A Comprehensive Study of Geomagnetic Disturbance (GMD) System Impact

Sarina Adhikari, sadhikari@enernex.com
Reigh Walling, rwalling@weconsult.com
Dave Mueller, dmueller@enernex.com
Adam J. O' Laughlin, Adam.OLaughlin@uinet.com

Introduction/Motivation

- Quasi-dc geomagnetically induced currents (GIC) due to GMD event flow through the neutrals of Y-g transformers causing half cycle saturation
- The saturated transformers act as large reactive power sinks that inject abnormally severe harmonic currents into the system
  - Potential risk of system voltage collapse
  - Equipment damage
- ***A thorough study linking GIC flow analysis, fundamental frequency power flow analysis and harmonic analysis***
- ***Comprehensive evaluation of potential GMD impacts on a utility system with a novel integration of diverse software tools***
- System voltage collapse may occur at GMD intensities less than that are likely to cause direct risk to transformers
- Harmonic impacts may be disruptive at lower GMD intensity than the threshold of voltage collapse

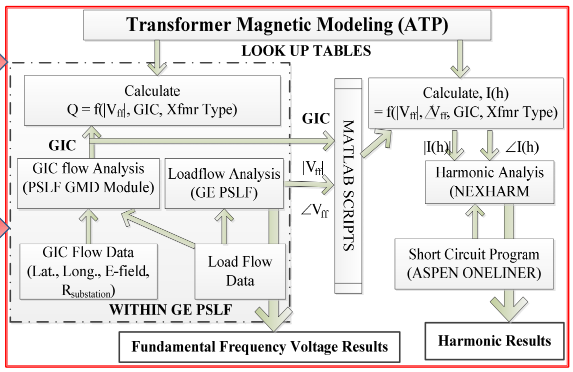
GMD Analysis Modeling Details

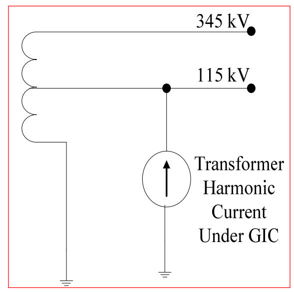
- GIC Flow modeling was performed in GE PSLF GMD module and Harmonic Analysis was performed in NexHarm software:
  - ***Study done in an extended United Illuminating company (UI) service area***
  - ***Study area: entirety of Connecticut, part of Rhode Island, and western part of Massachusetts.***
  - All data required for GIC model : longitude, latitude, grounding resistance, transformer types, etc., were utilized and entered thoroughly

- ***This study found out that GIC model is more accurate if a 115 kV system data is also included in the model. NERC's GMD planning standard TPL-007-1 standard suggests modeling the transmission lines and transformers only above 200 kV.***

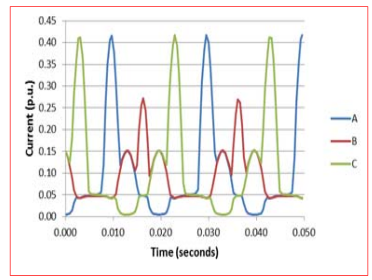
Potential GMD impact on a utility system:

- **Novel Integration of Diverse Software Tools**
- **Realistic Assumptions on transformer GIC characteristics**
- **Detailed transformer magnetic modeling results utilized for GIC calculation and harmonic analysis**





Placement of transformer harmonic current under GIC



Example of harmonic current characteristics for a 3 phase, 5 leg core type transformer at 0.1 pu GIC

Transformer Magnetic Modeling, Load Flow and Harmonic Analyses and Results

- **Conventional practice:** Reactive demand of a GIC saturated transformer = K × the net GIC;
- The reactive current is voltage independent

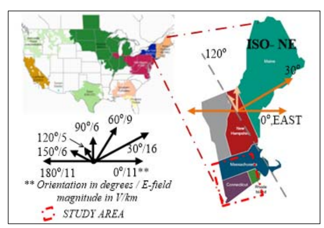
Standard E-field in United Illuminating (UI) area in V/km

$$E = 8 \times 0.001e^{0.115\times 52} \times 0.81 = 2.56$$

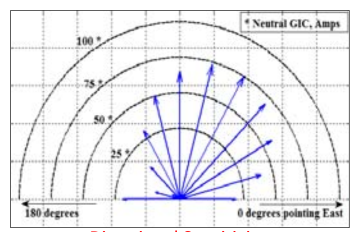
- Majority of transformers in the UI system: three phase units that have ***relatively non-linear reactive current Vs GIC characteristics***. Reactive currents of these transformers are also very sensitive to bus voltage magnitude

- **Contributions:** Above assumptions for three phase transformers lead to an excessively pessimistic reactive demand during GMD events. Therefore, in this study:
  - Tables defining the reactive current as a function of GIC and voltage level were developed using detailed magnetic circuit modeling for different types of transformers
  - These tables are utilized by PSLF GMD package while calculating realistic GIC flows
  - The same magnetic duality models were used to obtain harmonic current magnitude and phase angle for various three-phase and single-phase transformer types

- **Harmonic Model:** Entire study area: 234 generators, 908 lines, 580 two-winding transformers, 126 three winding transformers, 131 loads and 42 capacitor banks: Extracted from ASPEN One-liner



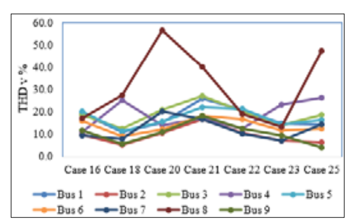
Breaking Point Analysis



Directional Sensitivity

Case	16	18	20	21	22	23	25
E-field (V/km)	7	3.4	10	15	8	5	5
Orientation (Degrees)	60	120	0	30	60	90	150

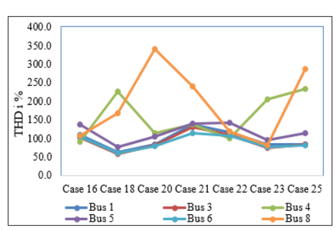
Harmonic Analysis Cases



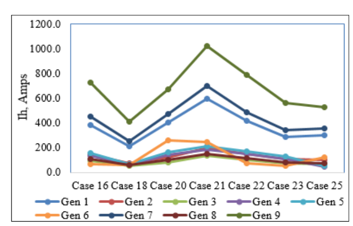
Voltage % THD (Higher E-field cases)

Conclusions

- A groundbreaking study of GMD impacts on a transmission system that included GIC flow, fundamental- frequency power flow and harmonic analyses
- Detailed magnetic duality modeling was used to develop relationships between reactive power demand, GIC and applied voltage that was used for calculation of GIC flow and also, to define harmonic current injection characteristics of GIC saturated transformers
- System collapse is not expected to occur for GMD up to the standard field intensities defined by NERC TPL-007-1, but could occur for higher intensities
- Harmonic resonances driven by GIC saturation of numerous transformers can:
  - result in very high levels of voltage distortions that interfere with protection systems
  - cause capacitor banks to trip making the system prone to voltage collapse



Current % THD (Higher E-field cases)



UI Area Generator Harmonic Currents (Higher E-field Cases)