Use of PMU Data for Geomagnetic Disturbance Model Validation

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Introduction

- Solar storms disturb the Earth’s magnetic field.
- Change of magnetic field induces electric field.
- Geomagnetic induced currents (GICs) flow through the lines.
- GICs are DC Currents.
- GICs have negative impacts on the network.
- The GICs cause half-cycle saturation of transformers.
- Reactive power loss is increased due to high magnetizing current and harmonics.
- Modeling the reactive power during GMDs is very important.
GIC-saturated reactive power loss is linearly related to the GIC at transformer neutral.

\[ Q_{GIC} = K V_{HV} I_{GIC} \]


**Example of K Values for Different Core Types**

<table>
<thead>
<tr>
<th>Core Type</th>
<th>K Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Phase</td>
<td>1.8</td>
</tr>
<tr>
<td>Three Phase, Shell Form</td>
<td>1.45</td>
</tr>
<tr>
<td>Three Phase, Core From Generic</td>
<td>1.5</td>
</tr>
<tr>
<td>Three Phase, 5-Legged</td>
<td>1.5</td>
</tr>
<tr>
<td>Three Phase, 7-Legged</td>
<td>1.2</td>
</tr>
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**GIC-Saturated Reactive Power Loss**

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Estimating the Transformer Mvar Parameter

\[ Q_{\text{loss}} = Q_1 - Q_2 = Q_{\text{loss, Normal}} + Q_{\text{GIC}} \]

\[ \implies Q_1 - Q_2 - I_2^2 X_s = K V_1 I_{\text{GIC}} \]

We have PMU data over time:

\( t_1, t_2, t_3, t_{k-1}, t_k \)
Per unit system for GICs:

\[ I_{\text{base, HV}} = \frac{S_{\text{base}}}{\sqrt{3}V_{\text{HV, Nominal}}} \]

\[ I_{\text{GIC, pu}} = \frac{I_{\text{GIC}}}{I_{\text{base, HV}}} \]

\[ Q_{\text{GIC, pu}} = \frac{Q_{\text{GIC}}}{S_{\text{base}}} = V_{\text{pu}} K I_{\text{GIC, pu}} \quad (K_{\text{pu}} = 1.154 K_{\text{Old}}) \]

We need P, Q, and V to calculate the current at low voltage side of the transformer:

\[ I_2 = \sqrt{\frac{P_2^2 + Q_2^2}{V_2}} \]

The required fields for estimating K are:

\[
\begin{bmatrix}
  P_1 \\
  Q_1 \\
  V_1 \\
  \vdots \\
  P_2 \\
  Q_2 \\
  V_2 \\
  I_{\text{GIC}}
\end{bmatrix}
\]
Simulation Setup

- A geomagnetic storm is enforced to the 20-bus test case [Horton et al., 2012] and the response of the system is monitored.
- Synthetic PMU data is generated using the transient stability toolbox. The data contains P, Q and V at all busses with frequency of 60Hz.
- Synthetic GIC data is generated using the GIC add on.
- Gaussian noise with signal-to-noise ratio (SNR) of 20 is added to all measurements.
The actual GIC-saturated reactive power ($Q_{GIC}$) as compared with the one obtained from PMU data.
K Value Estimation

The variation of the GIC-saturated reactive power with respect to the GIC (The slope is used to estimate K).
A Two segmented model may be used to relate GICs to reactive power loss.

Piecewise linear regression techniques are used to estimate $K_1$ and $K_2$.

- The break point current is .038 and is assumed to be given to the estimator.
- $K_1$ and $K_2$ are estimated with high accuracy.
# K Value Estimation

<table>
<thead>
<tr>
<th>Transformer ID</th>
<th>Actual</th>
<th>Estimated</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>1.75</td>
<td>1.71</td>
<td>2.49</td>
</tr>
<tr>
<td>3</td>
<td>1.75</td>
<td>1.7</td>
<td>2.79</td>
</tr>
<tr>
<td>4</td>
<td>1.75</td>
<td>1.71</td>
<td>2.1</td>
</tr>
<tr>
<td>5</td>
<td>1.75</td>
<td>1.69</td>
<td>3.23</td>
</tr>
<tr>
<td>6</td>
<td>1.63</td>
<td>1.62</td>
<td>1.05</td>
</tr>
<tr>
<td>7</td>
<td>1.63</td>
<td>1.61</td>
<td>1.35</td>
</tr>
<tr>
<td>8</td>
<td>0.82</td>
<td>0.81</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>0.82</td>
<td>0.81</td>
<td>0.87</td>
</tr>
<tr>
<td>10</td>
<td>0.82</td>
<td>0.8</td>
<td>1.52</td>
</tr>
<tr>
<td>11</td>
<td>0.82</td>
<td>0.8</td>
<td>2.06</td>
</tr>
<tr>
<td>12</td>
<td>1.14</td>
<td>1.13</td>
<td>0.85</td>
</tr>
<tr>
<td>13</td>
<td>1.14</td>
<td>1.13</td>
<td>1.58</td>
</tr>
<tr>
<td>14</td>
<td>1.18</td>
<td>1.18</td>
<td>0.05</td>
</tr>
<tr>
<td>15</td>
<td>1.18</td>
<td>1.17</td>
<td>1.37</td>
</tr>
</tbody>
</table>

**Maximum Error < 4%**
Effect of K Value on Voltage

All transformers have K value of 1.8

Total GIC Losses 2344.9 Mvar

All transformers have K value of 0.9

Total GIC Losses 1733.6 Mvar
Conclusions

- Modeling of the transformers reactive power loss during geomagnetic disturbances is presented.
- PMU data is used to estimate the transformer parameters.
- The effectiveness of the proposed estimation technique is validated through simulation using a 20-bus test case.

Future Work

- Use actual PMU data for real systems instead of the synthetic data for a test case.
- Explore the possibility of using the PMU data at only one side of the transformer for estimating its parameters.
Thank You

Questions & Comments
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