

# *TVA Response to Geomagnetic Storm*

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**Abstract**—The Space Weather Prediction Center began issuing alerts for a significant geomagnetic disturbance on the morning of May 10, 2024. TVA began noticing effects 5/10/2024 at about 10:00AM system time (15:00UTC) and began accessing data from all available devices to monitor the effects on the transmission system. The highest GICs measured were over 40Adc (compared against an action threshold of 225Adc). TVA also monitored for system harmonics but noted only a slight increase in system harmonics. No equipment issues were reported or observed. No capacitor banks tripped due to harmonics. There were no observed increases in the reactive losses in any power transformer. Also, for this GMD, the neutral blocking device located at a TVA substation inserted 12 times from 5/10/2024@12:05 system time to 5/12/2024@23:39 system time. TVA evaluated the GIC measured at adjacent and nearby transmission sites during the times the NBD was in-service and determined the effects were minimal.

**Keywords**—*geomagnetic storm; geomagnetically induced current; magnetometer; neutral blocking device; harmonics; space weather; solar flare; coronal mass ejection*

### I. INTRODUCTION

The Tennessee Valley Authority (TVA) is a federally owned, self-financed corporation with the mission to provide navigation, flood control, and electric power in the Tennessee Valley Region. TVA operates the Nation's largest public power system, with a service area covering parts of seven states and 80,000 square miles (over 200 km<sup>2</sup>) serving 9 million people. It is primarily a wholesaler of power to distributors, but it also sells power directly to larger industrial customers. The TVA transmission system consists of over 16,000 circuit miles (25,000 km) of transmission lines and 513 transmission substations, with transmission operating voltages primarily at 500kV and 161kV. TVA has over 50 power transformer banks with high-side windings rated 500kV and configured wye-grounded [12].

A transfer of energy from the Sun to the Earth's magnetosphere leads to a geomagnetic storm. This type of storm is a result of variations in the solar wind which is a continuous outflow of charged particles and magnetic fields from the Sun. The attributes of the solar wind which are most impactful in creating geomagnetic storm are continued periods of high-speed solar wind which typically ranges from several to many hours, along with a southward-directed magnetic field which is the opposite of the Earth's field direction. These conditions are a conduit for a very effective transfer of energy from the Sun to the Earth's magnetosphere which results severe magnetosphere disturbances [1], [11]

Many solar wind conditions exist near the Sun but relatively few reach the Earth's magnetosphere. Some of the largest storms caused by the solar wind conditions that reach the Earth are associated with solar coronal mass ejections (CMEs). During these CMEs approximately a billion tons of plasma consisting of charged electrons and ions along with the magnetic field from the Sun's upper atmosphere reach the Earth's magnetosphere in a matter of two to three days. [1],[11]

Rapid fluctuations of the Earth's geomagnetic field occur as the charged solar particles reach the Earth's magnetosphere. As a result, the time-varying magnetic field induces an electric field that drives geomagnetically induced currents (GICs) which can adversely affect the bulk transmission system. For purposes of power-grid studies, GICs change slowly over time (an AC waveform with a period of over several minutes) and, as such, can be treated as quasi-direct current (DC) in the frequency band of 10  $\mu$ Hz to 1 Hz. Like other currents, GICs flow according to Kirchhoff's and Ohm's Law. Available paths for GICs include extra high voltage (EHV above 200kV) transmission lines and transformers. When flowing through power transformer windings, the GICs cause part-cycle transformer core saturation which, in turn, causes significant heating from stray flux, increases reactive losses that can depress system voltages, and can damage the transformer itself. Core saturation can generate harmonic distortion that impacts other elements in the electric system such as capacitor banks. [9], [11]

GIC can flow through the neutrals of wye-grounded windings of extra-high voltage (EHV) power transformers, resulting in half-cycle saturation that can result in the following phenomena:

- In some extreme cases can damage the transformer core due to winding hot spots.

- Harmonic currents are generated that can flow in capacitor bank neutrals. These harmonic currents can cause tripping of the capacitor banks by relays with flat frequency response.<sup>1</sup>
- Excessive reactive power drawn by power transformers undergoing half-cycle saturation, which could cause low voltage or even collapse.

Static VAR compensating devices are also susceptible to damage caused by voltage distortion which can result in commutation failure and shutdown.

GMD events can occur at any time based on sunspot activity, but the number of events generally increases every 11 years based on the sunspot cycle, with roughly 200 significant events during that cycle [1].

## II. GMD ALERTS

The Space Weather Prediction Center (SWPC) of the National Oceanic and Atmospheric Administration (NOAA) monitors space weather using satellites located between the earth and the sun. By measuring different aspects of the solar wind, the SWPC issues alerts that can provide advance warning of possible earth impacts including geomagnetic storms, solar radiation storms, and radio blackouts.

The intensity scales for geomagnetic storms include G3 Strong, G4 Severe, and G5 Extreme, with associated physical measurements using planetary K indices of K7, K8, and K9, respectively [1].

## III. GMD MONITORING NETWORK

To better understand the power system impacts of geomagnetic disturbances (GMD), the Tennessee Valley Authority (TVA) has developed a network of monitors in cooperation with the Electric Power Research Institute (EPRI). The network includes devices to measure geomagnetically induced current (GIC) in the neutrals of about two dozen 500kV power transformers, along with a network of twelve magnetometers geographically dispersed around the TVA system. The goal is to install a GIC monitoring device on all 500kV power transformers.

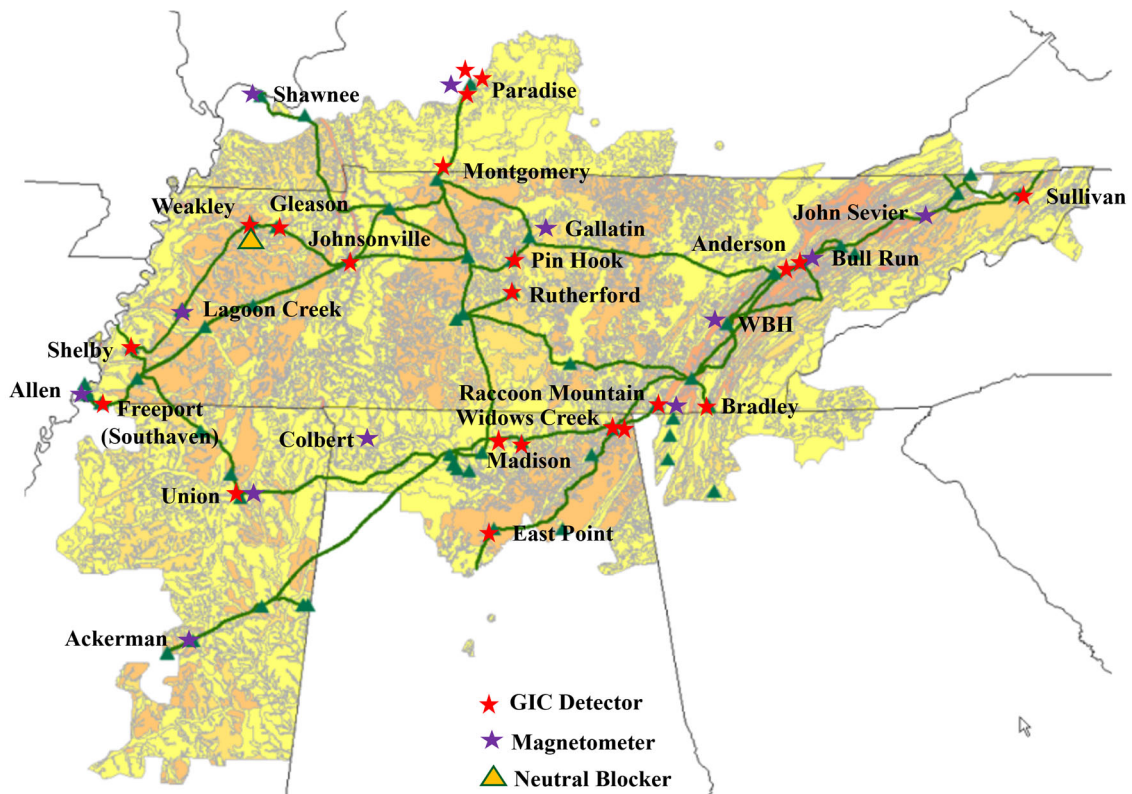
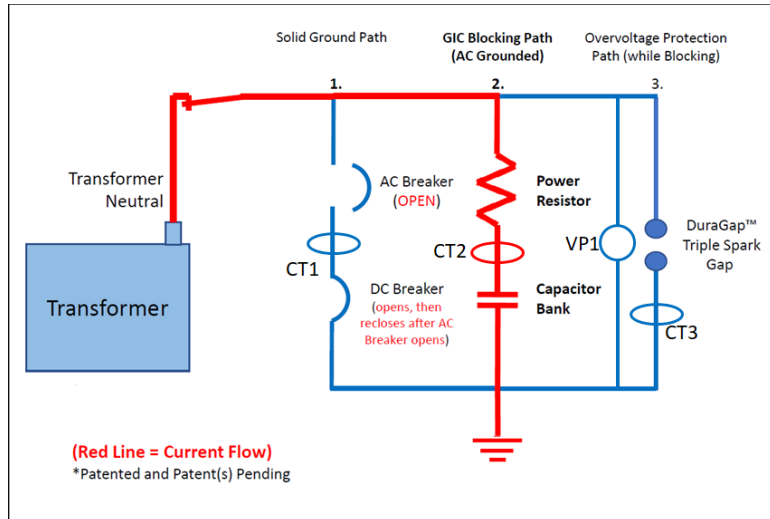


Figure 1. TVA GMD Monitoring Network

<sup>1</sup> On 7/15/2000, TVA experienced 15 different trips of 161kV capacitor banks over a 12-hour period at 6 different sites.



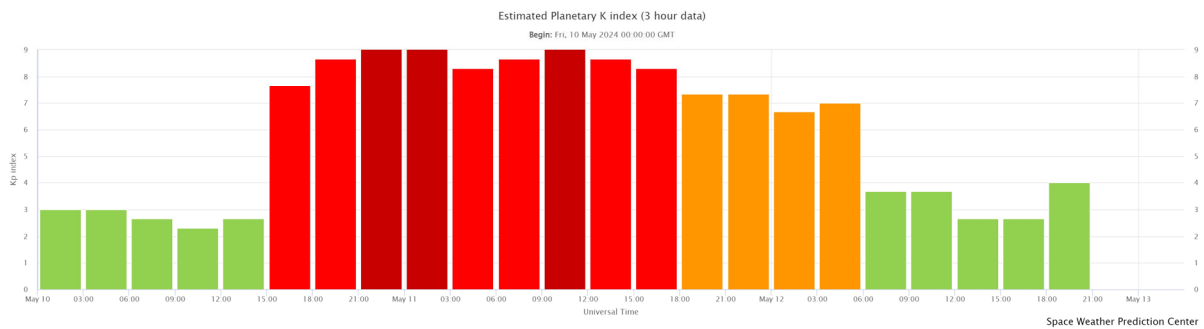


**Figure 3. GIC blocker - inserted**

## V. THE STORM

The SWPC began issuing alerts on May 9, predicting a G3/K7 (Strong) or G4/K8 (Severe) GMD event. From May 10 at 1716 UTC until May 10 at 2243 UTC, alerts up to and including K9 were issued, predicting the event could last into May 13.

This was considered unusual in that most GMD events last less than 12 hours.



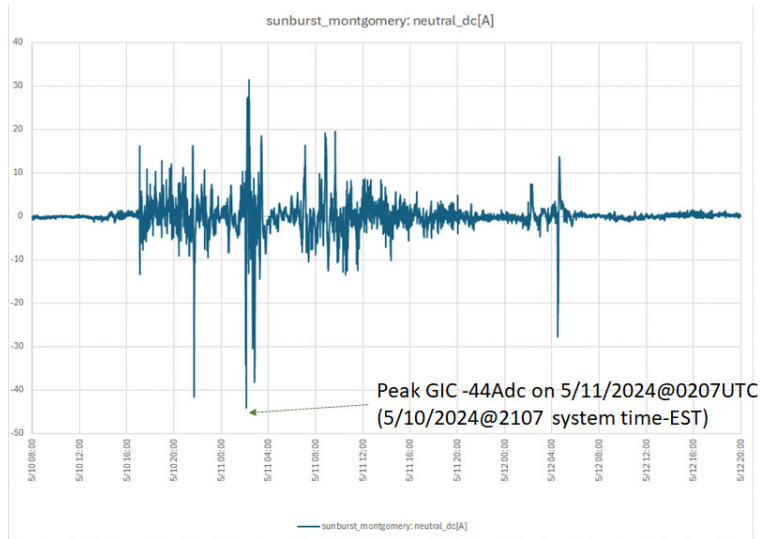
**Figure 4. Estimated Planetary K index (courtesy of SWPC)**

## VI. TVA GIC MEASUREMENTS AND NBD OPERATION

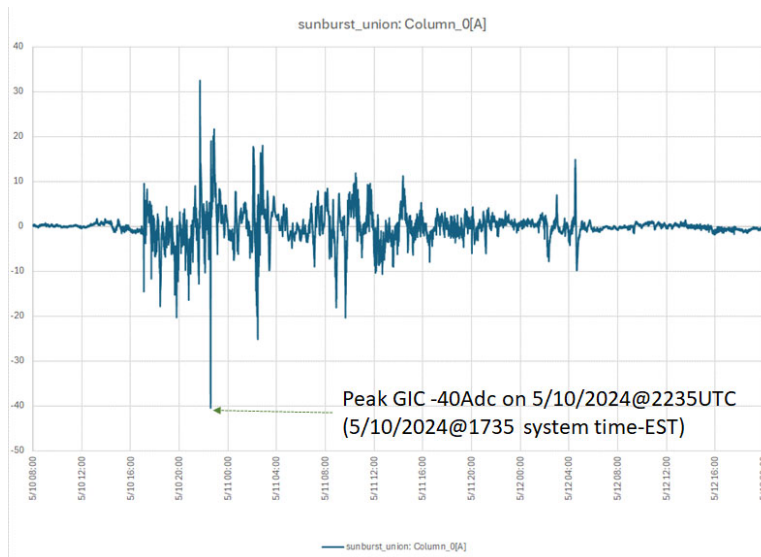
TVA began noticing effects 5/10/2024 at about 10:00AM system time (15:00UTC).

### A. GIC Measurements

Highest GICs were observed at Montgomery (44Adc) and Union (40Adc) stations.



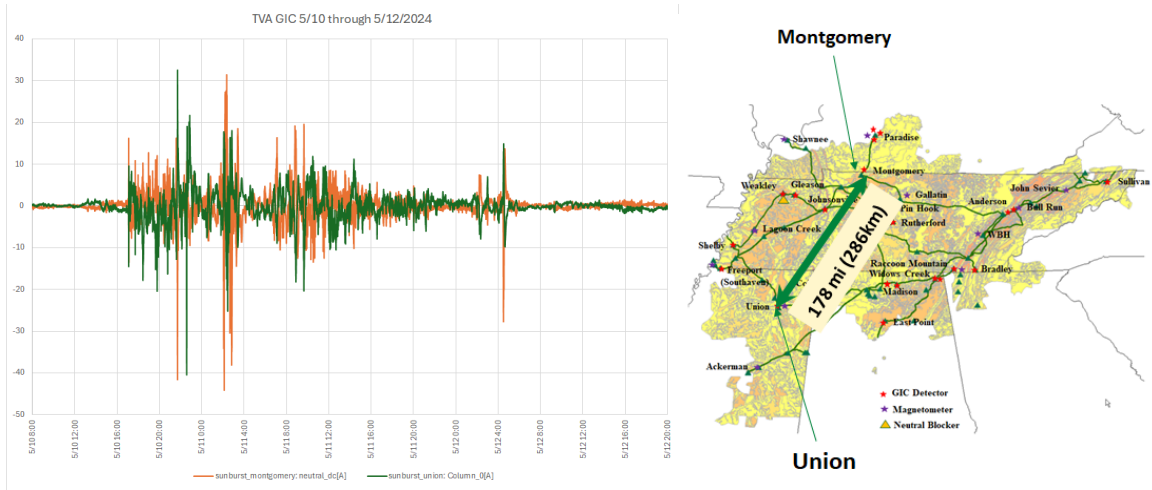
**Figure 5. Montgomery: Peak GIC -44Adc**



**Figure 6. Union: Peak GIC -40Adc**

Through observations and inspection of data from previous GMD events, TVA noticed that Montgomery and Union stations, which are located about 178 miles apart from each other, GICs are nearly a mirror image in amplitude but opposite in direction. This GMD event data illustrated a similar GIC pattern for the two stations. See Figure 7.

There is GIC data available for sixteen other TVA stations for this event. However, the GIC impacts to these stations were insignificant. Hence, the discussion for these sites will be omitted in this paper.

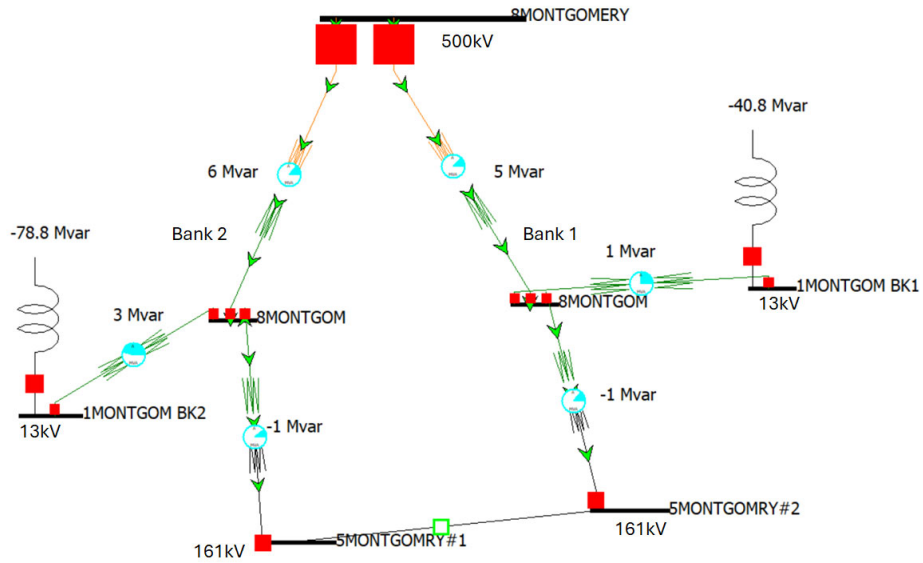


**Figure 7. Highest GICs at Montgomery & Union**

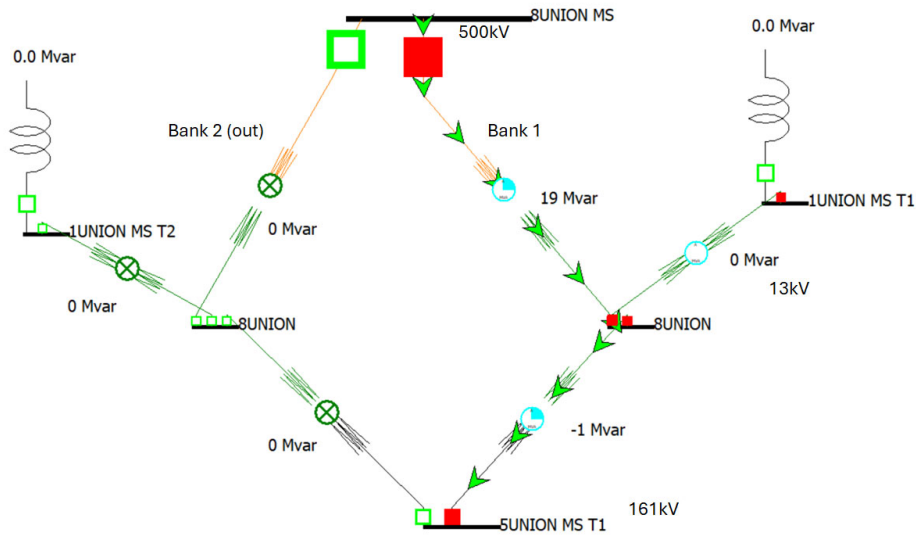
Data was also available from Anderson, Bull Run, Bradley, East Point, Gleason, Montgomery 2, Johnsonville, Paradise 7, Pin Hook 2, Raccoon Mountain, Shelby, Southaven, Sullivan 3, Union 1, Weakley, Widows Creek 17. No data was available from Madison 1 or 2, Limestone, Paradise 5 or 6, Widows Creek 10.

**B. Reactive Power Losses**

We did check the reactive power losses for these banks, since power transformers under half-cycle saturation can draw excessive MVAR. But the GIC was short-lived, so the reactive losses were minimal (see Figure 8 and Figure 9). (The MVAR values next to each winding are the losses.)



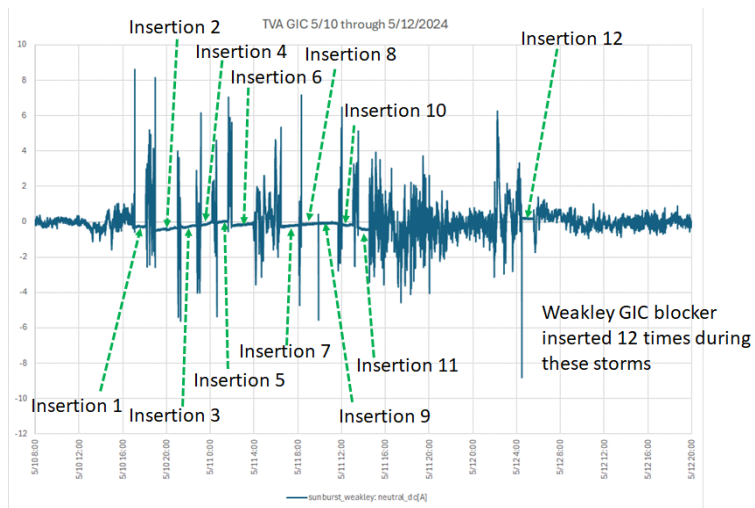
**Figure 8. Montgomery - Bank MVAR losses**



**Figure 9. Union - Bank MVAR losses**

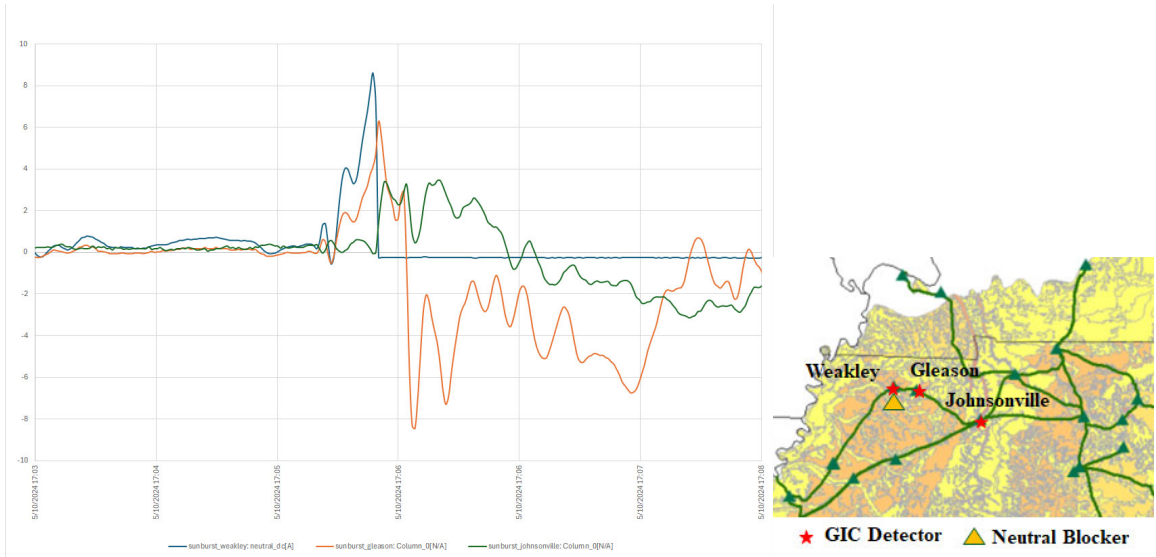
*C. NBD Operation*

The NBD operated twelve times during the storm. In most cases the device switched back out (was bypassed) after one hour, but in half of those cases the device remained in-service longer than one hour, even as long as two hours (see Figure 10).



**Figure 10. NBD Insertions During GMD Event**

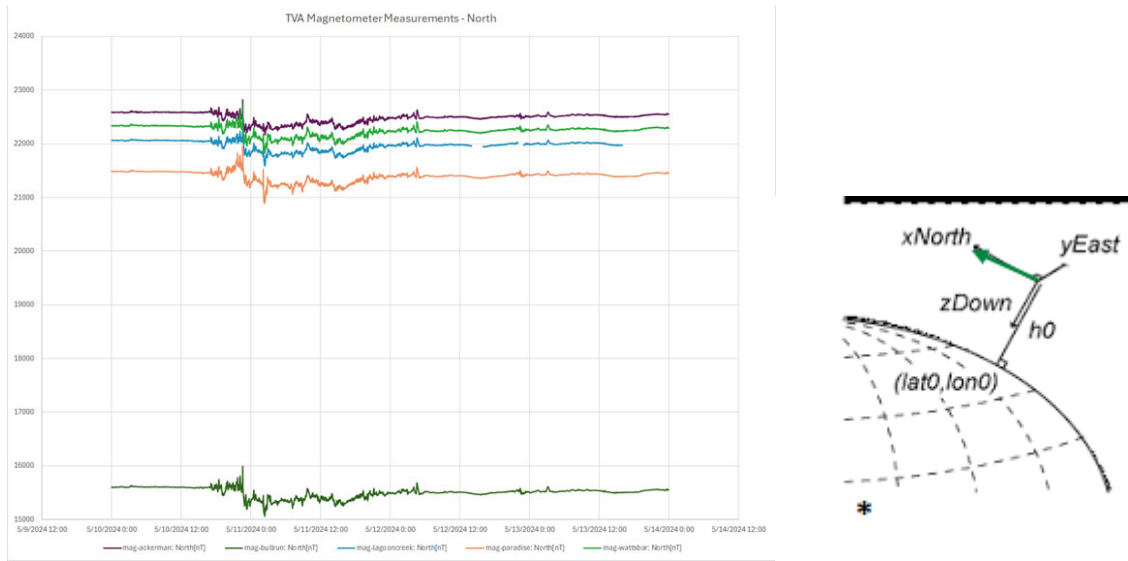
The impacts of the NBD insertions on adjacent stations of Montgomery and Gleason were evaluated. The setpoint of the NBD control is sensitive such that when it switches in at 5A DC, the redistribution of GIC to nearby sites does not present significant impact. See Figure 11.



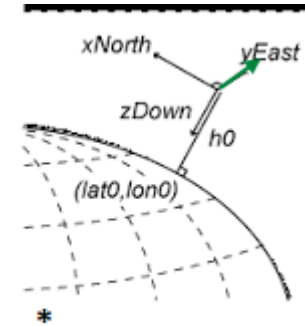
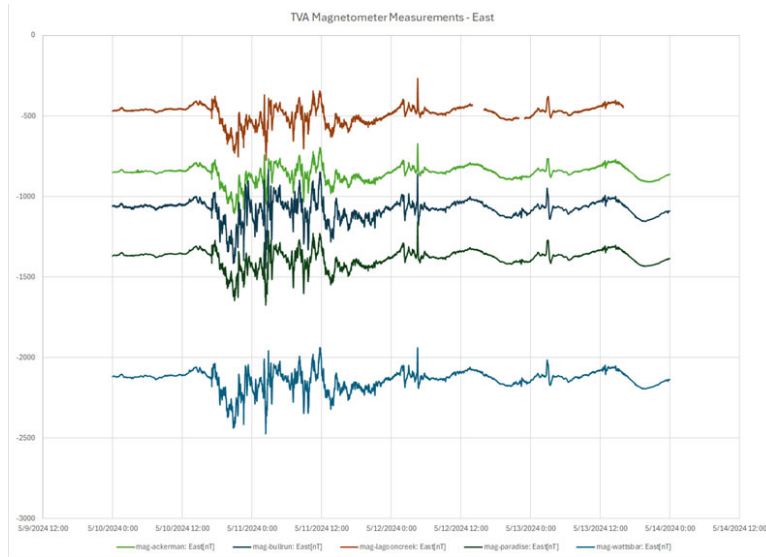
**Figure 11. Change in Johnsonville/Gleason GIC when Weakley GIC blocker inserts 12:05:54EST**

### VII. TVA MAGNETOMETER DATA

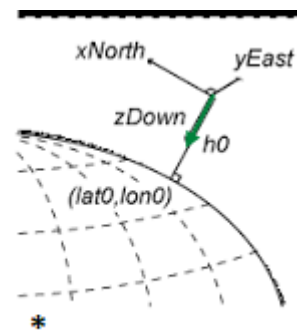
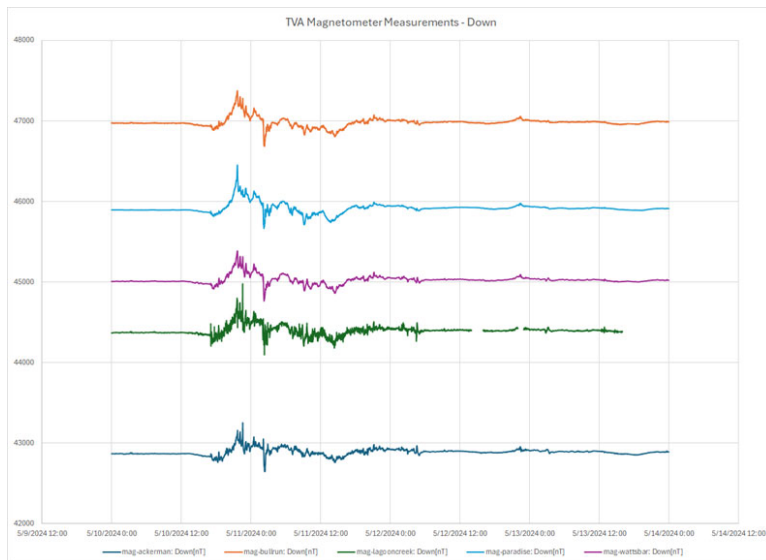
Magnetometer data from available sites is presented in Figure 12, Figure 13, and Figure 14. This data is only presented to illustrate qualitative response.



**Figure 12. TVA Magnetometer Data-North**



**Figure 13. TVA Magnetometer Data-East**

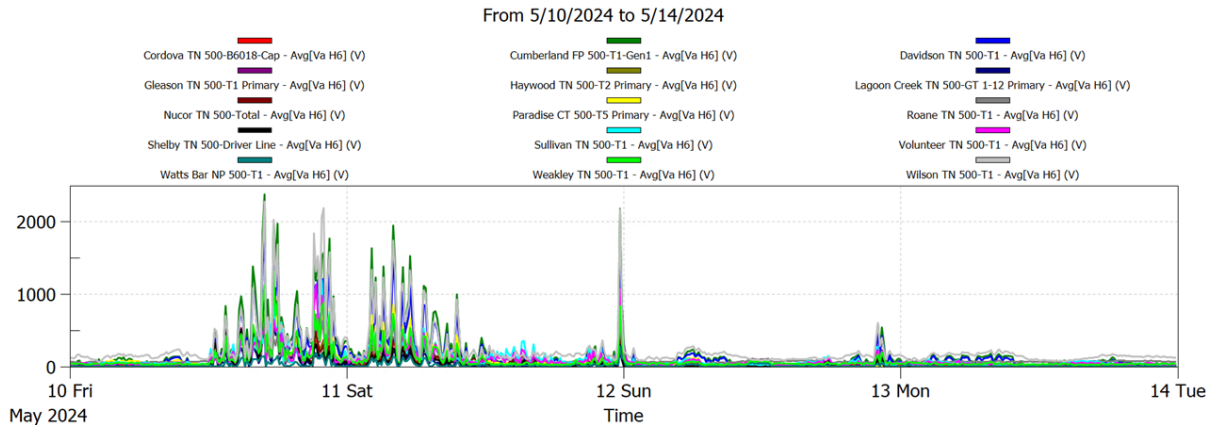


**Figure 14. TVA Magnetometer Data-Down**

\*<https://www.mathworks.com/help/map/choose-a-3-d-coordinate-system.html>

### VIII. HARMONICS

Changes in system harmonics were monitored during the event. TVA noted only slight increases. See Figure 15. No capacitor banks tripped during this GMD event.



**Figure 15. TVA Harmonic Measurements**

## IX. CONCLUSION

Due to widely dispersed monitoring devices throughout the system, TVA was able to determine there were no adverse system impacts from this relatively intense and longer-duration GMD event.

TVA continues to observe and study the data provided by the monitors to better understand the GIC flows and their effect on the TVA system and equipment.

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## BIOGRAPHY

Ulyana Elliott is an Electrical Engineer working at Tennessee Valley Authority Reliability Analysis group. She received B.S. in Applied Mathematics Actuarial Science in 2008, M.S. in Engineering Management in 2010, and B.S. in Electrical Engineering in 2015. Ulyana is an IEEE and IEEE PES member. She started her career at TVA in summer of 2012 in Stochastic Analysis group in System Planning where she worked as an intern supporting several large projects. In the Fall, she transferred to the Forward Applications where she supported Balancing Authority System Operations. In 2014, she moved to the Reliability Analysis group where she became full time electrical engineer. Ulyana has had several responsibilities, including modeling, facility ratings, system outage studies, voltage schedules, software support (Var Management System (VMS), DSA Tools (PSAT/VSAT/TSAT/SSAT)), Geomagnetic Disturbance, special studies and analysis (voltage and unit stability).

Gary Kobet is an Electrical Engineer for the Tennessee Valley Authority (TVA) in Chattanooga, Tennessee. His responsibilities include developing and maintaining operating guides and advising operators on system and equipment protection issues. He has performed stability studies and post-event disturbance analysis, and also

provided oversight of TVA's Phasor Measurement system and applications. He has also worked in the System Protection department scoping relaying schemes for transmission and generation projects, as well as developing relay set point calculations and performing electromagnetic transient studies. Previously he worked as a field engineer and as power quality specialist. Mr. Kobet earned the B.S.E. (electrical) from the University of Alabama in Huntsville in 1989 and the M.S.E.E. from Mississippi State University in 1996. He is a member of the IEEE/PES Power System Relaying and Control Committee and is a registered Professional Engineer in the state of Alabama.