

Resiliency with High-Impact, Low-Frequency (HILF) Events (Task 6.1)

Thomas J. Overbye

University of Illinois at Urbana-Champaign
overbye@illinois.edu



PSERC Future Grid Initiative
May 29, 2013

High-Impact, Low-Frequency (HILF) Events

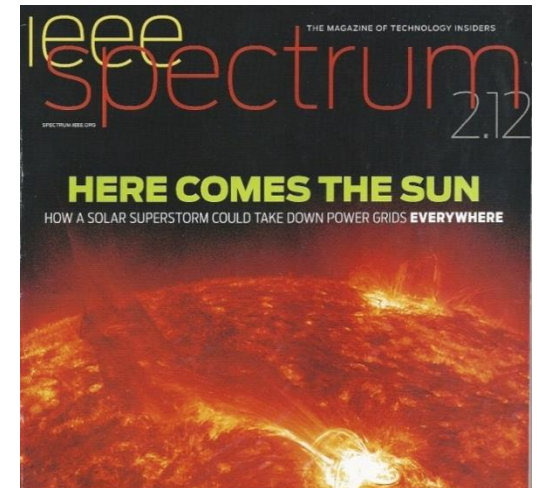
- Several types of HILFs identified by NERC in June 2010 report: 1) Coordinated Attack, 2) Pandemic, 3) Geomagnetic Disturbances (GMDs), 4) Electromagnetic Pulse (EMP)
 - Task has focused on GMD
- GMDs, which are caused by solar storms, have the potential to severely disrupt the power grid. Prior to the start of this project power engineers had few tools to help them assess the impact of GMDs on their systems

Others Involved in Project

- At UIUC project staff included Komal Shetye (staff engineer), Trevor Hutchins (grad student), Maryam Kazerooni (grad student), Yuchen Hughes (undergrad), Hao Zhu (UIUC postdoc and new faculty member starting in January 2014!)
- Involvement with industry has been key! Throughout the project we've worked with NERC (through its GMD Task Force), EPRI, government, a number of individual electric utilities, outside scientists, and software and hardware manufacturers.
- Results have been commercialized!

Geomagnetic Disturbances (GMDs)

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



Electric Fields and GICs

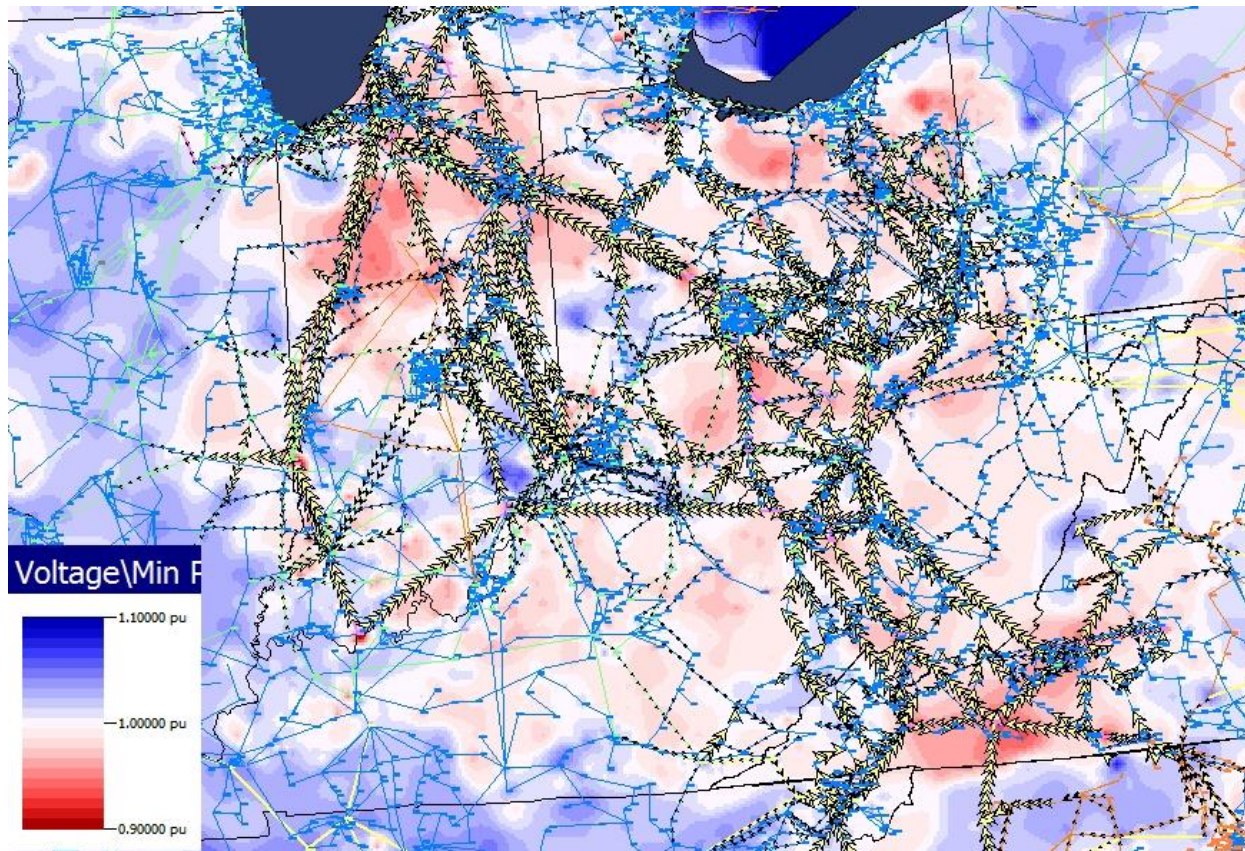
- Electric fields are vectors with a magnitude and direction; values are usually expressed in units of volts/mile (or volts/km); induce a quasi-dc voltage in transmission lines
 - A 2400 nT/minute storm could produce 5 to 10 volts/mile.
- The electric fields cause geomagnetically induced currents (GICs) to flow in electrical conductors such as the high voltage transmission grid
- GICs cause transformer saturation resulting in higher heating and reactive power losses that could result in a large-scale voltage collapse

Integration of GMD into the Power Flow

- By integrating GMD 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
 - Substation grounding resistance, transformer grounding configuration, transformer coil resistance, whether auto-transformer, whether three-winding transformer, generator step-up transformer parameters
 - Can be estimated when actual are not available

GMD Power Flow Studies

- We've worked with a number of utilities and EPRI to do actual system studies

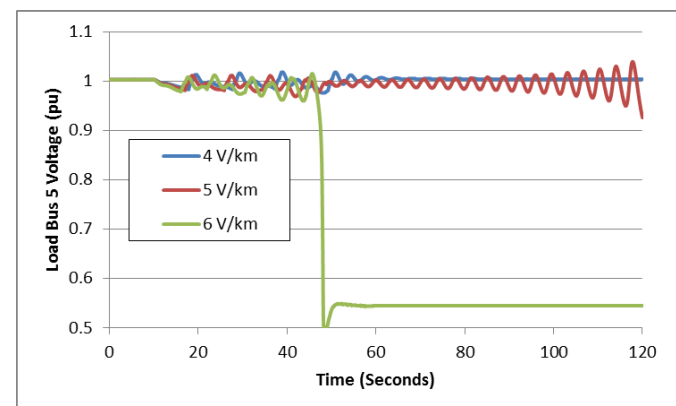
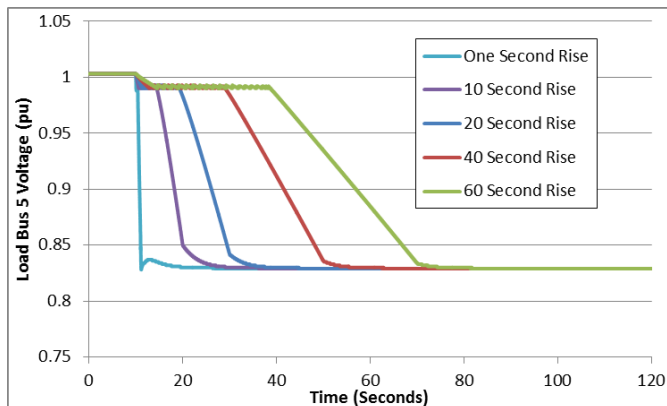


GMD Sensitivity Analysis

- Recent efforts have focused on determining the sensitivity of the GICs to the assumed electric fields on the transmission lines
 - An IEEE Transactions paper has been submitted detailing a sensitivity analysis algorithm
- Results indicate the GICs on a particular transformer are usually contributed by nearby transmission lines (e.g., <1% of lines in a case contributed >99% of the GICs)
 - Detailed electric field models are usually only needed for the footprint being studied (and perhaps immediately adjacent areas)

Dynamic Aspects of GMD

- We've recently been looking at the dynamic interactions between GMDs and power system short-term voltage stability
 - 100 year GMD storm scenarios show rise times on the order of seconds
 - Whether power system models experience short-term voltage collapse can be sensitive to load and transformer tap modeling assumptions



Conclusions and Future Directions

- By working closely with the ongoing industry led efforts the task has helped to advance GMD modeling and analysis capabilities, and has helped in the commercialization of GMD analysis in power flow and transient stability packages
- More research is certainly needed in this area
 - Advanced sensitivity analysis to determine which parameters are most important in a study
 - Importance of dynamic modeling of GMD impacts
 - Validation of results using actual utility measurements of both GICs and increased transformer reactive power losses

Questions and Discussion

