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Grid of the Future

Model, Monitor & Mitigate Geomagnetically Induced Currents

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CIGRE Grid of the Future

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AEP®

Solar Storm Impacts

- Coronal mass ejections' (CME) earth effects
  - Geomagnetic disturbances when earth directed
  - Perturbs earth's **E**, **H** fields – orientations vary
  - Creates quasi-DC currents in earth's crust
  - Influenced by geology & geography (latitude)
- Potential Impact on the Electric Grid
  - Electrical grid provides an alternate current path
  - Quasi-DC **H**-fields cause geomagnetically induced current (GIC) in line conductors
  - GIC greatest in higher kV transmission lines
    - Dependent on geography and geology
    - Due to greater length, lower resistance
  - Can cause half-cycle saturation of transformers
    - Dependent on storm intensity, orientation
    - Increased reactive power demand
    - Lower system kV, with potential for voltage collapse
    - Generates harmonic currents
    - Possible heating in transformers

Source: NASA

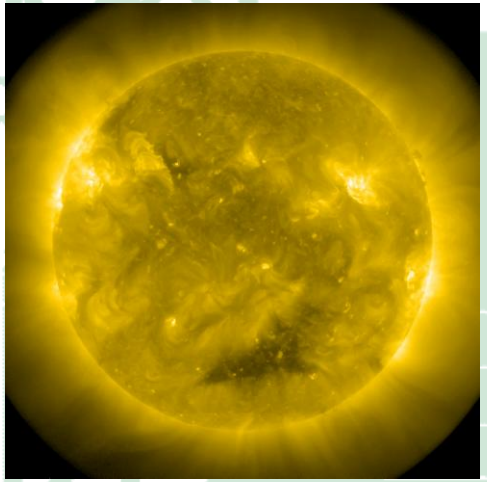
Past Industry Experience

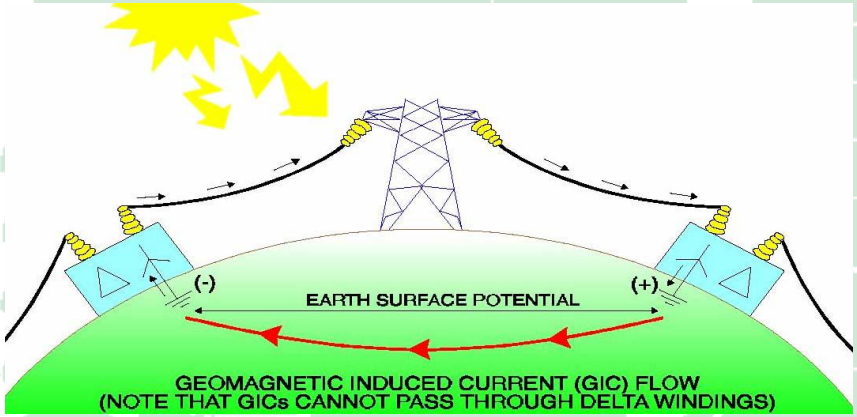
The current solar cycle is SC24

- Carrington – 1859
  - Affected telegraph lines and operators
  - “Northern lights” visible in Cuba
- Quebec – 1989
  - Harmonic currents caused relay misoperation
  - SVCs on long 765 kV lines tripped when most needed
  - Outage duration of 9 hours
- Halloween – 2003
- AEP Experience
  - No observed lasting impacts
  - Have monitored during last 3 solar cycles
  - No evidence of low voltage from GMD

AEP Experience with GMD

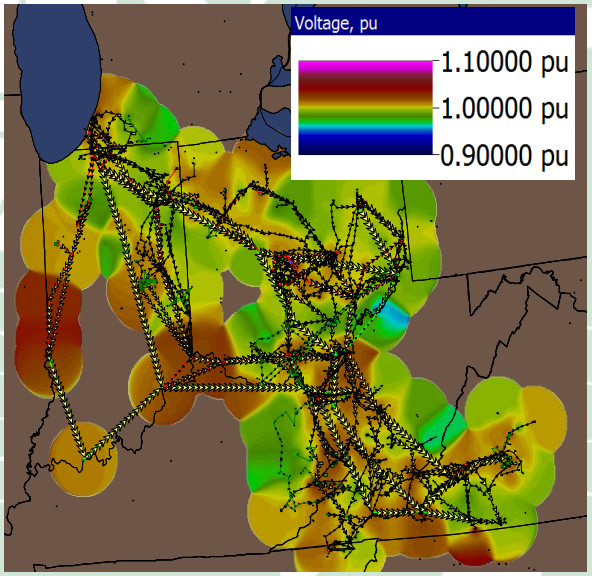
- Historical GMD observations at AEP
  - AEP EHV system in operation for ~60 yrs
  - Performed autopsies on EHV transformer failures
  - Monitored GIC during 3 solar cycles: I_{MAX} = 87A
  - Observed no lasting impacts from GIC to date
- AEP approach to address GMD impact
  - Model: identify and prioritize risks
  - Monitor: for awareness & model validation
  - Mitigate: intrinsic grid strength, specs, operating procedures, spare availability, avoid crutches
  - Mutual Collaboration
    - NERC GMD TF
    - EPRI
    - PJM (and other AEP RTOs)
    - PSERC & Universities

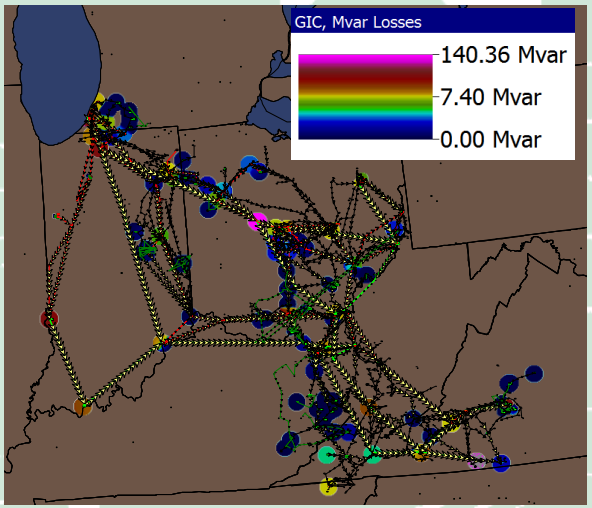




Modeling GMD

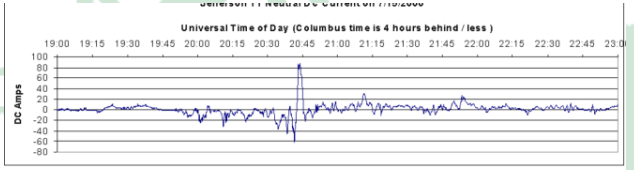
- Three AEP model efforts to date – Consultant, University, Internal
- Model Development
  - AEP in PJM, SPP, ERCOT; need models for all
  - Finding supporting data can be challenging
    - Manual review of transformer test reports
    - Station ground resistances not readily available
    - Generator information limited
- Key Sensitivities – Need Corroboration
  - Station ground resistances
  - Transformer K-factors
- Analysis Observations
  - 765 kV transformers of greatest interest
  - System configuration matters

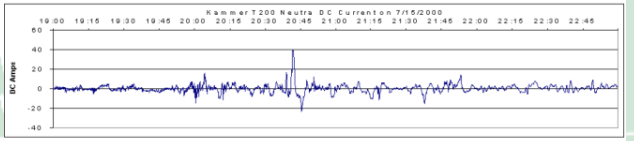


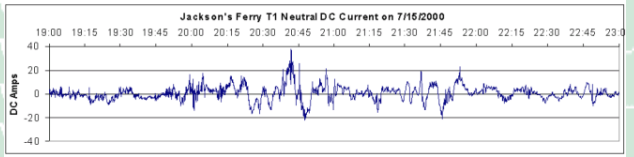


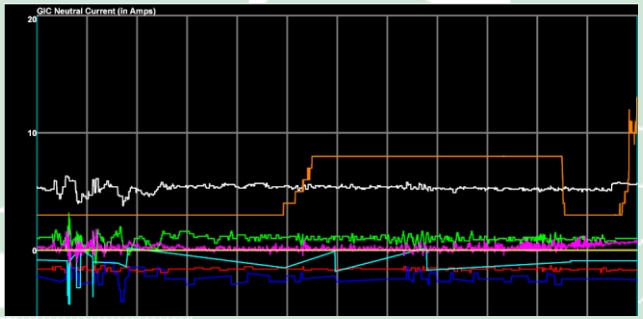
Monitoring GMD

- I_{MAX} for prior, current cycles: 87A, 26A, respectively
- GIC monitors at 13 sites, more planned
- Dashboard captures & records real time event data
  - NOAA alert level
  - GIC current in transformer neutral
  - Harmonic currents
  - Voltage and MVAr demand
  - Transformer temperature
  - Transformer dissolved gas analysis (post event)
  - GIC data will be fed to new asset health center
- Magnetometers at 3 locations
- Monitors provide awareness & model validation
- Installed permanently (temporary in prior cycles)









Mitigation of GMD

- General principle: intrinsic grid resiliency
- Equipment specs addressed GIC over last 20yrs
  - Include GIC withstand (300/120A)
  - Detailed design reviews include GIC
- Assess susceptibility of older designs
- Develop simple operating procedures
- Maintain ample spare population
  - GSU spares – 30%, 13% @ 765, 345 kV, resp.
  - System ties – 17%, 7% @ 765, 345 kV, resp.
  - Asset renewal program freeing up more spares
- Evaluating (but not applying) blocking devices
  - Blockers unproven, introduce other risks
  - Displaces GIC to other transformers
  - High cost and added complexity

No Regrets Approach

- Model GIC impacts on bulk transmission using validated tools
- Monitor sites across North America to learn from current solar cycle
  - RTO(s) would be ideal for real time notification of geographically specific issues
  - Validate models using monitored data
- Develop robust GIC standards and testing procedures for large transformers
- Identify vulnerable equipment to more closely monitor and mitigate issues
- Maintain adequate spare transformers for vulnerable class
  - Keep up to date inventory, such as NERC spare database
  - Retain as spares operable transformers that are being replaced by asset renewal
- Employ risk-based approach to balance customer costs and benefits
- Seek to achieve robust, intrinsic grid withstand capability
- Continue collaboration and encourage reporting of what is learned