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Measuring the Earth's Magnetic Field Variations – AEP's Experience with the Design and Commissioning of a Magnetometer Measurement System

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SUMMARY

Geomagnetic Disturbances (GMD) are a result of the interaction of the earth's magnetic field and the particles discharged from the sun during a solar storm. Changes in the earth's magnetic field will induce a quasi dc voltage, which will result in flow of Geomagnetically Induced Currents (GIC) through grounded transformers and high voltage transmission lines.

American Electric Power (AEP) commissioned a magnetometer system close to one of its 765 kV Substations to measure variations in the earth's magnetic field. The magnetometer system is located about 400 feet outside of the substation fence and installed inside an underground enclosure to reduce interference from current-carrying conductors, metallic structures, and moving objects.

This paper describes AEP's experience on the design and commissioning of a magnetometer system. The magnetic field data is being collected to better understand the magnetic field changes in a GMD event and validate existing transformer GIC models.

KEYWORDS

Geomagnetic Disturbances (GMD), Geomagnetically Induced Currents (GIC), Magnetometer, sensor

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MAGNETOMETER SYSTEM DESIGN

AEP has been a pioneer in addressing the impact of GMD to ensure continued reliable operation of the nation's largest transmission grid. AEP has been working with transformer manufacturers and research institutions to study the impact of GIC on large EHV power transformers [1]. In addition, to improve power system GMD models, AEP has installed permanent GIC monitors across the system to detect and evaluate GMD impacts on large transformers [2]. In order to more accurately correlate measured transformer neutral GIC currents with simulated GIC currents based on the model of transformer, local earth magnetic field variations are needed.

This project was designed to install a fluxgate magnetometer close to, but outside of, a 765 kV substation. The sensor was installed on a non-metallic enclosure, below ground level, and outside of the substation fence to reduce interference from current carrying conductors, metallic structures, and moving objects. The intent of the underground installation is to minimize the impact of seasonal temperature variations. The magnetometer system is powered by an isolated solar panel and a battery backup module.

The magnetometer sensor will measure the magnetic field strength in the direction of X-axis, Y-axis, and Z-axis, and produce a quasi-dc voltage output, which is connected to the data acquisition unit and an automation controller. The automation controller will measure and process these three axis magnetic field measurements with a low-pass filter and calculate the total magnetic field strength. These data points are time synchronized with a satellite synchronized clock and all of the values are transmitted to the substation using a serial radio transceiver. A serial radio receiver at the substation control house receives the data and transfers it the AEP network via a serial to ethernet converter. The overall system design is shown in Figure 1.

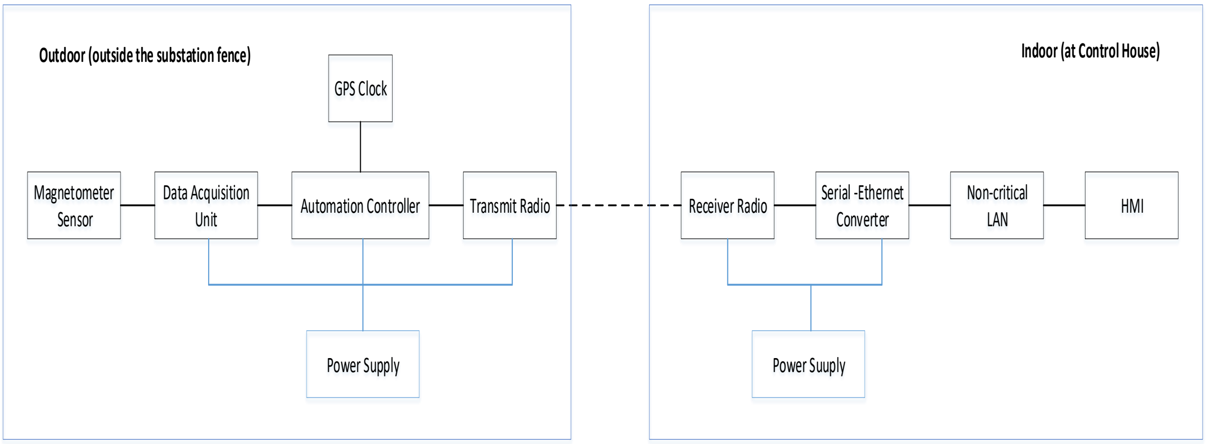

Figure 1: Magnetometer Design

Figure 2 shows the magnetometer system location with the solar array, battery, automation controller GPS and radio antennas.

Figure 2: Magnetometer System

Detailed design aspects of each component are provided in the following sections.

A. UNDERGROUND ENCLOSURE

Magnetometer sensors are very sensitive to any metallic objects and moving objects. Therefore, the sensor was installed inside a non-metallic fiberglass enclosure which was installed below ground level. As shown in Figure 3, the sensor was installed on a wooden platform within the enclosure. The bottom of the enclosure was left open and sitting on 6 inches of gravel. A drainage conduit running below the gravel surface was added to avoid any possible flooding of the enclosure.

Figure 3: Magnetometer Sensor installation

B. DATA ACQUISITION UNIT AND AUTOMATION CONTROLLER MAGNETIC COMPONENTS

The following inputs from the three-axis magnetometer sensor were connected to the Data Acquisition Unit (DAU).

1. X-Axis magnetic field measurement
2. Y-Axis magnetic field measurement
3. Z-Axis magnetic field measurement

The Direction of Magnetic Axes are shown in Figure 4. The automation controller calculates the total magnetic field strength (F) as:

$$F = \sqrt{(X\_Axis)^2 + (Y\_Axis)^2 + (Z\_Axis)^2}$$

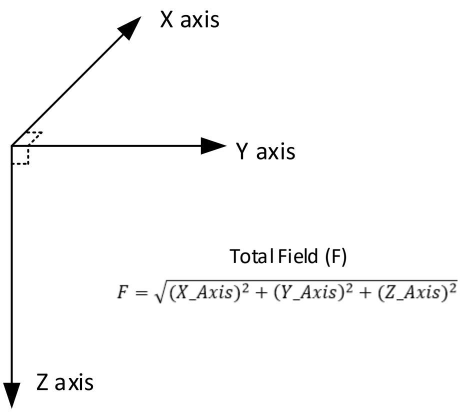

Figure 4: Magnetic Axes

PARAMETER SCALING

The three-axis magnetic sensor will generate a quasi-dc voltage based on the magnetic field it measures. The measuring range of the magnetometer sensor is +100 µT to - 100 µT and the scaling factor of the sensor is 0.1 V / µT. Therefore, defining a measuring range in Volts of +10 V to -10 V. Automation controller scales the measured signal (+10V to -10V) to a nano Tesla range by multiplying by 10,000 as shown in Figure 5.

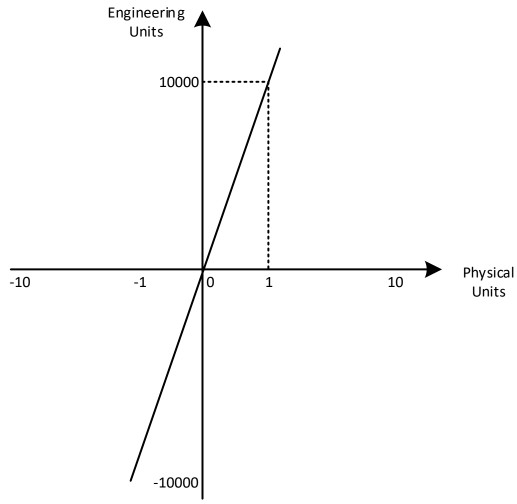

Figure 5: Automation Controller Scaling

DATA TRANSFER AND COMMUNICATION

Magnetometer measurements and calculated values are being transferred to the substation through a serial radio network. Serial radios are preferred over the ethernet radios as they offer extra data security.

POWER SUPPLY

An isolated power supply was required for the magnetometer system based on its physical location and to reduce any external interference as much as possible. The system was powered by a solar array with a 12 Vdc battery pack. The solar array capacity was selected based on the average winter sun hours available per day for the area [3]. The battery Amp-hour capacity was selected based on the total power consumption of the sensor, data acquisition unit, automation controller, GPS clock, and the serial radio.

The solar array will charge the battery through a solar charge controller which uses the Maximum Power Tracking (MPPT) technology to extract maximum power from the solar panel. MPPT will track the solar array maximum power point voltage as it varies with weather conditions, to extract maximum power during the day. The battery charging algorithm has four stages: bulk charge, absorption, float, and equalization.

Power supply to the automation controller is crucial to the reliable operation of the system. Battery and solar array charging parameters and voltage profiles are monitored through the solar charge controller which is communicating with the automation controller, which in-turn sends the data to the substation through the serial radio network.

SUBSTATION EQUIPMENT

Receiver serial radio at the substation control house will transfer the received data to the AEP network through serial to ethernet converter. An HMI is configured to monitor the magnetometer data and device condition using various graphical plots.

LAB TESTING

Before deploying at the substation site, an initial test was performed in a laboratory environment as shown on Figure 6 to verify the data transfer and accuracy.

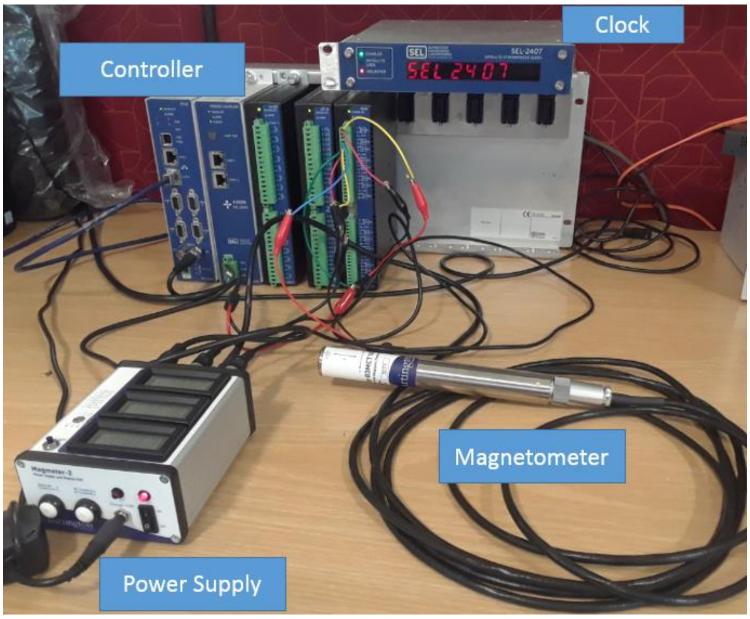

Figure 6 : Lab Testing Setup

All three magnetic axes and the calculated total magnetic strength profiles were observed as shown in Figure 7.

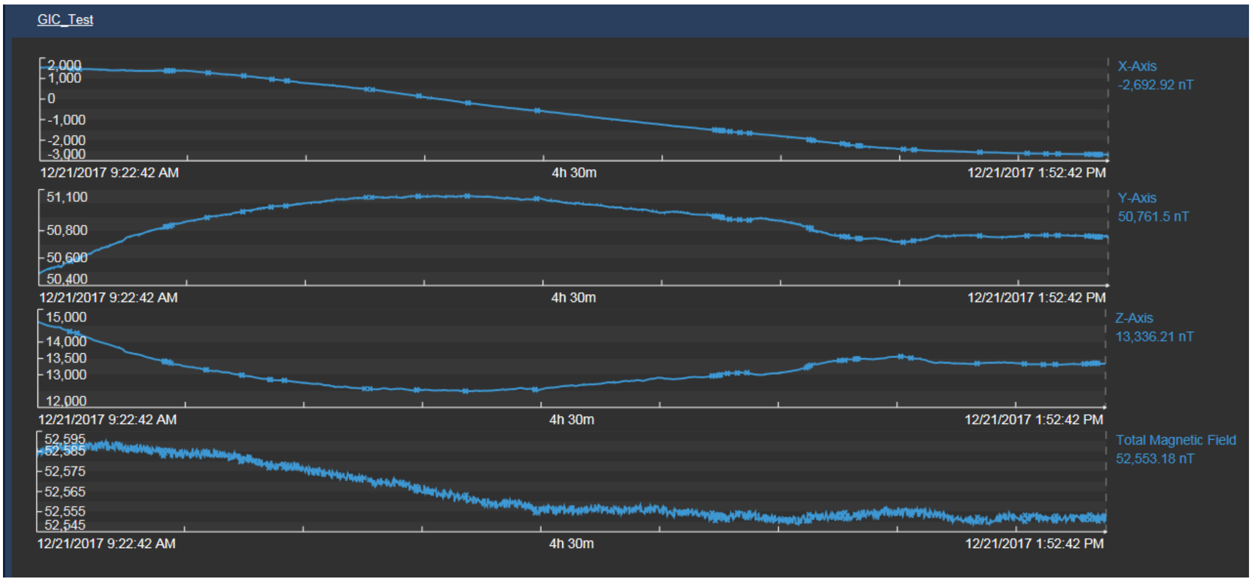

Figure 7 : Lab Testing Results

COMMISIONING EXPERIENCE - INSTALLATION AND CALIBRATION

Selecting a location for the placement of the magnetometer system was critical as magnetometer sensors are sensitive to current carrying objects and moving objects such as foot or vehicle traffic. The selected location for our installation was about 400 feet outside of the substation fence and far away from any roads or transmission line paths.

After installing the magnetometer sensor in the underground enclosure, the sensor was calibrated per the World Magnetic Model [4] data for the Substation location, which has a west declination of 6.89-degree (Magnetic north is 6.89-degree counter clock wise from true north) as shown in Figure 8.

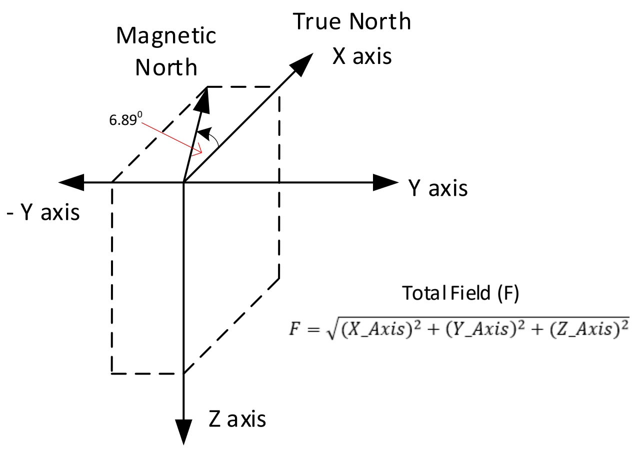

Figure 8: Magnetic Axis

Sensor X-axis was aligned towards the true north and calibrated the other two axes with respect to the X, Y, Z axes values calculated for the site location per World magnetic model data as shown in Table 1.

Table 1: Magnetic parameters for sensor location

Fields	Values	Changes/yr	Uncertainty
D (deg)	-6.89^0	-0.04^0	0.36^0
I (deg)	67.6^0	-0.08^0	0.22^0
F (nT)	52576.5	-115.05	152
H (nT)	20033.6	23.65	133
X (nT)	19888.8	21.67	138
Y (nT)	-2404	-17.76	89
Z (nT)	48610.1	-134.18	165

Figure 9 shows the adjustments required to calibrate all three axes of the sensor. Several repeated adjustments are required as the sensor is highly sensitive for each movement. The sensor could be rotated, turned clockwise (CW), turned counter clockwise (CCW) or level adjusted using the built-in leveling platform and its three leveling screws.

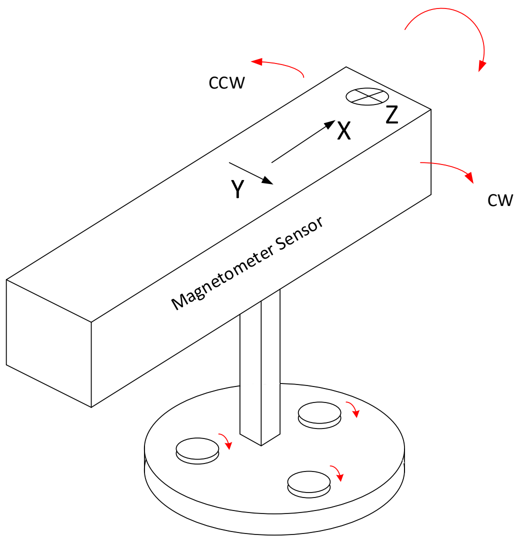

Figure 9: Sensor Adjustments

During the sensor calibration process, measured magnetic axis values and total magnetic field strength were observed from the automation controller. Parameter scaling and communication settings were also programmed on the automation controller at the same time.

DATA VALIDATION CASE #1 – GEOMAGNETIC EVENT ON 8/26/2018

On August 26th, 2018 at 3.38 AM (EST) the Space Weather prediction center issued an alert for a geomagnetic storm with a k-index of 7 as shown in Figure 10:

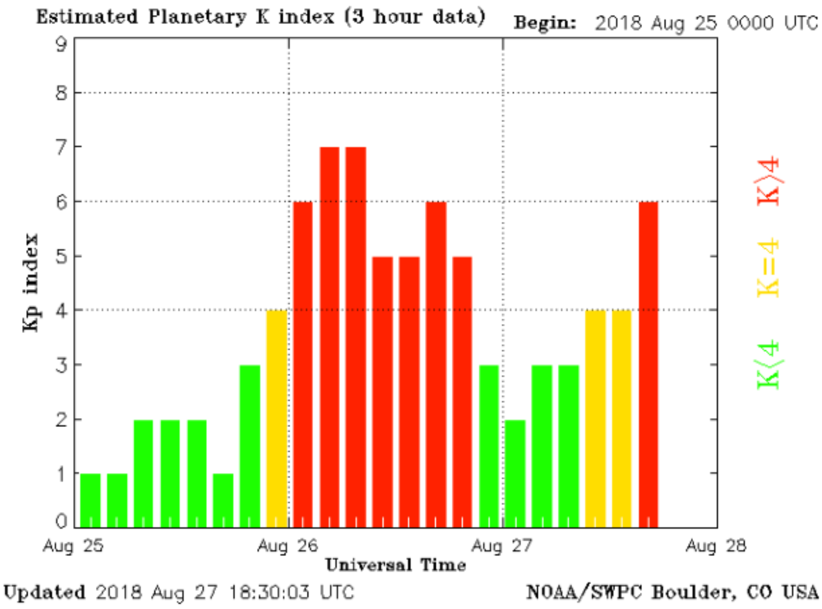

Figure 10: Geomagnetic storm with a k-index of 7

Figure 11 documents the magnetic field data for the above event from the deployed magnetometer system.

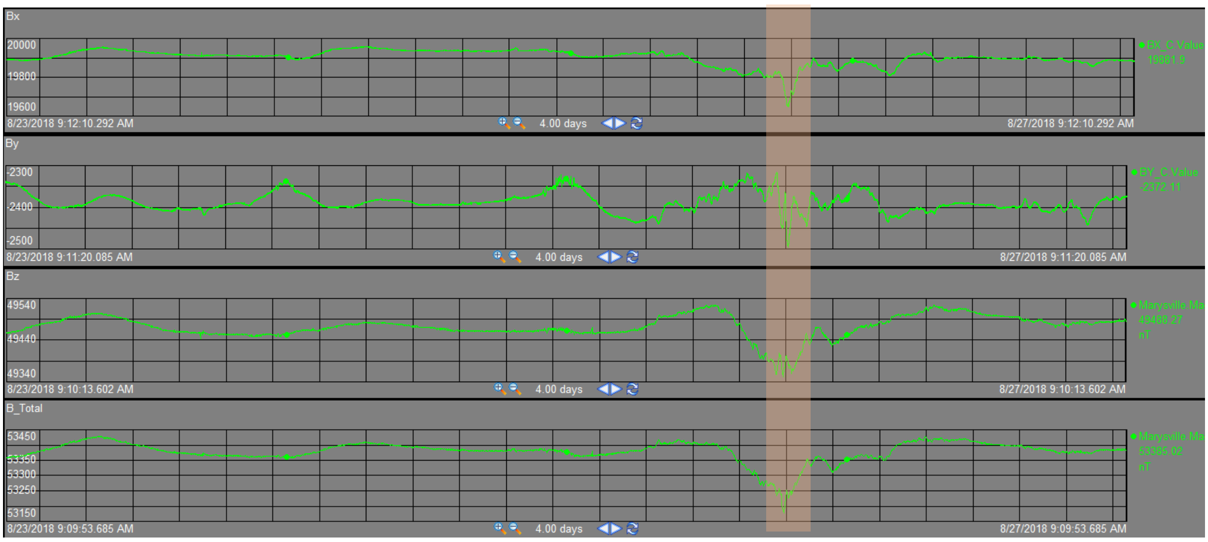

Figure 11: Magnetic field data for the event from AEP magnetometer

The magnetic field data for the same event from USGS (Fredericksburg observatory) [5] – UTC time are shown in figure 12.

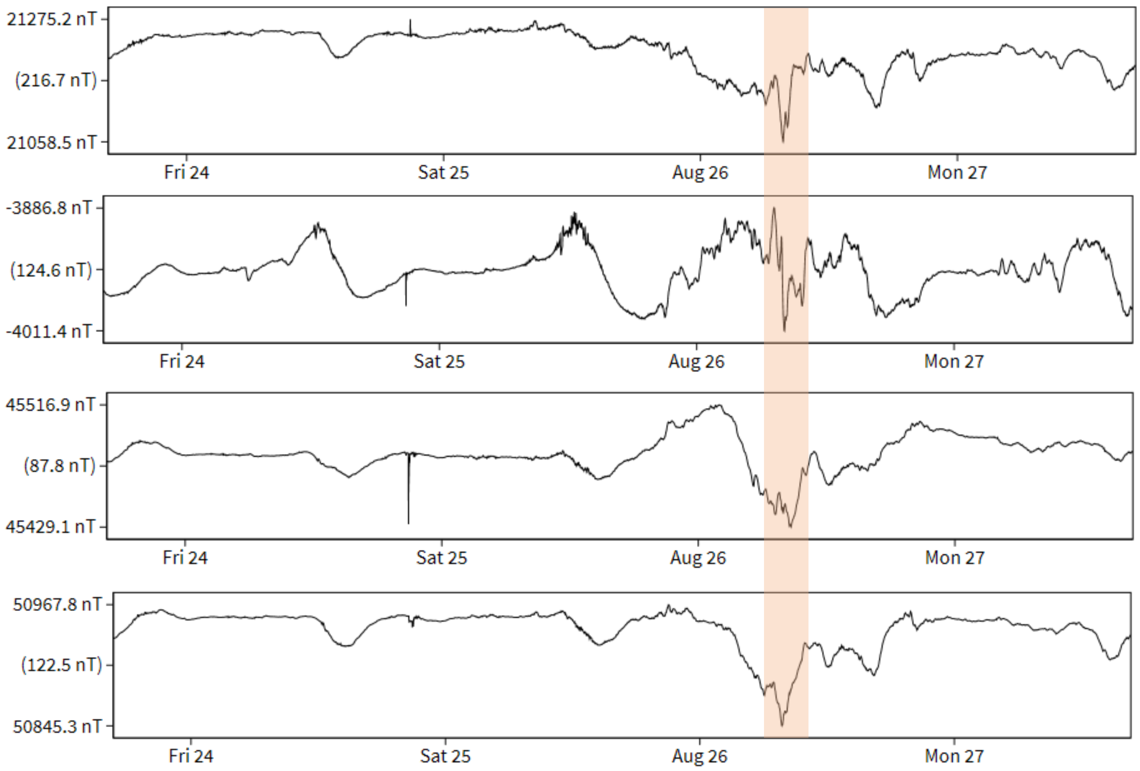

Figure 12: Magnetic field data for the event from USGS (Fredericksburg observatory)

According to the above figures, the magnetic field data captured by our deployed magnetometer system for this event follows the same trend as the USGS Fredericksburg observatory measurements.

DATA VALIDATION CASE #2 – GEOMAGNETIC EVENT ON 5/14/2019

NOAA Space weather prediction center issued an alert of geomagnetic K-Index of 7 at 8.59 UTC (4.59 AM EST) on 5/14/2019. Below is the planetary K-Index issued by NOAA Space weather prediction center [6].

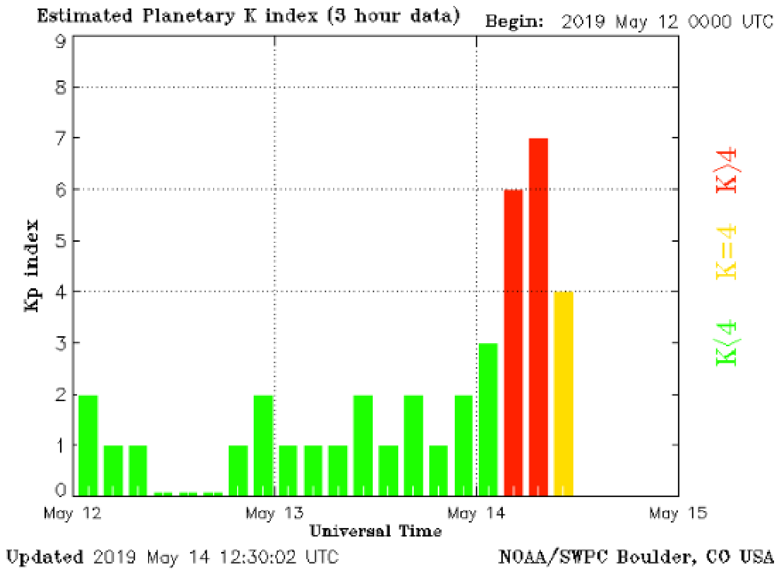

Figure 13: Planetary K-Index issued by NOAA Space weather prediction center

Shown below are the magnetic field measurements from our deployed magnetometer system compared to the USGS Fredericksburg, VA observatory measurements.

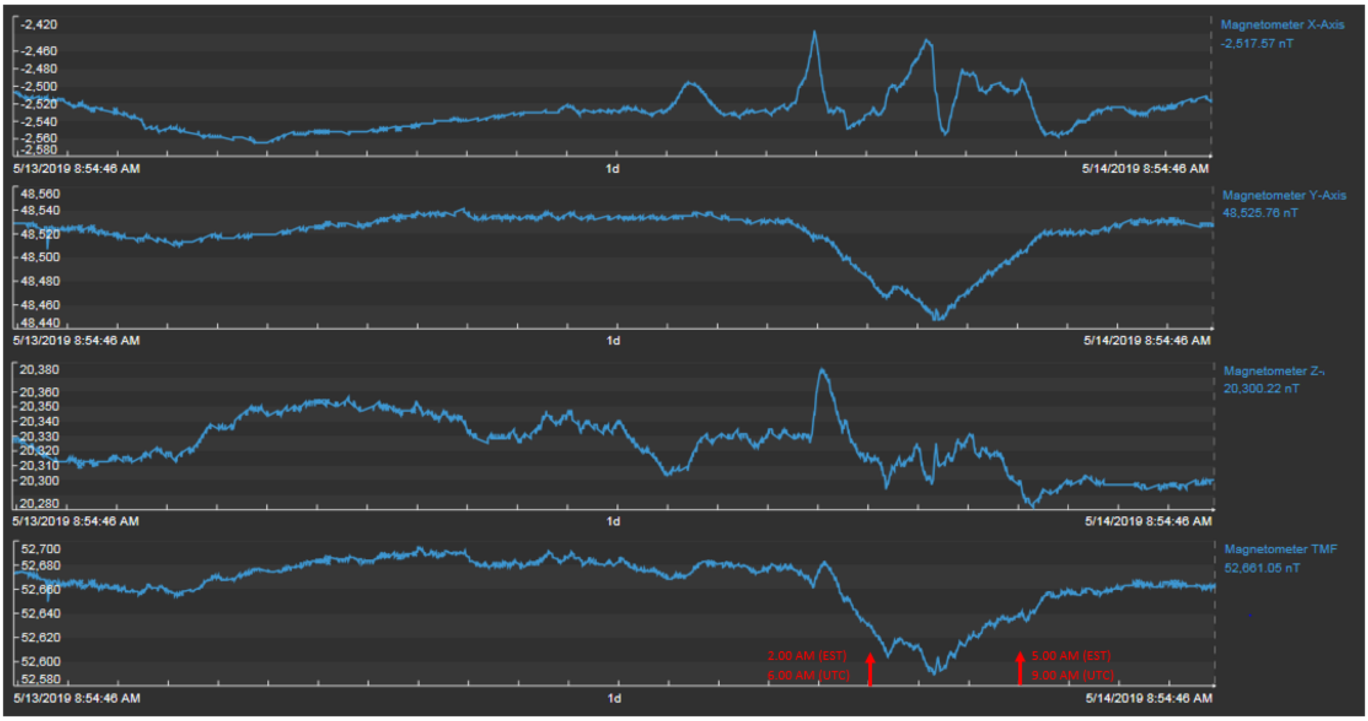

Figure 14: AEP Substation Magnetometer Data

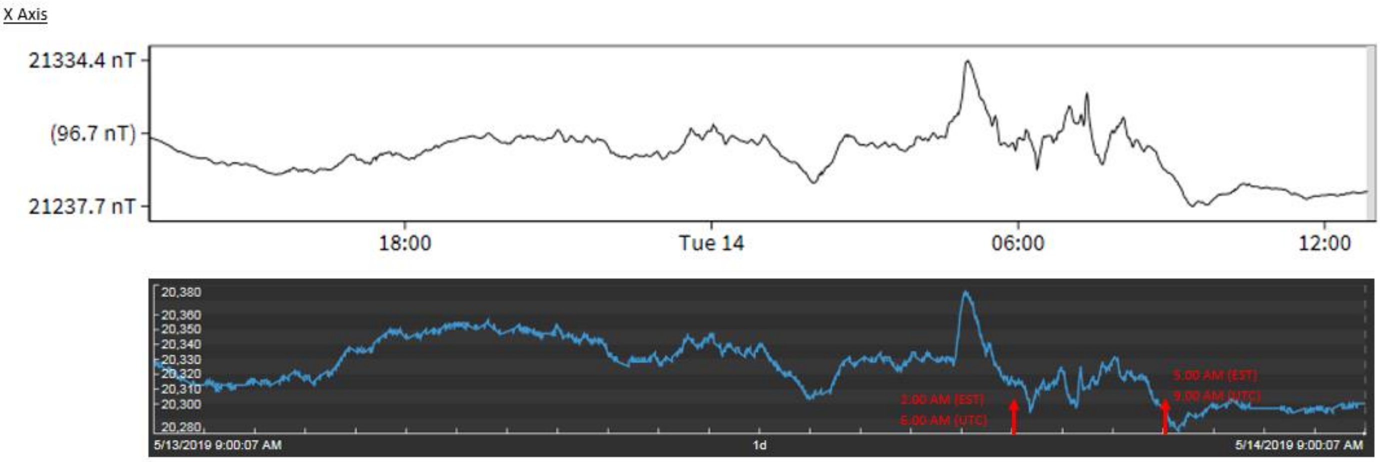

Figure 15: Comparison of USGS Fredericksburg, VA observatory data and AEP Vassell Substation Magnetometer Data – X-Axis

Y Axis

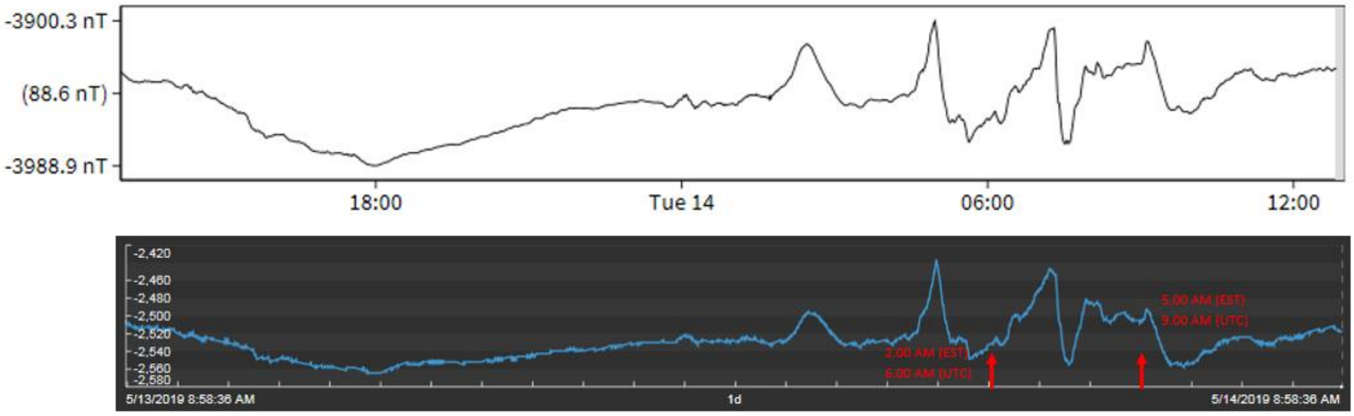

Figure 16: Comparison of USGS Fredericksburg, VA observatory data and AEP Vassell Substation Magnetometer Data – Y-Axis

Z Axis

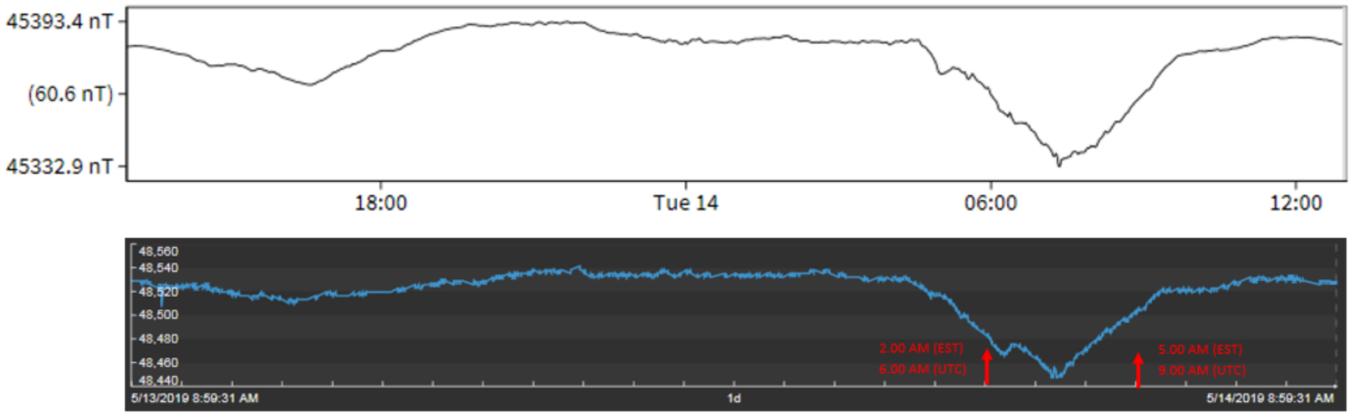

Figure 17: Comparison of USGS Fredericksburg, VA observatory data and AEP Vassell Substation Magnetometer Data – Z-Axis

Total Magnetic Field

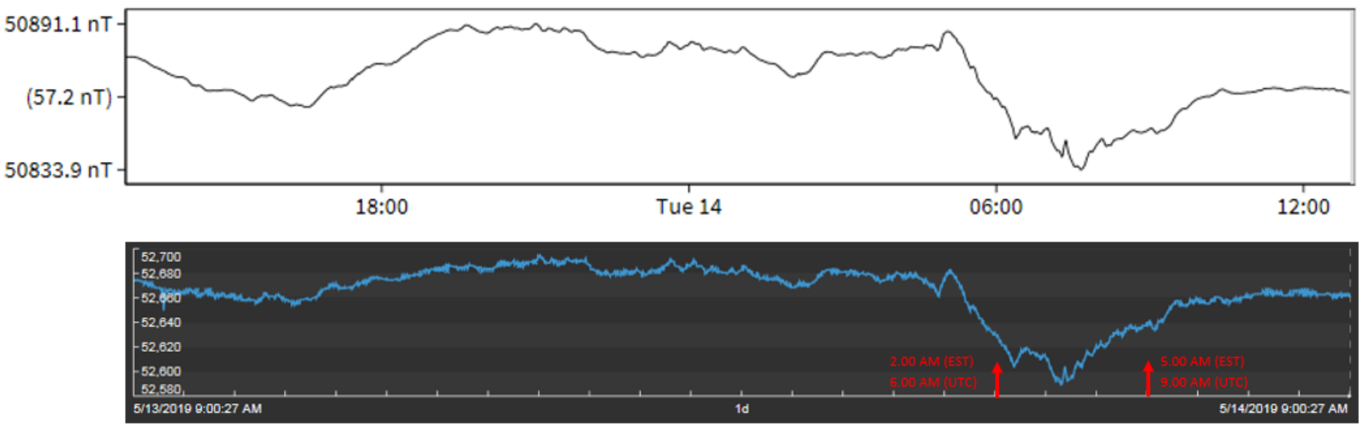

Figure 18: Comparison of USGS Fredericksburg, VA observatory data and AEP Vassell Substation Magnetometer Data – Total Magnetic Field

CONCLUDING REMARKS

This paper documents AEP's experience in designing and commissioning a magnetometer measurement system to measure the earth's magnetic field variations during solar storms. AEP will be using this data along with transformer GIC measurements to help in the validation of our GIC system models and also to gain a better understanding of the impacts of GMD events on our system. This will enable AEP to prepare for and better understand the impacts of GIC on our system and take possible mitigating actions in the future.

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BIBLIOGRAPHY

[1] Effect of GIC and GIC capability of EHV Power Transformers – A Case Study on an AEP 765kV Power Transformer Design, CIGRE US National Committee 2013 Grid of the Future Symposium, Q. Qiu, D. Ball, J. Fleeman, and etc.
[2] Geomagnetic Disturbance Impacts and AEP GIC/Harmonics Monitoring System, CIGRE US National Committee 2012 Grid of the Future Symposium, Q. Qiu and J. Fleeman
[3] Sun Wise Solar System Design Guide
[4] World Magnetic Model, https://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml
[5] USGS Data, https://www.usgs.gov/natural-hazards/geomagnetism/monitoring?qt
[6] NOAA Space Weather prediction Center data https://www.swpc.noaa.gov/