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Geomagnetic Disturbances

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ComEd

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GMD Background

- ✓ Solar Disturbances
- ✓ Impacts
- ✓ Monitoring
- ✓ Events

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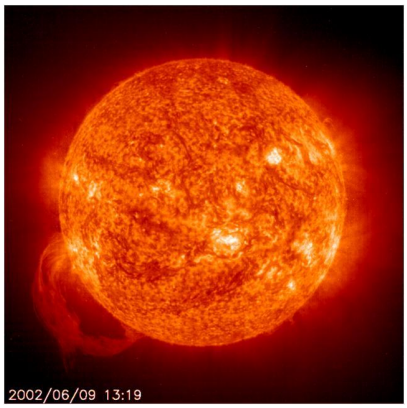
Solar Disturbances

- ✓ Geo-Magnetic Disturbances (GMD) result from Coronal Mass Ejections (CME)
  - CMEs originate from disturbances on the sun
  - Release large mass of charged particles
  - Can reach earth in 14 to 96 hours



http://www.swpc.noaa.gov/ImageGallery/full/arch11.gif

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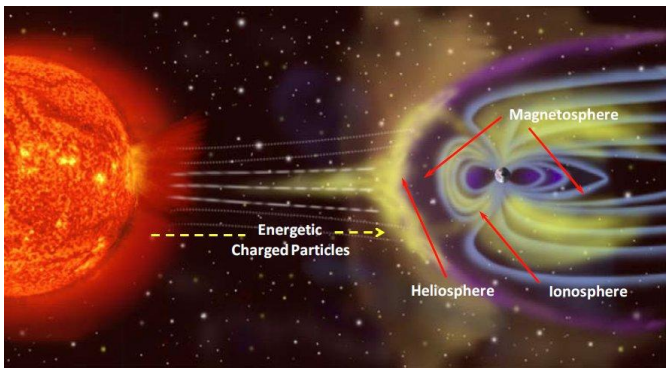
CME Impact

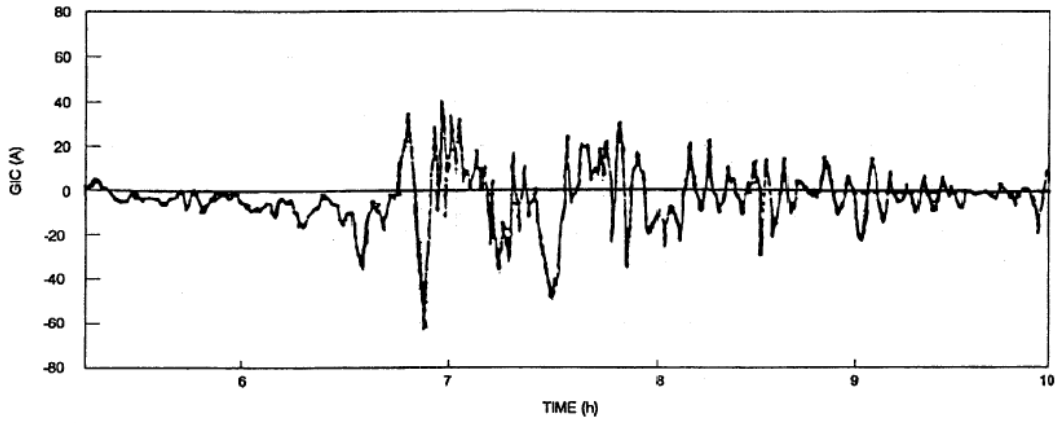
- ✓ Earth-directed CMEs interact with earth's magnetic field
  - Affect atmospheric currents, auroras
  - Voltages induced on surface of earth
  - Quasi-DC Geo-Magnetically Induced Currents (GIC) flow in transmission lines, pipelines, and railways



Source: NERC GMDTF Interim Report, February 2012

Example GIC Measurement

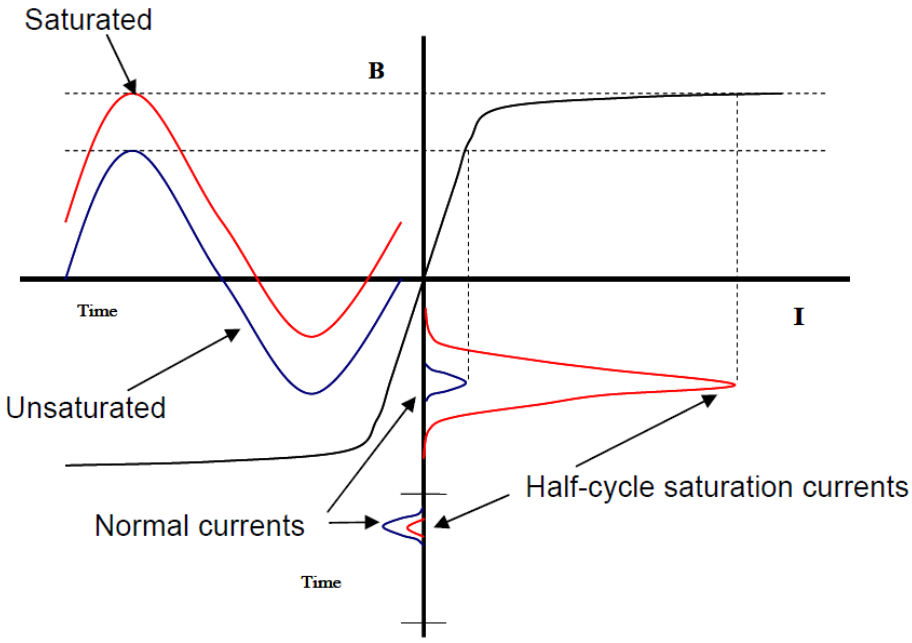
- ✓ Low frequency (typically 0.1mHz to 0.1Hz)
  - Effectively DC with respect to power system



Impact on Power Systems

- ✓ One significant impact of GIC is transformer core saturation. This can result in:
  - Abnormal transformer heating
  - Increased transformer VAR losses
  - Harmonics
  - Inadvertent equipment trips
  - Generator heating and vibrations
- ✓ Factors that can influence GIC magnitudes include
  - Strength and orientation of CME
  - Latitude
    - Latitudes near poles experience greater impact
  - Geology
    - Low conductivity regions experience larger voltage gradients
  - System configuration, line length and orientation

Transformer Half-Cycle Saturation



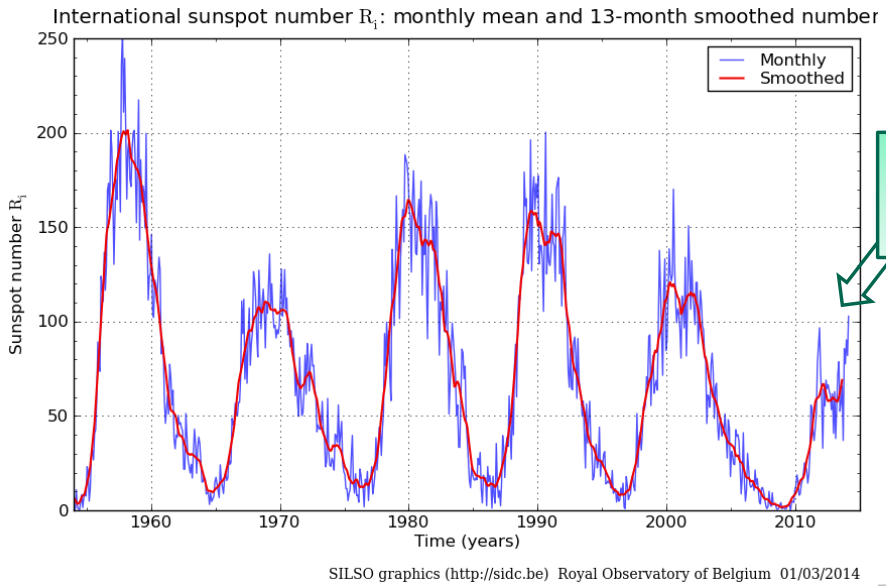
Source: NERC GMDTF Interim Report, February 2012

Space Weather Monitoring

- ✓ Monitored with satellites and earth-based measurements
  - Occurrence of CMEs cannot be predicted well, but propagation and impact can be estimated once it occurs
  - Once disturbance has reached the "ACE" satellite, more accurate prediction of severity can be issued – an hour or less before impact
- ✓ Space Weather Prediction Center (SWPC) in Boulder, CO
  - Real-time monitoring and prediction for U.S.
  - Issues forecasts, warnings, watches, and alerts
  - Dissemination of alerts to power system operators
- ✓ K index
  - Classifies magnitude of disturbance.
  - K ranges from 0 to 9, with 9 being the most severe.

Solar activity varies on an 11-year cycle

- ✓ Correlated with observation of sunspots
- ✓ CMEs occur more frequently during cycle maximum, but significant events can still occur during minimums.



We are currently in Solar Cycle 24

Past Events

- ✓ 2003 Halloween Solar Storm
  - Largest event during last solar cycle (23)
  - Affected communications and satellites
  - U.S. power systems saw increased GIC and some capacitor trips
  - Northern Europe saw some large GIC flows. Brief blackout in Sweden due to line trip on high harmonic currents
- ✓ 1989 Hydro Quebec Blackout
  - Severe K9 GMD event
  - Resulted in blackout of the system
  - Long (1000 km) 735 kV transmission and low-conductivity geology contributed to high GIC flows
  - Harmonics from saturated transformers caused 9 SVCs to trip

Past Events (continued)

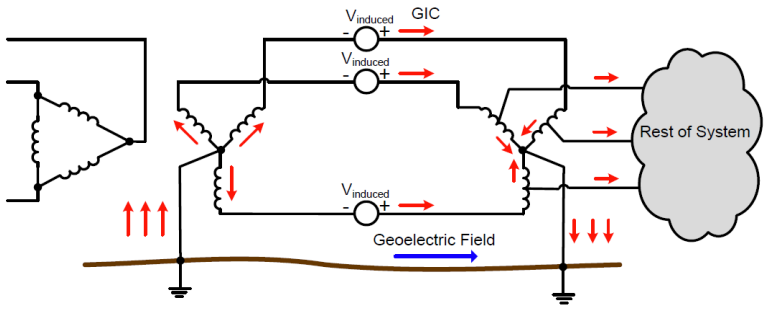
- ✓ 1921 Solar Storm
  - Auroras observed as far south as Caribbean
  - Disrupted telegraph operations in U.S.
- ✓ 1859 Carrington Event
  - Largest GMD event recorded to date (possibly 50% stronger than 1921 disturbance)
  - Auroras observed as far south as Panama
  - Disrupted telegraph operations in North America and Europe

Studies and Analysis

- ✓ System Studies
- ✓ Transformer analysis and testing
- ✓ Mitigation

GIC Modeling

- ✓ GMD-induced voltages modeled as DC voltage sources on HV transmission lines
  - Voltage determined by line length and orientation, assumed electric field magnitude and direction
  - Zero sequence: path to ground needed for GIC flow
  - GIC flows depend on DC resistances (lines, transformers, ground)



Source: NERC GIC Application Guide, 2013

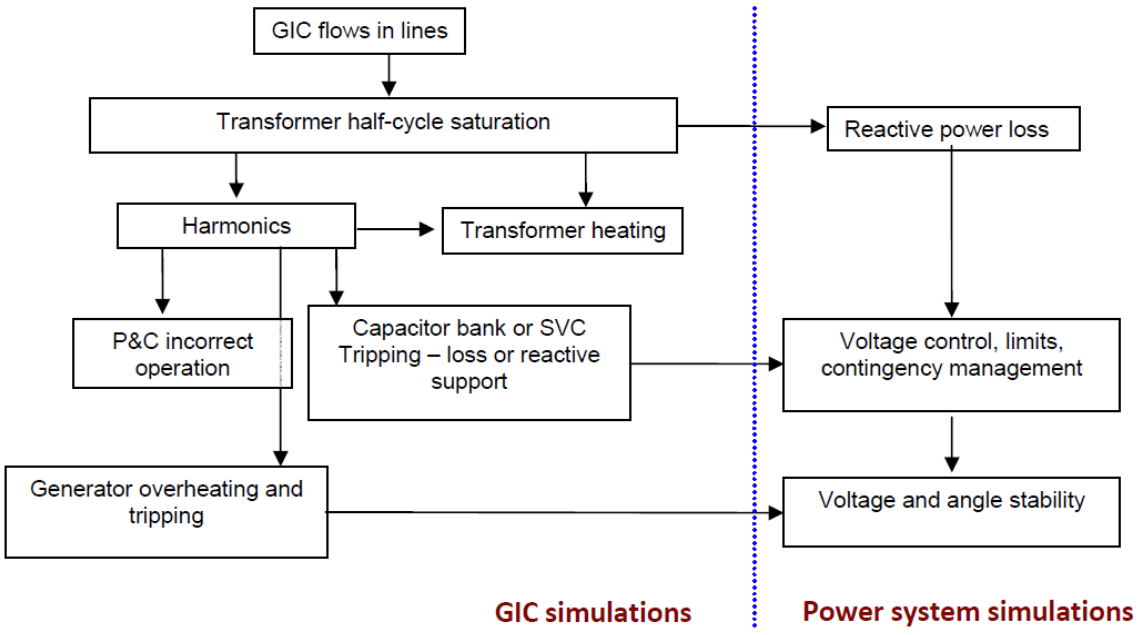
Performing GIC Studies

- ✓ Data needed:
  - Power flow topology model
  - Substation geographic coordinates
  - Line & transformer DC resistance
  - Grounding resistance
  - Transformer winding configuration & grounding
  - Transformer MVAR vs. GIC relationship
- ✓ Uniform electric field uniform is often assumed
  - Linear combination of results from N-S and E-W fields can be used to calculate results for any field direction and strength
- ✓ Study tools available for several power flow applications
  - Commercial: Power World, PSS/E, PSLF
  - OpenDSS (EPRI)

Using GIC Study Results

- ✓ Power flow studies
  - Additional transformer MVAR losses due to GIC added to model
  - Evaluate voltage stability, reactive margins
  - Contingency studies
    - Loss of lines, transformers, capacitors, e.g.
  - Mitigation
    - Operational strategies
    - Mitigation devices
- ✓ Transformer impacts
  - Evaluate GIC with respect to capabilities
  - Thermal assessments
- ✓ Identify prospective GIC monitoring locations
- ✓ Harmonic Analysis
- ✓ Time-domain simulation

Evaluating GIC Impacts



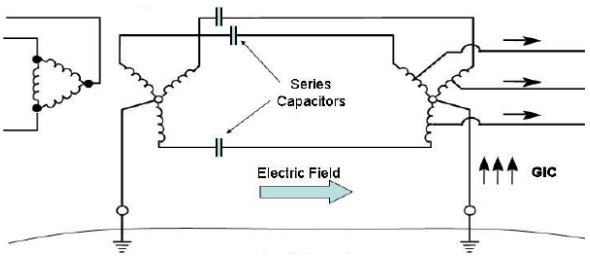
Source: NERC GMDTF Interim Report, February 2012

GMD Mitigation

- ✓ Mitigation strategies
  - Conservative operation
  - Restore outages
  - Monitoring (e.g., GIC, transformer heating, harmonics)
  - Switching (e.g., opening long lines, transformers over limits)
  - Blocking GIC flow
- ✓ GIC mitigation devices
  - Series capacitors
  - Neutral blocking devices
    - Involves insertion of capacitance or resistance in transformer neutral connection
    - Potential concerns with wide-scale use
    - May just move the problem elsewhere, aka: “whack-a-mole”
    - Prototype device installed on ATC system

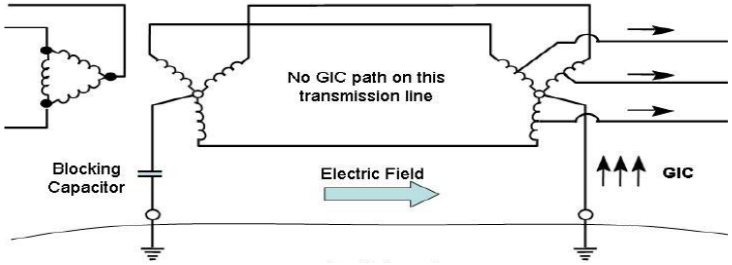
GIC Blocking

- ✓ Series capacitors



Source: Geo-magnetic Disturbances (GMD):Monitoring, Mitigation, and Next Steps, EPRI (2011)

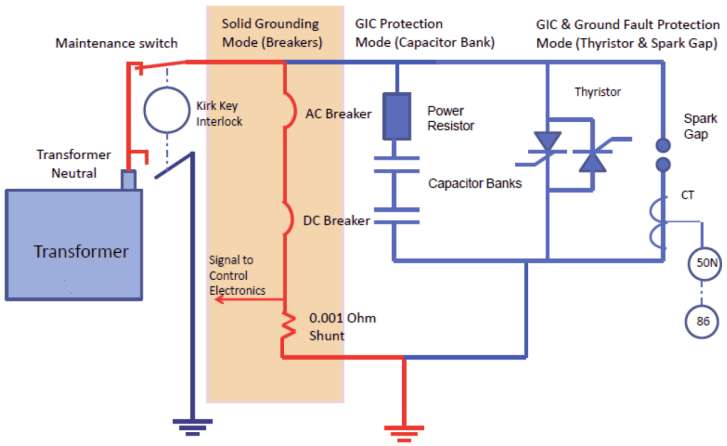
- ✓ Blocking capacitor in transformer neutral



Source: Geo-magnetic Disturbances (GMD):Monitoring, Mitigation, and Next Steps, EPRI (2011)

Example GIC Blocking Device

- ✓ ABB/Emprimus SolidGround™ device
  - Normal solid-ground connection through CBs
  - Capacitor inserted in neutral when GIC is detected
  - ATC has installed one of these devices for evaluation



Source: www.emprimus.com

Industry Activity

Recent Industry Activity

- ✓ Reports and studies: NERC, EPRI, DOE, Others
  - Primary concerns:
    - Transformer failures
    - Voltage collapse
- ✓ 2011 NERC GMD Alert
  - Considerations for operations and long-term planning
- ✓ NERC GMD Task Force
  - 2012 Interim Report
    - Comprehensive overview of GMD issues, analysis, and response
    - Recommended improved tools and information exchange, review of standards
    - Most likely result from worst-case scenario: voltage collapse
- ✓ FERC Order 779 (May, 2013)
  - Required development of GMD reliability standards
    - Phase 1 (2014) – GMD operating procedures
    - Phase 2 (2015) – Vulnerability assessments and mitigation plans
  - Standard Drafting Team formed June 2013

GMD Reliability Standards – Phase 1

- ✓ EOP-010-1
  - Approved by the NERC Board November 2013
- ✓ Requirements
  - R1. Reliability Coordinators (RC) to develop, maintain, and implement a GMD Operating Plan.
  - R2. RCs to disseminate forecasted and current space weather information.
  - R3. Transmission Operators (TOP) to develop, maintain, and implement GMD Operating Procedures to mitigate effects of GMD.
    - Systems 200kV and above
- ✓ FERC proposed approval January 2014
  - Subject to enforcement 6 months after approval by FERC

GMD Reliability Standards – Phase 2

- ✓ TPL-007 under development
- ✓ Anticipated requirements:
  - "Benchmark GMD events" that must be assessed
    - Definition of "100-year" event proposed with consideration for geo-magnetic latitude and local geology
  - Initial and continuing assessments of the potential effects of benchmark events on the system
  - Develop and implement plans to protect against instability, uncontrolled separation or cascading failures of the system.

What's Being Done?

- ✓ Monitoring/participating in standards development
- ✓ GIC studies
- ✓ Monitoring
  - Neutral GIC flow
  - Transformer heating, VARs, harmonics
- ✓ Operating procedures
- ✓ Transformer specifications, modeling, testing
- ✓ Evaluation of blocking devices

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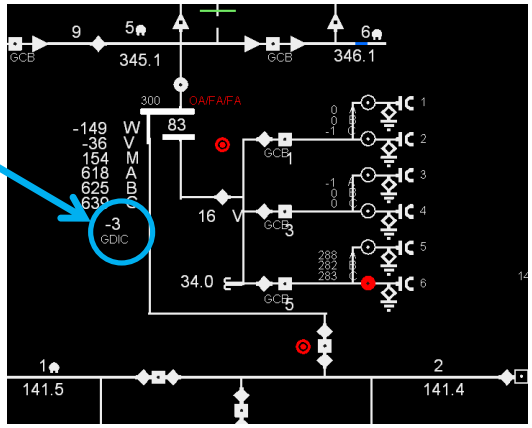
- ✓ Internal technical team formed
- ✓ Transformer monitoring
- ✓ Transformer testing and specifications
- ✓ Operating procedure review
- ✓ Studies

ComEd - Transformers

- ✓ Electronic transformer monitoring systems are installed on all ComEd transmission-level autotransformers
  - Includes oil and winding temperatures.
- ✓ GIC requirements added to specifications for large transformers
- ✓ Transformer manufacturer GIC testing, simulations
- ✓ GIC monitoring installed on several autotransformers
  - CT installed on neutral
    - Hall Effect device to detect DC
  - SCADA alarms at defined levels of GIC
  - Data provided to PJM
  - Historical data available

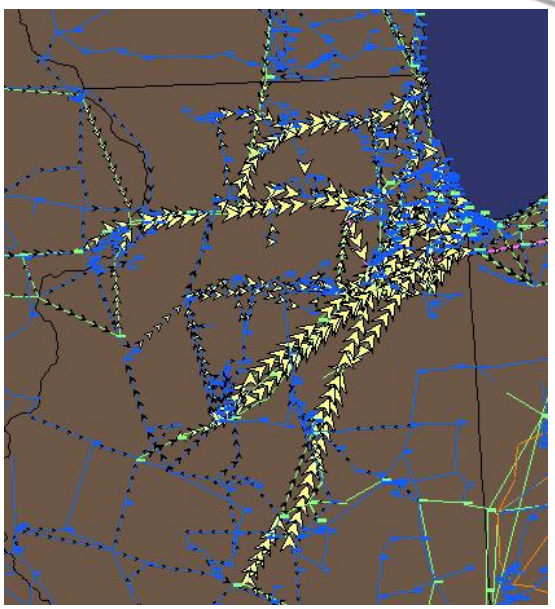


ComEd - Transmission Operations

- ✓ ComEd Transmission Operations Guidelines
  - Restore outages to return the system to normal if possible.
  - Avoid unnecessary switching of transmission equipment.
  - Turn on capacitor banks to increase generator reactive reserves.
  - Attempt to control transmission voltages to near normal levels and maintain sufficient reactive reserves.
  - Monitor alarms for high transformer temperature.
  - Monitor for transformer GIC alarms
- ✓ ComEd operations coordinated with PJM
  - PJM GMD procedure in Manual 13: Emergency Operations
- ✓ Operator training
  - Operator training includes overview of GMD issues and operating guidelines

ComEd System GMD Study

- ✓ Performed by University of Illinois using PowerWorld
- ✓ Simulation results
  - Transformer GIC flows and reactive losses calculated
  - Tested various storm magnitudes and directions
- ✓ Applications
  - Identify locations for additional GIC monitoring
  - Insight into facilities most affected
  - GMD magnitudes at which system issues might occur



ComEd - Ongoing/Future Work

- ✓ Additional GIC monitoring
  - Ideally, want monitoring geographically dispersed through ComEd area
- ✓ Support PJM GMD studies
- ✓ Maintain involvement in related industry activity
  - NERC Task Force
  - Standards development
  - Industry forums

More Information

- ✓ Space Weather Prediction Center (SWPC)
  - www.swpc.noaa.gov
    - Reports, forecasts
    - NOAA Product Subscription Site: https://pss.swpc.noaa.gov
- ✓ NERC
  - www.nerc.com
  - Various GMD Task Force reports and presentations include:
    - 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System, NERC, February 2012
    - Application Guide: Computing Geomagnetically-Induced Current in the Bulk-Power System, NERC, December 2013
    - Geomagnetic Disturbance Planning Guide, NERC, December 2013
- ✓ IEEE
    - "Here Comes the Sun", IEEE Spectrum, February 2012
    - "Geomagnetic Disturbances, Their Impact on the Power Grid", IEEE Power & Energy Magazine, July/August 2013

Thank You!

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