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The first solar-powered Magdas-9 installation and possible geomagnetically induced currents study at Johor, Malaysia

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Abstract. The Magnetic Data Acquisition System (MAGDAS-9) was successfully installed at Universiti Teknologi MARA Johor, Pasir Gudang Campus, Malaysia (JOH station), under the joint collaboration between International Center for Space Weather Science and Education (ICSWSE), National Space Agency (ANGKASA) and UiTM Johor. This is the first solar-powered magnetometer under the Magnetic Data Acquisition System of Circum-pan Pacific Magnetometer Network (MAGDAS/CPMN). In this paper, construction process, installation process and analysis of first geomagnetic observations at MAGDAS JOH station are presented. In addition, analysis on time derivative of horizontal component of geomagnetic field (dH/dt) to indicate the possibility of Geomagnetically Induced Currents (GIC) occurrences is also presented in this paper. The obtained geomagnetic components: H, D, Z and Total F are approximately similar to World Magnetic Model 2015 (WMM2015) while the diurnal variation from this geomagnetic observation showing a good variation pattern. The analysis of dH/dt has indicated 2 significant events of GIC.

1. Introduction
MAGDAS is a real-time Magnetic Data Acquisition System introduced by International Center for Space Weather Science and Education (ICSWSE) which was deployed for the International Heliophysical Year programme (IHY; 2007-2009) [1][2][3]. By using MAGDAS system, a few scientific objectives can be conducted which are a real-time monitoring and modelling of (1) the global 3-dimensional current system, (2) the ambient plasma density and (3) electric field in order to understand Sun-Earth Coupling System[4]. In present, MAGDAS/CPMN was constructed along the 3 unique chains of magnetic observatories; (1) 210° magnetic meridian, (2) African Longitude Sector and (3) Magnetic Equator as shown in Figure 1[5]. Currently 73 stations are actively operating.

1.1 Installation of MAGDAS in Malaysia
Until December 2017, there are five (5) installed MAGDAS’s magnetometers in Malaysia. Malaysia is a strategic location for the magnetometer installation due to its geographic location that is near to the geomagnetic equatorial. On 8th September 2006, the first MAGDAS magnetometer was installed in Malaysia which is located at the Langkawi National Observatory (LNO), Langkawi district (LKW) at Kedah state. The geographic and geomagnetic latitudes coordinates of LKW station are (6.30°, 99.78°) and (-3.30°, 172.44°) respectively. Next on 30th March 2013, the second installation of MAGDAS-9
magnetometer was installed in Universiti Malaysia Sabah (UMS), Sabah (SBH). The geographic and geomagnetic latitudes coordinates of SBH station are (6.02º, 116.07º) and (-3.56º, 188.66º).

Next, on 19th November 2016, installation of fourth MAGDAS II magnetometer in Malaysia is located in Agensi Angkasa Negara (ANGKASA) at Banting, Selangor state, (BTG) station. The geographic and geomagnetic latitudes coordinates of BTG station are (2.78º, 101.53º) and (-6.86º, 174.10º) respectively. The latest installation was at UiTM Johor Kampus Pasir Gudang, (JOH) station on 17th February 2017. JOH station uses the latest ICWSE magnetometer called MAGDAS-9. MAGDAS-9 is more sensitive and provides accurate geomagnetic field data. The geographic and geomagnetic latitudes coordinates of JOH station are (1.53º, 103.87º) and (-7.99º, 176.79º) respectively. This station was selected for MAGDAS-9 magnetometer installation due to a few requirements which are to fill in observation gap between Davao (DAV) station in Philippines and Manado (MND) station in Indonesia for precise geomagnetic measurement of 210º magnetic Meridian, and it is located in equatorial regions and near to geomagnetic equator. The next MAGDAS installation will be followed by “TER” station located in Universiti Sultan Zainal Abidin (UnisZa), Terengganu, Malaysia. The installation locations are selected based on the requirement for the magnetometer installation which is having low disturbance from any human activities. As shown in figure 2, it can be observed that there are a few degrees of latitude differences between all installed magnetometers covering upper, middle and lower part of peninsula of Malaysia. Table 1 shows the geographic and geomagnetic coordinates for five installed magnetometers in Malaysia.

1.2 World’s Magnetic Model
In order to validate the geomagnetic components, the results obtained from the magnetometer installed in JOH station were compared with the World Magnetic Model (WMM). The WMM 2015 is the latest world magnetic model used as standard or reference to provide information on magnetic declination at any desired location on the globe. It also provides the complete geometry of the field from 1 km below the earth’s surface to 850 km above the surface [6]. In this paper, WMM2015 is used to compare with
the geomagnetic field measurement taken at JOH station for duration of 3 months. The WMM2015 valid from 1st January of 2015 to 31st December of 2019.

Table 1. The Coordinates location of MAGDAS station in Malaysia

| Stations Location | Station Name | Abbreviation | Geographic Coordinate | Geomagnetic Coordinate |
|-------------------|--------------|--------------|-----------------------|-----------------------|
| Langkawi National Observatory (LNO), | Langkawi | LKW | (6.30º, 99.78º) | (-3.30º, 172.44º) |
| Universiti Malaysia Sabah (UMS) | Sabah | SBH | (6.02º, 116.07º) | (-3.56º, 188.66º) |
| University Perguruan Sultan Idris (UPSI), | Perak | PER | (3.72º, 101.53º) | (-5.92º, 174.14º) |
| Agensi Angkasa Negara ANGKASA, Selangor | Banting | BTG | (2.78º, 101.53º) | (-6.86º, 174.10º) |
| Universiti Teknologi MARA UITM, Johor | Johor | JOH | (1.53º, 103.87º) | (-7.99º, 176.79º) |

1.3 Geomagnetically Induced Currents (GIC)
Geomagnetically induced current (GIC) is the ground level manifestation of solar activity which potentially can cause detrimental effects to earth surface technologies and buried equipment such as power network, electrical equipment, pipelines, railways, telecommunication technology and oil and
gas technology [16-18]. During geomagnetic disturbances, the rise of solar wind input energy contributes to rapid changing of magnetic fields and subsequently the GIC will be generated through a process called electromagnetic induction. The phenomena of GIC can be linked with the Faraday’s Law of induction where the induced electric field on the earth’s surface can be computed from the rate of change of magnetic field as presented in eq. 1.

\[ \nabla \times E = -\frac{\partial B}{\partial t} \]  \hspace{1cm} (1)

GIC are also considered as quasi-dc current because of their low frequency characteristic and it flows along electric transmission lines and electrically-conducting infrastructure.

2. Methodology

2.1 Overview of Magnetometer System in MAGDAS

As mentioned in [7], MAGDAS system is a real time monitoring system where the measured data is sent to ICSWSE via the internet. The MAGDAS-9 is a second generation of magnetometer system after the first generation of magnetometer system called MAGDAS-I. As presented in figure 3, MAGDAS-9 unit consists of 3-component ring-core fluxgate type magnetic sensor (magnetometer) with 7 meter cable, pre-amplifier (preamp), GPS (Global Positioning System) antenna with cable, data logger for data control and 70 meter cable. The type of geomagnetic sensor used is 3-axial components ring-core flux gate with ±70,000nT/32bits dynamic range and a 0.01nT resolution. The magnetic field data are obtained with the sampling rate of 16 Hz and then the averaged data are transferred to ICSWSE at real time. The ambient magnetic fields expressed by H (geomagnetic northward), D (geomagnetic eastward) and Z (vertical downward) are digitized by using field-cancelling for the dynamic range of ±70,000 nT/32 bits [7][8].

![Figure 3. The component of MAGDAS-9 magnetometer system](image-url)
2.2 Installation of MAGDAS-9 at JOH station

The first job that need to be implemented before installing the magnetometer in JOH station was surveying the potential location for instrument placement. For the isolation of noise or interferences contributed by external factor, the criteria of placement that need to be considered is (1) the distance from the sea must be greater than 1000 meter to minimize the noise and avoid the effect from the sea [9] and (2) distance from road or building must be more than 100 meters to minimize the noise contributed by human activities [10]. For the installation of MAGDAS-9 in JOH station, the magnetometer sensor is placed around 10 kilometres from the sea, 700 metres from nearest building and 3 kilometres from main road. The location of MAGDAS-9 installation at JOH station is as illustrated in Figure 4.

The architecture layout of MAGDAS-9 is as illustrated in figure 5. The installation of MAGDAS-9 can be divided into 3 stages which are (1) Construction of data logger cabin, pre-amplifier hut and sensor hut, (2) Installation of solar panel and (3) Installation of MAGDAS-9 unit. The cabin is where the data logger and GPS are placed. They are connected to the Amplifier Hut and Sensor Hut where the pre-amplifier and the magnetometer sensor are set up. The distance between data logger cabin and pre-amplifier hut is 40 meters while the distance from pre-amplifier hut to sensor hut is about 5 meters.

2.3 Horizontal component of geomagnetic field

The horizontal component of geomagnetic field is extracted from the Johor station (JOH), one of the observatories under the MAGDAS network and it can be obtained from Eq. 2. In this study, in order to identify the possibility of GIC’s occurrence, time derivative of horizontal component of geomagnetic field (Eq. 3) was used. Previous studies [17, 19-24] discovered that the time derivative of horizontal component exceeding 30 nT/min (dH/dt > 30 nT/min), indicates the possibility of GIC presences at the ground surface thus can cause an adverse effect to power network. Therefore in this study, H-component data ranged from March 2017 to October 2017 were observed and the derivative of H-component was performed.
3. Result and Discussion

3.1 First observation at JOH station

In this paper, the preliminary results of geomagnetic components; H, D, Z and Total F obtained from the first MAGDAS-9 measurement at JOH station are presented. Figure 6 shows the geomagnetic observations obtained by using MAGDAS-9’s magnetometer from 13 June 2017 – 17 June 2017. As seen on Figure 6, the variation of H, D, Z and total F for above mentioned date shows a similar pattern and consistent for each component. The variation of obtained geomagnetic component values are tabulated in table 2. The value of geomagnetic components; H, D, Z and Total F are approximately similar to the WMM2015 (figure 7). Based on this model, Malaysia is located in ranges of between ± 40000 nT for H and F elements. As seen on table 2, the acquired value of H and Total F elements are almost identical. These results can be related to the main field of inclination (I) of WMM2015 as shown in figure 8 and the formula of inclination, I by [11] as presented in Eq. 4:

\[ \cos I = \frac{H}{F} \]  

where the degree of inclination (I) is approaching 0 for Johor area since the obtained value for H and F elements from the geomagnetic measurement in JOH station is almost similar. Next analysis is on the diurnal variation where the analysis is performed based on the data collected on 15 June 2017. As indicated in figure 9, diurnal variation of geomagnetic components H, D, Z and F are observed in 24 hours local time (LT). The amplitude of each geometric component element indicates increment during daytime from 0800 LT to 1400 LT. From the observation, the highest amplitude of geomagnetic component is during noon time. During night-time, low variation of geomagnetic component is observed from 1900 LT to 0700 LT. For H component, the highest peak value is \(4.081 \times 10^4\) nT during noontime (1200LT to 1300LT). The amplitude of declination (D) component during peak hour (1100LT) is approaching to 0 nT. The highest amplitude for the Z component is
− 9760 nT at 1400LT. As for F element, the amplitude and peak hour is almost identical with H element. During night-time, the variation of geomagnetic components is maintained from 1900LT to 0700LT.

Table 2. The variation of geomagnetic components based on the first observation at JOH station

| Geomagnetic Component | Geomagnetic Variation (nT)          |
|-----------------------|------------------------------------|
| H component           | $4.078 \times 10^4$ nT until $4.085 \times 10^4$ nT |
| D component           | −38 nT until 10.24 nT              |
| Z component           | −9778 nT until −9753 nT            |
| Total F               | $4.192 \times 10^4$ nT until $4.196 \times 10^4$ nT |

Figure 6. Geomagnetic data obtained from MAGDAS-9’s magnetometer from 13 June 2017 till 17 June 2017; (a) Horizontal (H) component, (b) Declination (D) component, (c) Vertical Downward (Z) component, (d) Total Field (F) component.
Figure 7. The Mercator projection of (a) Main Field Horizontal Intesity (H). Malaysia is located in range of 40 000 nT (b) Main Field Declination (D). Malaysia lies near green line 0° (c) Main Field Down Component (Z) Malaysia lies between -20 000 to 10 000 nT (d) Main Field Total Intensity (F). Malaysia is located in range of ±40 000 nT.

Figure 8. The Mercator projection of Main Field Horizontal Inclination (I). Contour interval is 2°. The colour contour represents as red positive (down); blue negative (up) and green is zero line. Malaysia is near to 0°
3.2 Analysis on possible occurrence of geomagnetically induced currents (GIC) at JOH stations

The possibility of the occurrence of GIC at surface of the ground can be obtained by performing time derivative of horizontal geomagnetic field (dH/dt). The value of derivative, dH/dt > 30 nT indicates the presence of GIC. Based on analysis, 2 significant events with dH/dt > 30 nT and corresponding dates are illustrated in figure 10. Table 2 summarise the maximum value, dH/dt and local time for these significant events.

**Figure. 9.** Diurnal variation of geomagnetic components on 15 June 2017; (a) Horizontal (H) component, (b) Declination (D) component, (c) Vertical Downward (Z) component, (d) Total Field (F) component.
Table 3. Maximum values of $dH/dt$ from the observed event during March17-October17 with corresponding time (UT & LT)

| Date         | Maximum $dH/dt$ (nT/min) | Time (UT) | Time (LT) |
|--------------|--------------------------|-----------|-----------|
| 8 June 2017  | 32.9 nT                  | 03:30     | 11:00     |
| 4 July 2017  | 73.54 nT                 | 09:00     | 17:00     |

Fig. 10. Time derivative of Horizontal Component of geomagnetic field ($dH/dt$) exceeding 30 nT/min; (a) $dH/dt$ on 8 June 2017, (b) $dH/dt$ on 4 July 2017.

3.3 Discussion

The first observation of the geomagnetic variation obtained at JOH station shows a good representation of geomagnetic elements and approximately similar to WMM2015. The daily and diurnal variation of geomagnetic field as observed in figure 6 and figure 9 is attributed by the ionospheric dynamo [12]. Ionospheric dynamo describes the electric field and current that result from the motion of neutral atmosphere current where the electrodynamic effects arise from collisions between neutral and plasma particles contributed to the geomagnetic field variation [13]. The ionospheric dynamo usually refers to the dynamo process at E-region height. The diurnal pattern is significantly increased during day-time and almost constant during night-time. These results are consistent with the previous studies of [14] and [15]. The electron density is known to be maximum close to noon time since the E-region drift velocities are maximum due to rising of the sun at E-layer height.

The analysis on the possibility of GIC occurrence at JOH station is a preliminary study to indicate or prove the existence of GIC study at equatorial region and low latitude region. Next analysis that can be carried out is investigating the significance of space weather parameter to the GIC occurrence specifically focused on low latitude and equatorial region. By performing this kind of analysis, an understanding on physical mechanism between the space weather parameter and GIC occurrence can be developed.

4. Conclusion

A MAGDAS-9 magnetometer is successfully installed at JOH station on 17th February 2017. Based on the first observations conducted at JOH station, it indicates reliable pattern of geomagnetic components. The amplitude variation of each geomagnetic component indicates an approximation to WMM2015. Therefore the observed data at JOH station are reliable and acceptable to be analysed for any related geomagnetic research purposes. The analysis on possibility of GIC occurrence have shown the existence of Geomagnetically Induced Currents at JOH station, therefore analysis can be extended.
into low latitude and equatorial region and also understanding on the physical mechanism beyond the generation of GIC.

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