Detecting and Managing Geomagnetically Induced Currents With Relays
Transformer Relay Connections

- Voltage
- Current
- Control
- RTDs
Transformer Protective Relay

- Measures differential current
- Harmonic blocking or restraint for security
- Volts/Hz (overexcitation) protection
- RTD inputs monitor top oil, “hot spot,” tank temperatures
Transformer Protection Functions

- Trip for internal faults
- Restrain for external faults
- Alarm and trip for overload
- Monitor thru-faults for cumulative mechanical damage
- Trip if overexcited or overheated
- …and, trip for excessive GIC, if desired
Detecting GIC Events

- Transformer relays measure fundamental, harmonics, and RMS quantities.
- Relays can also produce GIC alarms.
- Information is continuously available to show harmonics, and is available to SCADA.
- It’s possible to incorporate data from USGS magnetometers and NOAA solar activity reports, to change settings and in logic.
## Transformer Metering Report

<table>
<thead>
<tr>
<th>Relay 1</th>
<th>Date: 04/12/2008</th>
<th>Time: 06:06:31.366</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station A</td>
<td>Serial Number: 2008030645</td>
<td></td>
</tr>
</tbody>
</table>

### Operate Currents (per unit)

<table>
<thead>
<tr>
<th>IOPA</th>
<th>IOPB</th>
<th>IOPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.32</td>
<td>1.32</td>
<td>1.32</td>
</tr>
</tbody>
</table>

### Restraint Currents (per unit)

<table>
<thead>
<tr>
<th>IRPA</th>
<th>IRPB</th>
<th>IRPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.91</td>
<td>3.91</td>
<td>3.91</td>
</tr>
</tbody>
</table>

### 2nd Harmonic Currents (percentage of IOPA, IOPB, IOPC)

<table>
<thead>
<tr>
<th>IOPAF2</th>
<th>IOPBF2</th>
<th>IOPCF2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>0.09</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### 4th Harmonic Currents (percentage of IOPA, IOPB, IOPC)

<table>
<thead>
<tr>
<th>IOPAF4</th>
<th>IOPBF4</th>
<th>IOPCF4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.10</td>
<td>0.06</td>
</tr>
</tbody>
</table>

### 5th Harmonic Currents (percentage of IOPA, IOPB, IOPC)

<table>
<thead>
<tr>
<th>IOPAF5</th>
<th>IOPBF5</th>
<th>IOPCF5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06</td>
<td>0.11</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Enabled Windings: S, T
Transformer Volts/Hertz Report

MET SEC T <Enter>

Relay 1
Station A

Date: 04/20/2008  Time: 06:47:23.494
Serial Number: 2008030645

Secondary Meter: Winding T

<table>
<thead>
<tr>
<th>Phase Currents</th>
<th>Sequence Currents</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA</td>
<td>IB</td>
</tr>
<tr>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td>MAG(A,sec)</td>
<td>4.37</td>
</tr>
<tr>
<td>ANG(deg)</td>
<td>164.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase Voltages - PT V</th>
<th>Sequence Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA</td>
<td>VB</td>
</tr>
<tr>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td>MAG(V,sec)</td>
<td>62.922</td>
</tr>
<tr>
<td>ANG(deg)</td>
<td>-0.13</td>
</tr>
</tbody>
</table>

Line-to-Line Voltage

<table>
<thead>
<tr>
<th>PT - V</th>
<th>PT - Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAB</td>
<td>VBC</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>ANG(deg)</td>
<td>29.89</td>
</tr>
</tbody>
</table>

FREQ (Hz) 59.991

Frequency Tracking = Y

V/Hz 99.56%
Transformer Relay Detection Features

- Harmonic Measurements – 2\textsuperscript{nd}, 4\textsuperscript{th}, and 5\textsuperscript{th}
- Volts/Hz
- Programmable Logic w/ Analog Quantities
- SCADA interfaces and alarms
Relay Filter Bank

Input current sum

Filter bank

Fundamental

2nd harmonic

4th harmonic

5th harmonic
Normal Harmonic Content

Input current sum

Filter bank

Output signals

1st

2nd

4th

5th

time
GIC Harmonic Content

Input current sum → Filter bank → Output signals

1st
2nd
4th
5th
Detecting and Tripping for GIC

- Relay calculates vector sum of currents, using instantaneous values.
- Presence of operating current, rich in harmonics, for prolonged time, on all three phases indicates GIC.
- A time-overcurrent element, driven by $I_{rms}$, and controlled by 2$^{nd}$ harmonic, with a long time curve could be used.
Programmable GIC Logic Alarms

Fundamental

Minimum Arming Current

2nd Harmonic
2nd PU Setting

4th Harmonic
4th PU Setting

5th Harmonic
5th PU Setting

GIC Alarm

PU = 500 ms
DO = 5 sec

Programmable GIC Logic
What Do You Trip?

• Internal faults: trip all sources to transformer.
• GIC: trip all GIC sources to transformer: e.g., don’t trip series-compensated lines.
Avoid GIC Blocking the Detection of Internal Faults

- Disable harmonic blocking, but use harmonic restraint.
- The large level of fault currents will exceed harmonic restraint.
- Harmonic restraint is still necessary for inrush protection.
- Relays also provide unrestrained differential elements, operating on the fundamental, which are not affected by harmonics.
Avoiding False Trips Due to GIC

• Differential elements are not a problem, when properly set.

• Residual overcurrent elements which measure fundamental will not respond.

• GIC element may be enabled only when second harmonic is present, when warnings are received, or for high transformer temperatures.
Relays have many capabilities to signal operators:

- Contact outputs wired to PLCs/RTUs
- Communication – DNP3, IEC-61850, FM
Substation Computation Devices

• Substation computing devices can automate GIC mitigation strategies
  ➢ Collect and process harmonic information
  ➢ Send information alarms to SCADA
  ➢ Using solar weather info, arm GIC mitigation strategy

• GIC substation strategy includes
  ➢ Insert series compensation capacitors
  ➢ Turn on transformer fans to pre-cool transformer
Wide Area GIC Notification

Utility “A” Control Center

Utility “B” Control Center

Regional Control Center

SCADA/EMS

Local Visualization

Substation PLC

Control Center

PLC

Substation PLC
Other IEDs Can Be Used for GIC Detection

Power Quality Meters

Line Current Differential Relays
GIC Effects on Other Protection

• Distance relays filter out everything except the fundamental: little or no effect.

• Overcurrent relays filter out everything except for the fundamental: little or no effect.

• Line-current differential relays are based on Kirchoff’s Current Law, using instantaneous quantities, and no new path is created by GIC.
GIC Effects on Instrument Transformers

- CCVT’s block DC: no effect.
- Wound VT’s: not frequently used on major transmission.
- Transmission CT: roughly 0.2% per amp DC, so 100 amps “uses up” around 20% of CT. Normal operation of CT needs only 5% of the core. Plenty left; relays are designed to manage some CT saturation anyway, due to much larger effects of “DC offset,” the decaying exponential current.
GIC Mitigation Options

- Use redundancy of power system to lower power level through redistribution.
- Series capacitors can be used to block GIC.
- Monitor power system, via harmonics, and isolate areas with high GIC.
- Trip lines contributing to GIC, try a reclose after a few minutes.
- Don’t trip series-compensated ones.
GIC Fix to Avoid – R in the Neutral

- Does not fully eliminate GIC
- Protection schemes impacted
- Overvoltage on unfaulted phases could cause flashovers
GIC Fix to Avoid – Caps in the Neutral

- Zero Sequence impedance impacts
- Requires fast bypass during fault condition
- Ferro-resonance concerns
Summary

• Your relays can detect and alarm for GIC.

• Get to know GICs on your system by monitoring info in the relays and meters.

• Transformers protection can detect GIC: temperature sensors, differential protection, excessive harmonics for extend period of time.

• Ensure 2\textsuperscript{nd} harmonic doesn’t block your protection.

• Trip lines that contribute to GIC; restore them after a few minutes.