Electric Power Grid Impacts of GMDs

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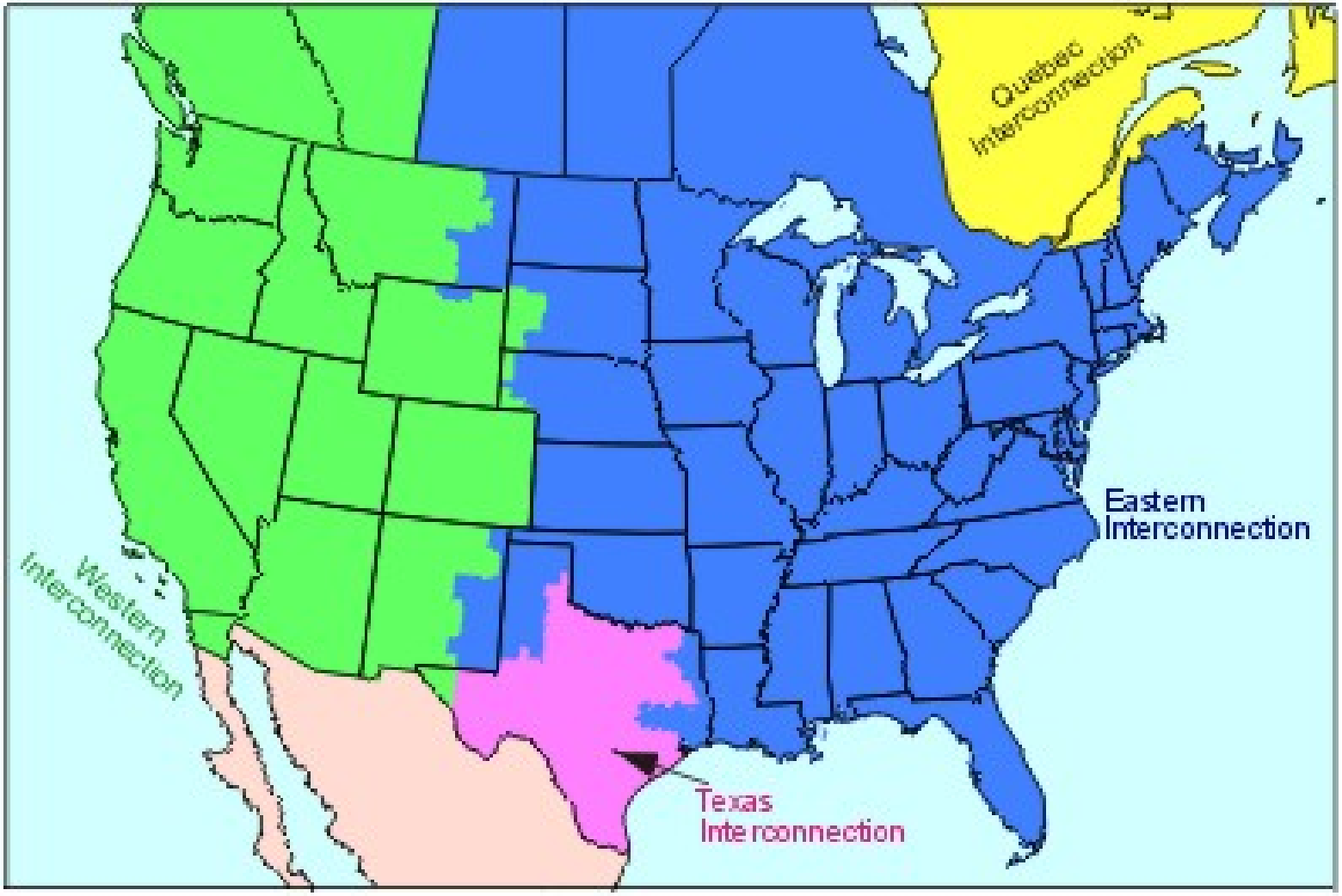
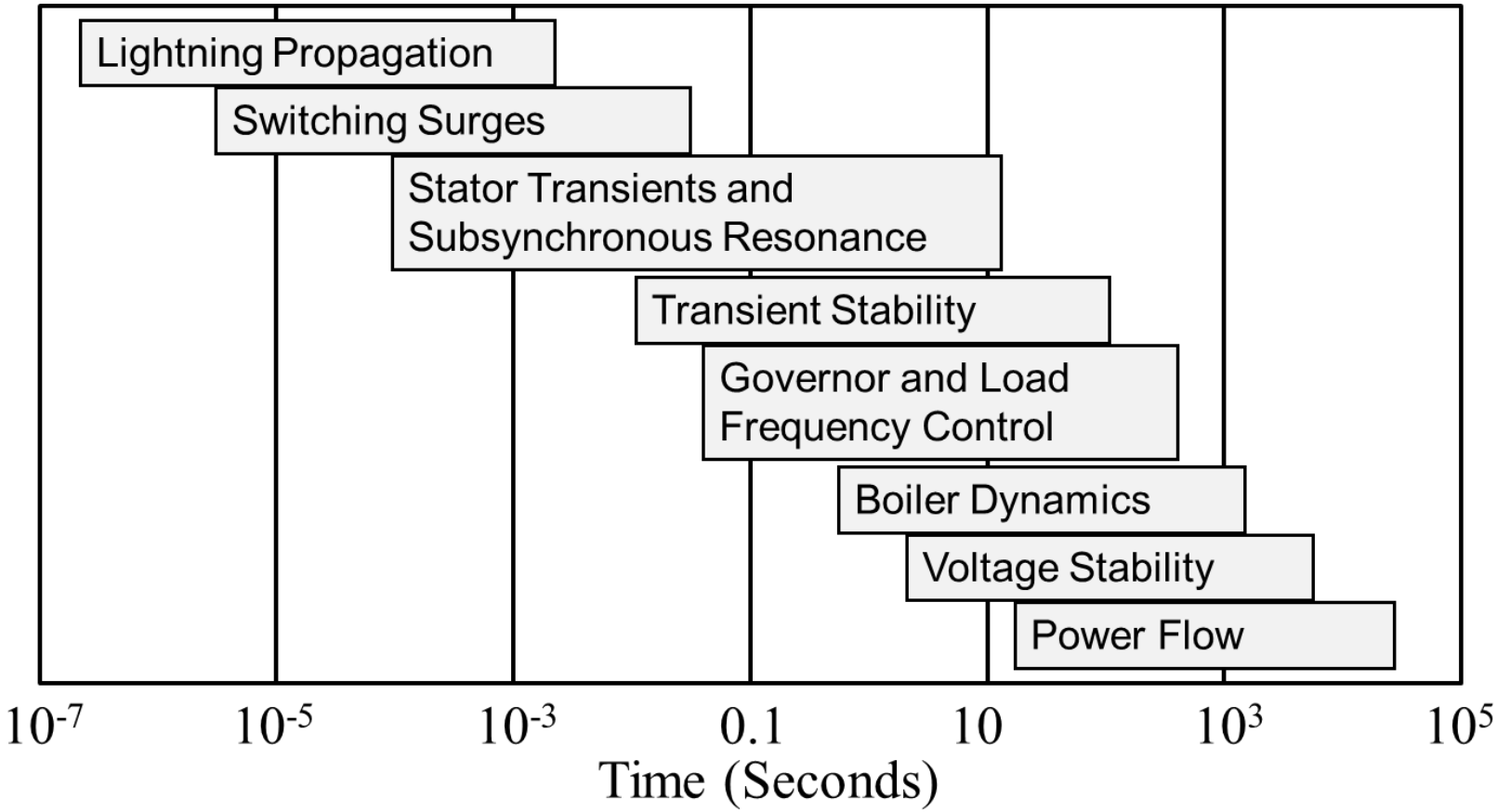
Geomagnetic Disturbances (GMDs)

- GMDs have the potential to severely disrupt operations of the electric grid by inducing quasi-dc geomagnetically induced currents (GICs) in the high voltage grid
- Until the last year or so power engineers had few tools to help them assess the impact of GMDs on their system
- GMD assessment tools are now moving into the realm of power system planning and operations engineers
  - GIC impact is certainly still an area of research, but tools are here now and are continuing to move forward
- Presentation provides overview of this process

Power Grids are Interconnected: North American Systems (all 60 Hz)



Analysis Requires the Potential Consideration of Many Different Time Frames

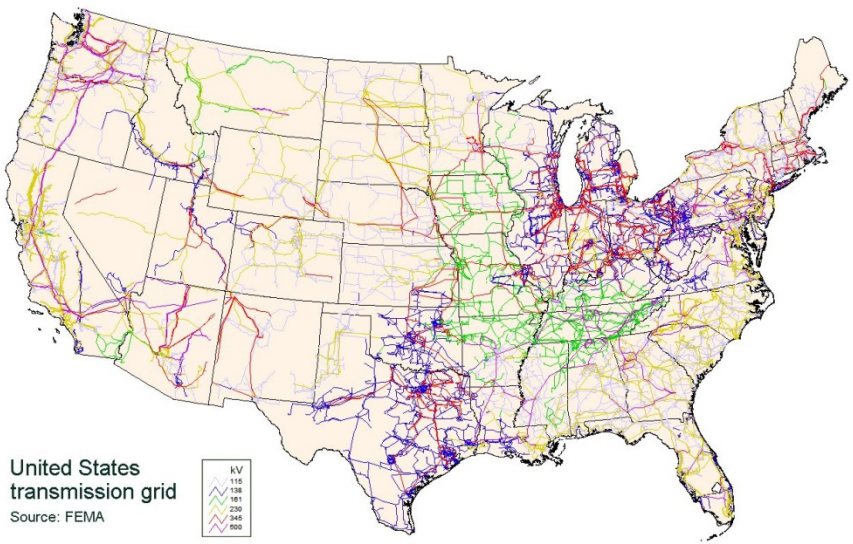


GMDs impact grid on time scale of many seconds to hours, quasi-steady state analyzed by power flow

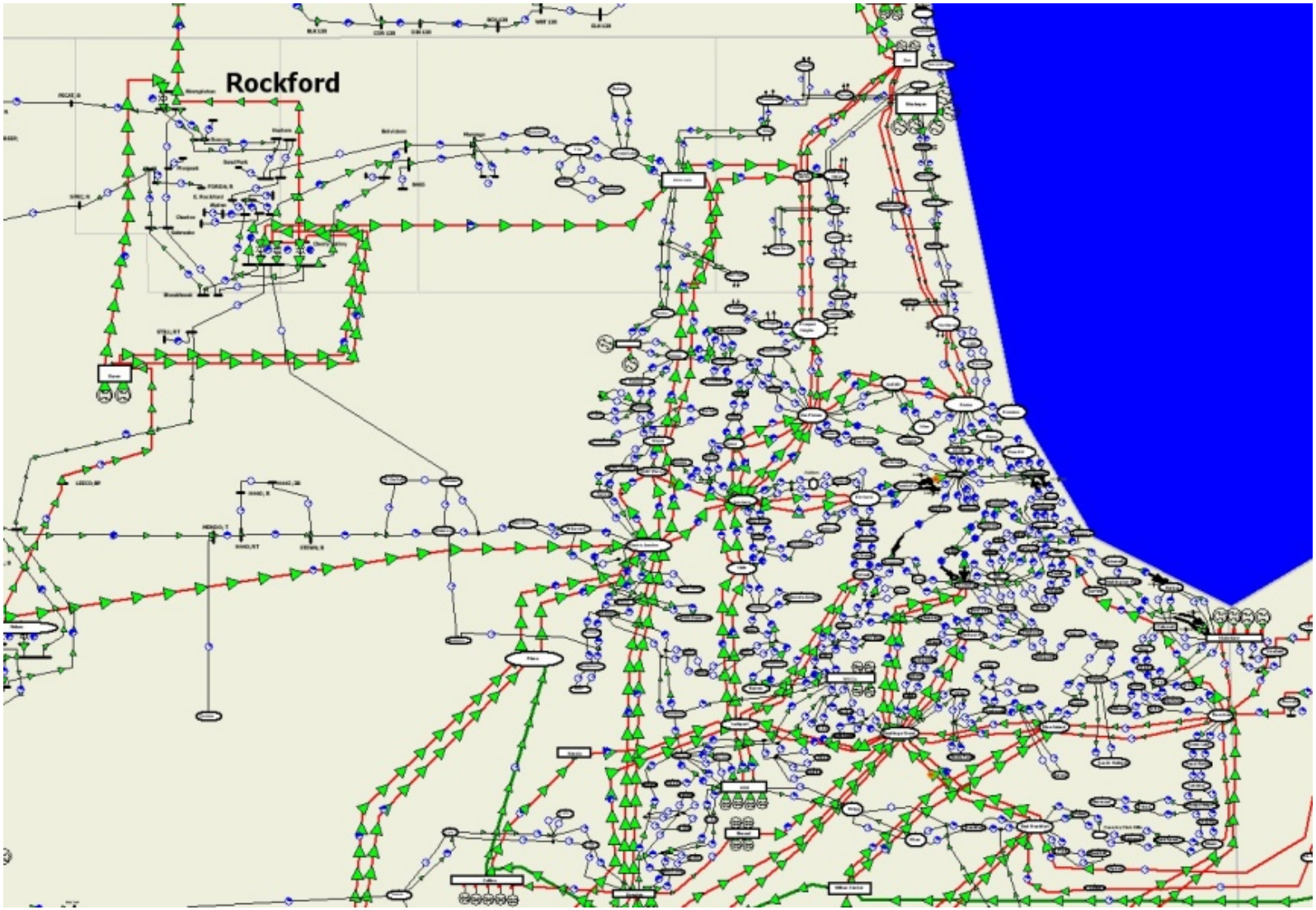
Image source: P.W. Sauer, M.A. Pai, Power System Dynamics and Stability, 1997, Fig 1.2, modified

Important Electric Grid Considerations in Power Flow (GMD) Time Frame

- Electricity cannot be economically stored
  - Generation must be continually adjusted to match changes in electric load and losses
- Electric power flow on high voltage transmission lines cannot usually be directly controlled
  - Control is indirect, by changing generation
- Customers have been in near complete control of their load
- Transmission system has finite limits, and is often operated close to its limit for economic reasons
  - Voltage limits are also quite important

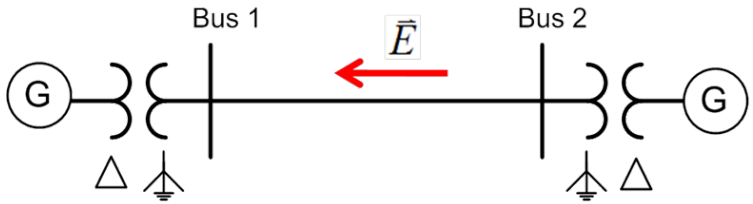


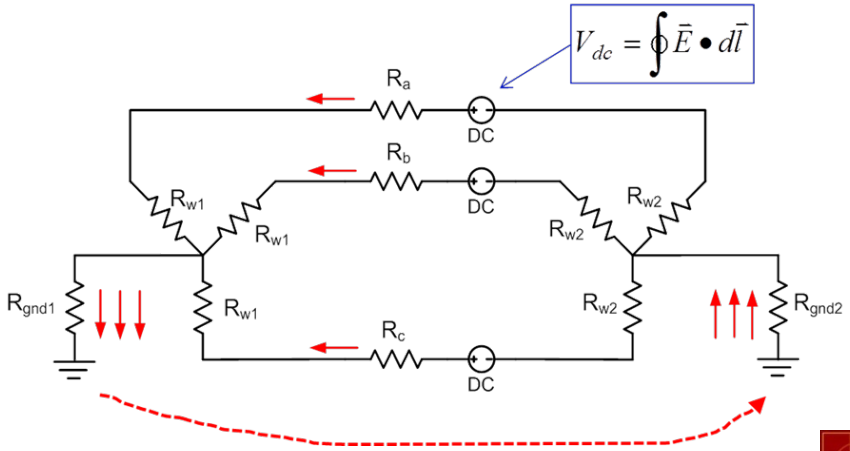
Quick Grid Operations Demo



Geomagnetically Induced Currents (GICs

- The impact of the GMD is to cause slowly varying (quasi-dc) electric fields
- Along length of a high voltage transmission line, electric fields can be modeled as a dc voltage source superimposed on the lines
- These voltage sources produce quasi-dc geomagnetically induced currents (GICs) that are superimposed on the ac (60 Hz) flows





Transformer Impacts of GICs

- The dc GICs, being superimposed upon the ac currents, push the flux on high voltage transformers into saturation for part of the ac cycle
- This can cause large harmonics; in the power flow these harmonics can be represented by increased reactive power losses on the transformer, which causes a voltage drop
- Also increased temperatures

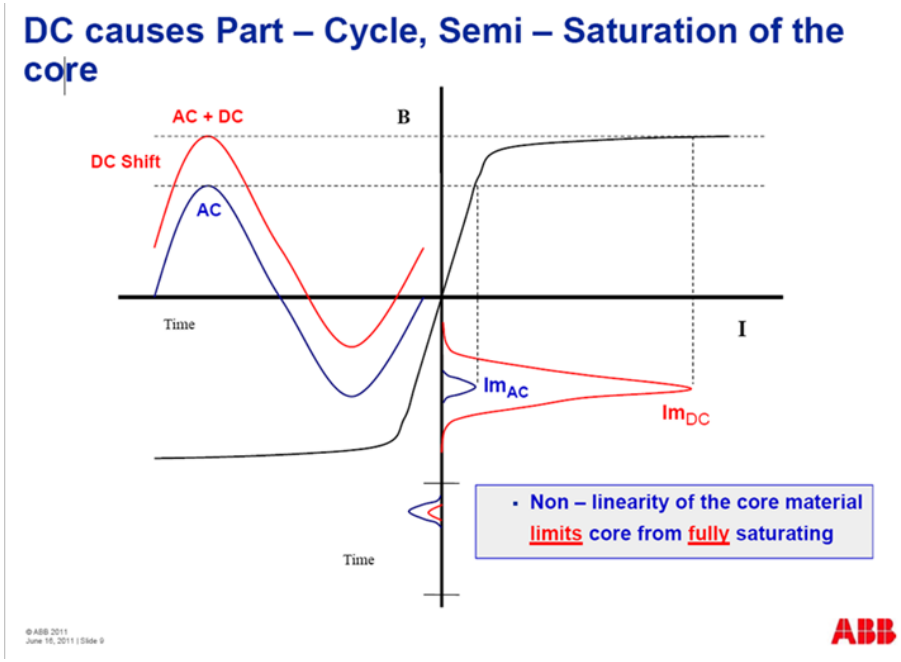
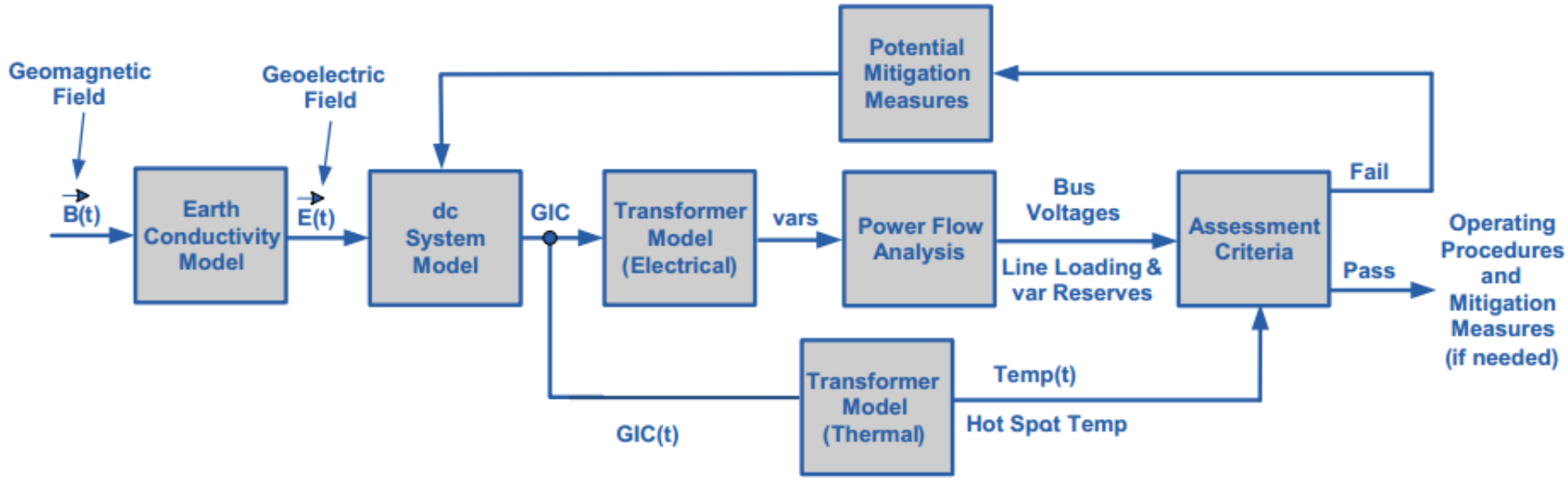


Image Source: Craig Stiegemeier, JASON Presentation, June 2011, Slide

GMD Enhanced Power Analysis Software

- By integrating GIC calculations directly within 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

Overview of GMD Assessments

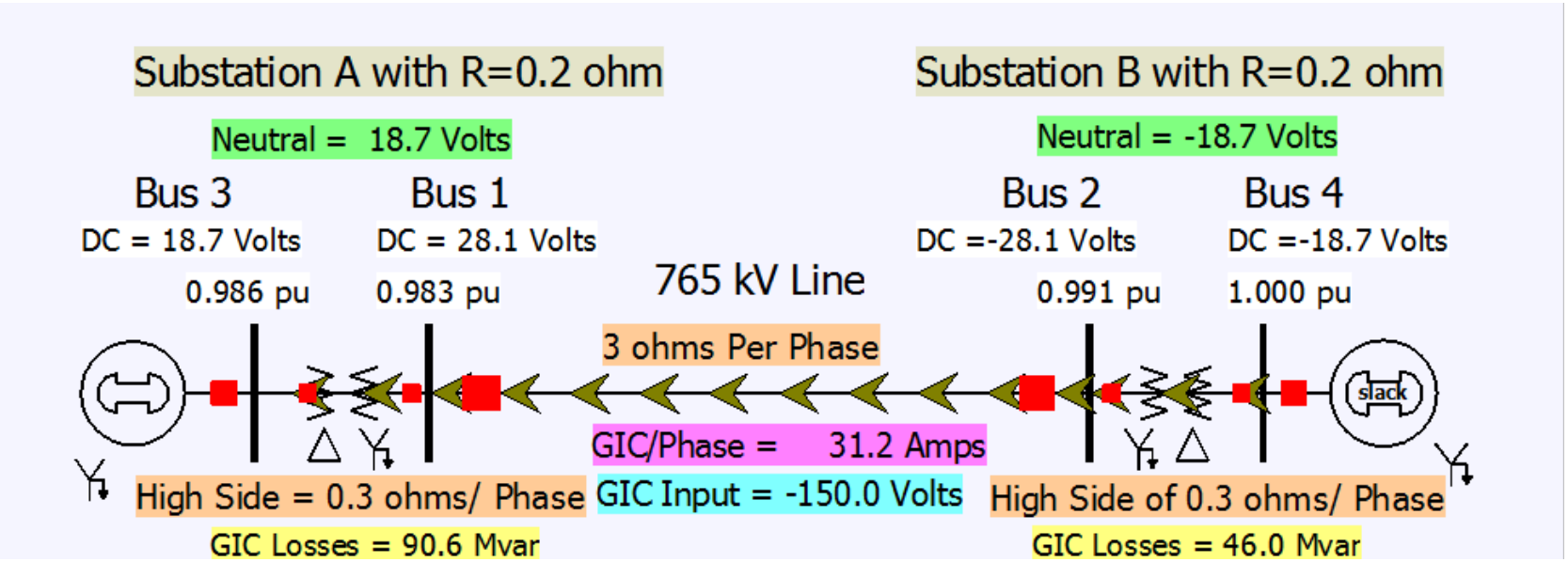


The two key concerns from a big storm are 1) large-scale blackout due to voltage collapse; bad but service restored in days, 2) permanent transformer damage due to overheating; catastrophic, with blackouts or reduced service lasting for months

Image Source: http://www.nerc.com/pa/Stand/WebinarLibrary/GMD_standards_update_june26_ec.pdf

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 current is three times this value.
Substation grounding values are total resistance.
Brown arrows show GIC flow.

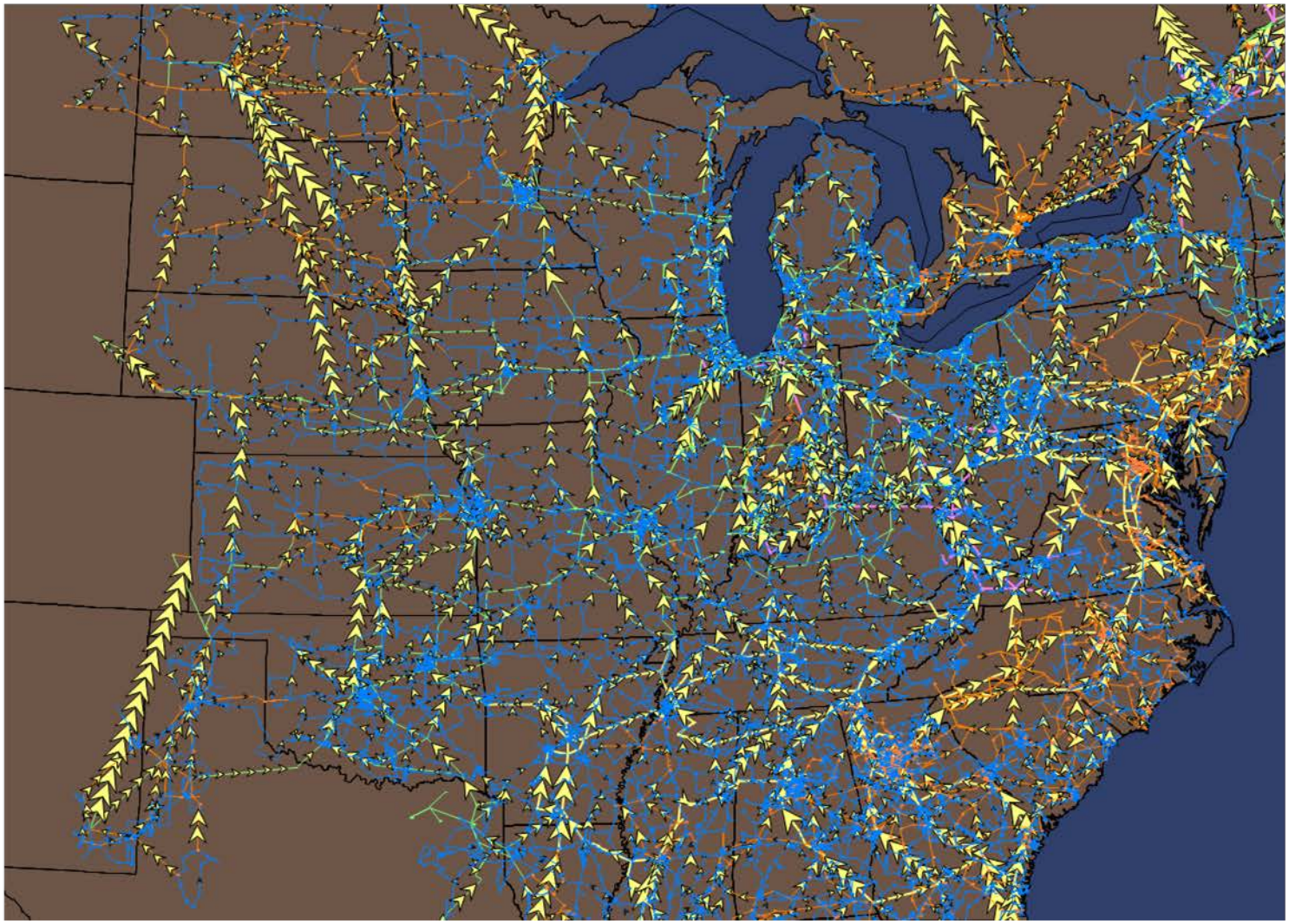
GMD Assessment Software Evolution

- Initial packages were stand alone, not integrated into commercial power flow or transient stability
- In 2011-2012 GMD assessment integrated into power flow
  - Uniform electric field assumption initially common
- More recently sensitivity analysis has been included
  - Sensitivity of GICs to input electric field assumptions (nearby lines provide vast majority of a transformers GICs)
  - Sensitivity of GICs to assumed substation grounding resistance (results indicate the values can be quite sensitive!)
- Much more detailed non-uniform electric fields are now being modeled
- Calculations are now also integrated into transient stability for possible dynamic considerations

Determining GMD Storm Scenarios

- The starting point for the GIC analysis in the power flow is an assumed storm scenario; this is used to determine the transmission line dc voltages
- Matching an actual storm can be complicated, and requires detailed knowledge of the associated geology
- GICs vary linearly with the assumed electric field magnitudes and reactive power impacts on the transformers is also linear
- Working with space weather community to determine highest possible storms
- Power industry started by considering uniform fields, but now has moved to non-uniform

GIC Flows in Eastern Interconnect for a Uniform 2.5 V/Mile, North-South Field

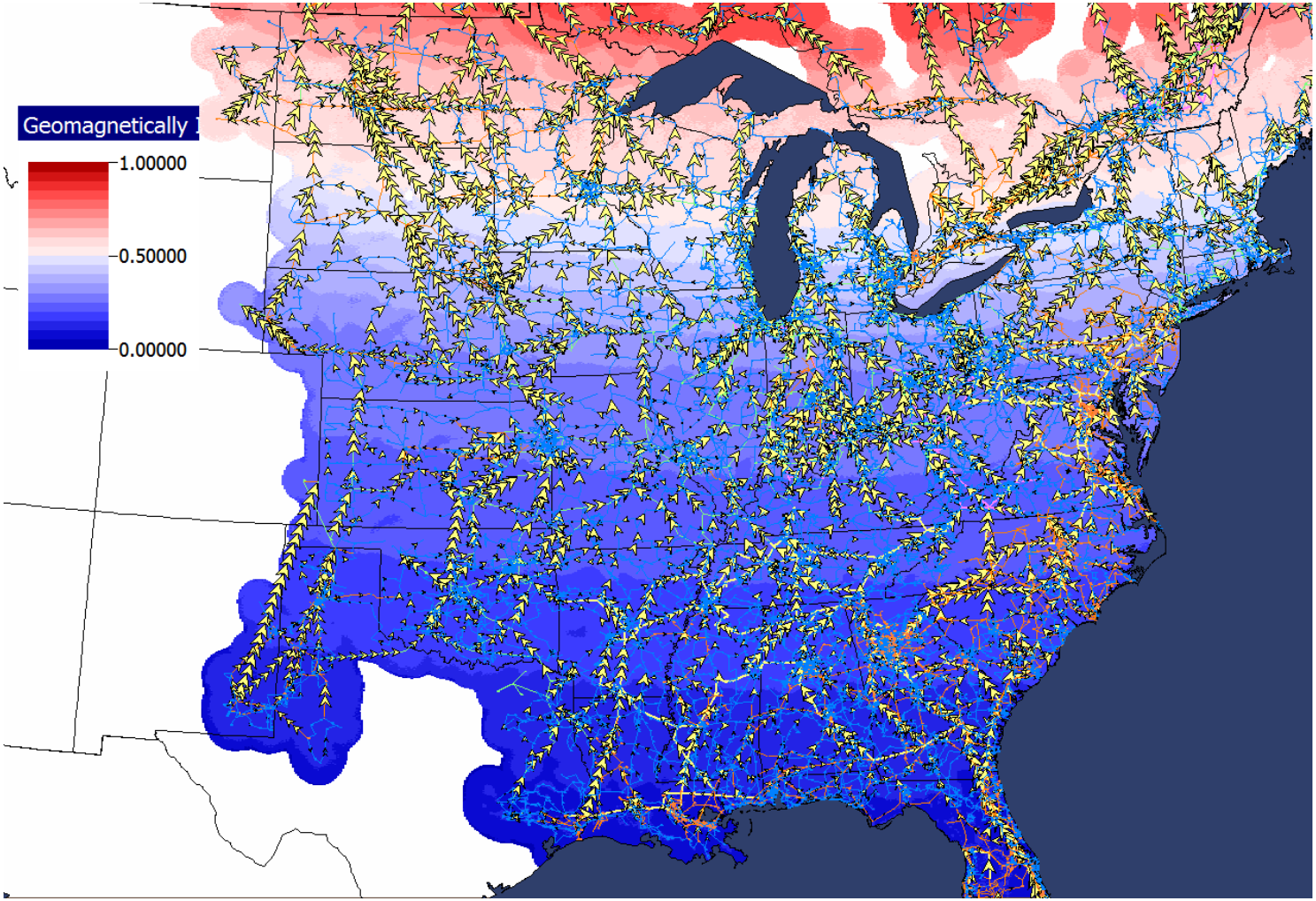


These flows are relatively easy to calculate, but studying such a GMD is probably not that realistic

Benchmark GMD Scenario

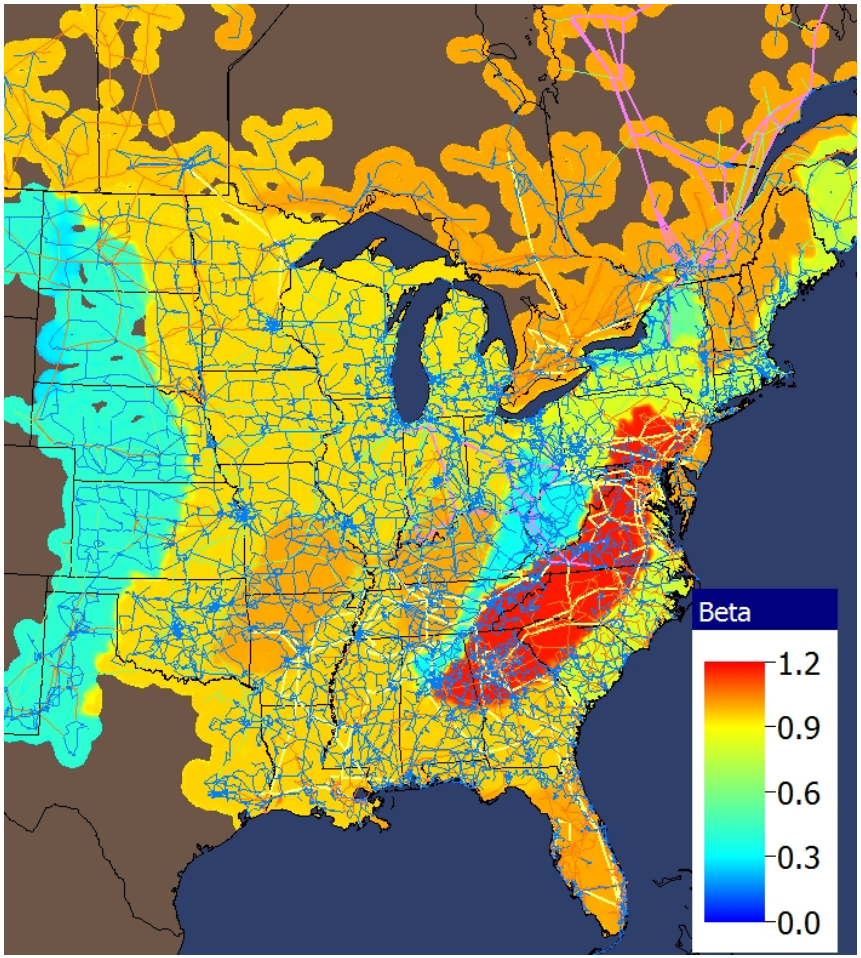
- Derived from the March 1989 event
- Peak electric field is 8 V/km for a reference location (60 deg. N, resistive Earth)
- Electric field for other regions scaled by two factors
  - $E_{\text{peak}} = 8 * \alpha * \beta$ V/km
  - "1 in a 100 year" event
  - Details can be found at
    - http://www.nerc.com/pa/Stand/Project201303GeomagneticDisturbanceMitigation/Benchmark_GMD_Event_June12_clean.pdf

PowerWorld GIC Calculations with Geomagnetic Latitude Scaling (α)



Magnetic latitude is about 10 degrees greater than geographic latitude

Earth Resistivity Scalar (β)



The earth resistivity layers can now be modeled in PowerWorld, allowing different scenarios to be considered

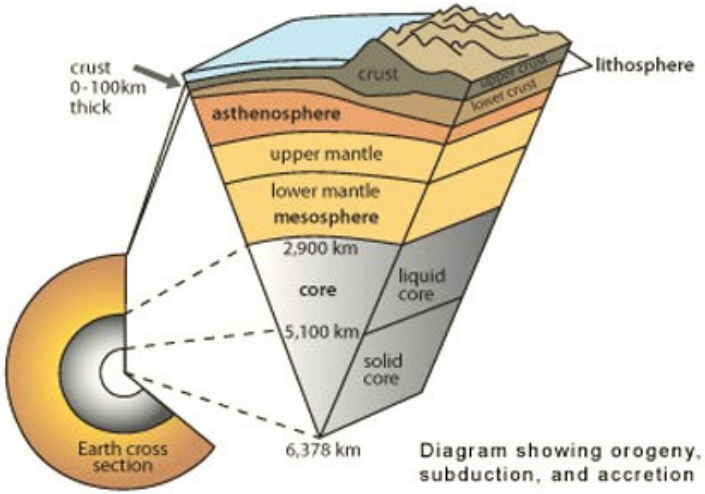


Image Source: http://www.naturalhistorymag.com/sites/default/files/imagecache/large/media/2009/05/0309partner2_jpg_18912.jpg

Conclusions

- GIC impact assessment has progressed to point at which it can be treated like other engineering problems with a cost/benefit assessment
  - There is lots of uncertainty, but power industry is use to dealing with uncertainty
  - Assumed storm size is crucial – too low we miss the big ones, too large we waste effort and perhaps capital
- Getting started with GIC assessment can be relatively straightforward, consisting of doing GIC enhanced power flow studies
  - Can be used to determine mitigation strategies and locations for monitoring equipment
- More advanced analysis techniques, including non-uniform fields are now available

Thank You!

Questions?