Measurement on the Geomagnetic Induced Current (GIC) at low latitude region in Malaysia

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Abstract. This paper study the existent of geomagnetic induced current (GIC) in Malaysia. The location for GIC measurement is conducted at Tenaga Nasional Berhad (TNB) substation 33KV transformer in Malaysia. The measurement is taken at the neutral cable of the 33KV transformer which is grounded to the earth. In order to verify the result of the GIC existence, the data from GIC measurement is observed with the data from the Solar Wind and Magnetic field of the earth. The measurement is taken using the HIOKI MR 8870-20 memory recorder, CT6846-05 current clamper, and CT9555 sensor unit. The study is conducted to identify the existence of the GIC in Malaysian Power Network transformer before conducting a further study on the harmful effect of the GIC level in Malaysia on the transformer performance. The data collected from the study to analyze and plotted using MATLAB software for further observation on the GIC level.

1. Introduction
Geomagnetic Induce Current is the natural phenomenon that occurs due to the solar event from the sun that collides with the earth's magnetic field. Geomagnetic induce current affected by a solar flare, coronal holes, coronal mass injection, and magnetic cloud[1]. The existence of GIC causes harmful effects on surface technologies as well as underground equipment. In transformer performance, it is suspected that GIC cause harmful effect to the transformer such as saturation, heating, miss operation, and burn of winding of the transformer core[2]. At earth ground, a geomagnetically induced current is induced due to the change in electro-jet which affected the geo-electric field. In the transformer, GIC will move from the earth’s ground to the electrical equipment of the transformer which is harmful to the transformer. GIC is a quasi-direct current that creates an offset to the regular AC current and leads to the half-cycle saturation in the transformer[3]. Figure 1 shows the GIC movement in 3 phase transformers.

Figure 1. GIC movement in between 3 phase transformer.
In low latitude region such as in Malaysia, GIC study is still in early-stage and findings on the existence of GIC in the transformer is vital. In case of the existence of GIC in Malaysia, it will gain awareness from people on the importance to provide sufficient protective equipment to prevent worst-case from GIC. The worst-case from the GIC is way back on 13 March 1989 where the high GIC current form and caused electrical system blackout in the entire zone of Quebec, it causes damage to the large step-up transformer on the generation side in power system[2]. Figure 1 shows the GIC movement in 3 phase transformers. GIC will flow from a high resistance pathway to a low resistance pathway through neutral cable and escape from the transformer through the other neutral cable[2]. GIC will find the easiest direction to enter and exit the transformer. In Quebec power station, it is estimated the dB/dt during the impact from s occurrence is 479nT/min. Sudden impulse (SI) and storm sudden commencement (SSC) also encourage the GIC to occur[4][5].

2. Background Study on Geomagnetic Induce Current (GIC)
Maxwell faraday law which state that time based magnetic field will generate induction electric fields. GICs are given by free $\vec{J}$ which can be obtained by multiplying ground conductivity structure ($\sigma$), electric field ($\vec{E}$) and magnetic field ($\vec{B}$) at the point simultaneously. Equation 1 is based on Maxwell faradays law while equation 2 based on ohms law which is current form dependent on the medium’s conductivity structure.

$$\vec{V} \times \vec{E} = - \frac{\partial \vec{B}}{\partial t} \quad (1)$$

$$\vec{J}_{free} = \sigma \vec{E} \quad (2)$$

Thus, the study of GICs requires at least one magnetometer measurement for the magnetic field components[6]. Then, assuming a conductivity structure, the electric field and GICs can be calculated using several methods; the simplest one being the plane-wave approach. The magnetic field we measure on Earth is the superposition of the Earth’s magnetic field (aka the main field), ionospheric currents, field-aligned currents (at high latitudes), and the geomagnetic induce currents. The frequency of geomagnetic variations is less than 1 Hz, and the GIC frequency range is typically between 0.01-0.0001 Hz. As a result, they are treated as quasi-de currents.

3. Methodology
The GIC measurement at the TNB substation required to support data from the solar events and magnetic field variation of the earth. During the measurement, it is compulsory to compare the data from GIC measurement with the data from the solar events and magnetic fields. This is due to the GIC induction is causes by solar event and magnetic field changes.

3.1. Installation of the Measurement Equipment at the TNB substation at Hotel UiTM Shah Alam
The data logger used for GIC measurement is HIOKI MR8770-20, The Current clamper used for the measurement is from CT6846-05 where the resolution for the current clamper is around 2mV/A. The current clamper is linked to the data logger through the CT9555 sensor unit where it will limit the input ADC value to prevent any equipment failure. Figure 2 shows the equipment set up at the ground station for GIC measurement from 10 AM 22th to 10 AM 24th October 2019.
Figure 2. Shows the GIC measurement setup at 33KV TNB transformer 10 AM 22nd to 10 AM 24th October 2019.

The 3 phase transformer is having a wye connection where measurement is connected to the neutral cable. From this measurement, it is compulsory to do some research and consult authorized employee that has a lot of knowledge on the ground station. The ground station worker will help to identify the exact location for the measurement setup. Figure 3 shows the TNB substation power flow layout for the GIC measurement. The location of the measurement is exactly in between the two 3 phase wye connection transformer as illustrated in Figure 3.

Figure 3. TNB substation power flow layout for GIC measurement

The high voltage transformer is quite dangerous and generating a lot of power which is dangerous to human activities[7]. The reason for choosing the high voltage Transformer for GIC measurement is due to the higher voltage value, the number of winding turns, and the possibilities to gather a bigger GIC. GIC flow in transformer architecture of bulk power system through winding where the GIC in the winding might increase. More current formed in the winding, more magnetic flux will be generated and will cause partial saturation [8]. Figure 4 shows the 33KV TNB transformer where the measurement is conducted.
3.2. Solar Event During GIC measurement

Solar event from the sun is the factor that affected the reading of the GIC. The solar wind continuously flows outward from the sun and consists mainly of photons and electrons in plasma and flows outward with the solar wind. Different regions of the Sun produce solar winds at different speeds and densities[9]. During the Measurement Setup at the ground station, the solar event is quite calm and producing solar wind speed below 400Km/s. The speed with is below 400km/s is considered as the low-speed solar wind. The low-speed solar wind is calm and usually, only high-speed solar wind higher than 800km/s will cause fluctuation on the GIC and magnetic field variation[9][10]. The data from the solar event will be used to study magnetic field variation together with the data from the magnetic field and GIC. Figure 5 shows the solar wind event on 23rd October 2019 which is during the calm state.

Figure 5. Shows the solar event on 23rd October 2019 during GIC measurement. (Source: SolarMonitor.org. (2019). Retrieved from: https://www.solarmonitor.org/full_disk.php?date=20191023&type=saia_00193&region= )
3.3. Gathered Magnetic field data from MAGDAS Langkawi and Banting to observe with GIC measurement

During the GIC measurement, magnetic data are gathered from the magnetic data acquisition system (MAGDAS) Langkawi (LKW) and Pusat Angkasa Negara, Banting (BTG) to become references for GIC measurement. The location of the Langkawi National Observatory (LNO) where MAGDAS is located is around 410.06KM from the GIC measurement ground station. The other MAGDAS station that was becoming the reference for GIC measurement is from Pusat Angkasa Negara, Banting (BTG) location around 31.35KM from the GIC measurement ground station. Figures 6 and 7 show the distance between LKW and BTG MAGDAS station with GIC measurement location.

![Figure 6. Location of MAGDAS BTG north-west of peninsular Malaysia](image1)

![Figure 7. Location of MAGDAS LKW north-west of peninsular Malaysia](image2)

The distance of the MAGDAS station both located in Malaysia where the LKW having Malaysia (geographic latitude and longitude: 5.117N, 100.00E and geomagnetic latitude and longitude: 4.32S,
173.07E) and BTG (geographic latitude and longitude: 5.117N, 100.00E and geomagnetic latitude and longitude: 4.32S, 173.07E). Table 1 summarize geographic and geomagnetic latitude and longitude on the location of LKW, BTG, and location of GIC measurement.

**Table 1.** Geographic and Geomagnetic Location of LKW, BTG and GIC Measurement at TNB Substation

| Latitude/ longitude | Location | LKW | BTG | TNB substation |
|---------------------|----------|-----|-----|----------------|
| GG latitude(◦)      | 6.3      | 2.78| 3.117|                |
| GG longitude(◦)     | 99.78    | 101.51| 101.00|               |
| GM latitude(◦)      | 3.30     | 6.86| 6.26 |                |
| GM longitude(◦)     | 172.44   | 174.10| 173.65|               |

### 4. Result and Discussion

The discussion on the result is divided into 2 sections which are the discussion on the GIC data from section 4.1. Section 4.1 also discussed the Plotted GIC data with MAGDAS data from LKW and BTG. Section 4.2 discussed the level of severity of Solar Wind that impacted the earth’s magnetic field. The data included during the discussion on section 4.2 include the interplanetary magnetic field, Bz (nT), Solar Wind speed (km/s), and also solar wind flow pressure level. The data included will be discussed together with the references from the author that study the cases.

#### 4.1. Plotted graph of GIC data, GIC data with MAGDAS data and symmetrical index of H

Figure 8 shows the data on the GIC level during the measurement from 10 AM 22nd to 10 AM 24th October 2019. Based on the data collected. It is observed that the measurement consists of positive and negative value. The data collected is from the neutral cable of the 33KV transformer. Based on the data collected, fluctuation existed on the positive side and the negative side of the data.

![Figure 8. Show the data from GIC measurement at the 33KV transformer](image)

The data collected is in the AC waveform, according to T.J. Overbye and K. S. Shetye, in high voltage transformer, the quasi-dc GIC produces an offset on the regular AC current that can lead to half-cycle saturation[3]. Therefore, the existence of the GIC is the mixture between the AC current with the GIC.
Based on the data collected, the positive current spikes as high as 24 Amps and negative current spikes as high as -25.2 Amps. According to C. Barbosa and L. Alves, GIC data that have been gathered from solar cycle 23 and 24 which is consisting of 270658 data and only 219 exceed 10A, the GIC values is between 1A to 30A range [11]. The study has been conducted at the low latitude region and the reading existed is in the form of the spike as well as the reading is taken from the GIC measurement conducted. Based on the data collected, the total data collected from positive current is 190107 and the total data that exceed 10Amps is around 17 data while on the negative side, the total data collected is 190107 and the value that lower than -10A is 22 data. Therefore, the data from the measurement produce spikes that are harmful to the operating system of the transformer. This spike could cause transformer saturation, heating, miss operation, and burn of winding of the transformer core[2]. The measurement is conducted at the 33kv transformer and might be higher if conducted at the higher voltage transformer. Due to the abnormal reading from GIC measurement, the measurement data need to be compared with the magnetic field and solar event data for further analysis. Figure 9 compares the data from GIC measurement with the data from MAGDAS LKW and BTG. This measurement is needed due to the relationship between the solar wind impact on Magnetic field and GIC occurrence. Together with the plotted data is the SYM/H(nT) which is the symmetric disturbance field from the solar event data. The data were collected from 22nd to 24th October 2019, during the measurement, it can be observed that the SYM/H (nT) is stable and off the pattern on 23rd October 2019 which might be due to the cloudy atmosphere. In the case of the solar event, SYM/H (nT) will spike above 10nT, however, during the measurement, the reading of the SYM/H (nT) is below 10nT.

The pattern from the LKW and BTG is high at day time and decrease at night time as well as the measurement at neutral cable which is low at night time and high at day time. Based on the LKW and BTG data, there is no solar event occurs during the GIC measurement. Both LKW and BTG produce calm data and only small spikes existed on the BTG magnetic field data.
4.2. Plotted Solar Event data from 22\textsuperscript{th} to 24\textsuperscript{th} October 2019

Figure 10 shows the plotted solar event which is the interplanetary magnetic field (Bz), solar wind speed, and solar wind flow pressure. Based on the data collected, solar wind speed is below 400km/s which is considered as low-speed solar wind\cite{9}. The range of the solar wind speed in between 319.4km/s to 370.3km/s. The interplanetary magnetic field, Bz (nT) in Figure 10 is still calm, during the high-speed solar wind the fluctuation of the Bz (nT). Solar wind flow pressure is also calm, during high-speed solar wind, flow pressure able to reach higher than 10 nPa. The highest value from solar wind flow pressure is 3.22nPa and the lowest one is around 0.63 nPa.

![Figure 10. Show the plotted Solar Event data which is interplanetary magnetic field, Bz, solar wind speed and solar wind flow pressure](image)

4.3. Findings from the GIC measurement

Based on the plotted data, the solar event is in a calm situation during GIC measurement. The situation of the solar event can be observed directly by looking at the plotted solar event and H(nT) data. Usually, during the solar storm, solar events and H(nT) will fluctuate. During the GIC measurement, the pattern from the measurement and the spikes existed is as the study cases study by C.Barbosa and L.Alves on solar cycles 23 and 24\cite{11}. Table 2 shows a summary of the data collected from GIC measurement, Magnetic field, and solar event parameters.

| Parameters          | GIC Current (A) | H (nT) BTG | H (nT) LKW | Bz, nT | Solar Wind speed | flow pressure | SYM/H (nT) |
|---------------------|-----------------|------------|------------|--------|-----------------|---------------|------------|
| Highest reading     | 1A to 24 A      | 41368.66   | 41741.23   | 3.98   | 370.3           | 3.22          | 8          |
| Lowest reading      | -1.6A to -25.2 A | 41289.27   | 41635.56   | -3.19  | 319.4           | 0.63          | -11        |

Table 2. The summary on the data collected from GIC measurement, magnetic field and solar event parameters.

Therefore based on the study on the real-time measurement, it can be concluded that the reading during the measurement for GIC on AC current on the positive side in between 1A to 24A and negative side from -1.6A to -25.2A. During the measurement, at day time the reading on GIC measurement is higher...
compared to the night time. Based on the study, the GIC reading higher at day time is due to the exposure to the solar radiation, during the exposure it cause magnetic variation increased which is corresponds to the increase in ionospheric current in the E-layer of the ionosphere. However at night time, there is no solar radiation, the ionospheric electric current is not flowing and causes low electron density in the ionospheric layer[12]. H(nT) from MAGDAS LKW and BTG is also increasing at day time due to the high ionospheric current at day time. The reading of the H(nT) BTG is between 41289.27nT to 41368.66nT and the reading of H(nT) from MAGDAS LKW is between 41635.56nT to 41741.23nT. Based on the solar wind parameters, the event occurs is low-speed solar wind due to the solar wind speed below 400km/s. In order to observe the high-speed solar wind, the measurement needs to place from 1 to 6 months to observe better results for GIC measurement. Section 4.1 shows the plotted graph of GIC measurement, Magnetic field, and symmetrical index data. It is positive that the pattern from the GIC measurement data is high at night time and low at day at the location of the measurement. This provides a clear indication that the GIC current existed at the neutral point of the transformer. However, the level of the GIC is not yet known and further study on the GIC level at the neutral point of the transformer in the Malaysian power network needs to be conducted. Furthermore, the measurement of the GIC is the mix of AC and DC current. The author needs to find the level of the DC alone which caused GIC formation by following the established method. Section 4.2 discussed on the plotted solar event data during GIC measurement. The pattern from the solar event is during calm space weather and not at the solar storm stated. Therefore, the study on the GIC can be studied during the solar storm and the possibilities of gathering high GIC magnitude is possible. Finally section 4.3 summarises the data from section 4.1 and section 4.2. The measurement on the GIC shows the existent of the GIC current at the Malaysian Power network transformer.

5. Conclusion
Based on the data collected from GIC measurement, GIC current existed in the Malaysian Power Network. However, the reading of GIC is mixing with the AC current due to the measurement at the transformer. Based on the comparison of the data from GIC measurement with the magnetic field and solar event data. The pattern from the GIC measurement is higher at day time compared to the night time. The pattern of GIC measurement data is similar to the pattern of the magnetic field data. This situation occurs to the ionospheric current from solar radiation exposure is higher at day time compared to the night time. For future work, the author would like to measure the neutral cable of the transformer for a longer period of time and might be measuring the GIC at the higher rating step-up transformer at the TNB substation.

6. Acknowledgement
First, the author would like to thank the Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), members of the Centre for Satellite Communication and Fundamental Research Grant Scheme (FRGS) 600-IRMI/FRGS 5/3 (017/2019) UiTM for the opportunity to participate in this project. I also would like to thank the Tenaga Nasional Berhad (TNB) for endless support during the project installation. The author also would like to give an acknowledgment to the National Space Agency (ANGKASA) and Langkawi National Observatory (LNO) for allowing to gather the Magnetic field data from MAGDAS station.

7. References
[1] Z. I. A. Latiff, N. M. Anuar, M. H. Jusoh, and S. A. E. A. Rahim, “Latitudinal investigation on the variation of solar wind parameters towards geomagnetically induced currents during 7-8 September 2017 disturbed period,” ICSET 2018 - 2018 IEEE 8th Int. Conf. Syst. Eng. Technol. Proc., no. September 2017, pp. 123–127, 2019.
[2] J. A. Patel, R. S. Mehta, S. B. Rathod, K. J. Patel, V. N. Rajput, and K. S. Pandya, “Analysis of geomagnetically induced current in transformer,” Int. Conf. Electr. Electron. Optim. Tech. ICEEOT 2016, pp. 3909–3912, 2016.
[3] T. J. Overbye, K. S. Shetye, T. R. Hutchins, Q. Qiu, and J. D. Weber, “Power grid sensitivity analysis of geomagnetically induced currents,” IEEE Trans. Power Syst., vol. 28, no. 4, pp.
4821–4828, 2013.

[4] R. A. Marshall, M. Dalzell, C. L. Waters, P. Goldthorpe, and E. A. Smith, “Geomagnetically induced currents in the New Zealand power network,” Sp. Weather, vol. 10, no. 8, pp. 1–13, 2012.

[5] R. A. Marshall et al., “Observations of geomagnetically induced currents in the Australian power network,” Sp. Weather, vol. 11, no. 1, pp. 6–16, 2013.

[6] E. C. Kalafatoglu, Z. Kaymaz, A. C. Moral, and R. Caglar, “Geomagnetically induced current (GIC) observations of geomagnetic storms in Turkey: Preliminary results,” RAST 2015 - Proc. 7th Int. Conf. Recent Adv. Sp. Technol., pp. 501–503, 2015.

[7] S. M. Korobeynikov, N. Y. Ilyushov, Y. A. Lavrov, S. S. Shevchenko, and V. A. Loman, “High-Frequency Transients Suppression at Substation,” ICHVE 2018 - 2018 IEEE Int. Conf. High Volt. Eng. Appl., 2019.

[8] N. Mohd Anuar et al., “Assessment of the Geomagnetically Induced Current (GIC) at Low Latitude Region based on MAGDAS Data,” J. Phys. Conf. Ser., vol. 1152, no. 1, 2019.

[9] R. Umar et al., “Magnetic Data Acquisition System (MAGDAS) Malaysia: installation and preliminary data analysis at ESERI, UNISZA,” Indian J. Phys., vol. 93, no. 5, pp. 553–564, 2019.

[10] R. Lukianova, L. Holappa, and K. Mursula, “Centennial evolution of monthly solar wind speeds: Fastest monthly solar wind speeds from long-duration coronal holes,” J. Geophys. Res. Sp. Phys., vol. 122, no. 3, pp. 2740–2747, 2017.

[11] C. Barbosa, L. Alves, R. Caraballo, G. A. Hartmann, A. R. R. Papa, and R. J. Pirjola, “Analysis of geomagnetically induced currents at a low-latitude region over the solar cycles 23 and 24: Comparison between measurements and calculations,” J. Sp. Weather Sp. Clim., vol. 5, 2015.

[12] S. N. Ibrahim et al., “First geomagnetic observation at sabah, malaysia by using MAGDAS array,” Int. J. Simul. Syst. Sci. Technol., vol. 17, no. 41, pp. 30.1-30.8, 2017.