Power System Impacts of Geomagnetic Disturbances

Thomas J. Overbye

Fox Family Professor of
Electrical and Computer Engineering

University of Illinois at Urbana-Champaign

overbye@illinois.edu

September 25, 2012

galvin center for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

PSERC

IEEE PES Power & Energy Society

Overview

- Geomagnetic disturbances (GMDs) have the potential to severely disrupt operations of the electric grid, yet until recently power engineers had few tools to help them assess the impact of GMDs on their systems

- Presentation covers GMD basics, setting stage for following ones

Geomagnetic Disturbances (GMDs)

- Solar events can cause changes in the earth's magnetic field (i.e., dB/dt). These changes in turn produces an electric field at the surface
  - Changes in the magnetic flux are usually expressed in nT/minute; from a 60 Hz perspective they produce an almost dc electric field

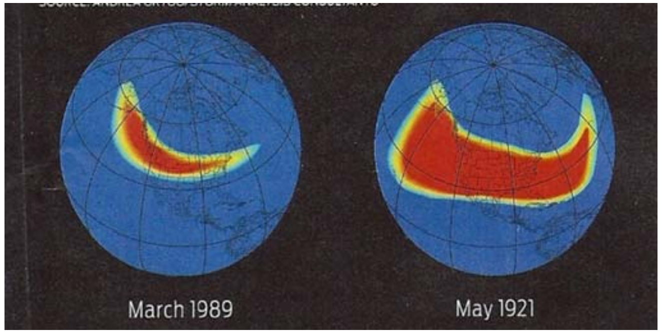


Image source: J. Kappenman, "A Perfect Storm of Planetary Proportions," *IEEE Spectrum*, Feb 2012, page 29

GMDs, cont.

- 1989 North America storm produced a change of 500 nT/minute, while a stronger storm, such as the one in 1921, could produce more than 5000 nT/minute variation
- Storm "footprint" can be continental in scale, for example covering much of the U.S.
- For reference, Earth's magnetic field is normally between 25,000 and 65,000 nT, with higher values near the poles

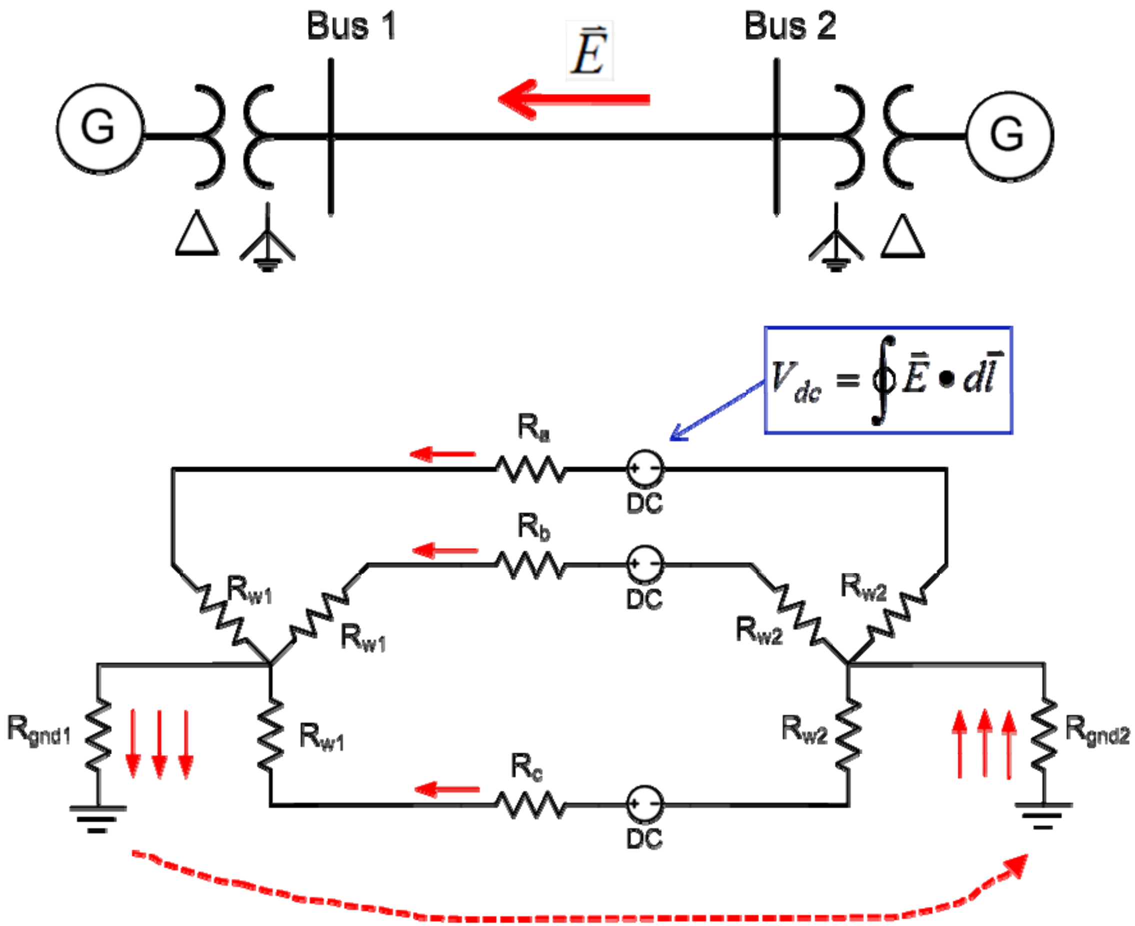
Electric Fields and Geomagnetically Induced Currents (GICs)

- As described by Faraday's law, changes in the magnetic flux intensity produce a (non-uniform) electric field on the surface; values are impacted by ground conductivity
  - Electric fields are vectors with a magnitude and direction; values are usually expressed in units of volts/mile (or volts/km);
  - A 2400 nT/minute storm could produce 5 to 10 volts/mile.

Electric Fields and Geomagnetically Induced Currents (GICs), cont.

- The electric fields cause geomagnetically induced currents (GICs) to flow in electrical conductors such has the high voltage grid
- From a modeling perspective the induced voltages that drive the GICs can be modeled as dc voltages in the transmission lines.
- The magnitude of the dc voltage is determined by integrating the electric field variation over the line length

Geomagnetically Induced Currents (GICs)



The impact of the electric field variation is modeled as dc voltages superimposed on the transmission lines. The GIC calculation then just involves solving a linear dc circuits problem

Power System Impacts of GICs

- The dc GICs are superimposed upon the ac currents. In transformers this can push the flux into saturation for part of the ac cycle
- This can cause large harmonics; in the positive sequence (e.g., power flow and transient stability) these harmonics can be represented by increased reactive power losses on the transformer.

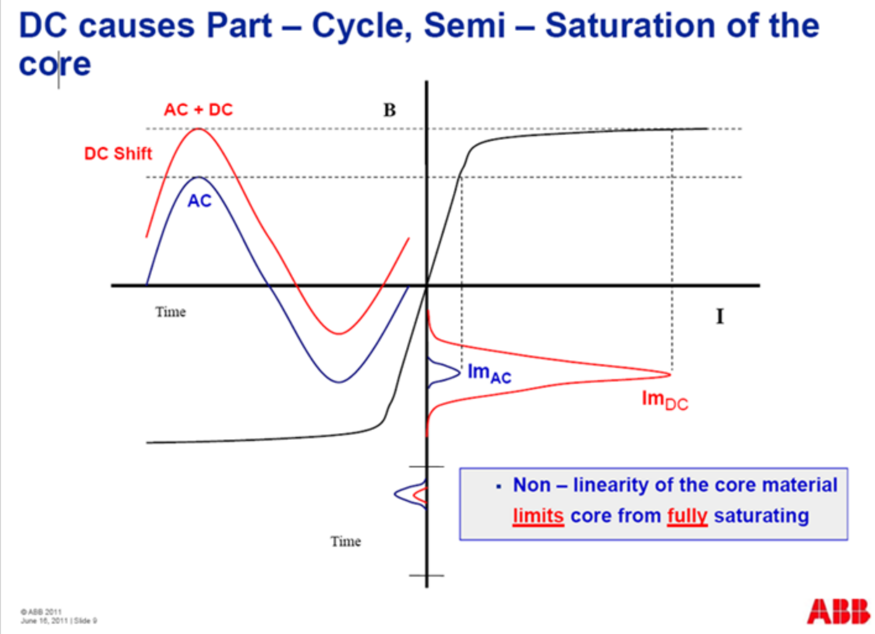


Image Source: Craig Stiegemeier, JASON Presentation, June 2011, Slide

Mapping Transformer GICs to Transformer Reactive Power Losses

- Transformer specific, and can vary widely depending upon the core type
  - Single phase (usually 500 or 765kV), shell, 3-legged, 5-legged
- Ideally this information would need to be supplied by the transformer owner
  - Current studies often use default values or a user specified linear mapping

The Impact of a Large GMD From an Operations Perspective

- There would be a day or so warning but without specifics on the actual magnitude
- It could strike quickly (they move at millions of miles per hour) with rises times of less than a minute with a continental footprint
- Reactive power loadings on hundreds of transformers could sky rocket, causing heating issues and potential large-scale voltage collapses

The Impact of a Large GMD From an Operations Perspective, cont.

- Power system software like state estimation could fail
- Control room personnel would be overwhelmed
- The storm could last for days with varying intensity
- Waiting until it occurs to prepare might not be a good idea

GMD Enhanced Power Analysis Software

- By integrating GIC calculations directly within power analysis software (like power flow) power engineers can readily see the impact of GICs on their systems, and consider mitigation options
- GIC calculations use many of the existing model parameters such as line resistance. But some non-standard values are also needed; power engineers would be in the best position to provide these values, but all can be estimated when actual values are not available
  - Substation grounding resistance, transformer grounding configuration, transformer coil resistance, whether auto-transformer, whether three-winding transformer, generator step-up transformer parameters

GIC G-Matrix

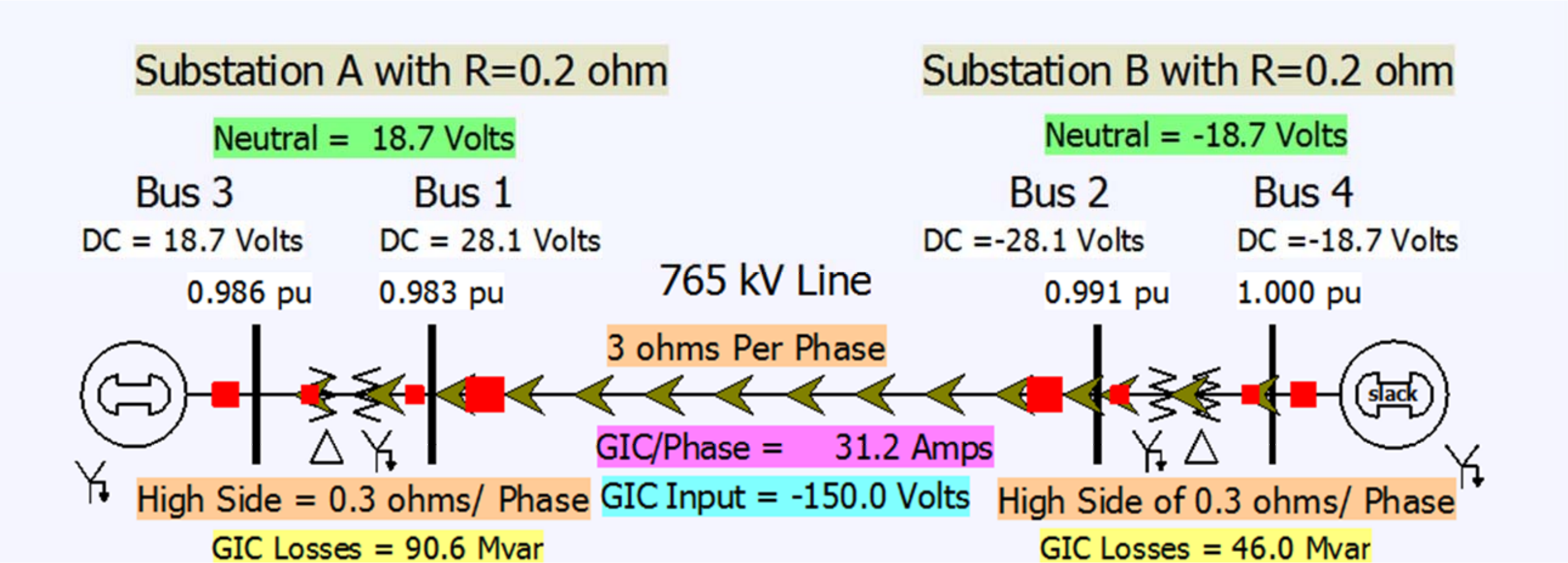
- With knowledge of the pertinent transmission system parameters and the GMD-induced line voltages, the dc bus voltages and GIC flows can be calculated by solving a linear equation

$$\mathbf{I} = \mathbf{G}\,\mathbf{V}$$

  - The G matrix is similar to the Y_{bus} except 1) it is augmented to include substation neutrals, and 2) it is just conductances
  - The current vector contains the Norton injections associated with the GMD-induced line voltages

Four Bus Example

$$I_{GIC,3Phase} = \frac{150\text{ volts}}{(1+0.1+0.1+0.2+0.2)\Omega} = 93.75\text{ amps or }31.25\text{ amps/phase}$$



The line and transformer resistance and current values are per phase so the total. Substation grounding values are total resistance. Brown arrows show GIC flow.

Large Study Issues

- The GMD impact on a grid depends upon the assumed storm scenario
  - Constant versus non-constant electric field; magnitude(s) and direction(s) of the storm
- Feb 2012 NERC report recommended for planning purposes the use of a uniform electric field
  - Maximum value in the 1989 Quebec storm was 1.7 V/km (2.7 V/mile); a hundred year storm could be cause values up to (perhaps?) 20 V/km.

Future Directions

- Tools exist now to allow utilities to assess the impact of GMDs on their systems
- Next presentations cover large system studies and utility experience
- More work is needed to further our understanding of GMD impact assessment
  - It will probably become part of the standard planning process

Questions?