Electric Fields, GIC Flow, and Transformer Response

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On behalf of

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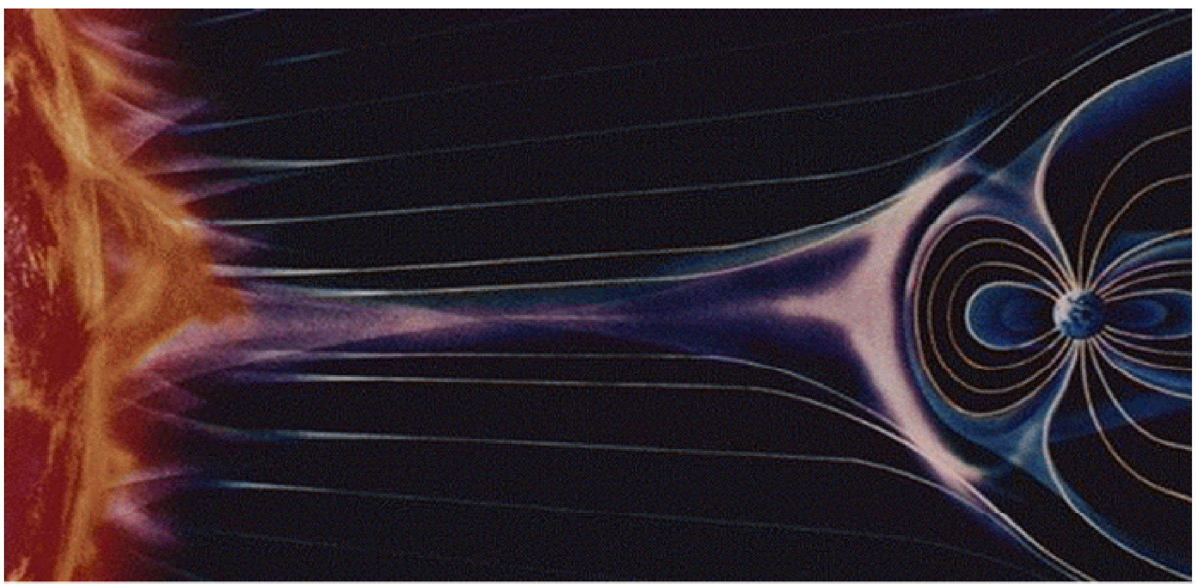
EPRI

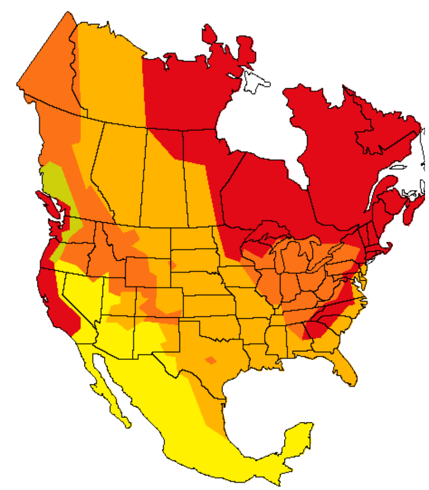
Geomagnetically Induced Current (GIC)

Space

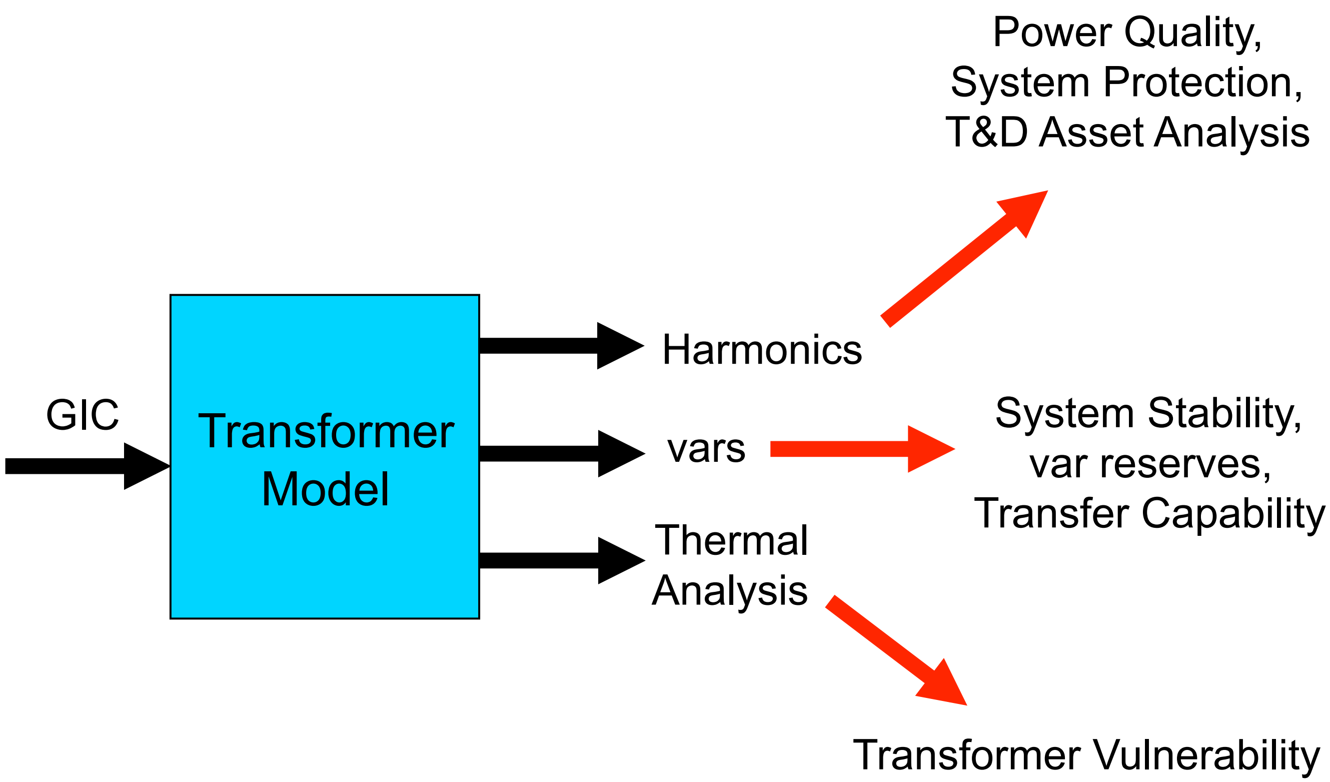
Near Earth's Surface

Solar Flare → Coronal Mass Ejection (CME) → Interaction with Earth's Magnetic Field → $\frac{\partial \vec{B}}{\partial t}$ → Maxwell Eq. & Earth Cond. Model → $\vec{E}$ → Grid Model → GIC





AC System Modeling and Analysis Approach



Questions That Need Resolution

1. **What is a reasonable solar storm scenario?**
2. **What would be the surface gradient generated in North America from such a storm scenario?**
3. **Given the surface gradient, what are the resulting GIC flows?**
4. Given the GIC flows in the transformers what is the harmonic generation and var consumption due to semi-saturation?
5. Are my transformers vulnerable? Given the GIC flows in the transformers what is the time to transformer thermal damage and failure?
6. Given the above, how will the system respond (Cap bank settings, generator tripping, protection and control settings, generators)?
7. Do I have adequate static and dynamic reactive reserves?
8. What are the optimal operational and hardware based mitigation strategies?

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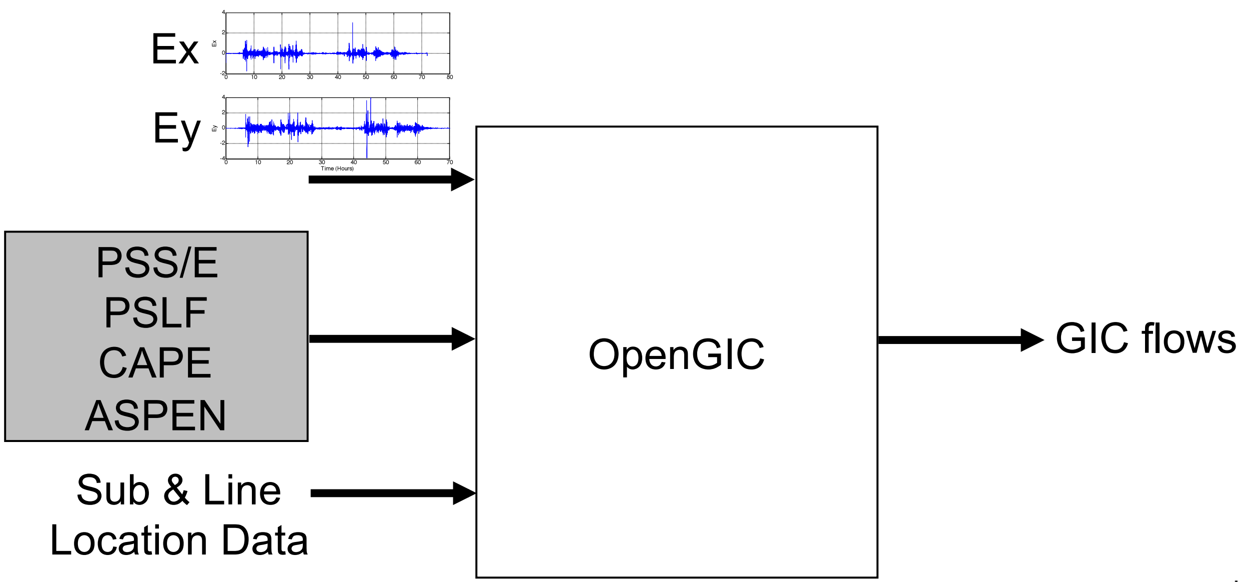
Geomagnetically Induced Currents

- Changes in the earth's magnetic field density with respect to time (i.e., dB/dt) due to CMEs produce an electric field at the earth's surface.
- The resulting electric field induces a voltage along the length of the transmission line via Faraday's Law.
- The resulting induced voltage drives geomagnetically induced currents (GIC) in the system wherever a path for current flow exists.
- **It is important to understand that the "driving force" behind GIC flow is the induced voltage in the lines, and the earth.**

OpenGIC

- An <u>open source</u> software program **has been** developed to determine GIC flows in the transmission grid.
  - Capable of performing dynamic GIC simulation and analysis with GIC blocking devices.
  - Can interface with Matlab, Excel, etc. via COM server.



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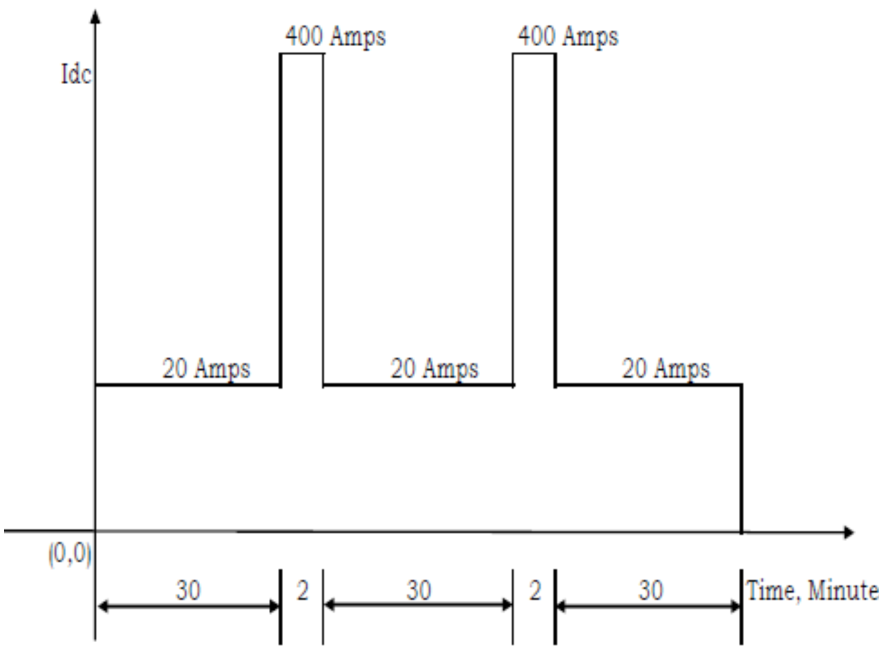
Impact of GIC on Power Transformers

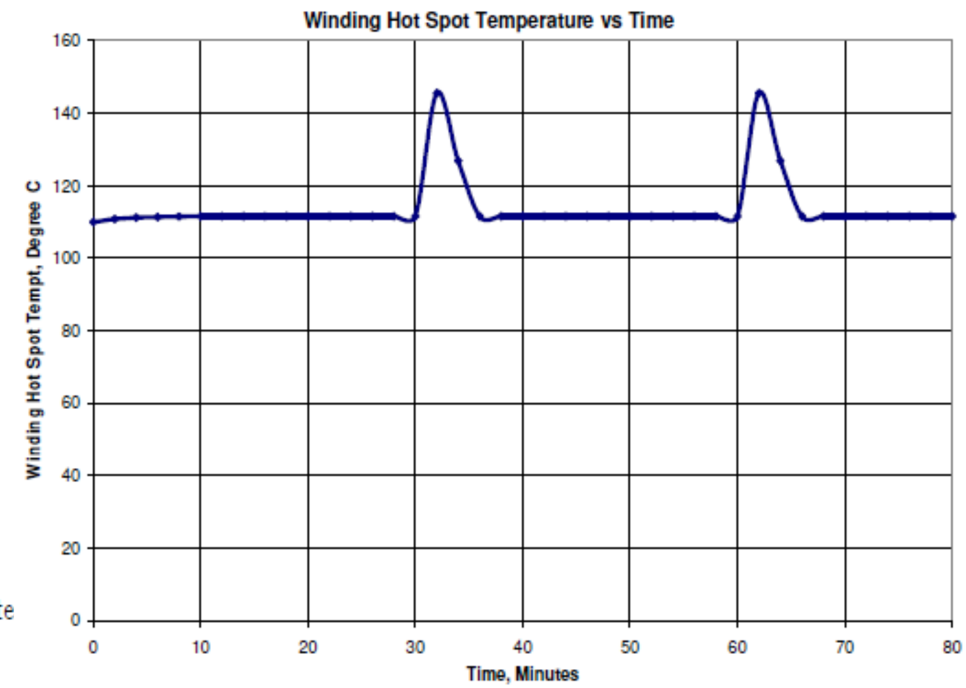
- The flow of dc current in power transformers causes semi-saturation of the core.
  - Commonly referred to as “half-cycle saturation”.
- Semi-saturation of the core causes:
  - Heating (detailed evaluations have to be performed by the transformer manufacturer)
  - Increased var demand
  - Harmonics

Detailed Thermal Analysis Can Only Be Performed By the Mfg.

Transformer Heating

- GIC pulse width matters!!





Transformer Heating

- There have been a few cases reported in the literature where transformer failure was attributed to GIC.
- There is much debate about cause of failures, and the issue has **NOT** been adequately resolved.
- Industry is working diligently to determine thermal effects of GIC.

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Reactive Power Demand (System Studies)

- Increased reactive power demand of power transformers can cause system-wide reduction in operating voltages.
- Generator var output can increase significantly.
- Change in Mvar flows at interfaces can effect voltage profile and stability.
  - Decrease in voltage at both ends can influence the transfer capability of the interfaces
- The constant impedance portion of the total system load will decrease as result of decrease in voltage profile

Transient Stability Studies Are Needed to Assess True Impact

Impact on System Protection

- Primary impacts to system protection are:
  - Saturation of current transformers
  - Transformer differential relays (2nd and 5th harmonic restraint)
  - Capacitor bank protection (susceptibility to harmonics)
- Harmonics are a primary cause for capacitor bank protection mis-operations during GMD events.
  - Older “static” type overvoltage and overcurent relays are particularly susceptible to low-order harmonics.
  - Modern microprocessor based relays typically filter out dc and all harmonics.

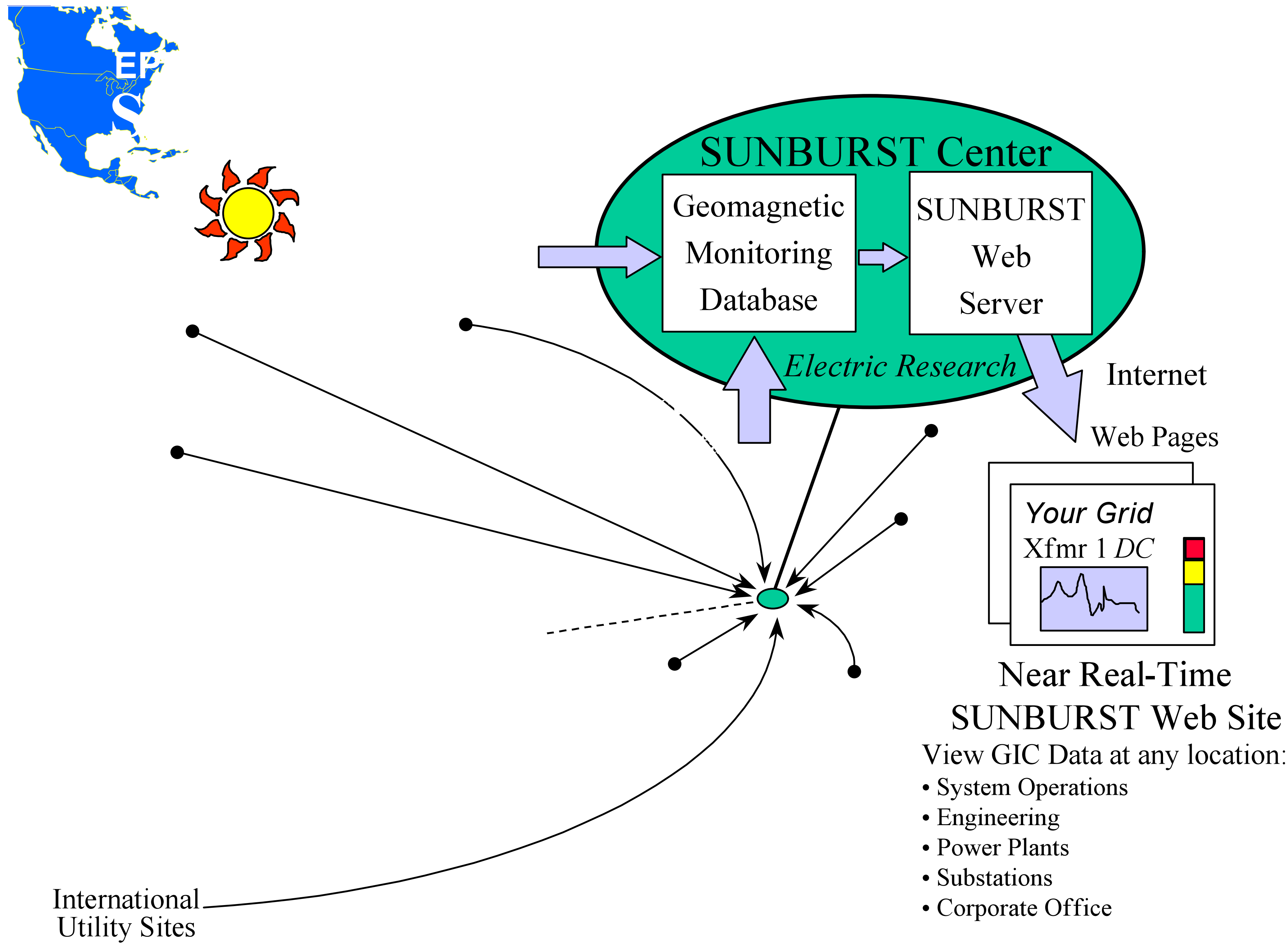
HV and EHV Circuit Breakers

- In some cases an appropriate mitigation strategy might include de-energizing a power transformer or line if it is subjected to a high level of GIC.
- HV and EHV circuit breakers are not rated to interrupt high levels of dc current.

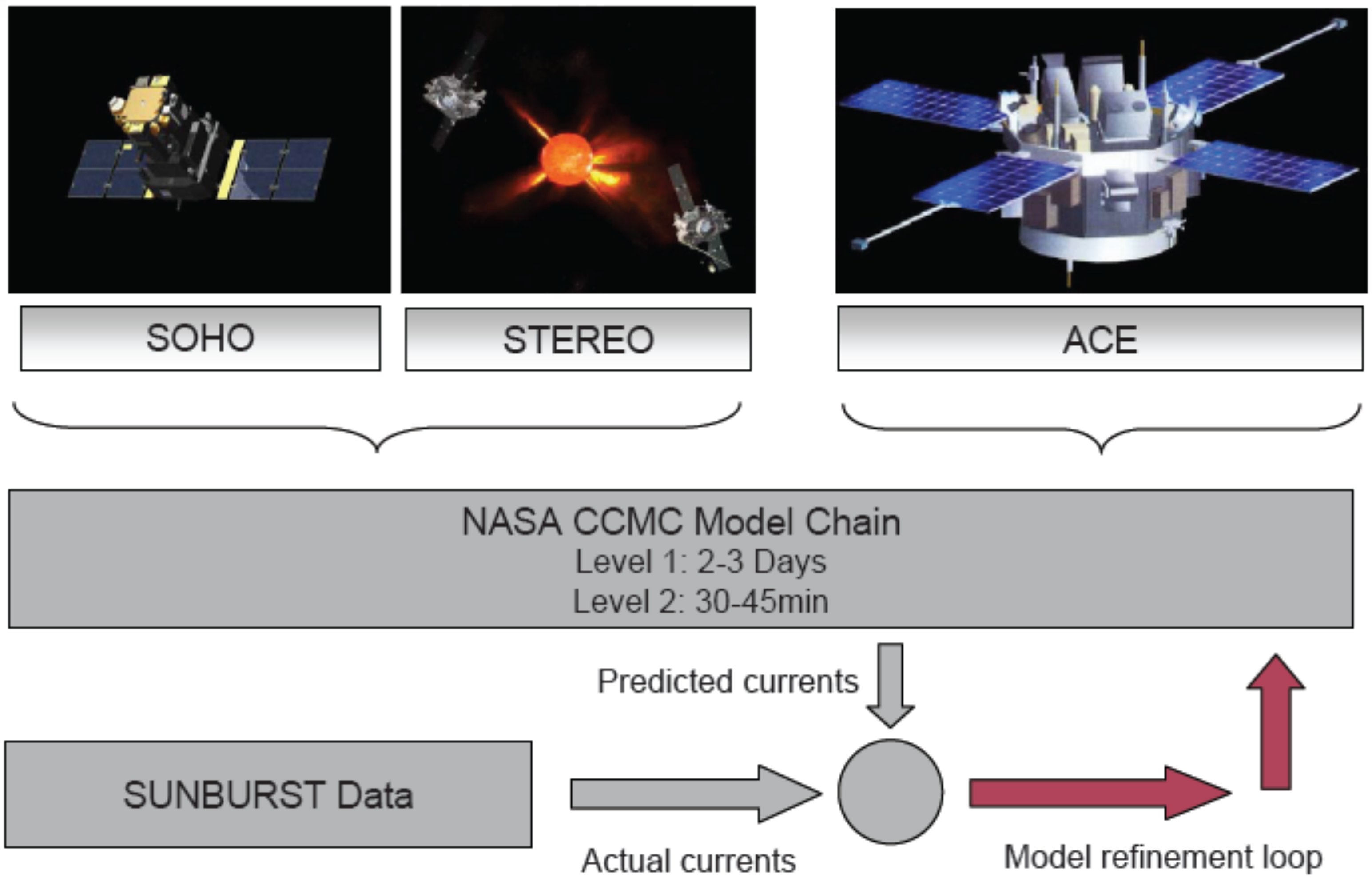
Contact Mfg. To Determine If Circuit Breaker Can Interrupt GIC

EPRI SUNBURST Project

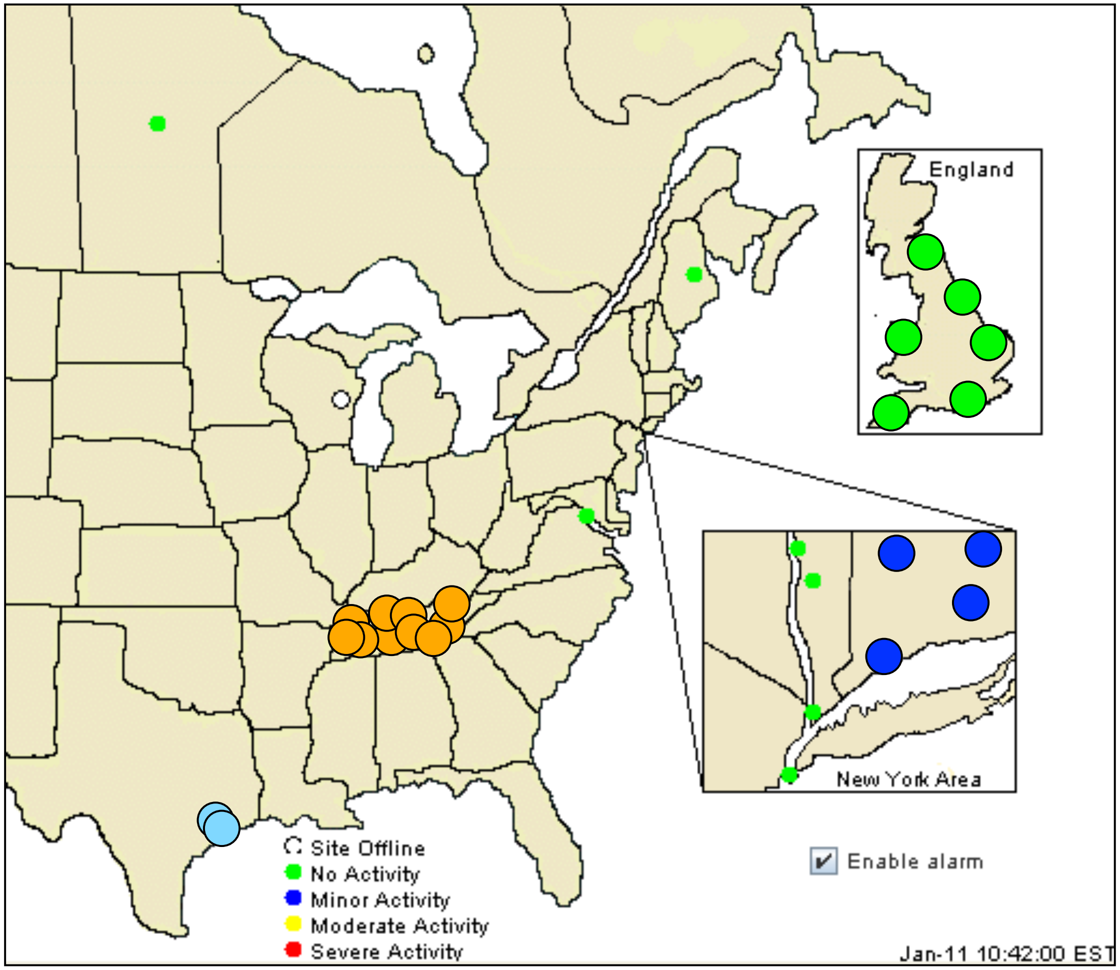
- Collaborative project to monitor GIC's and their impact on the power grid
- Network consists of substation monitoring sites
- A server site collects all GIC data and makes data available to members via Internet
- Provides power grid operators with local & global view of GIC impacts in near real-time
- Helps electric utilities assess vulnerability, provides data for researchers
- Provides automated email alerts based on measured GIC levels


SUNBURST Center
Geomagnetic Monitoring Database
SUNBURST Web Server
Electric Research
Internet
Web Pages
Your Grid
Xfmr 1 DC
Near Real-Time
SUNBURST Web Site
View GIC Data at any location:
• System Operations
• Engineering
• Power Plants
• Substations
• Corporate Office
International
Utility Sites

Using SUNBURST Data for Forecast Research



SUNBURST Monitoring Sites



Solar cycle cranking up

Sign ups are crucial

Membership and new installations

SUNBURST expansion:
- 6 in National Grid UK
- 10 in TVA
- 2 in National Grid USA
- 2 in CenterPoint

Nextgen SUNBURST expansion:
- 4 in United Illuminating

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2009 – 2011 Activity Summary

- Very little GIC activity over the last several years due to where we are in the solar cycle.
- Activity has picked up last several months.
- Several K-6 alerts from NOAA since August.
- One K-7 alert issued on August 5, 2011.
- Two significant events recorded: one on August 5-6, 2011 and one on September 26-27, 2011.
- Not considered severe events (40 A) – only reached moderate levels.
- Peak site showed neutral DC currents up to approximately 30A during September 26-27 event.
- No severe level GIC (> 40 A) since August 24, 2005.

Proposed DOE Expansion of Sunburst - Value Proposition for Wide Area Sunburst

- Validate the predictions of GIC events
- Improve our understanding of GIC and geology
- Improve our understanding of GIC and latitude
- Improve our understanding of GIC and transformer response, including harmonic generation and var consumption
- Determine the effectiveness of blocking devices
  - Multiple nodes can be installed in a single substation; one node on a transformer with a blocking device, and one on a transformer with no blocking device

Proposed DOE Expansion of Sunburst - Anticipated Activities

Increased monitoring, by aggregation of disparate monitoring systems, by integration with available magnetometer systems, additional nodes, and additional analysis.

- Location analysis
- Integration of non-Sunburst nodes
- Installation of new nodes
- Integration of magnetometers
- Analysis
- Period of Performance: Through this cycle 24

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