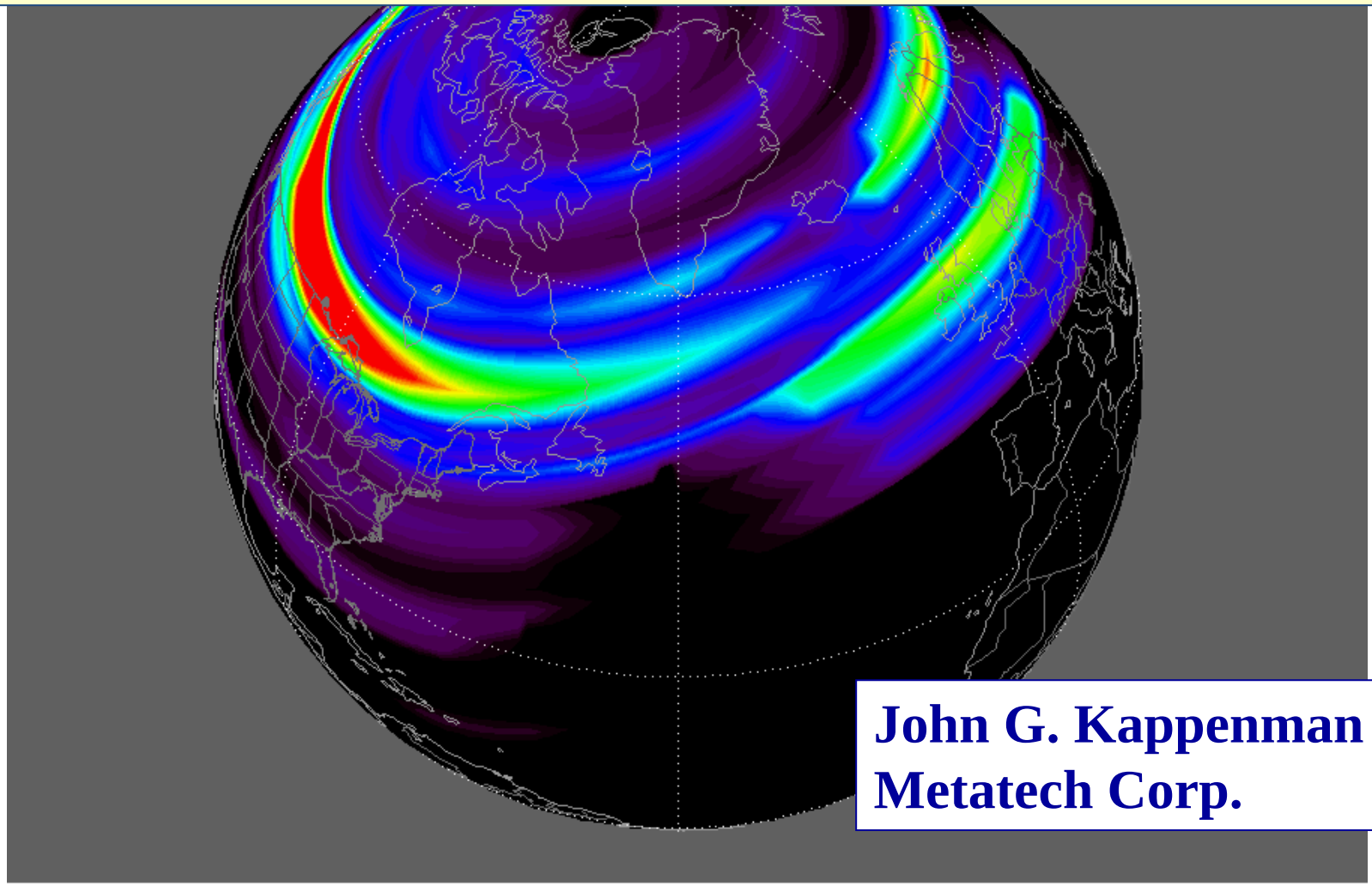
The Vulnerability of the US Electric Power Grid to Severe Space Weather Events and Future Outlook

"There is a non-zero probability that GIC could cause a wide-area blackout for a severe geomagnetic storm" - Albertson, Kappenman, et.al. IEEE PAS February 1981



John G. Kappenman
Metatech Corp.

A Review of Power Grid Vulnerability to Extreme GIC Events

•Design Vulnerability Trends have greatly increased potential impact of Geomagnetic Storms – Infrastructures have evolved similarly in other Developed Regions of the World

•Most World Infrastructures of Concern generally between +/- 60^{o} Magnetic Latitude (concentration between +/-50^{o} latitudes)

•EMP Commission and FEMA Exec Order 13407 Threat Investigation Results Indicate GIC Risks have potential to create Large Scale Blackouts, Permanent Damage to Transformer Assets and Lengthy Restoration

•Impacts on Interdependent Infrastructures – Potable Water distribution impacted within several hours, loss of perishable foods and medications in about 12-24 hours, immediate or eventual loss of heating/AC, sewage, phones, transportation, fuel resupply, etc.

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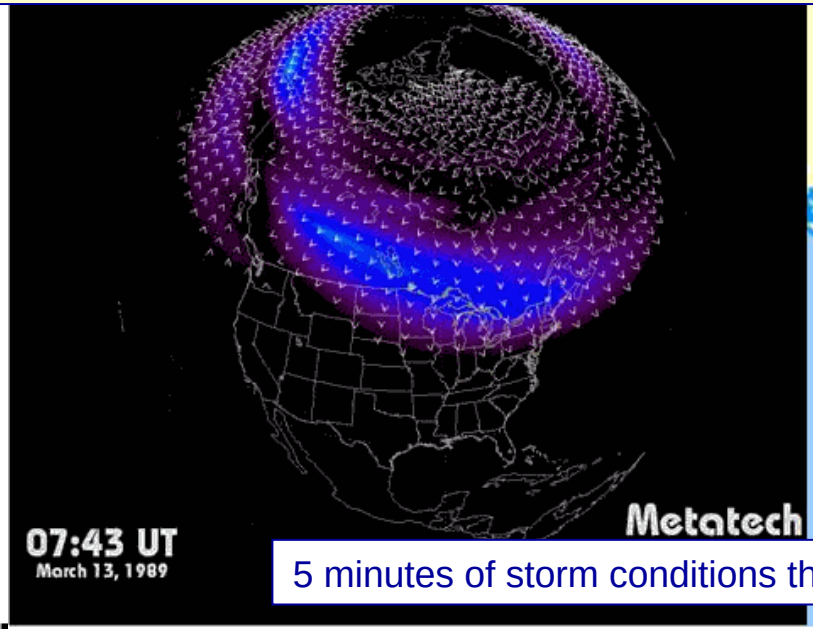
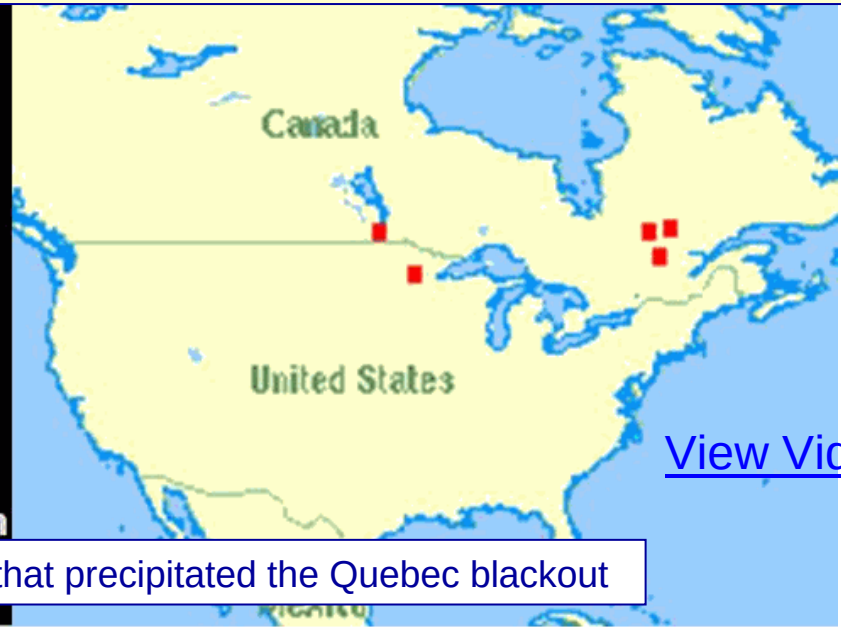
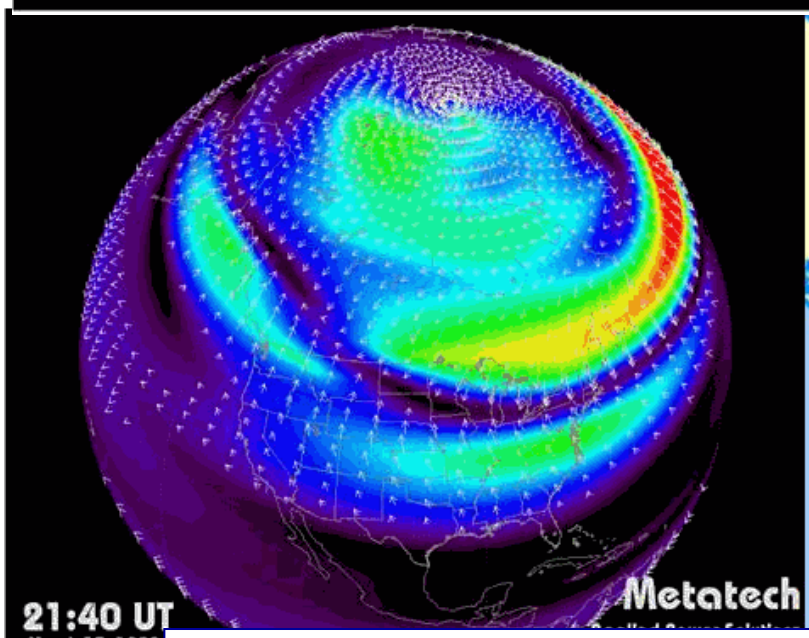
A Quick Overview of the March 13-14, 1989 Geomagnetic Storm and North American Power Grid Impacts





[View Video 1](#)

5 minutes of storm conditions that precipitated the Quebec blackout



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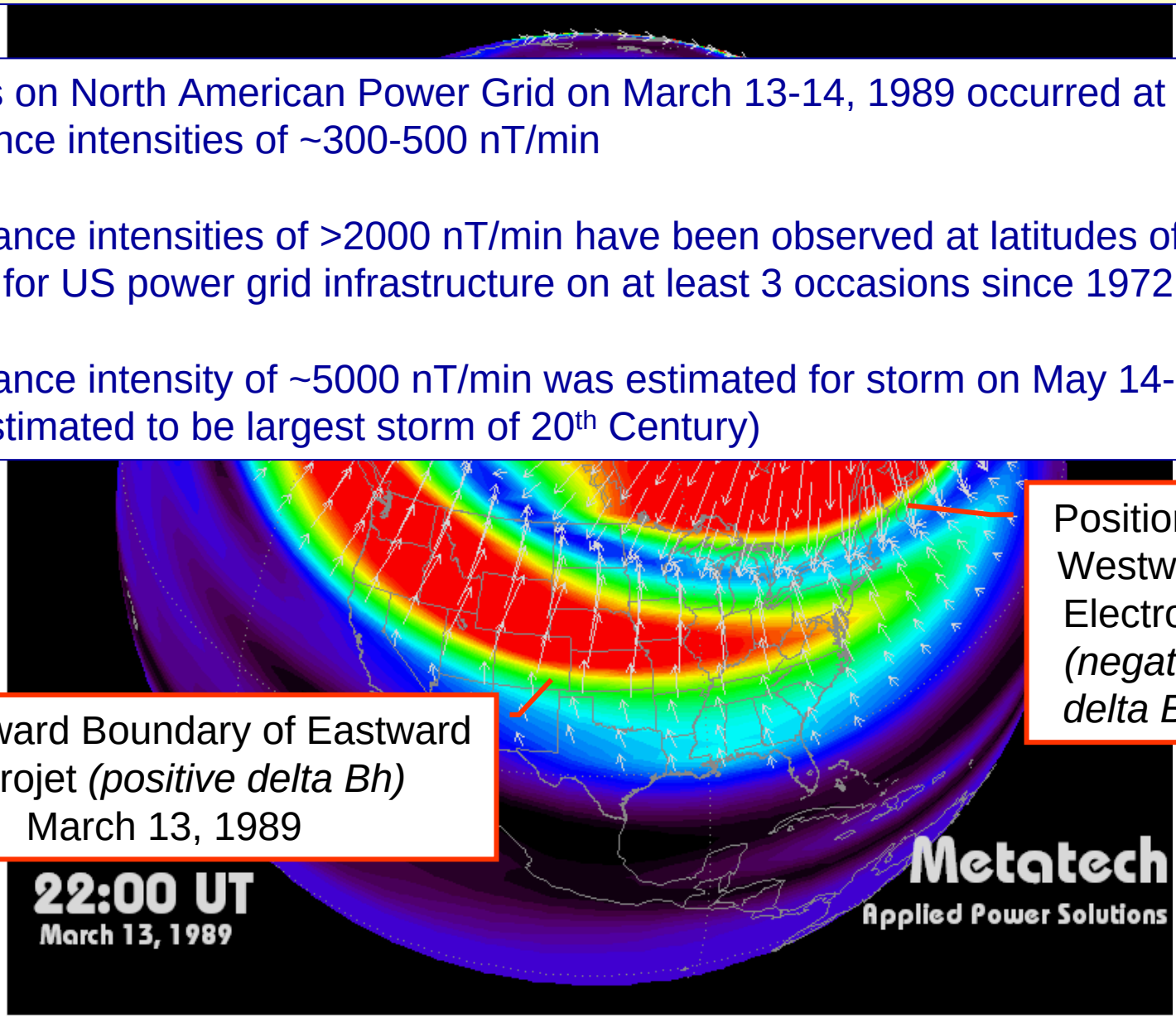
30 minutes of storm conditions later that day and impacts observed across the US

Storm Morphology Analysis & Developing Great Storm Scenarios
March 1989 Superstorm & May 1921 Storm Comparisons

- Impacts on North American Power Grid on March 13-14, 1989 occurred at disturbance intensities of ~300-500 nT/min

- Disturbance intensities of >2000 nT/min have been observed at latitudes of concern for US power grid infrastructure on at least 3 occasions since 1972

- Disturbance intensity of ~5000 nT/min was estimated for storm on May 14-15, 1921 (estimated to be largest storm of 20th Century)



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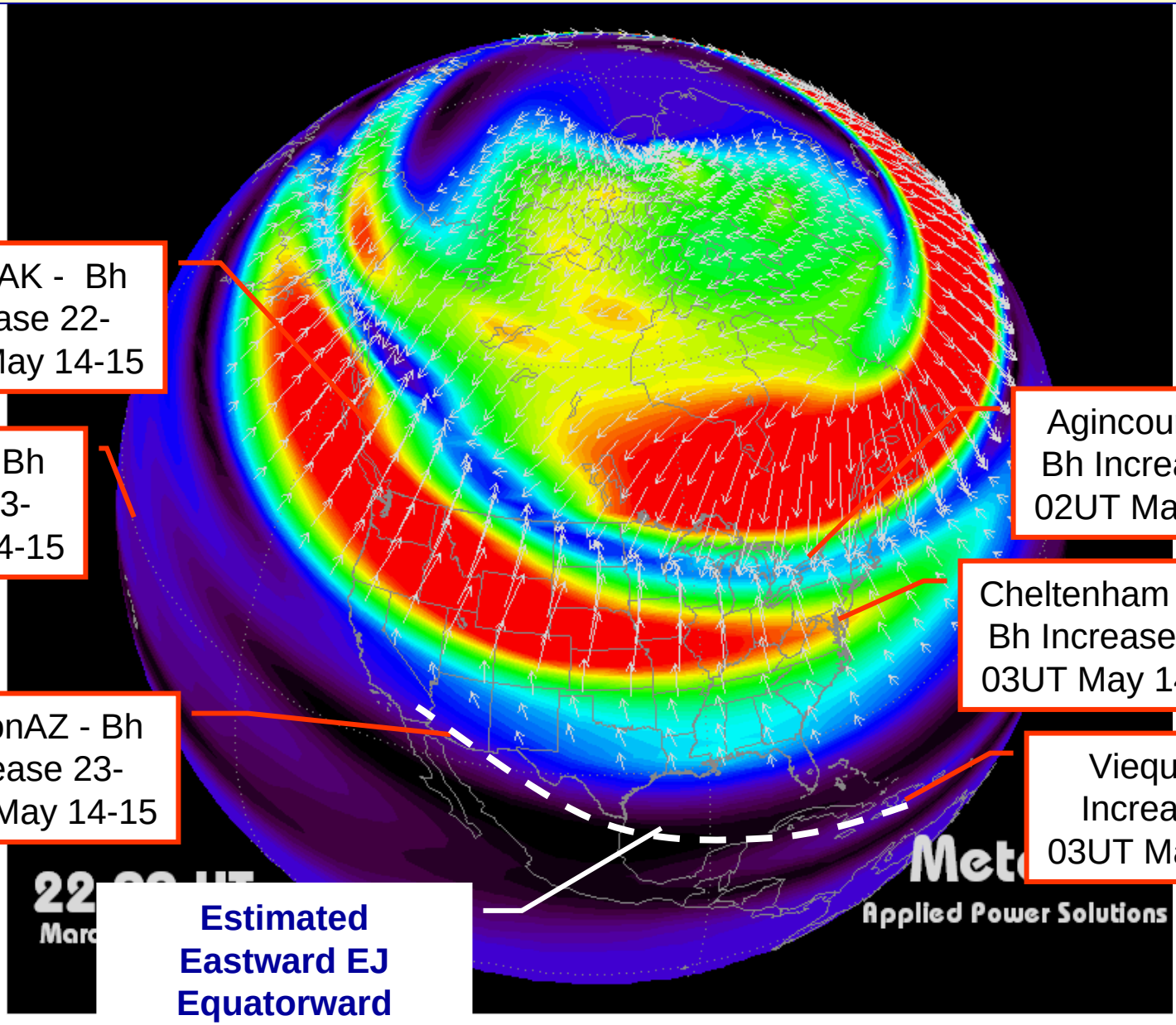
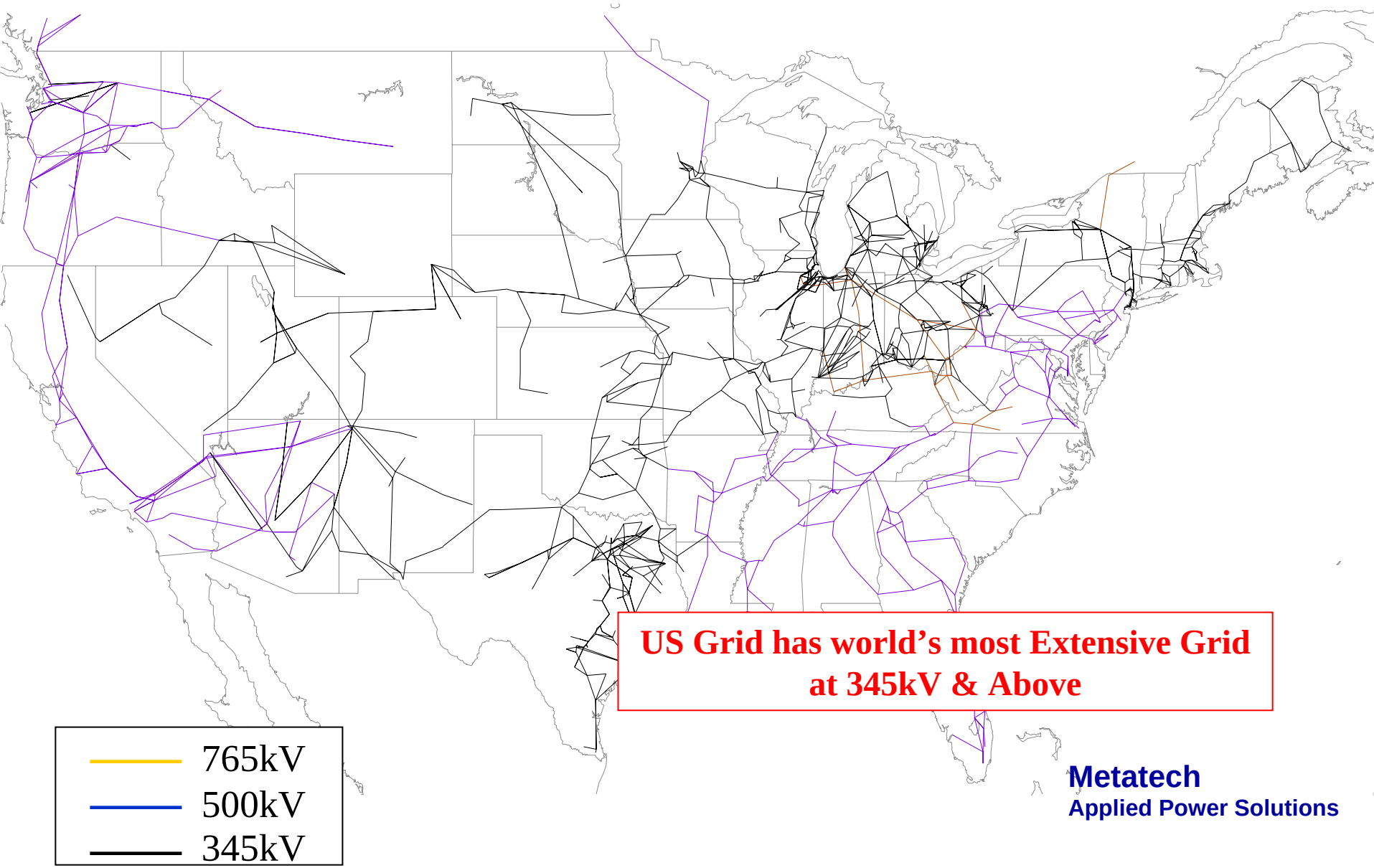


US High-Voltage Transmission Network Model for GIC Simulation



US Grid has world's most Extensive Grid at 345kV & Above

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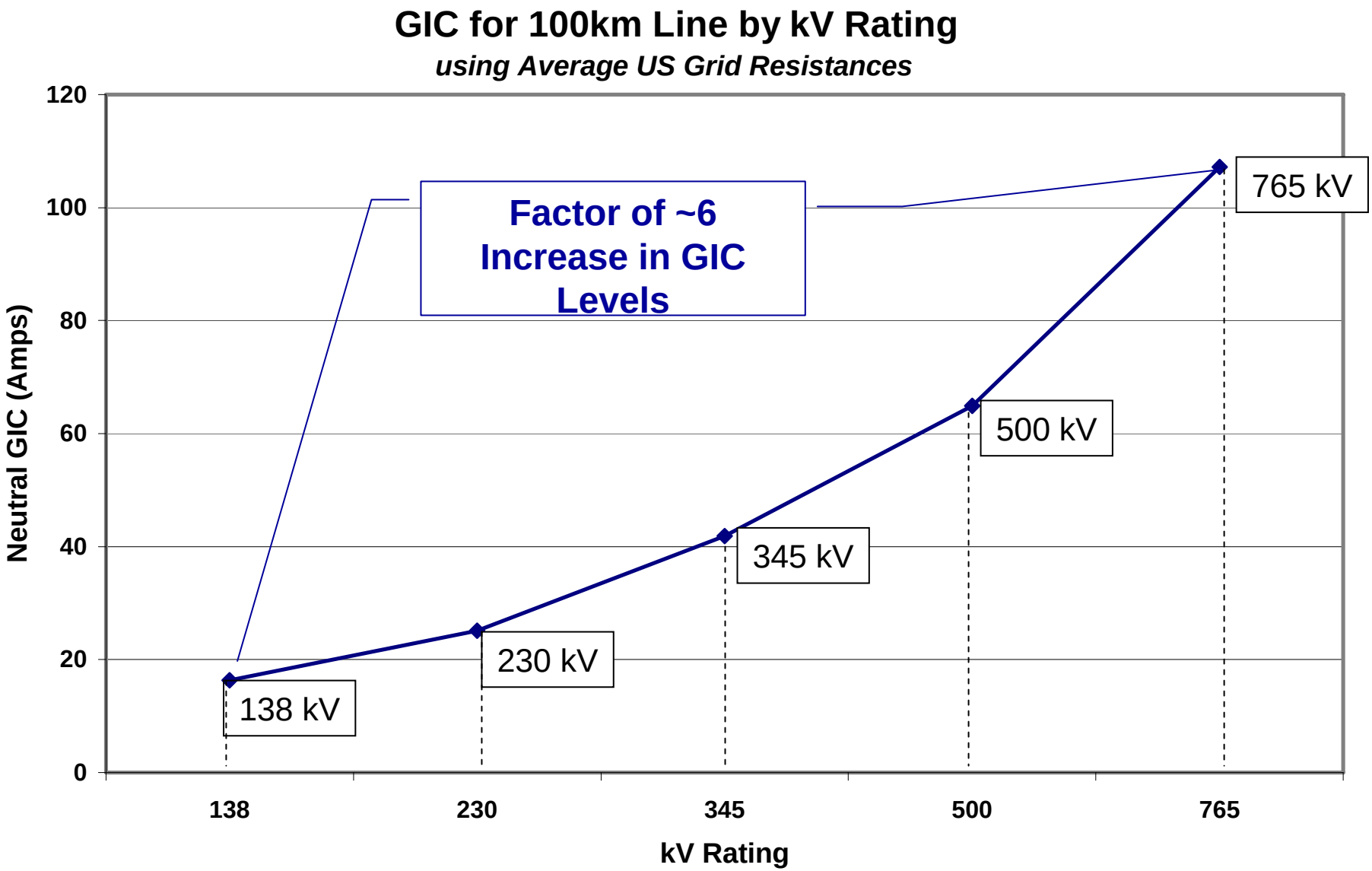
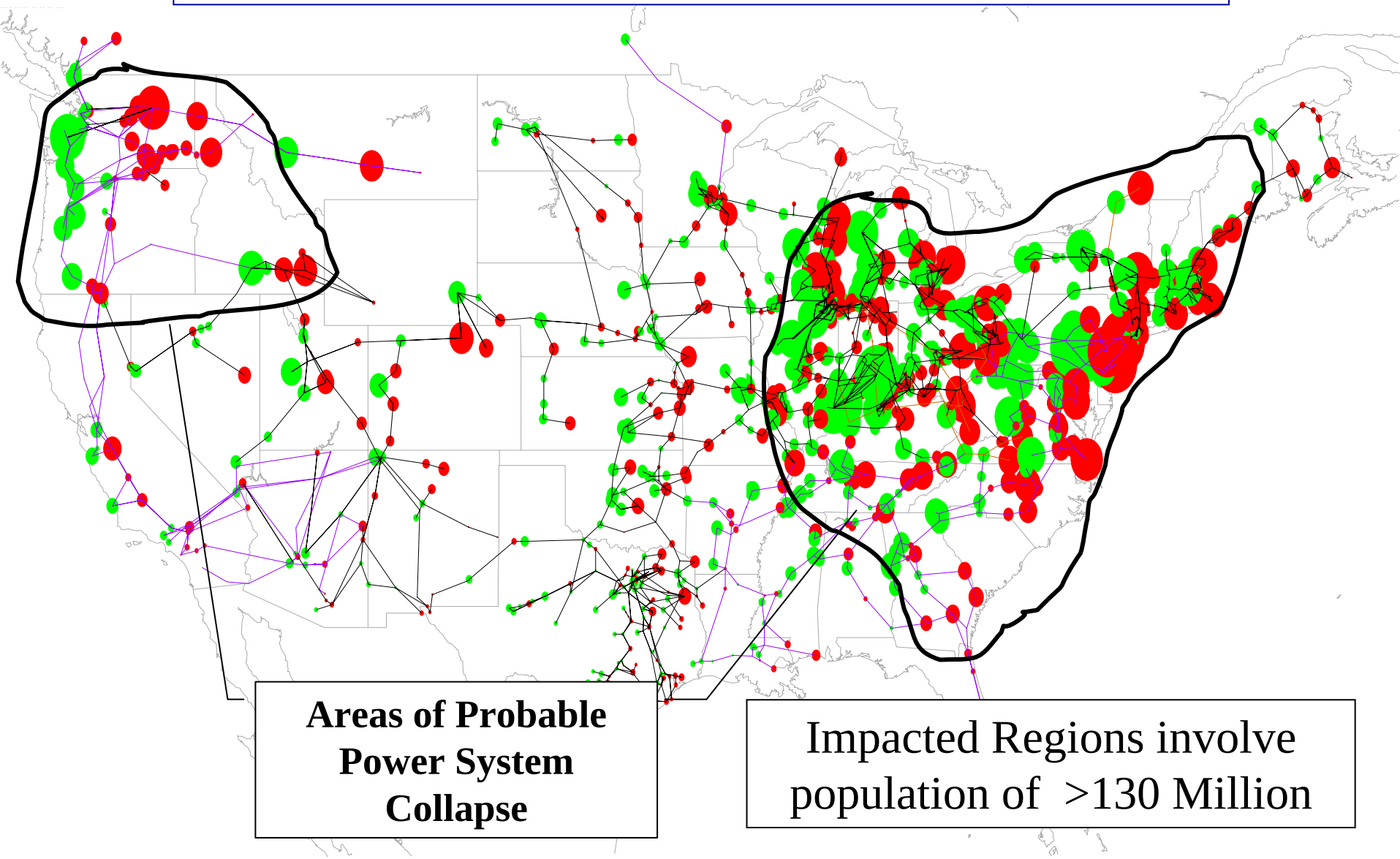
GIC Risk Factor – Growth of Transmission Network

The larger the Grid – the Larger the Antenna to cause GIC



Severe Electrojet Disturbance Scenario

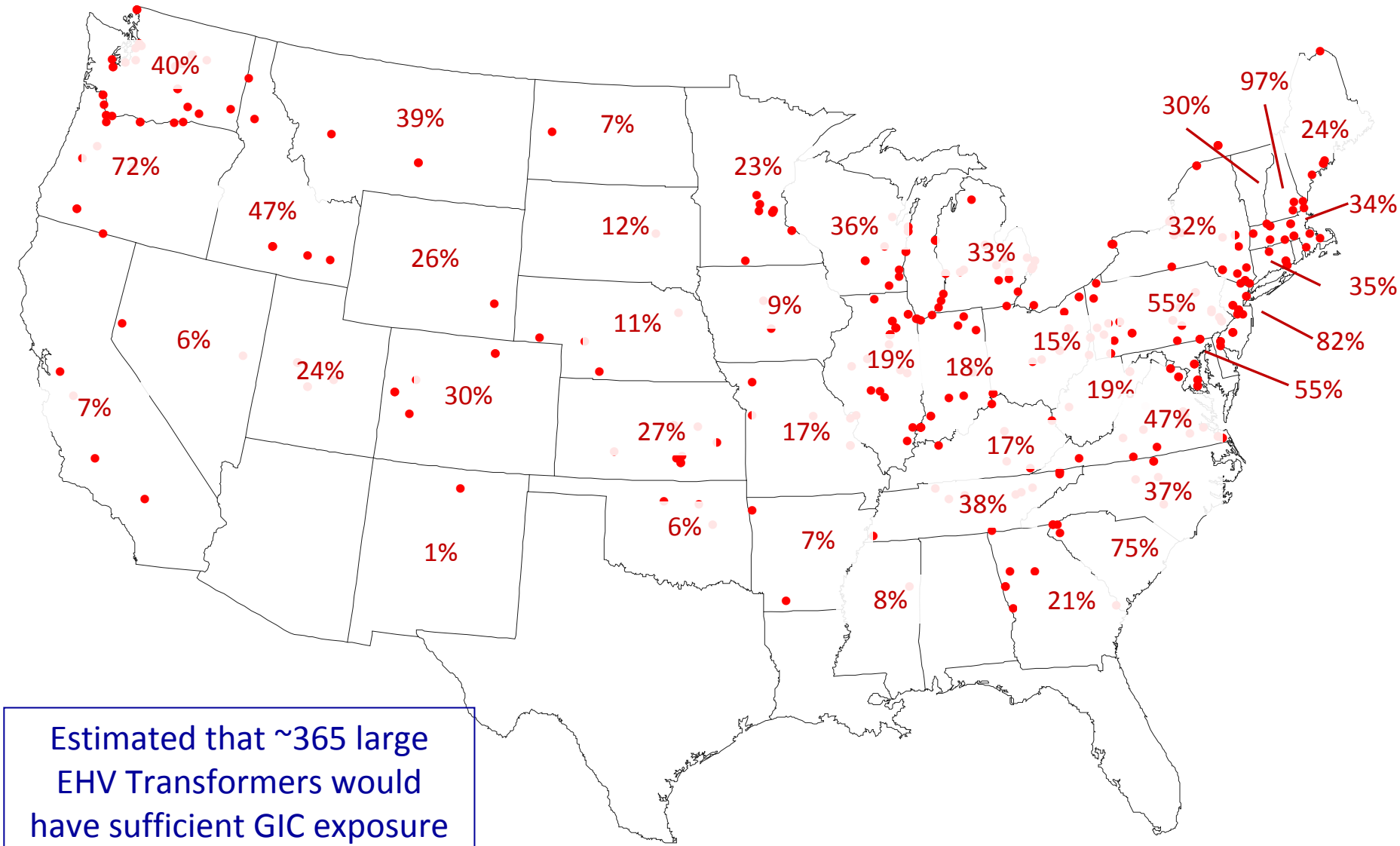
Power System Disturbance and Outage Scenario of Unprecedented Scale



Areas of Probable Power System Collapse

Impacted Regions involve population of >130 Million

Severe Geomagnetic Storm Scenario
At-Risk 345kV, 500kV, & 765kV Transformers



Estimated that ~365 large EHV Transformers would have sufficient GIC exposure to be At-Risk of permanent

Power Grid Vulnerability and Future Outlook Summary

•Significant US Power grid Impacts and Equipment Damage has been observed at moderate intensity disturbance levels

•Historical Evidence points to Storm Intensities that are as much as ~10 Times Larger

•Present US Grid Operational Procedures are based largely on limited experience, generally do not reduce GIC flows and are unlikely to be adequate for historically large disturbance events

•Historically large storms have potential to create Power Grid Blackouts and Transformer Damage of unprecedented proportions, long term blackout, lengthy restoration times, and chronic shortages (multiple years) are possible

•Economic and societal costs could be also of unprecedented levels;

- •August 14, 2003 Northeast Blackout Cost Estimate - **$4 - $10 Billion**
- •Hurricane Katrina Cost Estimate - **$150 - $300 Billion**
- •Severe Geomagnetic Storm Scenario **~$1 - $2 Trillion in 1st Year**

Depending on Damage, Full Recovery could take 4 – 10 Years

•Improved Situational Awareness for Power Grid Operators is needed and is readily available, Emphasis on disturbance environments/GIC levels instead of ambiguous K/G Indices

•**Major Emphasis should be focused on Preventing Storm-Related Catastrophic Failure** - Remedial Design measures (transformer neutral resistors) are readily feasible and cost effective (~$100M) and have potential to reduce GIC 60-70%.

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