Geomagnetic Storms and the Power Grid

October 1, 2014
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Research, Development, and Special Studies
Contents

✓ The Solar Cycle
✓ Geomagnetic Storms
✓ Geomagnetic Induced Currents
✓ History
✓ Power System Impact
✓ Transformers
✓ Risk of Severe Storm
✓ Potential Impact of Sever Storm
✓ Mitigating Risks
✓ NERC Compliance
✓ Conclusion
✓ References
The Solar Cycle

- 11 year solar magnetic activity cycle
- Observed by counting the frequency and placement of visible sun spots
- Statistically more likely during periods close to solar cycle maxima
- Next maxima due 2013 – 2014
- www.swpc.noaa.gov
Geomagnetic Storms

- Caused by a Coronal Mass Ejection (CME)
- CME: a large, violent eruptions of plasma and magnetic fields from the Sun’s corona
- Causes a large mass of charged solar energy particles to escape from the sun’s corona
- When CME’s are directed at the earth, they affect the earth’s magnetic field configuration
- Can reach earth in 15 – 72 hrs
- Geomagnetic Induced Currents (GIC) on earth are the result
Geomagnetic Induced Currents (GIC)

- GICs are electric currents driven in technological systems due to a geomagnetic storm
- Violent change ($dB/dt$) in Earth’s geomagnetic field during CME produces a horizontal electric field on earth of varying intensity depending on location
- GICs (Quasi-dc current $\sim 1$Hz) are then induced and driven in the power system
- Intensity of GICs depends on geoelectric field magnitude and relative orientation to transmission lines
History – Carrington Event of 1859

- Solar Storm during solar cycle 10
- One of the largest storms on record
- Aurora seen worldwide
- 17hrs and 40 min from Sun to Earth
- Affects:
  - Telegraph network outages
- A similar event today could be cost trillions of dollars
History – Quebec Event of 1989

- Hydro-Quebec system collapse causing 6 million people without power for 12 hours
- Static compensators damaged and system failure resulted
- NEISO also impacted
- 3 days to reach earth

Figure ES-1: Geomagnetic intensity—March 1989 storm

Typical Auroral Zone Location

Auroral ZoneExtreme onMarch 13, 1989
History – Halloween Event of 2003

- Affected industries:
  - Swedish and Scottish power system infrastructure
  - Aviation industry
  - Japanese Satellite communications
- 50,000 people lost power
- 1 day to reach earth
- Lasted 18 days
- Solar cycle was in decline
The most important effects of GICs are those related to their impact on large power transformers.
Transformer Magnetic Circuits

✓ The iron core of the transformer provides the path for magnetic flux
✓ The iron core concentrates and increases the effect of the magnetic fields produced by the current in the primary
✓ The magnetizing current, \( i_\phi \), is the current required to magnetize the core of the transformer
Transformers

- Non-Linear magnetizing characteristic
- Normal operation in linear range
- Operating >1.1 pu voltage, transformer may operate in the non-linear area (saturation).
- Magnetic flux is forced into other parts of the transformer
- Magnetizing current no longer sinusoidal
Impact of GICs on Transformers

When DC currents exist, a DC flux, proportional to the DC current, is impressed on the core. The DC flux adds to the AC flux during half the 60hz cycle and subtracts from the other half, thus shifting the operating point on the magnetic characteristic. This is **Half-Cycle Saturation**.

- Winding and structural element **hot spots** are created and the mechanical strength of winding insulation is degraded
- **Harmonics** are generated
- Increased **Reactive power absorption**
Impact of GICs on Transformers

These Key Assets may take a Year or More to Replace
An aged transformer that’s been exposed to repeated injury is far more likely to fail than a new transformer

Salem Nuclear Plant
GSU Transformer Failure, March ‘89
Impact of GICs on Transformers

Latent Impacts of March 1989 Storm – Delayed Failures of Large Transformers at Nuclear Plants suspected across US

1. Salem
2. Oyster Creek
3. South Texas
4. Shearon Harris
5. Surry 1
6. Zion 2
7. WNP 2
8. Peach Bottom 3
9. D.C. Cook 1
10. Susquehanna
11. Maine Yankee
12. Nine-Mile
Risk of Severe Storm

Likelihood of a Severe Geomagnetic Storm
Potential Impact of Severe Storm

- Transformer Failures
- Increased transformer reactive power consumption places additional constraints on the grid
  - Voltage instability
  - Possible Voltage Collapse
- Mis-operation of relays
- Over-currents, heating, and possible damage to shunt capacitor, SVCs and HVDC filters
- Increased generator stator heating
Mitigating Risks

✔ As a response to a warning
  ✔ Closely monitor reactive power consumption
  ✔ Switch off reactors and add restraint to capacitor trip circuits
  ✔ Reduce loading on susceptible transformers
  ✔ Reduce power transfers
  ✔ Revise maintenance work schedule

✔ Long term steps
  ✔ Changes in transformer design
  ✔ Retrofit existing transforms with GIC blocking devices such as neutral blocking resistors or capacitors
NERC Compliance Requirements

- Requires a **GMD Vulnerability Assessment** of the system for its ability to withstand a Benchmark GMD Event without causing a wide area blackout, voltage collapse, or damage to transformers, once every five years.
  - **Applicability:** Planning Coordinators, Transmission Planners

- Requires a **Transformer thermal impact assessment** to ensure that all high-side, wye grounded transformers connected at 200kV or higher will not overheat based on the Benchmark GMD Event
  - **Applicability:** Generator Owners, Transmission Owners
GeoElectric Field Calculation

$$E_{\text{peak}} = 8 \times \alpha \times \beta \text{ (in V/km)}$$

where,

- $E_{\text{peak}}$ = Benchmark geoelectric field amplitude at System location
- $\alpha$ = Factor adjustment for geomagnetic latitude
- $\beta$ = Factor adjustment for regional Earth conductivity model

8 V/km is the peak geoelectric field amplitude at reference location (60° N geomagnetic latitude, resistive ground model)

White paper available at:
http://www.nerc.com/pa/Stand/Pages/Project-2013-03-Geomagnetic-Disturbance-Mitigation.aspx
Transformer Assessment

- Thermal impact of GIC flow from the benchmark GMD event in applicable transformers will be assessed.
- Each transformer will see a different GIC(t).
- Two assessment methods:
  - Manufacturer-provided GIC capability curves.
  - Transformer thermal response simulation.
- A floor of 15 Amperes (A) has been established for Transformer Thermal Assessment. If calculated GIC is 15A or less, no further transformer thermal analysis is required since, based on transformer testing, continuous 15A exposure does not result in temperatures of concern.
Conclusion

✓ Geomagnetic Storms can impact the power system
✓ Severe GM Storms have greater impact
✓ Likelihood of a severe storm impacting SPP is low
✓ Power Transformers are the most vulnerable
  ✓ Reactive Power Over-Consumption could cause voltage collapse
  ✓ Thermal response could cause failure
✓ NERC will require assessments to determine impact of above vulnerabilities
• CENTRA Technology, Inc. on behalf of Department of Homeland Security, Geomagnetic Storms, International Futures Programme, 2011
• EPRI White Paper, “Approaches for Minimizing Risks to Power System Infrastructure due to Geomagnetic Disturbances”, October, 2010
Questions?