching surge discharge voltage, and time to voltage crest in microseconds.

- Crest Voltage Margin
- 0.5 μs Discharge Voltage Margin
- Arrester MCOV
- Switching Surge Margin
- Full Wave Margin (IR Discharge Voltages)

- Time to Voltage Crest in Microseconds
- DynaVar metal-oxide arrester 8.4 kV maximum continuous operating voltage
- Protection for equipment of 95 kV basic impulse insulation level
Arrester Type vs. Protective Level

25 kV Class

15.3 kV MCOV/18 kV Rated Normal Duty

125 kV BIL – No Lead Length

Diagram showing Front-of-Wave Strength, Chopped Wave Test, Crest Voltage in kV, Time to Voltage Crest in Microseconds, and other parameters. The diagram illustrates the relationship between voltage and time, with specific values indicated.

DynaVar metal-oxide arrester 15.3 kV maximum continuous operating voltage

Protection for equipment of 125 kV basic impulse insulation level
Arrester Type vs. Protective Level
25 kV Class
15.3 kV MCOV/18 kV Rated Heavy Duty
125 kV BIL – No Lead Length
Arrester Type vs. Protective Level
25 kV Class
15.3 kV MCOV/18 kV Rated Riser Pole
125 kV BIL – No Lead Length

- Front-of-Wave Strength
- Chopped Wave Test
- BIL: 125 kV
- SIL: 104 kV
- Switching Surge Discharge Voltage
  - Full Wave Margin (IR Discharge Voltages): 156 kV
  - Switching Surge Margin: 49 kV
- Crest Voltage in kV
  - 0.5 μs Discharge Voltage Margin: 169 kV
  - 53.4 kV
- Time to Voltage Crest in Microseconds
- DynaVar metal-oxide arrester
  -保护设备电压: 15.3 kV 最大连续操作电压
  - 125 kV 基本冲击绝缘水平
Arrester Type vs. Protective Level
35 kV Class
22 kV MCOV/27 kV Rated Normal Duty
150 kV BIL – No Lead Length
Arrester Type vs. Protective Level
35 kV Class
22 kV MCOV/27 kV Rated Heavy Duty
150 kV BIL – No Lead Length
Arrester Type vs. Protective Level
35 kV Class
22 kV MCOV/27 kV Rated Riser Pole
150 kV BIL – No Lead Length

Front-of-Wave Strength
Chopped Wave Test
0.5 μs Discharge Voltage Margin
119 %
78.6 kV

20 kA
10 kA
5 kA

Arrester MCOV 22 kV
Full Wave Margin (IR Discharge Voltages)
108 %

108 kV

20 %

BIL 150 kV
Switching Surge
139 %
125 kV
Margin

Switching Surge Discharge Voltage
139 %
52 kV

Time to Voltage Crest in Microseconds
DynaVar metal-oxide arrester 22 kV maximum Continuous operating voltage
Protection for equipment of 150 kV basic impulse insulation level
## Arrester Type vs. Protective Level

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>BIL</th>
<th>Type</th>
<th>MCOV</th>
<th>Lead Length</th>
<th>FOW Margin %</th>
<th>BIL Margin %</th>
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<td>108</td>
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I HAVE A 12.47 kV SYSTEM SHOULD I USE 9 OR 10 kV RATED?
Base Case – 12.47 kV System
8.4 kV MCOV/10 kV Rated Heavy Duty
95 kV BIL No Lead Length

Diagram:
- Crest Voltage in kV
- Front-of-Wave Strength
- Chopped Wave Test: 109.25 kV
- BIL: 95 kV
- SIL: 79 kV
- Switching Surge Margin: 223%
- Full Wave Margin (IR Discharge Voltages): 201% @ 10 kA
- DynaVarmetal-oxide arrester: 8.4 kV maximum Continuous operating voltage
- Protection for equipment of: 95 kV basic impulse insulation level
Base Case – 12.47 kV System
7.65 kV MCOV/9 kV Rated Heavy Duty
95 kV BIL No Lead Length
Recommendation

• Use 10 kV Rated
• “Universal Donor” – can be used on 12.47, 13.2 and 13.8 kV
• 9 kV rated can only be used on 12.47 kV
• Protection is essentially equal
• Price is nearly the same
OK PLEASE ENOUGH WITH THE CURVES
Underground Distribution – Protection

- Base Case – Develop Fundamentals
- Voltage Class vs. BIL vs. Arrester Protective Level
Introduction

• Calculation Methods per ANSI/IEEE C62.22-2009
• Protective Levels from On-Line Catalog Data
• IEEE guide says compare FOW Arrester to Cable BIL
• Margin Must Be Greater Than 20%
IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems

IEEE Power & Energy Society
Sponsored by the Surge Protective Devices Committee
6.7.4 Protection of equipment on underground systems (including cables)

For gapped arresters, compare the greater of:

Doubled FOW protective level (if determined by sparkover)
Doubled sum of FOW protective level (if determined by discharge voltage) and connecting lead voltage with CWW for liquid-filled transformers and with BIL for dry-type transformers and cables

For both gapless and gapped arresters, compare the doubled sum of the discharge voltage, at the assumed discharge current, and the connecting lead voltage with transformer and cable BIL. Then, using a recommended protective margin of 20%:

Oil insulation: \[ CWW \geq 1.2 \times 2 \times FOW \]
Dry insulation: \[ BIL \geq 1.2 \times 2 \times FOW \]
Both insulations: \[ BIL \geq 1.2 \times 2 \times LPL \]

CWW = Chopped Wave Withstand
LPL = Lightning Protection Level
FOW = Front of Wave (Protective Level)
BIL = Basic Lightning Impulse Insulation level
6.7.4 Protection of equipment on underground systems (including cables)

Another protection method is to use an arrester at the riser pole and a second arrester at the remote end of the cable, which is a reflection point for the traveling wave. The voltage at the reflection point will be limited to the discharge voltage of the remote arrester at a current of less than one fourth of the current through the riser pole arrester (unless the cable is very short) (Miller and Westrom [B138]; Owen and Clinkenbeard [B148]). Because the remote arrester appears as an open circuit until it becomes conductive, it permits the reflection of a portion of the incoming wavefront, which is then superimposed on the approaching surge voltage wave. Therefore, the voltage at intermediate points in the cable circuit will usually be higher than at either end. The maximum voltage at intermediate points will be the protective level of the riser pole arrester (discharge voltage plus lead voltage drop), plus some fraction of the discharge voltage of the reflection point arrester. A conservative number to use for coordination is the discharge voltage of the riser pole arrester plus one half of the 1.5 kA discharge voltage of the reflection point arrester. (The 1.5 kA value is obtainable from the published literature of the manufacturer and, because of the nonlinear characteristics of metal-oxide valve elements, will yield a value very close to one fourth of any assumed current through the riser pole arrester.) A computer simulation of this effect can be found in Smith et al. [B166].
# Hubbell PDV-100 Protective Levels (Catalog 31)

## Electrical Characteristics

### Heavy Duty

**PDV100-Optima**

![Front of Wave]

<table>
<thead>
<tr>
<th>Rated Voltage (kV)</th>
<th>MCOV (kV)</th>
<th>Unit Number</th>
<th>0.5 μsec 10kA Maximum IR-kV</th>
<th>500 A Switching Surge Maximum IR-kV</th>
<th>8/20 Maximum Discharge Voltage - kV</th>
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<table>
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<tr>
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<th>1.5 kA</th>
<th>3 kA</th>
<th>5 kA</th>
<th>10 kA</th>
<th>20 kA</th>
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---

*All Ohio Brass Arresters are fully compliant with ANSI/IEEE C62.11 Standard*

(1) Maximum discharge voltage for a 10-kA impulse current wave which produces a voltage wave cresting in 0.5 μs. This can be used for coordination where front-of-wave sparkover was formerly used.

(2) Based on a 500A surge of 45-μs time to crest.
# Hubbell PVR Protective Levels
(Catalog 31)

## Riser-Pole
### PVR-Optima

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<tr>
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<th>MCOV kV</th>
<th>Unit Catalog Number</th>
<th>0.5 μsec 10kA Maximum IR-kV (1)</th>
<th>500 A Switching Surge Maximum IR-kV (2)</th>
<th>8/20 Maximum Discharge Voltage - kV</th>
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<td></td>
<td></td>
<td>1.5 kA</td>
</tr>
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# Hubbell ELA Protective Levels (Catalog C8)

## Protective Characteristics

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<th>MCOV kV</th>
<th>Rating kV</th>
<th>0.5 μsec 5 kA Max IR-kV</th>
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15 kV URD System Protection
8.4 kV MCOV Arrester
Insulation Coordination Comparison

<table>
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<tr>
<th>Overhead Arrester</th>
<th>MCOV</th>
<th>FOW Protective Level (kV)</th>
<th>Open Point Arrester</th>
<th>1.5 kA Discharge Voltage (kV)</th>
<th>BIL (kV)</th>
<th>Max Voltage Stress (kV)</th>
<th>Protective Margin</th>
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<td>61.0%</td>
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<td>8.4 kV</td>
<td>34.0</td>
<td>Hubbell ELA</td>
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<td>95</td>
<td>47.5</td>
<td>100.0%</td>
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<td>29.5</td>
<td>Hubbell ELA</td>
<td>27.0</td>
<td>95</td>
<td>43.0</td>
<td>120.9%</td>
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Max Voltage Stress = 2 * FOW
Protective Margin = (((BIL / (2*FOW))-1)*100

Max Voltage Stress = FOW+ (1.5 kA Discharge Voltage/2)
Protective Margin = (((BIL / (FOW + (1.5 kA Discharge Voltage/2))) -1)*100
### 25 kV URD System Protection
#### 15.3 kV MCOV Arrester

**Insulation Coordination Comparison**

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<th>MCOV</th>
<th>FOW Protective Level (kV)</th>
<th>Open Point Arrester</th>
<th>1.5 kA Discharge Voltage (kV)</th>
<th>BIL (kV)</th>
<th>Max Voltage Stress (kV)</th>
<th>Protective Margin</th>
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<td>125</td>
<td>79.4</td>
<td>57.4%</td>
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**Formulas:**

- Max Voltage Stress = 2 * FOW
- Protective Margin = ((BIL / (2*FOW))-1)*100

- Max Voltage Stress = FOW+ (1.5 kA Discharge Voltage/2)
- Protective Margin = ((BIL / (FOW + (1.5 kA Discharge Voltage/2)))-1)*100
### 35 kV URD System Protection
#### 22 kV MCOV Arrester
#### Insulation Coordination Comparison

<table>
<thead>
<tr>
<th>Overhead Arrester</th>
<th>MCOV</th>
<th>FOW Protective Level (kV)</th>
<th>Open Point Arrester</th>
<th>1.5 kA Discharge Voltage (kV)</th>
<th>BIL (kV)</th>
<th>Max Voltage Stress (kV)</th>
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<td>78.60</td>
<td>None</td>
<td>N/A</td>
<td>150</td>
<td>157.2</td>
<td>-4.6%</td>
</tr>
<tr>
<td>Optima-100</td>
<td>22.0 kV</td>
<td>91.90</td>
<td>Hubbell ELA</td>
<td>78.0</td>
<td>150</td>
<td>130.9</td>
<td>14.6%</td>
</tr>
<tr>
<td>Optima PVR</td>
<td>22.0 kV</td>
<td>78.60</td>
<td>Hubbell ELA</td>
<td>78.0</td>
<td>150</td>
<td>117.6</td>
<td>27.6%</td>
</tr>
</tbody>
</table>

**Max Voltage Stress** = 2 * FOW  
**Protective Margin** = \(((BIL / (2*FOW)) - 1) * 100\)

**Max Voltage Stress** = FOW + (1.5 kA Discharge Voltage/2)  
**Protective Margin** = \(((BIL / (FOW + (1.5 kA Discharge Voltage/2))) - 1) * 100\)
Substation Transformer Protection

• Base Case – Develop Fundamentals
• Voltage Class vs. BIL vs. Arrester Protective Level
• Explore Impact Arrester Type (Heavy, Normal, and Riser)
• SiC Arrester Considerations vs. Reduced (Aged) BIL
• Summary Tables (69, 138, 230 and 345kV) – Bang for the Buck
Base Case – 230 kV System
140 kV MCOV SVN (75mm Dia.)
650 kV BIL No Lead Length
# Substation Arresters

System Voltage vs. BIL vs. Arrester Protective Margin

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>BIL</th>
<th>Block Diameter</th>
<th>MCOV</th>
<th>FOW Margin %</th>
<th>BIL Margin %</th>
<th>S/S Margin %</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>250</td>
<td>75</td>
<td>42</td>
<td>116</td>
<td>107</td>
<td>121</td>
</tr>
<tr>
<td>138</td>
<td>450</td>
<td>75</td>
<td>84</td>
<td>95</td>
<td>87</td>
<td>100</td>
</tr>
<tr>
<td>230</td>
<td>650</td>
<td>75</td>
<td>140</td>
<td>68</td>
<td>62</td>
<td>65</td>
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<tr>
<td>345</td>
<td>900</td>
<td>75</td>
<td>2069</td>
<td>56</td>
<td>50</td>
<td>44</td>
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</tbody>
</table>
Substation Arresters
Arrester Type vs. System Voltage Arrester
Protective Margin

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>BIL</th>
<th>Block Diameter</th>
<th>MCOV</th>
<th>FOW Margin %</th>
<th>BIL Margin %</th>
<th>S/S Margin %</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>250</td>
<td>48</td>
<td>42</td>
<td>94</td>
<td>79</td>
<td>89</td>
</tr>
<tr>
<td>69</td>
<td>250</td>
<td>56</td>
<td>42</td>
<td>98</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>69</td>
<td>250</td>
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<td>79</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>138</td>
<td>450</td>
<td>75</td>
<td>84</td>
<td>95</td>
<td>87</td>
<td>100</td>
</tr>
<tr>
<td>230</td>
<td>650</td>
<td>56</td>
<td>140</td>
<td>62</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>230</td>
<td>650</td>
<td>75</td>
<td>140</td>
<td>68</td>
<td>62</td>
<td>65</td>
</tr>
<tr>
<td>345</td>
<td>900</td>
<td>75</td>
<td>209</td>
<td>56</td>
<td>50</td>
<td>44</td>
</tr>
</tbody>
</table>
## Substation Arresters
### Aged BIL – 20% Reduction
### Silicon Carbide vs. MOV Arrester Protective Margin

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>BIL</th>
<th>Block Diameter</th>
<th>MCOV</th>
<th>FOW Margin %</th>
<th>BIL Margin %</th>
<th>S/S Margin %</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>200</td>
<td>SiC</td>
<td>60 Rated</td>
<td>21</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>69</td>
<td>200</td>
<td>75</td>
<td>48</td>
<td>73</td>
<td>65</td>
<td>77</td>
</tr>
<tr>
<td>138</td>
<td>360</td>
<td>SiC</td>
<td>108 Rated</td>
<td>27</td>
<td>47</td>
<td>22</td>
</tr>
<tr>
<td>138</td>
<td>360</td>
<td>75</td>
<td>84</td>
<td>56</td>
<td>49</td>
<td>60</td>
</tr>
<tr>
<td>230</td>
<td>520</td>
<td>SiC</td>
<td>180 Rated</td>
<td>6</td>
<td>26</td>
<td>5</td>
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<tr>
<td>230</td>
<td>520</td>
<td>75</td>
<td>140</td>
<td>35</td>
<td>29</td>
<td>32</td>
</tr>
</tbody>
</table>
Line Protection
Suspended Line Arrester Configuration
Typical Dead-End Line Arrester Configuration

15 kV Class
Part No.
612009-G1-G0-001
National Grid

• Champion International Paper Co.
  – Operates 363 days/year, 24 hours/day
  – One interruption costs $50-100k

• No. 2 line - 115 kV, 70 years old
  – Hired PTI
  – Installed new OHSW
  – Improved footing resistances
National Grid 115 kV Line without Surge Arresters
National Grid 115 kV Line with Surge Arresters

Photo courtesy of National Grid
Wrap Up Questions