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Estimation of Geomagnetically Induced Currents Affect on Power Grid Based on Measurements of Mid-Latitude Geomagnetic Observatories

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***Abstract* — The estimation of geomagnetically induced currents that can affect the power grid system was conducted based on measurements from mid-latitude geomagnetic observatories in this study. To accomplish this, the grid line in the territory of Amaty oblast, Kazakhstan, was selected, and the geophysical conditions in the region were investigated. It was determined that due to geomagnetically active periods, Kazakhstan's energy systems affect by geomagnetically induced currents for a significant duration that depends on the geomagnetic storm value and time of its lasting, with the rate of geomagnetic field changes exceeding 17 nT/min. And the value of the geomagnetically induced currents can vary from fractions of mA to tens of mA.**

Keywords — geomagnetically induced currents, overhead power transmission line, geomagnetic storm

I. Introduction

The release of strong magnetic cloud due to flares at intense Solar periods leads to perturbations in the magnetic field of Earth. These perturbations give rise to varying currents within the ionosphere and magnetosphere. That leads to the negative effect of the occurrence of geomagnetically induced currents (GIC) in conductive ground networks [1-2].

GIC research in the high latitude area began after the disaster pin the Quebec energy system (Canada), which occurred one and a half minutes after the start of a very large magnetic storm (historically referred to as a “great” magnetic storm) on the night of March 13-14, 1989. The storm was caused by powerful proton flares of X-class and M-class on the Sun [3].

Studies of geomagnetically induced currents in Europe, including Sweden [4], Austria [5], Greece [6], and in Brazil [7], Japan [8], South Africa [9], Australia [10], and New Zealand [11], have shown that induced currents, reaching magnitudes of tens of amperes, can occur at middle and low latitudes. A study conducted by Chinese scientists has revealed that the topology and parameters of the power system are key factors influencing GIC levels at medium and low latitudes, and significant GICs can be observed in these regions [12].

In regions at medium and low latitudes, large geomagnetic fluctuations are caused by increased ring current resulting from intense solar wind flows.

In this research, we estimated the influence of GICs on the power grid by utilizing measurements from mid-latitude geomagnetic observatories.

II. Measurements of Mid-Latitude Geomagnetic Observatories and GIC Estimation Model

The information obtained from four magnetic observatories belonging to the INTERMAGNET network was taken taken into consideration. These observatories include: Alma-Ata Observatory, Kazakhstan located at 43.25°N, 76.92°E, Novosibirsk Observatory located at 54.85°N, 83.23°E, Irkutsk Observatory, Russia located at 52.17°N, 104.45°E, and the Beijing Ming Tombs Observatory, Beijing, China located at 40.3°N, 116.2°E. The locations of the geomagnetic observatories are shown in Figure 1.

The considered area includes overhead power transmission lines, with a total length of 4,216,900 km (via circuits) with voltages across ranging from 0.4 kV to 500 kV. Additionally, there are 12 substations with voltages ranging from 35 kV to 500 kV, with a combined capacity of 4,894.2 MVA (figure 2).

For the estimation of GIC values we’ve used the one-layer model represented in the [20]:

$$E_x(t) = \frac{1}{\sqrt{\pi\mu\sigma}} \sum_{i=1}^{T} \left(\frac{1}{\sqrt{t-i}} U[t-i]\big(B_y[i] - B_y[i-1]\big) \right) \quad (1)$$

where $E_x(t)$ is the electrostatic field x-component, B_y is the geomagnetic field y-component, U is the potential and σ is the electric conductivity of the ground.

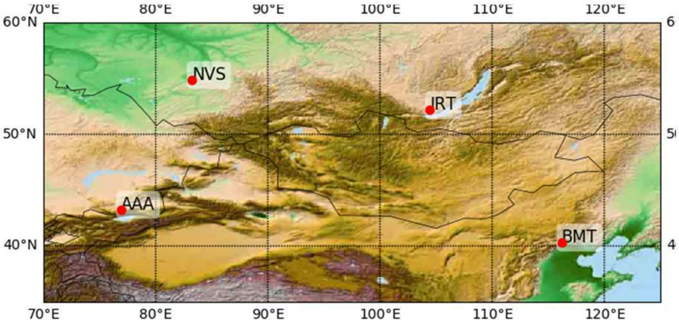

Fig. 1. Location of Alma-Ata Geomagnetic Observatories (AAA), Novosibirsk (NVS), Irkutsk (IRT) and Beijing Ming Tombs, Beijing (BMT).

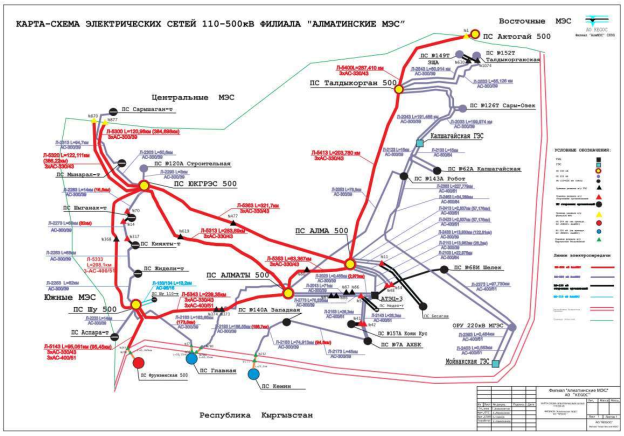

Fig. 2. Overhead power transmission lines.

III. Results and Discuttion

Founded on measurements of the geomagnetic field characteristics, calculations were conducted to determine the value of geomagnetically induced currents. The minute values of the northern X and eastern Y components of the magnetic field were used for these calculations. Based on the data obtained from the four observatories, the induced electromotive force (EMF) values were calculated for very large geomagnetic storms. An analysis was conducted on the fluctuations in the horizontal component (H) of the magnetic field vector and its rate of change over time (dH/dt). Histograms were constructed to illustrate the distribution of |dH/dt| and the directions of H and dH/dt. In Figure 3a, the histograms display the distribution of |dH/dt| based on the data from the selected observatories during the magnetic storm that occurred on May 12-13, 2021. Figure 3b presents histograms of the distribution of dH/dt directions for the same observatories during the same magnetic storm on May 12-13, 2021.

During significant geomagnetic storms, Kazakhstan's energy systems experience prolonged exposure to geomagnetically induced currents, lasting from tens of minutes to several hours. The magnitude of |dH/dt| during these events can reach or exceed 17 nT/min. The estimation of geomagnetically induced currents was done according to the assumption that the self-induction electromotive force (EMF) is directly proportional to the rate of change in magnetic field strength and computations was based on Eq. (1) and Ohm's law.

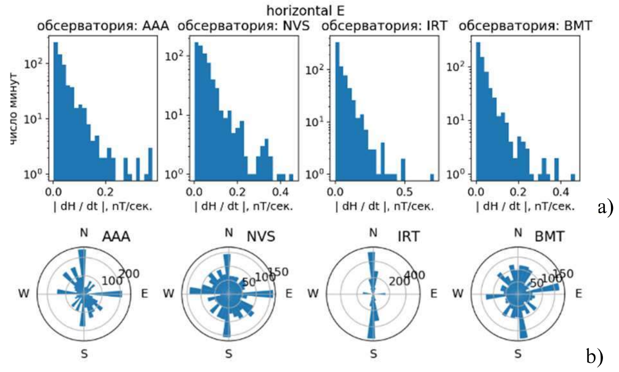

Fig. 3. Histograms of the distribution of the time derivative |dH/dt| (a) and the directions of the time derivative dH/dt (b) during the MBM on May 12-13, 2021

We conducted a study on the geomagnetically induced currents (GICs) resulting from disturbances in the geomagnetic field. The purpose was to assess the potential threat to the electric power system caused by GICs. Alongside geomagnetic variations, geoelectric changes also occur. In closed-circuit power lines spanning long distances, the geoelectric field induces currents. Therefore, calculating GICs involves two steps: determining the geoelectric field and then assessing the corresponding GIC values. In our paper [20], a retrospective analysis of the geophysical conditions from 2016 to 2021 was performed using data from the Alma-Ata geomagnetic observatory. A total of 120 geomagnetic events with disturbances in the geomagnetic field were studied, and GIC values were calculated for all these events. The study examined the characteristics of GIC occurrence at middle latitudes.

In the case of regular geophysical conditions without a magnetic storm, the amplitude of GICs rises maximally up to 0.05 mA (Figure 4-5).

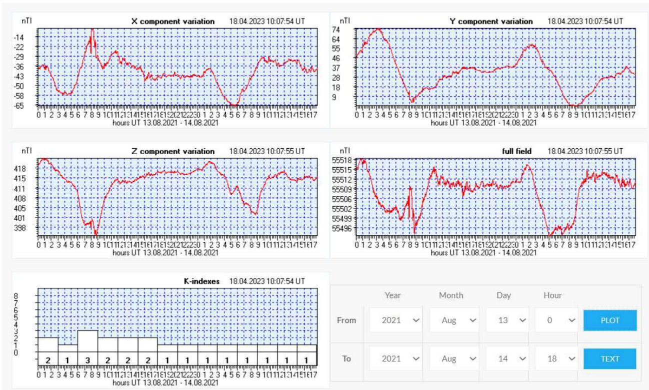

Fig. 4. Variations of geomagnrtic field at 2021.08.13 – 2021.08.14

It was observed that during large geomagnetic storms, the amplitude of GICs ranged between I = 0.4-0.6 mA (figure 6). For example, during large geomagnetic storm at 2017.09.07 – 2017.09.09 (figure 7) the amplitude of GIC variation rises till 0.4 mA. For average magnetic storms, the amplitude was approximately I = 0.1-0.3 mA. The example of geomagnetic field parameters and GIC variation shown in the figures 8-9. During weak magnetic storms, the amplitude values varied between (0.06 - 0.15) mA (figures 10-11).

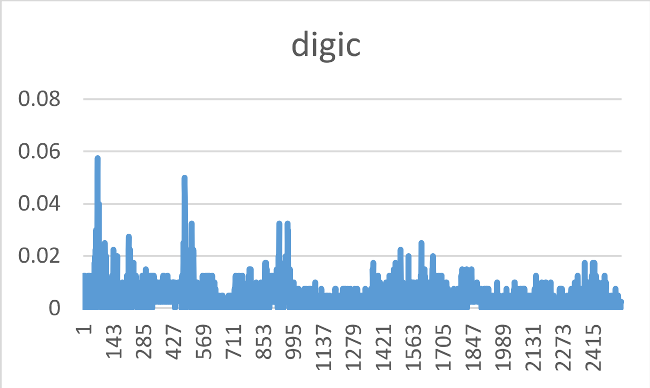

Fig. 5. Variations of GIC induced by geomagnetic field variations at 2021.08.13 – 2021.08.14

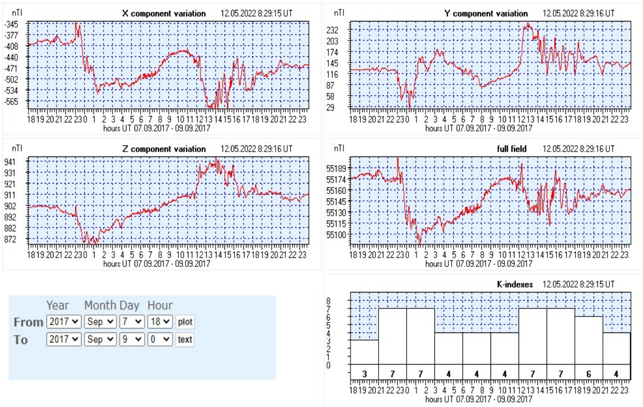

Fig. 6. Variations of geomagnrtic field during large geomagnetic storm at 2017.09.07 – 2017.09.09

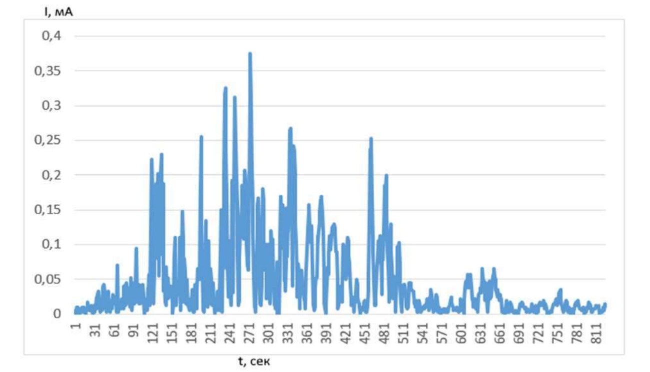

Fig. 7. Variations of GIC induced by geomagnetic field variations during large geomagnetic storm at 2017.09.07 – 2017.09.09

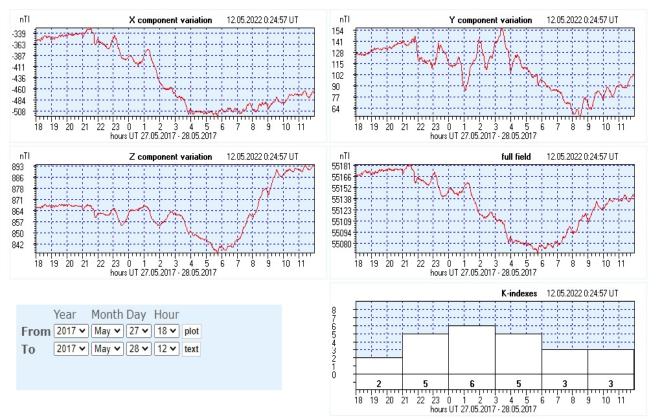

Fig. 8. Variations of geomagnrtic field during average geomagnetic storm at 2017.05.27 – 2017.05.28

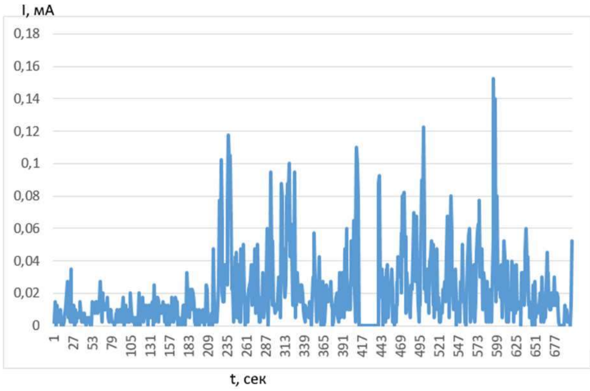

Fig. 9. Variations of GIC induced by geomagnetic field variations during average geomagnetic storm at at 2017.05.27 – 2017.05.28

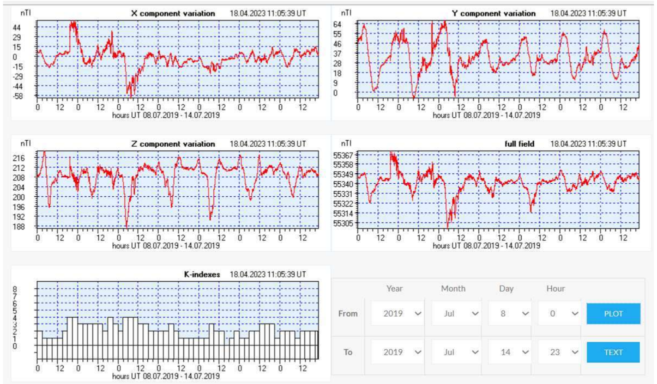

Fig. 10. Variations of geomagnrtic field during small geomagnetic storm at 2019.07.08 – 2019.07.09

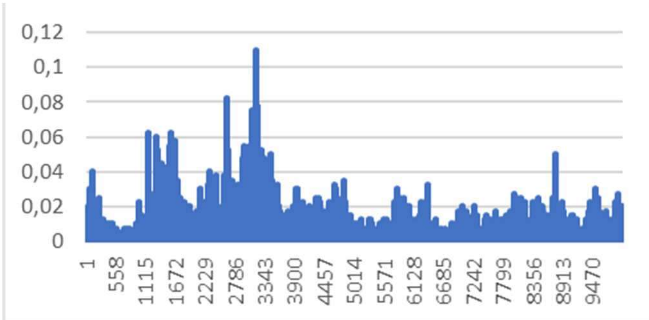

Fig. 11. Variations of GIC induced by geomagnetic field variations during small geomagnetic storm at 2019.07.08 – 2019.07.09

In cases of storms with sudden onsets at 2018.08.25 – 2018.08.26 (figure 12), the induced current amplitude occasionally increased up to I = 0.75 mA (figure 13).

Generally, the value of GICs is dependent on the intensity of the geomagnetic storm, although there are some exceptions. For instance, a storm with a sudden onset, classified as a weak geomagnetic storm according to the planetary index, exhibited a higher GIC value than during a large geomagnetic storm. The detailed estimations provided by the authors in their article [13], it shown there that the GIC values can range from fractions of mA to tens of mA.

During extremely severe geomagnetic storms, the energy systems in Kazakhstan experience prolonged exposure to geomagnetically induced currents (GIC) that can last from tens of minutes to several hours. This occurs when the magnitude of the rate of change in the horizontal component of the magnetic field (|dH/dt|) reaches 17nT/min or higher.

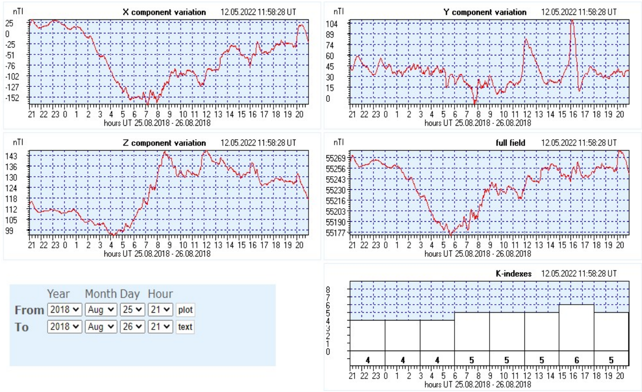

Fig. 12. Variations of geomagnrtic field during storm with sudden onsets at 2018.08.25 – 2018.08.26

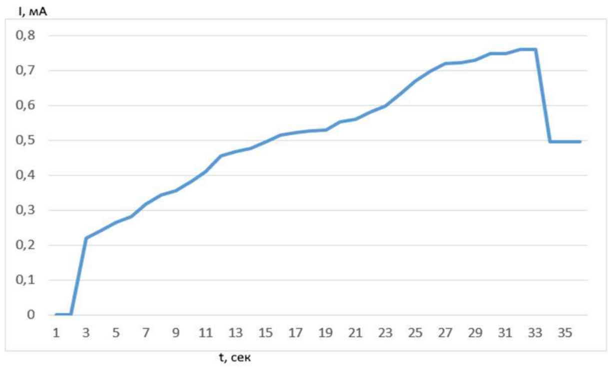

Fig. 13. Variations of GIC induced by geomagnetic field variations during storm with sudden onsets at 2018.08.25 – 2018.08.26

The estimation of GIC is based on the calculation that the self-induction electromotive force (EMF) is directly proportional to the rate of change in magnetic field strength. According to estimations done by authors, the GIC value can vary from hundreds of fractions of mA to tens of mA. For more accurate calculations, it is essential to consider factors such as the electrical system's topology, the nature of the underlying surface, and other elements that influence the susceptibility of individual components within the power system.

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