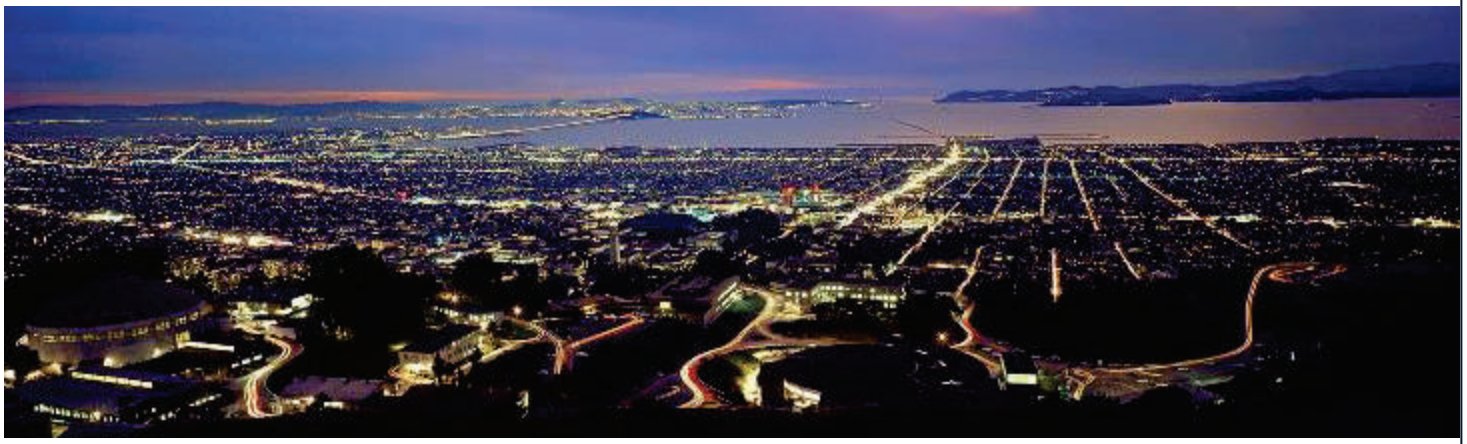
U.S. DEPARTMENT OF
ENERGY

Infrastructure Security
& Energy Restoration

Prepare. Respond. Adapt.



Space Weather Impacts and Potential Mitigation and Protection for the Electric Grid

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Space Weather Effects

- **GIC Effects on Transformers:**
  - Causes half-cycle saturation with quasi-DC current
  - Significantly increases core noise and vibration
  - Creates harmonics
  - Increases absorption of reactive power
  - Causes voltage instability
- **GIC Effects on Other Parts of Bulk Electric System:**
  - May trip protective equipment
  - Could trip generators
  - Could result in grid imbalances
  - Interferes with precision timing devices

Impacts on the Electric Grid

- **Voltage Collapse is Biggest Concern Due to:**
  - Increase in Absorption of Reactive Power
  - Tripping of Generators and Other Equipment
- **Damage to Transformers from Heat and/or Vibrations**
- **Wear and/or Damage to Other Equipment**
  - Fuses and Breakers May Open
  - Bearings
- **Voltage Instability Can Lead to Power Quality Issues**
  - Lights Flickering
  - Damage to Customer Equipment?

Mitigation Current Systems

- Adjust Protective Equipment to Reduce False Trips
- Have Ample VAR Compensation Available
- Reduce Load on Vulnerable Transformers
- Cool Transformers Prior to Arrival of GICs
- Reconfigure Grid to Reduce or Eliminate Movement of Electricity on Long Distance Transmission Lines

Mitigation Future Options

- **Deploy new transformers with lower susceptibility to adverse impacts from GI**
- **Rely more on distributed energy resources**
- **Consider factors that affect strength of GICs when siting new substations:**
  - Latitude
  - Geology
  - Large Bodies of Water
  - Orientation of Transmission Lines
  - Adjust Protective Equipment to Reduce Trips

Current Protection and Cost to Enhance

- **Current Protection**
  - GIC blockers on transformer neutrals
  - Series compensation on transmission lines
  - Transformers with high GIC withstands
  - Protective device settings to prevent premature trips

- **Potential Protection Measures**
  - Transformers with higher GIC withstands
  - Configuring and building systems with less reliance on high voltage equipment and/or long distance power lines

DOE Actions

- **Data Collection**
  - Sunburst – GIC monitors
  - Variometers – magnetic field changes
  - GMD monitoring plan

- **Assessment, Modeling, Testing**
  - Susceptibility of Eastern Grid
  - Assessment of GMD benchmark event
  - Assessment and testing of transformers

- **Mitigation and Protection**
  - Plan for pilot program to deploy mitigation or protection devices on grid

Questions?