Geomagnetic Disturbances (GMD) Impacts on Protection Systems

IEEE PSRC K28 WG Summary Paper

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Presentation outline

- Introduction
- Impacts on power systems
- GMD impacts on protection systems
- Mitigating GMD impacts on protection systems
- Geomagnetic current and field monitoring methods
- Conclusion

Introduction

- Geomagnetic disturbances (GMD) creates low frequency primary currents (quasi-DC), i.e., geomagnetically induced current (GIC), that circulates between transmission lines, high-side Y-grounded transformers and ground.
- GMD events may cause unanticipated damage to high voltage equipment, impact radio/satellite communications used as timing source or for protection and control functions.
- This paper summarizes main findings of previous events and current practical experiences on protection systems.

Impacts on power systems

- GMD background
  - Caused by interaction between the cloud of charged particles produced by a Coronal Mass Ejection (CME) from a solar storm and the earth magnetic field.
  - Many solar storms and CMEs occur during a 4-6 year interval. GMD events appear on Earth 1~4 days after an earth-directed flare or eruption on the Sun takes place.
  - CMEs interact with the Earth's magnetosphere and cause slow-varying electrojet currents about 100 km above earth, which results in changes on Earth's surface magnetic field (geomagnetic field) that induces GIC in transmission lines and associated equipment.

Impacts on power systems

- Harmonics produced by GIC-induced saturation
  - GIC may cause transformer core to saturate.
  - Single-phase transformers, transformers with five leg cores, and shell type transformers are more susceptible to applied DC current. These types of transformers can present the highest risk to system reliability should core saturation occur.
- GMD impacts on power systems
  - Historical GIC observations. BC Hydro has observed GIC caused excitations in its 138 kV line, mitigated by placing a GIC blocking cap in the neutral of the transformer at the receiving terminal of the line.

Impacts on power systems

- GMD impacts on power systems
  - Capacitor bank tripping. During the March 1989 solar storm, thirteen capacitor banks within the Dominion Energy Virginia Power (DVE) service territory tripped within two minutes due to a protection scheme susceptible to harmonic distortion.
  - GIC impacts on transformers. Transformer Core saturation due to GIC is highly undesirable as the transformer will become incapable of delivering the required rated power to the load. In addition, localized heating and general overheating will occur due to stray magnetic flux that induces eddy currents in conductors and metal components within the transformer tank.

Impacts on power systems

- GMD impacts on power systems
  - GIC impacts on generators.
    - Generator harmonics. Harmonic currents caused by transformer saturation can flow into a generator and pose a considerable risk to the machine.
    - Rotor heating. Both positive and negative sequence harmonics result in a magnetic field that is rotating with respect to the rotor, and thus eddy currents will be induced in the rotor. IEEE Std C50.12-2005 and C50.13- 2014 specify negative sequence current withstand capabilities for salient-pole and cylindrical-rotor synchronous generators.
    - Mechanical resonance excitation. The interaction between rotating magnetic fields induced by synchronous generator stator harmonic currents and the DC magnetic field produced by the rotor causes mechanical torque pulsations.

GMD impacts on protection systems

- A. CT saturation due to GIC
  - The quasi-DC GIC drives the flux linkage closer to the knee-point of the CT excitation curve
  - CT saturation due to GIC is of transient nature, and is generally short-lived
  - The error is increased compared with no DC present, but the differences observed in simulations show negligible impact
  - May be worthwhile to check CT conditions of equipment after a known GMD with measurable impact on nearby stations

GMD impacts on protection systems

- B. GMD impacts on protection and control schemes
  - 1) Capacitor bank protection and GIC impact
    - Capacitor bank protection schemes are described in IEEE Std C37.99-2012. Various sensitive protection schemes measure unbalanced currents or voltages for protection
    - In general, digital relays are able to measure fundamental frequency currents for protection and filter out other frequencies
    - Electromechanical and solid-state relays may be susceptible to undefined performance in presence of harmonics. Some severe GMD events have led to tripping of multiple shunt capacitor banks

GMD impacts on protection systems

- 2) Transformer protection and GIC impact
  - Impact of GIC on electrical protection elements includes CT saturation and harmonics
  - Primary side of the CT acts as a high pass filter, filtering out low frequency components and allow for nominal frequency component to be correctly utilized for protection
  - In general, the quasi-DC is not large enough to generate sufficient operating current in the differential measuring element to jeopardize security of the element
  - By taking GIC into account when selecting a primary CT tap, it could minimize the GIC impact on the protection for external faults.

GMD impacts on protection systems

- 3) Generator protection
  - Harmonics may cause heating of generator rotors. However, protection relays available today are not designed to protect the generators from the harmonic impacts present during the GMD.
  - Many modern digital relays operate on fundamental frequency currents. Legacy electromechanical and static protection negative sequence overcurrent relays use phase shifting circuits, which do not provide proper phase shift to identify negative sequency currents at harmonic frequencies. So they may over or under protect a generator.

GMD impacts on protection systems

- 4) Transmission line protection
  - Series compensated lines are generally not vulnerable to GMD
  - For uncompensated lines, the protection systems, particularly legacy protection systems, may misoperate due to their unknown response to harmonic currents flowing in the lines during a GMD.
  - Some utilities have reported line relay operation by sensitive unbalance (negative and zero sequence) overcurrent protection during a GMD. Another relay misoperation is attributed to the ground time overcurrent relay undesirably responding to harmonic distortion.

GMD impacts on protection systems

- C. GMD impacts on communications
  - 1) Loss of GPS signals
    - GPS is an accurate time reference for IEDs to synchronize event reporting
    - A minor solar storm in October-November 2003 disabled the USA Federal Aviation Administration's new GPS system for nearly 30 hours
    - As utilities expand the use of IEC 61850 and synchrophasor-based wide-area control schemes, there will be more exposure to system operational issues associated with loss of a GPS clock.

GMD impacts on protection systems

- C. GMD impacts on communications
  - 1) Power line carrier.
    - High frequency harmonics cause lower signal to noise ratio, which could lead to failure to trip or an overtrip
    - Mitigation methods:
      - Use of single or double frequency resonant traps may have better harmonic blocking characteristics than the wide band type
      - Carrier sets employed today can be specified with higher power output ratings
      - Fiber-based communication/protection system are effectively immune to the effects of GIC

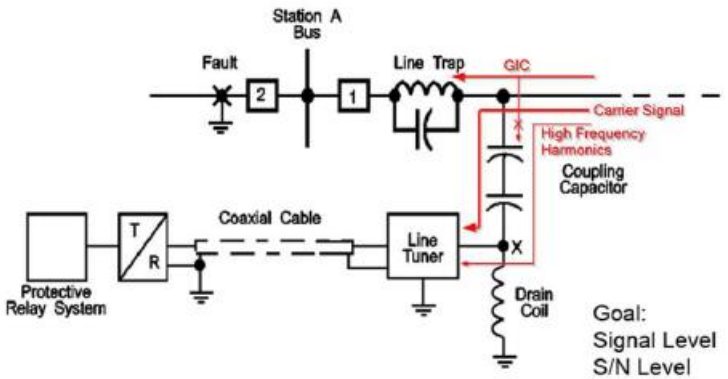


Fig. 2 GIC Flow Path with the Carrier Communication System

GMD impacts on protection systems

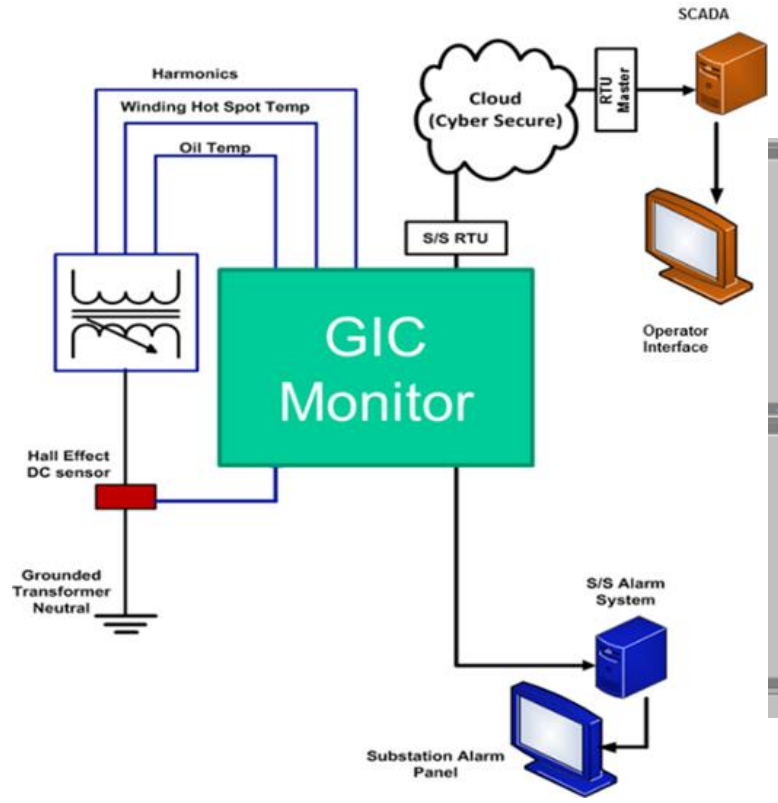
- C. GMD impacts on communications
  - 1) Microwave and satellite
    - 300 MHz to 300 GHz. GMD causes a wide spectrum of radio noises.
    - Several satellites were powered down during the March 13, 1989 storm to avoid possible damage. Solar storm on February 16, 2011 caused temporary radio blackouts and risk to satellites.
    - Gusts of solar wind can also affect a satellite's ability to navigate, possibly causing a satellite to go out of control. If solar wind gusts are successfully predicted, satellite operators can switch to back-up momentum control systems, thereby minimizing risk to the satellite.

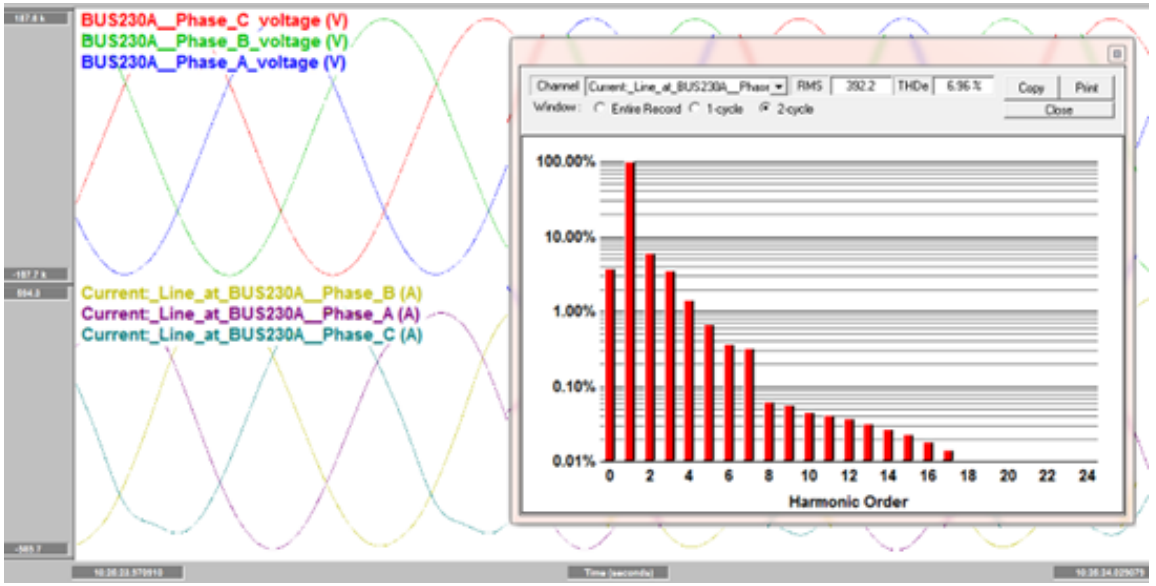
Mitigating GMD impacts on protection systems

- Using passive devices, or active devices that are capable of injecting counterposing currents into a transformer to cancel out the effect of GIC.
- The ideal solution is a device that bocks GIC flow from passing into the power system through the neutral of grounded wye transformers without compromising the operation of the power systems.
- To mitigate the impact of addition of resistance or capacitance to the neutral of a transformer to mitigate for GIC, blocking capacitance can be sized with a sufficiently small impedance to retain effective system grounding for ground faults not caused by GIC, to allow the zero-sequence current contribution of the transformer.

Geomagnetic current and field monitoring methods

- GIC in the neutral can be detected with a non-invasive DC sensor like a Hall Effect sensor





Conclusions

- The risk of false tripping of capacitor banks or harmonic filter banks due to GICs can be reduced by careful relay coordination studies and implementation of relay settings that should have sufficient margins to handle GIC effects.
- Conventional transformer protection using digital relays will normally operate reliably in the presence of GMD. However, these relays are not designed to protect transformers from damage due to excessive heating caused by GMD events. Specialized monitoring system may help.
- There is still some uncertainty on the impact of severe GMD on generators.
- Finally, the non-operation of protection and control (P&C) devices during a GMD event does not necessarily mean that the GMD impact was insignificant. It is desirable that most electrical equipment including P&C devices are inspected to detect potential failures or misoperation during GMD events.

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Questions/answers

- Thank you!