Incorporating Geomagnetically Induced Current Modeling into Power Flow Analysis

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Key Questions About GMD

- Could it cause permanent damage to critical infrastructure, such as transformers?
- How could it affect SCADA, communications, and the ability of automated protection schemes and system operators to observe and control the system?
- How could it affect the stability of the power grid?

Considerations

- Reactive power does not travel well due to transmission line reactance and generally must be supplied close to the point of demand
- Power systems are designed with reactive power supplies close to normal demand centers
  - Loads that consume reactive power
  - Low-voltage transmission and distribution lines
  - Wind turbines
- GIC-induced half-cycle transformer saturation causes increased Mvar losses
- Some Mvar losses may occur in parts of the system that do not normally experience high reactive power demand

Approaches

- Simulate a range of electric field intensities
  - 2 V/km was the estimated maximum during the event that caused the 1989 blackout in Quebec
  - A 100-year event could cause fields of 5-20 V/km, depending on ground resistivity
- Simulate a range of electric field orientations
  - North-south and east-west should be examined
  - Include the orientation that aligns with most of the transmission lines in the area of interest

Approaches

- Simulate GMD effects in one area of interest (AOI) at a time, including a buffer area of first-tier neighbors
- Identify the minimum uniform electric field strength that could lead a to voltage collapse at each field orientation, for the AOI
- Identify transmission lines that carry high GIC current and transformers with high Mvar losses
  - Simulate the use of GIC reduction devices on these lines and transformers

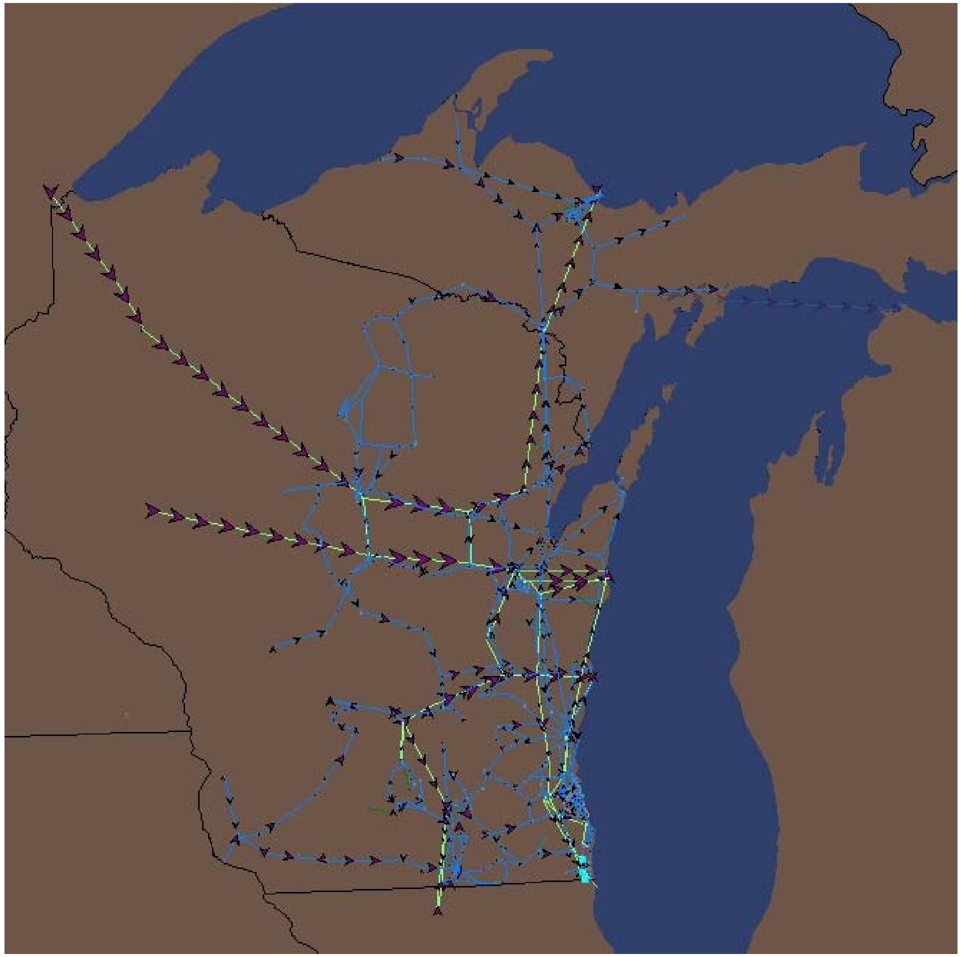
Mitigation

- Install meters for observability of GMD events
  - Perform direct GIC measurements on a variety of lines of different orientations in different parts of the system
- Series compensation to block DC flow in transmission lines
- Transformer capacitive neutral protection
- Remedial action schemes
  - Line switching
  - Generation redispatch
  - Adjust voltage controller setpoints
  - Islanding
  - Load shedding

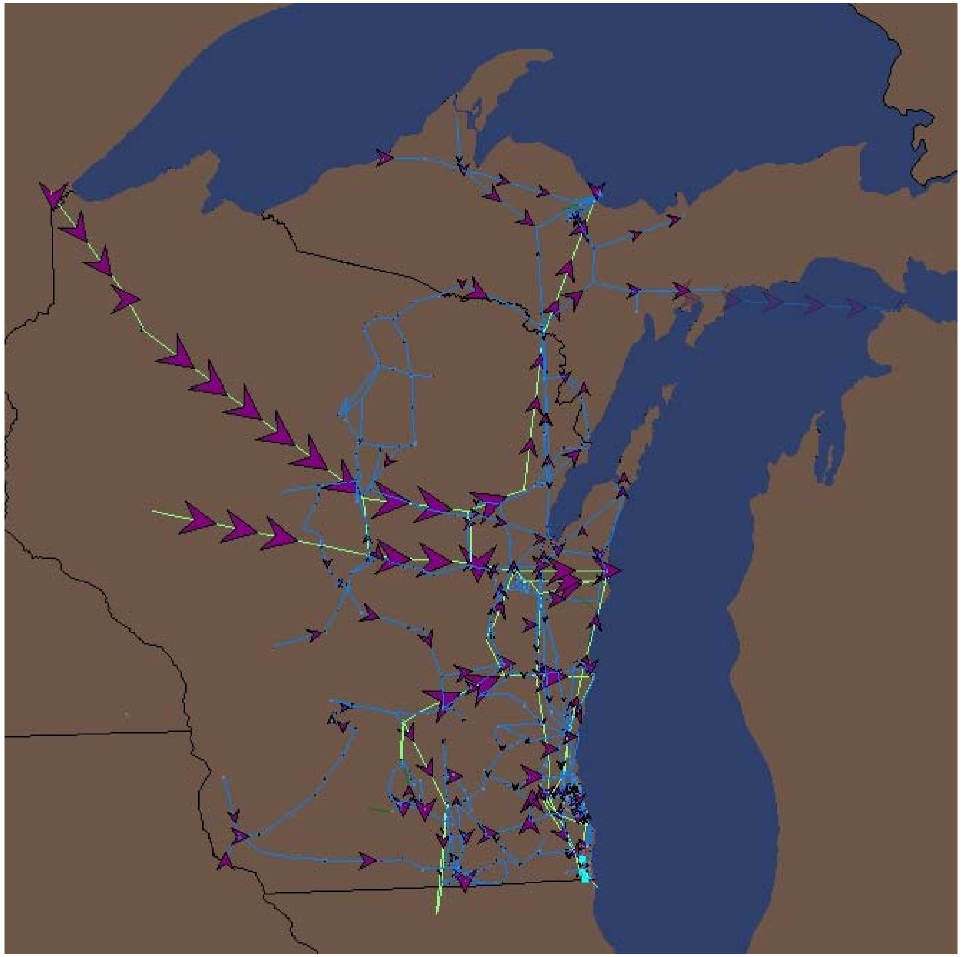
Example: GIC Simulation

- Examine high-voltage transmission grid in Wisconsin and Upper Michigan
- Simulate various uniform electric field strengths at 0 degree (north-south) and 90 degree (east-west) orientations
- Perform QV-type analysis to identify field strength that causes voltage collapse: increase field strength in small increments, until the last valid power flow solution is achieved

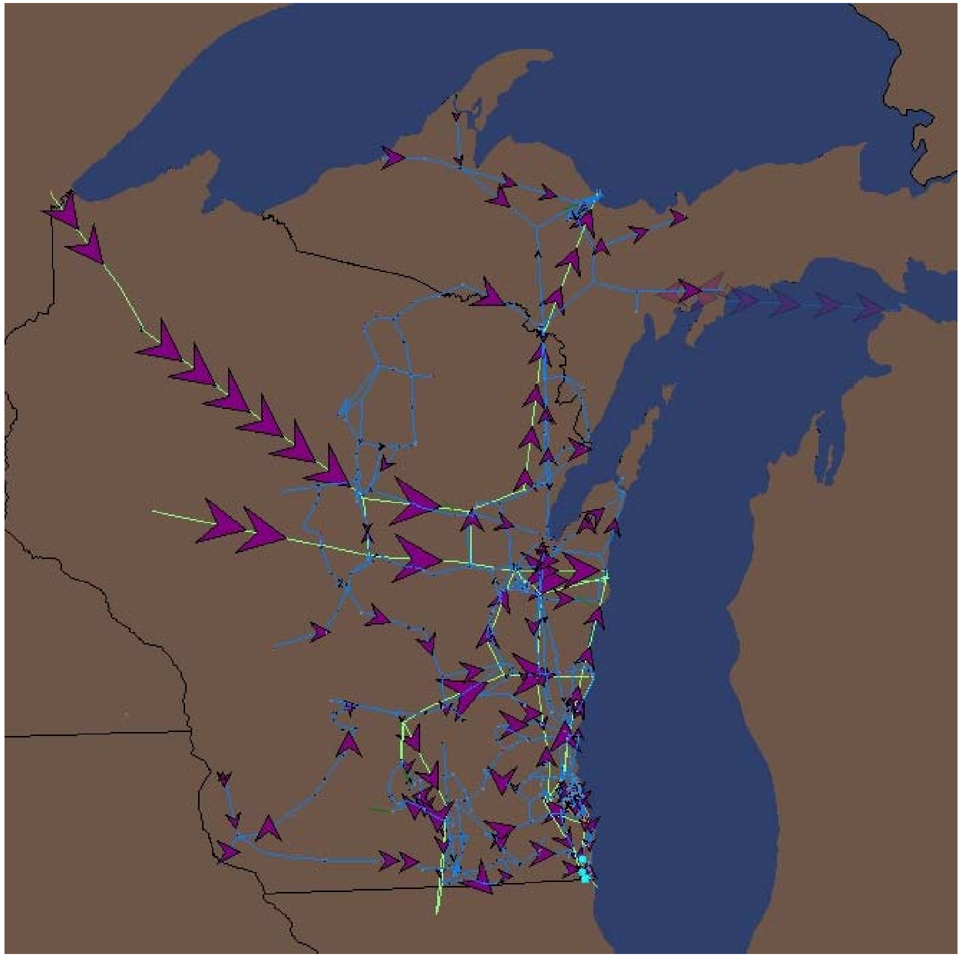
GIC flow at 2 V/km, 90 degrees



GIC flow at 10 V/km, 90 degrees



GIC flow at 17.5 V/km, 90 degrees



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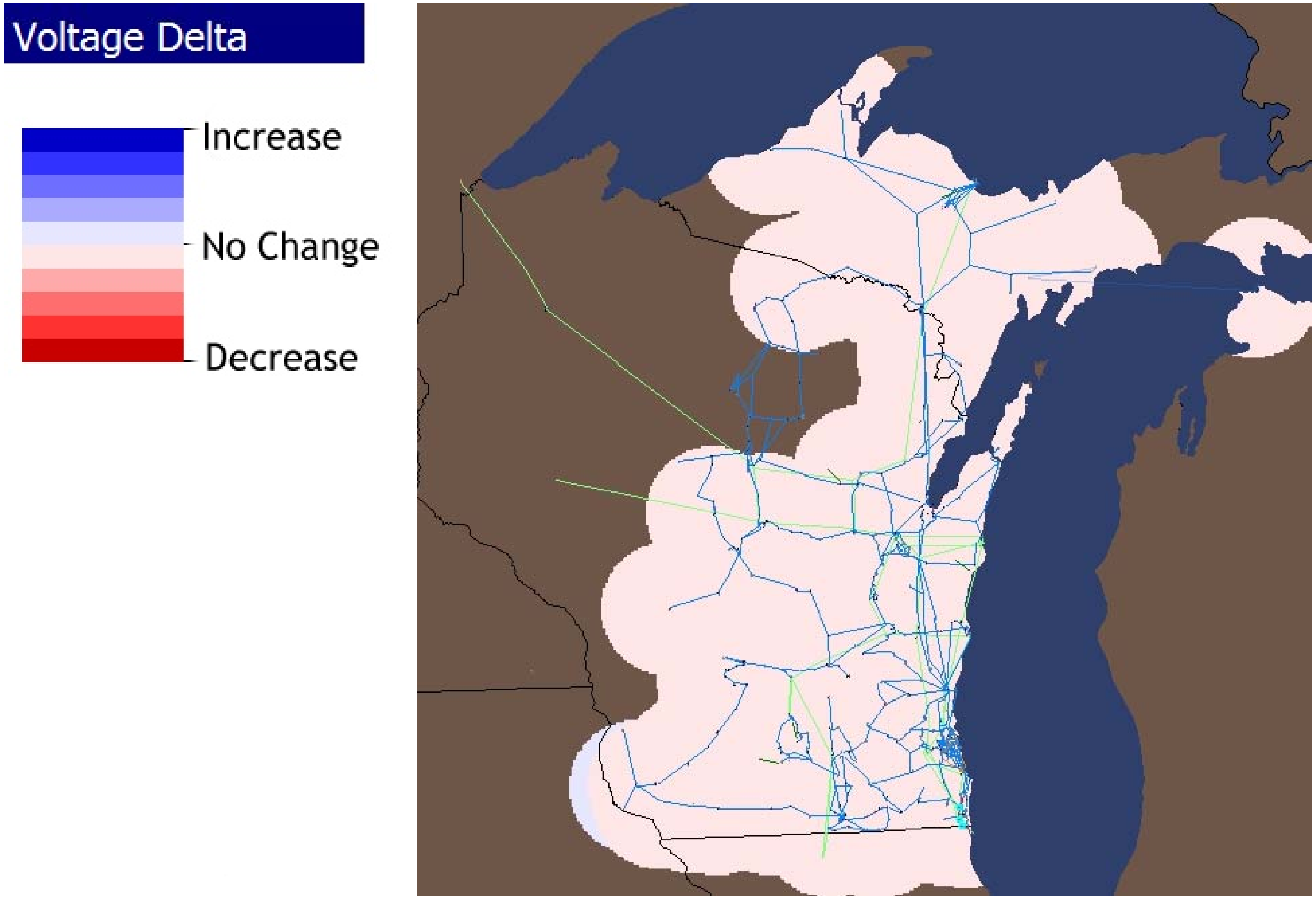
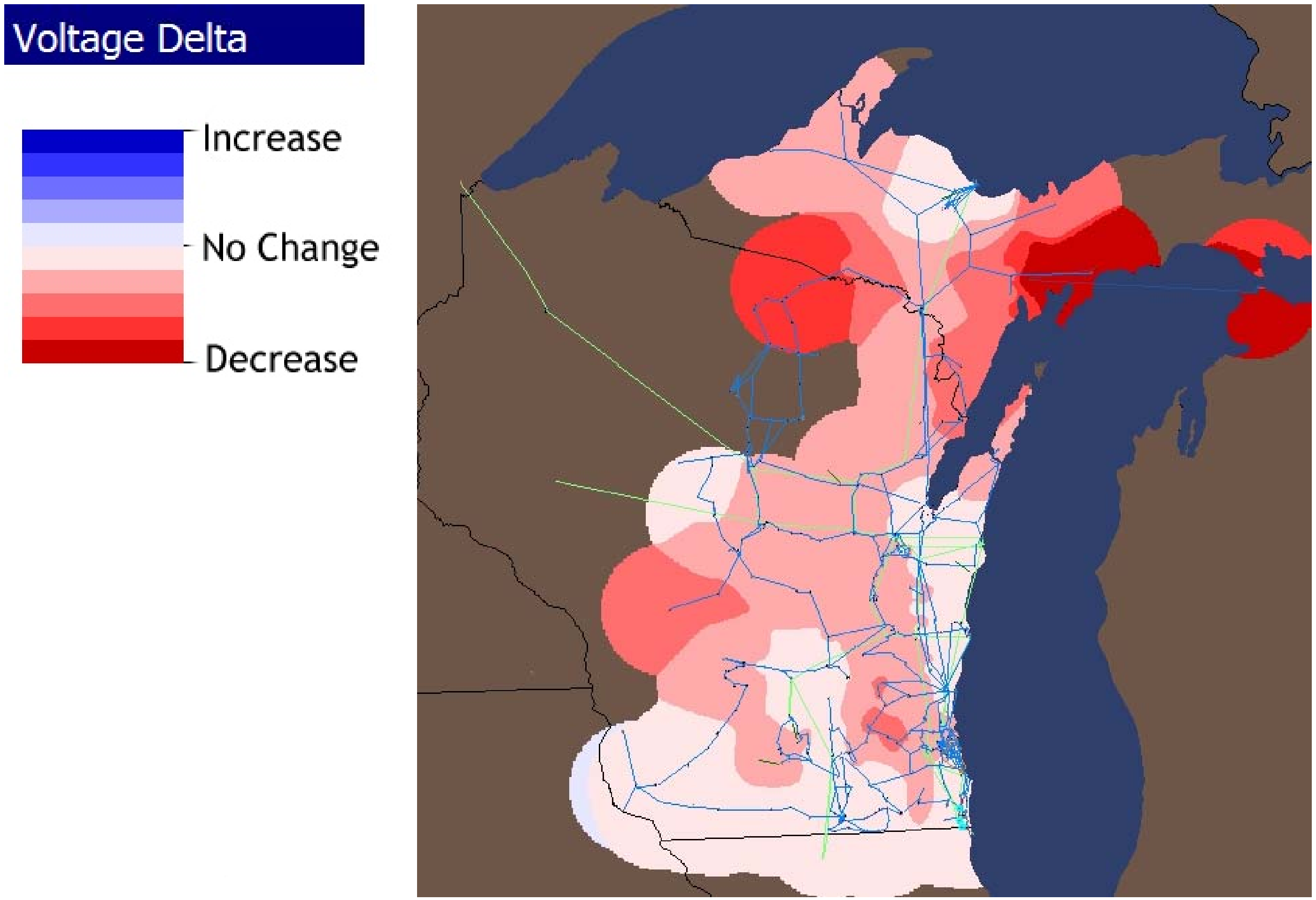
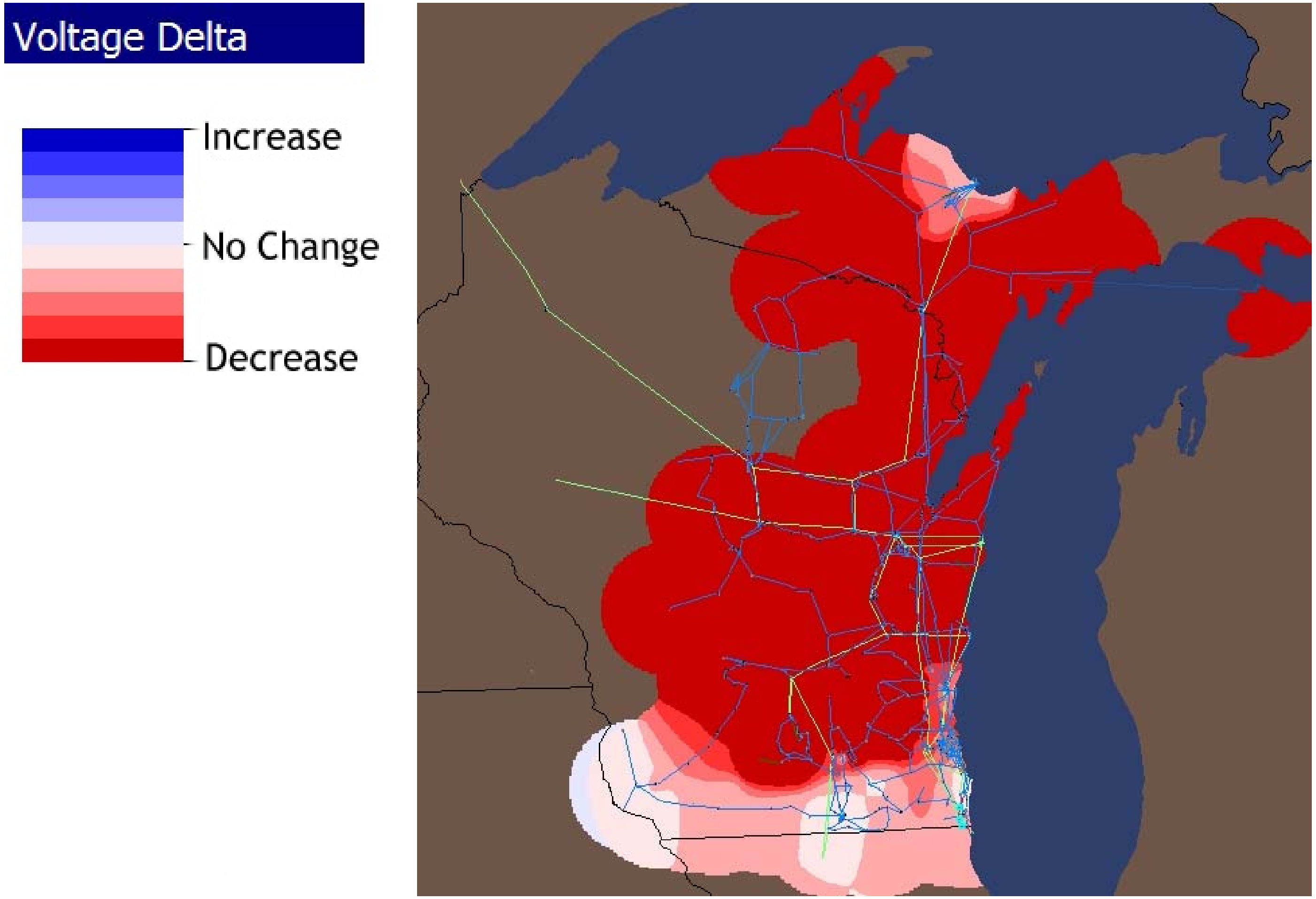
Voltage Delta at 2 V/km, 90 deg



Voltage Delta at 10 V/km, 90 deg



Voltage Delta at 17.5 V/km, 90 deg

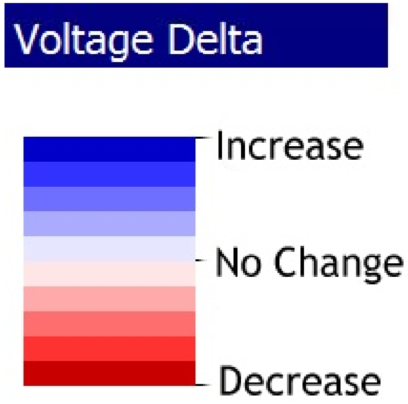


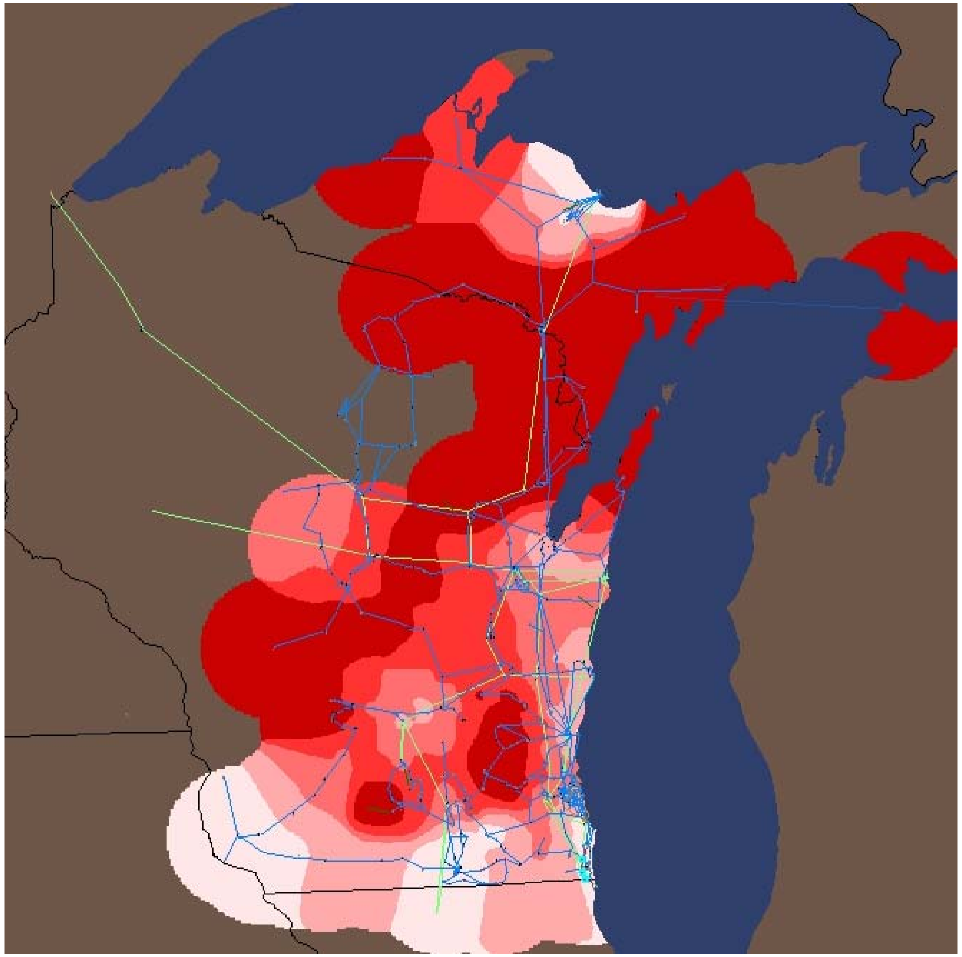
Example: GIC Mitigation

- Voltage collapse occurs at 18 V/km, 90 degrees
- Capacitive neutral protection was simulated on 15 high-voltage transformers in the AOI
  - Improved voltage profile at 17.5 V/km
  - Increased minimum field strength that causes voltage collapse by 31%, to 23.5 V/km

Voltage Delta at 17.5 V/km, 90 deg

with neutral DC protection on 15 transformers





Future Directions

- Optimization of mitigation actions is an area of ongoing research
- Future mitigation studies should examine optimal placement of series compensation or transformer neutral protection to minimize system GIC flow or Mvar losses