A Process for Evaluating the Degree of Susceptibility of a fleet of Power Transformers to Effects of GIC

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Outline of Presentation

- Background
- Purpose of Paper
- Process of GIC Total Susceptibility Evaluation
- Design – Based Susceptibility
- GIC – Level Susceptibility
- Study Case
- Benefits of Fleet GIC Susceptibility Evaluation
Back Ground

- Misconception in the electric power industry
  - GIC has caused, and would cause, significant damaging overheating to a large majority of power transformers

- Overreaction => Calling for:
  - Conservative operating procedures (Unnecessarily reducing load at low levels of GIC)
  - Installation of expensive GIC Blocking devices
  - Paying more attention to thermal effects in transformers and not to the true issue of increased VAR Demand and effect of harmonics on power system components

- A recent study confirmed that because of the nature of the GIC currents:
  - Only a finite number of power transformers with certain design features could experience damaging overheating
  - A larger # of transformers would be susceptible to core saturation & some overheating
  - The rest of the transformers would not be susceptible to either core saturation or damaging overheating
Purpose of the Paper

Describes a process, where a fleet of power transformers can be properly evaluated to determine:

- Which Transformers would be susceptible to damaging overheating
- Which Transformers would be susceptible to only core saturation & moderate overheating
- Which transformers would have a low level of susceptibility to either effects of GIC
- Which Transformers would not be susceptible to effects of GIC
Process of GIC Total Susceptibility Evaluation

- Total susceptibility of a power transformer to effects of GIC is determined by:
  - Transformer Design – Based Susceptibility
  - GIC Level – Based Susceptibility

- Process was applied to a fleet of over 1600 > 500 KV Large power transformers on the US Power Grid, as a Case Study

- Does not apply to shunt reactors and Specialty Transformers; such as Phase shifters, Rectifier transformers, Furnace Transformers, etc.
Design – Based Susceptibility

- Category – I:
  - Transformers not susceptible to effects of GIC
- Category – II
  - Transformers least susceptible to core saturation
- Category – III
  - Transformers susceptible to core saturation and some windings & structural parts overheating
- Category – IV
  - Transformers susceptible to both core saturation as well as possible damaging windings and / or Structural parts overheating
Parameters Used for Evaluating Design – Based Susceptibility

- **Voltage Ratings**
  - Higher voltage transformers would be exposed to higher levels of GIC

- **Type of transformer (GSU vs. Auto transformers)**
  - EHV Auto transformers are Y - Y and typically have a Delta tertiary, which makes them susceptible to overheating in the Tertiary winding

- **Shell-form vs. Core Form**
  - Shell-form transformers, regardless of their core type, are susceptible to core saturation
  - Older GSU designs are susceptible to damaging winding overheating due to high circulating currents when the core saturates

- **Single-phase vs. three-phase and Core-type**
  - 3-Phase core form transformers with 3-limb cores are least susceptible to saturation due to GIC
Parameters Used for Evaluating Design – Based Susceptibility, cont.

- **Winding connections**

  - Designs with a Delta LV (other than GSU(s)) or TV winding are susceptible to overheating of this winding because:
    - Different phases in a bank of 1-phase transformers, or a 3-phase transformer, will experience core saturation at different points on the cycle.
    - This results in a net voltage in the delta winding leading to high circulating currents.
  
  - The magnitude of this current is a function of the transformer design and the magnitude of GIC.
  
  - Current is limited by the impedance seen by this winding.
GIC Level – Based Susceptibility

- Level of GIC is determined by:
  - Geographical region where the transformer is located
  - Location of transformer in the power system
  - Closeness to a large body of water (Ocean / Sea / Lake)
  - Resistance of the soil in that location
  - KV of HV side of Transformer
  - Direction of HV transmission lines

- GIC – Level susceptibility divides transformers into 3 categories:
  - High, Medium, and Low

- These categories are determined using either of the following data:
  - Calculated relative levels of GIC that transformers in a certain location would be subjected to for a predetermined reference GMD storm
  - Using published information on relative levels of GMD that different geographical regions would be exposed to.
Case Study

- 1593 large power Transformers in service
- ≥ 500 kV part of the US Electric Power grid
- 1300+ single – phase transformers & 200+ three – phase transformers
- 600+ different designs
- 700+ shell-form transformers and 800+ core-form transformers.
- 200 different shell-form designs and 400 different core-form designs.
- 1400+ transformers are 500 kV transformers and the rest are 765 kV
- 100 MVA – 1000 MVA Power Ratings
- 900+ Autotransformers / 450 Generator Step-Up transformers / 200 other Multi-winding transformers.
Results of Case Study

### Summary of results of Design – Based assessment of GIC susceptibility

<table>
<thead>
<tr>
<th>Number of transformers</th>
<th>Categories of Design-Based Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td><strong>Actual Count</strong></td>
<td>1593</td>
</tr>
<tr>
<td><strong>% of Total</strong></td>
<td>100 %</td>
</tr>
</tbody>
</table>

### Summary of # of transformers susceptible to different levels of GIC

<table>
<thead>
<tr>
<th>Number of transformers</th>
<th>Susceptibility to Level of GIC Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td><strong>Actual Count</strong></td>
<td>1538</td>
</tr>
<tr>
<td><strong>% of Total</strong></td>
<td>100 %</td>
</tr>
</tbody>
</table>

### Summary of results of Total GIC susceptibility of transformers

<table>
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<th>Number of transformers</th>
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<tr>
<td><strong>% of Totals</strong></td>
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</tbody>
</table>
Final Results of Case Study

- 2/3rd of transformers were determined, based on their designs, to have a high level of susceptibility to possible damaging overheating, this group drops to about 1 in 8 when considering the locations of these transformers.
- Number of transformers that have a medium level of Total susceptibility is only a little lower than that determined to have that level of susceptibility based on the design alone.
- The group of transformers determined to have low Total susceptibility to effects of GIC increased from being 1 in 20, when considering the design alone, to about 60% of all transformers in this study when considering the GIC exposure of these transformers to GIC.
Benefits of Fleet GIC Susceptibility Evaluation

- Allows Utilities to focus their mitigation / studies effort
  - Utilities could request manufacturers of transformers, identified to be susceptible to core saturation, to provide data on the additional VAR consumption and current harmonics as a function of the level of GIC the transformer would be exposed to
  - Power system analysts would use such data, to perform system simulations for evaluating the response of the power system and its components during a GMD storm. As a result of these studies:
    - Proper contingencies can be built in the Power System for such magnitudes of VAR, so Voltage Collapse and possible grid black-outs can be avoided.
    - Increasing robustness of the network; including providing additional network protection and adjusting settings of relays and other susceptible equipment.
    - Developing special / proper operating procedures during a GMD storm; such as line load-sharing, desensitization of susceptible equipment, and minimizing voltage regulations.
    - Installation of appropriate GIC blocking devices, if needed
  - System blackouts and possible damages to some transformers can be avoided in future GMD events
Utilities can request manufacturers of the transformers, identified as being highly susceptible to damaging windings, and/or structural parts overheating, to perform more detailed thermal analysis to determine the GIC Capability of these transformers; hence avoiding possible damaging overheating.
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