SolidGround™ Transformer Neutral Blocking System

Presentation to 2013 PowerWorld Client Conference January 22, 2013

Power World Grid Modeling with GIC and Neutral Blocking
Agenda

- GMD Threats to the Power Grid
- Estimated 100 Year Geo-Electric Field Magnitudes
- Geomagnetically Induced Current (GIC) Grid Modeling
- SolidGround™ Transformer Neutral Blocking System
- System testing at KEMA and the Idaho National Laboratories (INL)
- SolidGround™ Economics
Geomagnetic disturbance is in the mainstream media

“Most power grids have no built-in protection against the onslaught of a powerful geomagnetic storm.”

“Scientists cannot be sure of the storm’s intensity until it reaches the ACE satellite – sometimes a mere 20 minutes before it slams into Earth.”

“The morally right thing to do once you’ve identified a threat of this magnitude is to be prepared... Not preparing for it has intolerable consequences.”
Solar Storms Damage the Power Grid

Protection Against HV Transformer Damage & Power Grid Voltage Collapse has Been Developed & can be Implemented
## 100 Year Geo-Electric Field Magnitudes
(for 4,800 nT/min Storm)

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### 100 Year Geo-Electric Field Magnitudes for 4,800 nT/min Storm

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<td>4.4 V/km</td>
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<td>5 V/km (3 to 15 V/km)</td>
<td>20 V/km (10 to 50 V/km)</td>
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GIC Grid Modeling

• Power World has recently added geomagnetic induced current (GIC) analysis to their power flow analysis
  – Provides analysis to help answer questions concerning:
    • grid instability from increased transformer MVAR loss
    • Identifies locations of potential damage to critical infrastructure (i.e. transformers, SVCs, etc.)
GIC Modeling – cont’d

ATC Approach:

- Requested transformer data from ATC for large Auto-transformers and GSUs
- Analyzed PowerWorld model to reflect correct transformer configurations and input data
GIC Modeling – cont’d

Approach:

• Simulate a range of electric field intensities (2 V/km to 80 V/km)
  – 2 V/km was the field that caused the 1989 blackout in Quebec
  – 20 V/km (range 10 to 50 V/km) for 100 Yr storm (A. Pulkkinen et. al.)

• Simulate a range of electric field orientations
  – North-south and east-west should be examined
  – Include the orientation that aligns with most of the transmission lines in the area of interest

• Simulate GMD effects in one area of interest (AOI)

• Identify electric field strength that leads to voltage collapse

• Simulate the grid stability improvements as GIC blocking devices are applied
Voltage Change at 2 V/km, East-West

Power World Power Flow & GIC Modeling
Voltage Change at 17.5 V/km, East-West

Power World Power Flow & GIC Modeling
Selection of ATC Transformers for Neutral Blocking Devices

<table>
<thead>
<tr>
<th>1st Five Transformers</th>
<th>2nd Five Transformers</th>
<th>3rd Five Transformers</th>
<th>4th Five Transformers</th>
<th>5th Five Transformers</th>
</tr>
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<tr>
<td>GSU Station C 345/22 #1</td>
<td>GSU Station B 345/19 #1</td>
<td>Substation E 345/138 #1</td>
<td>Substation E 138/13 #1</td>
<td>Substation OC 345/138 #2</td>
</tr>
<tr>
<td>GSU Station C 345/22 #2</td>
<td>Substation C 345/138 #2</td>
<td>Substation E 345/138 #2</td>
<td>Substation K 345/138 #1</td>
<td>Substation A 230/115 Kv</td>
</tr>
<tr>
<td>Substation B 345/19 #1</td>
<td>Substation C 345/138 #1</td>
<td>Substation K 345/138 #2</td>
<td>Substation C 345/138 #1</td>
<td>Substation SF 138/69 #1</td>
</tr>
<tr>
<td>GSU Station E 345/22 #1</td>
<td>Substation WM 345/138 #1</td>
<td>Substation SL 345/161 #1</td>
<td>Substation C 138/69 #1</td>
<td>Substation OC 345/138 #1</td>
</tr>
<tr>
<td>GSU Station K 345/20 #1</td>
<td>GSU Station E 345/22 #1</td>
<td>Substation C 345/138 #3</td>
<td>Substation SG 138/25 #1</td>
<td>GSU FW 138/35 #1</td>
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Solid Ground GIC Mitigation

• Preliminary Results show:
  – ATC Voltage collapse occurs at 21.1 V/km (E-W)
  – Solid Ground capacitive neutral protection was simulated on 5, 10, 15, 20 and 25 transformers in the AOI
  – Field strength for voltage collapse for 25 neutral blocking devices increased to 27.2 V/km (E-W) or + 29%

Significant Increases in Field Strength for Increased Number of Neutral Blocking Devices
Wisc. Voltage Collapse Simulation versus 100 Yr Storm Prediction

- Power World Estimated Field for Wisconsin Voltage Collapse:
  - 21 V/km mean, +/- 20% give range of 17 to 25 V/km
- 100 Year Predicted Geo-electric Field [1]:
  - 20 V/km mean, with range of 10 to 50 V/km

[1] Estimates from A. Pulkkinen et.al. are from Space Weather publication in 2012
Neutral Blocking Devices Impact at Columbia Site, Field 20 V/km N-S (three phase GIC currents in amps)

<table>
<thead>
<tr>
<th>Columbia Transformers</th>
<th>No Blocking North-South Field</th>
<th>5 Blocked – Columbia GSUs Blocked</th>
<th>10 Blocked – Columbia Auto-Transformers #2 Blocked</th>
<th>15 Blocked – Columbia Auto-Transformers #3 Blocked</th>
</tr>
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<tbody>
<tr>
<td>GSU Station C 345/22 #1</td>
<td>818 amps</td>
<td>0 amps</td>
<td>0 amps</td>
<td>0 amps</td>
</tr>
<tr>
<td>GSU Station C 345/22 #2</td>
<td>826 amps</td>
<td>0 amps</td>
<td>0 amps</td>
<td>0 amps</td>
</tr>
<tr>
<td>Substation C 345/138 #1</td>
<td>50.0 amps</td>
<td>275 amps</td>
<td>534 amps</td>
<td>775 amps</td>
</tr>
<tr>
<td>Substation C 345/138 #2</td>
<td>154 amps</td>
<td>833 amps</td>
<td>0 amps</td>
<td>0 amps</td>
</tr>
<tr>
<td>Substation C 345/138 #3</td>
<td>51.0 amps</td>
<td>277 amps</td>
<td>539 amps</td>
<td>0 amps</td>
</tr>
<tr>
<td>Substation C 138/69 #1</td>
<td>13.0 amps</td>
<td>193 amps</td>
<td>385 amps</td>
<td>563 amps</td>
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PowerWorld GIC & Power Flow Simulation
Results to Date

• Geo-electric field for voltage collapse is close to the predicted peak 100 year mean field value
• Insertion of transformer neutral blocking at points of highest GIC (i.e. five units at a time) shows improved field collapse values
• Ten (10) & twenty five (25) neutral ground devices show field collapse improvements of 26% and 29%
• Blocking GIC current at a sub-station will require blocking on all station transformers
  – A single SolidGround™ device can be used for one to three transformers at a sub
• Placement of single neutral blocking device does not improve power system voltage degradation
  – But a blocking device will decrease heating and out-gassing and thereby increase the expected life of the transformer
Potential Further Detrimental Factors

• Effects of contingencies, i.e. loss of shunt capacitors, loss of generation, etc.
• Variations of at off-peak and shoulder load levels
• Effects of operating strategies – reactive switching during events and additional generation
• Variations in soil conductivity within an area of interest
Geomagnetic Induced Current (GIC) causes transformer half-cycle saturation and large VAR consumption on the grid. 

**SolidGround™**

- Automated protection (with manual overrides)
- Transformer is *always* effectively grounded
- Uses commercially available components
- Laboratory and field verified
- Factory assembled; arrives ready to install
- Offers financial operating advantages
- Applicable to HV transformers, SVC’s, station power

*Grid Resiliency System*

Protects the power grid from solar storms and Electromagnetic Pulse (EMP) threats.
There is a long history measuring issues related to geomagnetic storms; dating back to 1859.

1859 / 1921 Rail and Telegraph outages
March, 1989, Quebec outage

March, 2001 and October, 2001 South African instabilities

University of Minnesota research

Mitigation of Geomagnetically Induced and DC Stray Currents
EPRI December, 1983

"Capacitors are the best solutions"

"Prefer a design with a solid ground"
The electric utility industry has researched GIC mitigation approaches over the same period.

Geomagnetically Induced Currents Conference: EPRI June, 1992

GIC Mitigation: A Neutral Blocking/Bypass Device Conceptual Design and Performance Evaluation

“Therefore, inserting blocking devices in neutral leads appears to be the most logical and effective means of preventing GIC flow.”

“The study concluded that a capacitor placed in the neutral of transformers is the most effective and practical blocking device”
DC Current Blocking System Diagram

Transformer Neutral

Transformer

Maintenance switch

Kirk Key Interlock

AC Breaker

1 ohm power resistor

4.0 kV Surge Arrester

1 ohm reactance capacitor bank (5,600 kVAR & 2.4 kV)

DC Breaker

To Quasi-DC Sensor

0.001 Ohm Shunt

CT

50N

86
Mode # 1: Full metallic ground through the switch assembly 99.8% of time

Mode # 2: Protection mode through resistor/capacitor bank 0.2% of time

Mode # 3: Surge arrester handles the rare potential of a simultaneous DC current & a ground fault
SolidGround operation has been validated in numerous ways:

Software Simulation Modeling at the Univ. of Manitoba

High Voltage Ground Fault Current Testing in Phil. PA

Idaho National Laboratory Grid Experiment

Before

After

20kA symmetrical
49kA peak

11.5 kV across arrester
American Transmission Co. (ATC) Installation Plans

• ATC is considering installing a SolidGround™ (SG-22) system at one of their northern region sub-stations

• With this installation, ATC plans to gain on-line experience of neutral GIC blocking during future GMD events

• Results will be used to determine ATCs future directions w.r.t. GMD mitigation planning

• Reports will be shared with the appropriate NERC committees, EPRI and the power industry

Helping to keep the lights on, businesses running and communities strong®
SolidGround™ Economics
Solid Ground Pricing

- ABB has proposed Solid Ground to several potential customers
  - Price for ranges from $210k to $250k depending on the quantity
  - Estimates of contractor installation costs range from $25k to $50k
  - Total cost ranges from $235k to $300k per Solid Ground installation
  - One Solid Ground can protect from one to three transformers

Solid Ground Average Cost is about $80k to $100k per Transformer
SolidGround™ Equates to Large Savings

• SolidGround™ Protection allows Utility Operators to Avoid the so called
  “Non-Economic Dispatch Procedure”

• Huge Annual Savings can be Realized

• “Solar Magnetic Disturbance: An Operator’s Wish List,” Greg A. Gucchi, PJM, EPRI-EPRI TR-100450: If we responded to every K alert of level 5 or greater, **PJM would have spent over $100 million in excess incremental operating costs**.......The ultimate protection against SMD is mitigation.”
Geomagnetic disturbance impacts utilities & consumers

“NextEra cuts N.H. Seabrook output due to solar activity”

July 16 | Mon Jul 16, 2012 10:35am EDT

(Reuters) - NextEra Energy Inc reduced the output of the 1,247-megawatt (MW) Seabrook nuclear power plant in New Hampshire to 68 percent from 85 percent due to solar magnetic activity, a spokesman at the U.S. Nuclear Regulatory Commission said Monday.

“The solar storms Sunday night caused high circulating currents in the Seabrook transformers, according to the NRC”

“The reduced output at Seabrook came at a time when the power grid was already stressed...”

This one small example represents a cost to industry consumers of ~$24,000 / hr. Preventive measure costs may be recovered by avoidance of just one event!
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Thanks for Your Attention