GMD Effects on Shunt Capacitor Banks

Dominion Virginia Power

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GMD Induced Currents

Ionospheric Electrojet

\[ \frac{\partial B}{\partial t} \]

EARTH SURFACE

EARTH-SURFACE POTENTIAL

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Effects on Power System Equipment

- GMD flowing in transformers causes saturation effects
  - Saturation effects power transformers produce harmonics
  - Saturation effects in power transformers consume system VAR’s
  - Current Transformers (CT’s), Not Split Core or Fiber Optic
  - Saturation effects power transformers heating
Terrestrial radio and satellite communications focus on systems used in emergency and contingency communications.

“Last Mile” photos courtesy of AT&T and FEMA
Effects on Communication and Impacts on Relay Protection

• Impact on Satellite Communication

  • Loss or Interference with Microwave Communications
    – Rural Utilities use Microwave Communications for line protection
    – Use of microwave communications for alarms and SCADA interrupted

  • Loss of Global positioning Systems (GPS)
    – Most Utilities use GPS for sync of relay and syncrophasers
    – Most Utility Companies Use GPS for navigation

  • Loss of L-band Satellite Phones
    – Most public safety organizations use L-Band Sat Phones
    – Many Utilities use L-Band Sat phones
Effects on Power System Equipment

• Saturation of transformers cause harmonics
  – Capacitor reliability, false trips and failures
  – Filter Banks reliability, false trips and failures
  – SVC’s reliability, false trips and failures (Filter Banks)

• March 1989 Dominion Tripped 13 115 KV Capacitor Banks
Effects on Capacitor Protection
Effects on Capacitor Protection
Effects on Capacitor Ratings

• IEEE 18 & IEEE 1036 Nominal Ratings
  – 110% of rated rms voltage
  – 120% of rated peak voltage, i.e. crest voltage not exceeding $1.2 \times \times$ rated rms voltage, including harmonics but excluding transients
  – 135% of nominal rms current based on rated kvar and rated voltage
  – 135% of rated kvar

• IEEE 1531 IEEE Guide for Specification and Application of Harmonic filters provides ratings guidance
  – Shunt Capacitor (Bank Ratings)
  – Harmonic Filter (Transmission) (Bank Ratings)
  – SVC Harmonic Filters (Bank Ratings)
Effects on Capacitor Ratings

- Capacitors are low impedance path for generated harmonics and will source them

\[ I_{rms} = \sqrt{(I_1)^2 + (I_2)^2 + (I_3)^2 + \cdots + (I_n)^2} \]

where \( n \) = harmonic number

**Table II.** Current harmonics\(^1\) generated by auto-transformers for no-load condition and 100 Amps/phase of GIC.
GUSs at Mt Storm are expected to generate different amplitude of harmonics.

<table>
<thead>
<tr>
<th>Harmonic Order</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-RMS TX1</td>
<td>54.68</td>
<td>38.51</td>
<td>21.74</td>
<td>10.29</td>
<td>5.79</td>
<td>4.93</td>
<td>4.67</td>
<td>2.34</td>
<td>1.75</td>
<td>1.63</td>
</tr>
<tr>
<td>I-RMS TX2</td>
<td>54.68</td>
<td>38.51</td>
<td>21.74</td>
<td>10.29</td>
<td>5.79</td>
<td>4.93</td>
<td>4.67</td>
<td>2.34</td>
<td>1.75</td>
<td>1.63</td>
</tr>
</tbody>
</table>

\[ I_{rms} = \sqrt{(150)^2 + (54.68)^2 + (38.51)^2 + (21.74)^2 + (10.29)^2 + (5.79)^2} \]

\[ \% \text{ overload} = \left( \frac{166.08}{150} \right) \times 100 = 111 \% \]
IEEE C37.99 section 11.2 “Capacitors Rated For Higher Voltages May Be Used”

\[ KVARE_2 = kvar_{E_1} \frac{(E_{vapplied})^2}{(E_{vrated})^2} \]

\[ KVARE_2 = 92.3 \frac{(500)^2}{(554.7)^2} = 75 \text{ MVAR} \]

Icap=KVAR / Vrated
Icap= 166.3 amps at 60 HZ
% overload =\( \frac{152.67}{166.3} \times 100 = 91.8 \% \)
Effects on Capacitor Ratings
Thank You
GIC Modeling & Assumptions

1. Calculation of Geoelectric Field (Induced Voltage), assumed 1 V/km.
2. Network Model (DC)
\[ I^e = (1 + Y^n Z^e)^{-1} J^e \]

\[ J_i^e = \sum_{j \neq i} J_{ji}^n \]

\[ J_{ij}^n = \frac{V_{ij}^0}{R_{ij}^n} \]

\[ Y_{ij}^n = \begin{cases} -\frac{1}{R_{ij}^n}, & i \neq j \\ \sum_{k \neq i} 1/R_{ik}^n, & i = j \end{cases} \]

\[ Z^e = \text{Diagonal}(R^e) \]
Autotransformers

- Autotransformers provide a direct path between both voltage levels for GIC.
- DVP has autotransformers in most of its transmission system.

<table>
<thead>
<tr>
<th>500/230/115</th>
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</thead>
<tbody>
<tr>
<td>Possum</td>
</tr>
<tr>
<td>Elmont</td>
</tr>
<tr>
<td>Yadkin</td>
</tr>
<tr>
<td>Bristers</td>
</tr>
<tr>
<td>Loudoun</td>
</tr>
<tr>
<td>Dooms</td>
</tr>
<tr>
<td>Suffolk</td>
</tr>
<tr>
<td>Lexington</td>
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</table>

500 kV line

500 kV

Series W.

230 kV line

230 kV

Common W.
Long Lines & Extreme Points

<table>
<thead>
<tr>
<th></th>
<th>GIC 1</th>
<th>GIC 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-13.1</td>
<td>-14.2</td>
</tr>
<tr>
<td>2</td>
<td>-2.6</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>2.6</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>13.1</td>
<td>14.2</td>
</tr>
</tbody>
</table>

\[ Re = 0.2\, \Omega \quad RL = 0.6\, \Omega \quad 1\, \text{Volt/km} \]

Total Length = 40 km
GIC Mitigation

• First Rule of Mitigation is Do No Harm

  • You should not be worse off with mitigation than you were before solution is applied

  • Law of unintended consequences. You change one component or to solve a problem and you create another problem
GIC Mitigation

• Model and Study The Problem
  
  • Mitigation should not be a solution looking for a problem
  
  • Develop strategies that may combine operating configurations and blocking devices
  
  • Strategies should be coordinated with neighboring utilities since what one utility mitigation will impact another
GIC Mitigation

• GIC Reduction
  – Series Capacitors are a Mature Technology
  – Transformer Neutral Blocking device
    • Resistance or Reactance
  • Capacitive Device
GIC Mitigation

Design Issues

- Harmonic or resonance study
- Feroresonance Study
- Insulation coordination study
- Stability issue generator with small signal noise
- Must use smallest impedance to reduce neutral overvoltage
- Impact of capacitive inrush on transformer when filter bank inserted
- Impact of TRV when filter bypassing
- Impact of resonant circuit on energization of transformer transient modeling
Thank You