TRAINING

Switching Over Voltages (SOV)

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Switching Studies

Objectives of a switching study:

- Determine the over voltage levels due to switching events
- Determine equipment insulation levels
- Assessing surge arrester requirements and compliance
- Identify network resonance issues

Type of studies:

- Switching frequency over voltage studies
- Temporary over voltage studies
Switching Over Voltages (SOV)

• Switching over voltages (SOV) result from the operation of breakers and switches or due to faults in a power system.

• Switching actions lead to travelling waves on transmission lines, in addition to initiating oscillations in local L-C elements.

• Such travelling waves and local oscillations can appear as high frequency voltage transients in the network. The switching transient frequencies can reach up to a few kHz.
## SOV and TOV Frequency Spectrum

<table>
<thead>
<tr>
<th>Class</th>
<th>Low frequency</th>
<th>Transient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous</td>
<td>Slow-front</td>
</tr>
<tr>
<td></td>
<td>Temporary</td>
<td></td>
</tr>
</tbody>
</table>

**Voltage on over-voltage shapes**
- $f = 50$ Hz or $60$ Hz
- $0.03 \text{ s} \leq T_1 \leq 3.600 \text{ s}$

**Range of voltage on over-voltage shapes**
- $10 \text{ Hz} < f < 500 \text{ Hz}$
- $20 \mu\text{s} < T_1 \leq 5000 \mu\text{s}$
- $T_2 \leq 20 \text{ ms}$
- $T_2 \leq 300 \mu\text{s}$
- $3 \text{ ns} < T_1 \leq 100 \text{ ns}$
- $0.3 \text{ MHz} < f_1 < 100 \text{ MHz}$
- $30 \text{ kHz} < f_2 < 300 \text{ kHz}$

Source: IEC Standard TR 60071-4 Insulation Co-ordination
Modelling Aspects:

• System represented at least up to two buses away from point of study
• Frequency dependent transmission line models
• Detailed transformer model including saturation data
• Shunt devices
• Surge arrester non-linear characteristics
• Equivalent voltage source models to represent network boundaries
Model expands to at least two buses away from the stations under study

Ex. 380 kV System

Line under study
Network boundary equivalence

Model data
- Bus voltage & angle
- Real power & reactive power
- Positive sequence impedance
- Zero sequence impedance
Transmission Line

Modelling type
- **PI-section Model**
  - Provide the correct fundamental frequency impedance, but do not provide an accurate full-frequency transient response.
  - Suitable for steady-state studies (such as a load flow).

- **Bergeron Model**
  - Represent the transmission line’s travelling wave characteristics.
  - It is accurate only at the specified frequency and is suitable for studies where the specified frequency load-flow is most important (e.g. relay studies).

### Bergeron Model Options
- Travel Time Interpolation: On
- Reflectionless Line (ie Infinite Length): No
Modelling type

- **Frequency-Dependent Model**
  - Represent the transmission line’s travelling wave characteristics.
  - It is accurate for all range of frequencies.

**Frequency Dependent (Phase) Model Options**

<table>
<thead>
<tr>
<th>Option</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Interpolation</td>
<td>On</td>
</tr>
<tr>
<td>Curve Fitting Starting Frequency</td>
<td>0.5 [Hz]</td>
</tr>
<tr>
<td>Curve Fitting End Frequency</td>
<td>1.0E6 [Hz]</td>
</tr>
<tr>
<td>Total Number of Frequency Increments</td>
<td>100</td>
</tr>
<tr>
<td>Maximum Order of Fitting for Yc</td>
<td>20</td>
</tr>
<tr>
<td>Maximum Fitting Error for Yc</td>
<td>0.2 [%]</td>
</tr>
<tr>
<td>Max. Order per Delay Grp. for Prop. Func.</td>
<td>20</td>
</tr>
<tr>
<td>Maximum Fitting Error for Prop. Func.</td>
<td>0.2 [%]</td>
</tr>
<tr>
<td>DC Correction</td>
<td>Disabled</td>
</tr>
<tr>
<td>Passivity Checking</td>
<td>Disabled</td>
</tr>
</tbody>
</table>
Transmission Line

Tower cross section
- Geometrical arrangement of conductors
- Ground clearance
- Line sag

Tower: H-Frame-3H4
Conductors: chukar
Ground_Wires: 1/2_HighStrengthSteel
Conductor Data (illustrative)

- Conductor type
- Radius
- DC resistance
- Bundle data
- Ground wire data
- Conductor sag

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Conductor type</td>
<td>xxx</td>
</tr>
<tr>
<td>2 Outer radius (effective)</td>
<td>0.590 [in]</td>
</tr>
<tr>
<td>3 DC resistance</td>
<td>0.9012 [ohm/mi]</td>
</tr>
<tr>
<td>4 Conductor sag</td>
<td>39 [ft.]</td>
</tr>
<tr>
<td>5 Bundle sub-conductors</td>
<td>2 [nos.]</td>
</tr>
</tbody>
</table>

Ground wire Data (illustrative)

- Conductor type
- Radius
- DC resistance
- Bundle data
- Ground wire data
- Conductor sag

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ground wire type</td>
<td>xxx</td>
</tr>
<tr>
<td>2 Outer radius (effective)</td>
<td>0.295 [in]</td>
</tr>
<tr>
<td>3 DC resistance</td>
<td>0.9656 [ohm/mi]</td>
</tr>
<tr>
<td>4 Conductor sag</td>
<td>32 [ft.]</td>
</tr>
</tbody>
</table>
Transmission Line

Line Transpose Data

Untransposed 200 km line

Transposed 200 km line in 4 segments (50 km each)
Transformer Model

Model data
• General Data
  • Ratings, impedance
• Saturation Data
Shunt Devices

Model

- Shunt reactor – with equivalent inductance
- Shunt capacitor – with equivalent capacitance
- Series compensation – with equivalent capacitance

\[ x = \frac{kV^2}{MVAr} \]

\[ x = \omega L \text{ or } \frac{1}{\omega C} \]
Generators and motors

Model data

- Bus voltage & angle
- Real power & reactive power
- Positive sequence impedance (Xd")
- Zero sequence impedance (if available)
Surge Arrester

Model data
- Arrester rating i.e. 360 kV
- V-I characteristic
- Energy absorption capability i.e. 13 kJ/kV
How to derive the surge arrester’s characteristics from data sheet?

Typical manufacturer’s data sheet
http://www.hubbellpowersystems.com/arresters/sub/hollowcore/station-312kv/

<table>
<thead>
<tr>
<th>Duty Cycle Rating kV rms</th>
<th>Maximum Continuous Operating Voltage (MCOV) kV rms</th>
<th>Maximum 0.5µs Discharge Voltage kV</th>
<th>Maximum Switching Surge Protective Level (kV)</th>
<th>TOV Capability 1 sec kV rms</th>
<th>TOV Capability 10 sec kV rms</th>
<th>Maximum Discharge Voltage using an 8/20 Current Wave-kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>132</td>
<td>106</td>
<td>334</td>
<td>261</td>
<td>126</td>
<td>121</td>
<td>1.5kA  3kA  5kA  10kA  20kA  40kA</td>
</tr>
</tbody>
</table>

**Surge Arrester's V-I Characteristics**

- Manufacturer’s data
- New tuning points

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Other models...

Cable model

- Bergeron model
- \( R, X, B \) (or Surge impedance and travel time)
- Frequency dependent model
- Based on Cable design data

Bergeron Model Options

- Travel Time Interpolation: On
- Reflectionless Line (ie Infinite Length): No

Manual Entry of Y,Z

- \( +ve \, R \): 0.000045e-3
- \( +ve \, XL \): 0.001278e-3
- \( +ve \, B \): 1.003e-3
- \( 0 \, R \): -estimated-
- \( 0 \, XL \): -estimated-
- \( 0 \, B \): -estimated-
Other models...

Cable model
• Pipe type
• Three cables flat or trefoil configuration
Model Validation

PSCAD model is validated against the load flow model on the following aspects

• Line power flows
  • Active power
  • Reactive power

• Source/ boundary equivalence power flows
  • Active power
  • Reactive power

• Fault levels

• Field results
## Model Validation

### Active Power Flow

<table>
<thead>
<tr>
<th>PSCAD [MW]</th>
<th>PSSE [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>685</td>
<td>686</td>
</tr>
<tr>
<td>382</td>
<td>379</td>
</tr>
<tr>
<td>324</td>
<td>325</td>
</tr>
<tr>
<td>118</td>
<td>121</td>
</tr>
<tr>
<td>834</td>
<td>837</td>
</tr>
<tr>
<td>434</td>
<td>436</td>
</tr>
<tr>
<td>647</td>
<td>650</td>
</tr>
<tr>
<td>405</td>
<td>409</td>
</tr>
<tr>
<td>207</td>
<td>203</td>
</tr>
<tr>
<td>237</td>
<td>238</td>
</tr>
</tbody>
</table>

### Fault Level

<table>
<thead>
<tr>
<th>PSCAD [kA]</th>
<th>PSSE [kA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.7</td>
<td>46.9</td>
</tr>
<tr>
<td>33.4</td>
<td>33.2</td>
</tr>
<tr>
<td>47</td>
<td>46.9</td>
</tr>
</tbody>
</table>
Model Validation
Simulation setup

- Point on wave impact - 100 points over a cycle
- Trapped charge on lines
- Statistical breaker
- Network topology (credible scenarios)
Point on wave impact

- Switching at different points over a 60 Hz cycle
  - 100 points over a cycle → 100 simulations
Point on wave impact

- Switching at 100 different points over a 60 Hz cycle
  - Multiple Run component
  - Multiple Run additional recording
Statistical Breaker

- Used in the single-pole operation of a 3-phase breaker, in a statistically distributed manner.
Trapped Charge

Simulation of trapped charge on transmission line
- Line reactor out of service

Simulation of trapped charge on transmission line
- Line reactor in service
Credible Scenarios

- 10 - 20 different scenarios for each line
- 100 point on wave simulations for each scenario

Ex. 1) Reactors in service
2) Reactors out of service
3) Circuit B in service
4) Circuit B out of service
SOV Results

- Voltage waveform
- Surge Arrester Energy
SOV Results – Statistical Summary

**Line switching result**

- Ex. Double circuit line
  - Circuit A energized from one end
  - Monitor the open end

<table>
<thead>
<tr>
<th></th>
<th>Closing Time</th>
<th>E_19011</th>
<th>E_31227</th>
<th>E_A1</th>
<th>E_A2</th>
<th>E_B1</th>
<th>E_B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum:</td>
<td>0.4</td>
<td>441.6869422</td>
<td>328.437343</td>
<td>441.687283</td>
<td>648.5288508</td>
<td>41.0001304</td>
<td>53.75910884</td>
</tr>
<tr>
<td>Maximum:</td>
<td>0.4166</td>
<td>486.3028315</td>
<td>333.013673</td>
<td>486.303169</td>
<td>667.127313</td>
<td>78.50546719</td>
<td>84.10483459</td>
</tr>
<tr>
<td>Mean:</td>
<td>0.4083</td>
<td>469.2023583</td>
<td>330.033559</td>
<td>469.202736</td>
<td>656.3111978</td>
<td>64.56812464</td>
<td>73.44458982</td>
</tr>
<tr>
<td>Std Dev:</td>
<td>4.86E-03</td>
<td>12.5280621</td>
<td>1.01570766</td>
<td>12.5280421</td>
<td>5.347866178</td>
<td>12.1054595</td>
<td>8.943241286</td>
</tr>
<tr>
<td>2% Level:</td>
<td>0.398310918</td>
<td>443.472864</td>
<td>327.94755</td>
<td>443.473283</td>
<td>645.3280233</td>
<td>39.70655001</td>
<td>55.0774175</td>
</tr>
<tr>
<td>98% Level:</td>
<td>0.418289082</td>
<td>494.9318526</td>
<td>332.119567</td>
<td>494.932189</td>
<td>667.2943723</td>
<td>89.42969926</td>
<td>91.81176214</td>
</tr>
</tbody>
</table>

**Voltage in kV**
Thank you