OPEN ACCESS Freely available online

Journal of Geography & Natural Disasters

ISSN: 2167-0587

Mini Review

A New Way of Protection of the Transmission Power System Against the Effects of Magnetic Storms

Daniel Mayer*

Department of Electrical Engineering and Computer Modeling, University of West Bohemia, Plzen, Czech Republic, Czechia

ABSTRACT

Severe collapses caused by anomalies in the Earth's magnetosphere, known as geomagnetic storms, have been reported in the operation of transmission power systems. A semi-saturating phenomenon occurs in which geomagnetic currents are induced very in high voltage lines, which cause the power transformers of the system to be overloaded with current and subsequently also thermally. The presented article describes a device that will either completely eliminate or at least significantly reduce the possibility of a power transformer accident. The essence of this device are frequency filters, which are automatically connected in parallel to the vhv windings of the power transformers at the beginning of the magnetic storm and are disconnected after the storm subsides. The online information about the effect of the magnetic storm on the system is provided by the indicator to the control workplace.

Keywords: Geomagnetic field; Coronal mass ejection; Geomagnetically induced currents; Magnetic semi-saturation; Frequency filter

INTRODUCTION

At present, when human civilization is heavily dependent on electrical engineering and electronics, magnetic storms can severely disrupt the functioning of various electrical engineering systems. The more advanced technology a person uses, the more vulnerable this technique is, and thus the threat of dangerous magnetic storms becomes relevant. In addition to various advanced technical devices (eg satellite of telecommunications networks, navigation systems, etc.), magnetic storms can damage electrical systems for the transmission of electricity, especially power transformers, and cause large power outages.

GEOMAGNETISM AND GEOMAGNETIC STORMS

The geomagnetic field forms the Earth's magnetosphere. The source of the geomagnetic field is both physical processes inside the Earth and physical processes in the heliosphere of the Sun. Thus, according to the source, we distinguish between internal and external geomagnetic fields.

INTERNAL GEOMAGNETIC FIELD

The idea of the Earth as a permanent magnetic dipole (William Gilbert) was abandoned after the discovery that the Earth's core had a temperature above Curie's temperature. Since 1919, a model called geodynamo has physically explained geomagnetism. According to this idea, the internal geomagnetic field is induced by the rotational flow of the Earth's liquid core around the magnetic axis. Since it is a moving electrically conductive medium that is exposed to a magnetic field (such as the Sun's magnetic field), very strong electric currents are induced in it, which generate a geomagnetic field. This relatively simple model was initially designed as stationary. However, he did not explain the well-known fact that the internal geomagnetic field changes with time there is talk of secular variations. Secular variations are very slow, being detected on a scale of tens to thousands of years. Therefore, the original idea that the geomagnetic field is induced by axially symmetrical, stationary flow was abandoned and the geodynamic model was gradually improved. Modern geodynamic theory envisages a very complex model, respecting turbulent and non-stationary magneto hydrodynamic flow. The intensity of the internal magnetic field varies with place on Earth. In our latitudes, the magnetic induction has a value of about 44 μT, at the poles around 60 μT and at the magnetic equator around 30 μT.

Correspondence to: Daniel Mayer, Department of Electrical Engineering and Computer Modeling, University of West Bohemia, Plzen, Czech Republic, Czechia, E-mail: mayer@fel.zcu.cz

Received: 23-Aug-2022, Manuscript No. JGND-22- 18976; **Editor assigned:** 26-Aug-2022, PreQC No. JGND-22- 18976 (PQ); **Reviewed:** 05-Sep-2022, QC No. JGND-22- 18976; **Revised:** 12-Sep-2022, Manuscript No. JGND-22- 18976 (R); **Published:** 20-Sep-2022, DOI: 10.35841/2167-0587.22.12.251

Citation: Mayer D (2022 A New Way of Protection of the Transmission Power System Against the Effects of Magnetic Storms. J Geogr Nat Disasters. 12: 251.

EXTERNAL GEOMAGNETIC FIELD

There are relatively fast variations of the geomagnetic field, which have their origin in solar activity. These massive explosions produce intense electromagnetic radiation in a wide range of spectra and create jets of solar matter. Solar matter containing electrically charged particles, especially electrons, protons, and high-energy alpha particles, can be torn off. They spread at high speed through interplanetary space and are referred to as Coronal Mass Ejection. Their flow is called the solar wind. If a wave of the solar wind comes close to the Earth, its internal geomagnetic field prevents electrically charged particles from hitting the Earth. Under the action of the Lorentz force, the electrically charged particles of the solar wind move in the direction of the magnetic field lines of the magnetosphere, bypass the Earth, deform the original symmetrical shape of the internal geomagnetic field and flow further into interplanetary space. The Earth's magnetic envelope thus shields the Earth from the solar wind, thus protecting the Earth's biosphere. Some of the electrically charged particles of the solar wind penetrate the higher layers of the Earth's atmosphere, turn to the Earth's magnetic poles and cause ionization of the Earth's atmosphere. The movement of electrically charged particles in the ionosphere represents an electric current that induces an external magnetic field in its vicinity. The intensity of the external magnetic field changes in the order of seconds or tens of seconds. Their amplitude varies: from small disturbances of 20 to 30 nT and occurring several times a day, to strong variations whose amplitudes can reach up to hundreds of nT–then there is talk of a geomagnetic storm.

GEOMAGNETICALLY INDUCED CURRENTS (GIC)

The geomagnetic field B(t) acts on the earth's crust and on metal structures placed above the earth's surface, eg on outdoor power lines. In this environment, an electric field E is induced, and because it is an electrically conductive environment (with conductivity $\gamma \neq 0$), Geomagnetically Induced Currents (GIC) of density J flow through it. According to the law of electromagnetic induction and Ohm's law is valid.

$$\mathrm{rot}\,\boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}, \ \boldsymbol{J} = \gamma\,\boldsymbol{E} \tag{1}$$

The magnetic induction B(t) and thus also the GIC have a random time course, and although there is talk of rapid variations in the external magnetic field, it changes relatively slowly, compared to alternating electrical quantities of industrial frequency. Depending on the time, GICs essentially behave as direct currents, we call them quasi-stationary. Only their ohmic resistances determine the distribution of GIC in the conductors of the transmission system. Inductances and capacitances of the electrical network do not affect the GIC.

EFFECT OF MAGNETIC STORM ON UNPROTECTED TRANSMISSION SYSTEM

The essence of the destructive effect of a magnetic storm on the transmission system is explained using a simple single-phase model of the system according to Figure 1. A source of harmonic voltage u(t) of frequency f supplies electrical power to the system a long line of vhv to the place of consumption, where vhv/lv is transformed and supplies the distribution network, from which electricity is taken by individual consumers. A magnetic storm characterized by magnetic induction B(t) acts on this transmission system. Vector B is a superposition of the internal magnetic field and the external magnetic field (it changes "slowly" with time, it is quasi-stationary). Only its vertical component Bz(t) is applied in Figure 1. In the loop formed by the vhv line, which is connected at its beginning and end to the vhv windings of the power transformers is induced a voltage.

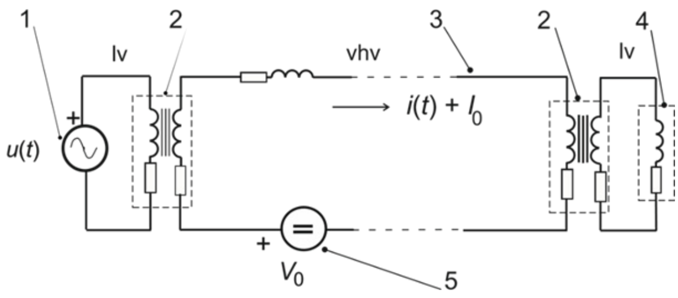

Figure 1: Simple model of transmission system: (1) Generator, (2) Power transformer, (3) vhv transmission line, (4) Distribution network, (5) Source quasi-variable voltage induced by magnetic strom.

$$V_0(t) = \frac{\mathrm{d}\Phi}{\mathrm{d}t} = S\frac{\mathrm{d}B_z}{\mathrm{d}t} \tag{2}$$

The magnetic induction flux Φ is linked with a loop whose area is S=a l, where l is the length of the vhv line and a is the distance between the conductors of the vhv line.

The induced voltage V_0 in the loop results in an induced GIC I_0. The internal geomagnetic field is stationary, ie according to (2) it does not contribute to the magnitude of the induced voltage V_0. The external geomagnetic field changes over time, but "slowly" (compared to the current supplied by the generator i(t), whose frequency is 50 Hz), is quasi-stationary. Only the resistances in this loop limit the magnitude of the current I_0 in the loop, formed by the vhv line and the high-voltage windings of both transformers. Geomagnetically induced current I_0 is superimposed to the working current i(t) supplied by the source, the current I_0+i(t) passes in the vhv line. Its rms value is a measure of dissipated thermal energy. This energy endangers the conductors of the vhv line, but above all the vhv windings of both transformers. It is more complicated with transformers.

The current I_0 will cause oversaturation of the magnetic circuit of the transformer in one half of the period of the current i(t) so-called semi-saturation. Due to the nonlinearity of the magnetization curve, the rms value of the current i(t) will increase significantly [1]. There is a current and eventually also a temperature overload of the vhv windings of both transformers.

A NEW WAY OF PROTECTING TRANSFORMER WINDINGS

A new method of protecting [1] consists in connecting a frequency filter in parallel with the vhv winding of both transformers, Figure 2. The frequency filter consists of a coil wound on a ferromagnetic core. It can be modeled by series connection of resistance R_f and inductance Lf, Figure 3. The current I_0 induced in the vhv line is divided into the current if passing through the frequency filter and the current it in the vhv winding of the transformer:

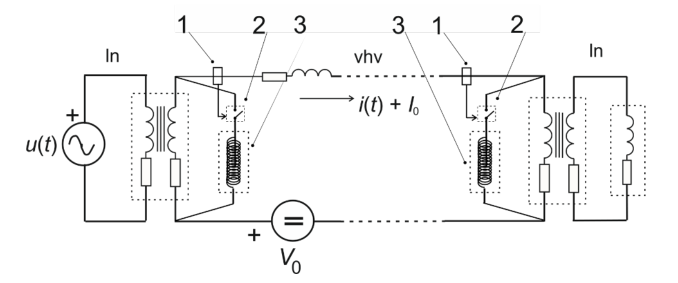

Figure 2: A simple model of a single-phase transmission system, whose power transformers are protected by superconducting reactors: (1) indicator of the current I0 (GIC) in the vhv line, (2) a switch that connects/disconnects the superconducting reactor to the high voltage winding of the power transformer, (3) single-phase superconducting reactor.

$$I_f = \frac{R_t}{R_f + R_t} I_0 , \qquad I_t = \frac{R_f}{R_f + R_t} I_0 \tag{3}$$

All three currents are quasi-stationary, so only by resistances are limited.

A frequency filter with zero resistance ($R_f \rightarrow 0$) will provide perfect protection. According to (3), all current I_0 then flows through the frequency filter ($I_f = I_0$), while no GIC passes through the windings of the transformers (It=0). Such a frequency filter can be realized by a coil (with a ferromagnetic core), made of a high-temperature superconductor. It is a superconducting reactor, which includes a cryotechnical device that produces liquid nitrogen, which cools the frequency filter coil to a critical temperature at which the coil resistance is $R_f \rightarrow 0$.

If the coil of the frequency filter is made for example from copper, $R_f \rightarrow 0$. The filter provides only partial protection. A frequency filter can be implemented with a conventional iron reactor. The sharper the inequality $R_f \rightarrow Rt$, the more efficient the protection by the frequency filter, but the greater the weight and dimensions of the reactor [2].

The frequency filter is connected to the transmission system only if a magnetic storm is predicted. The connection/disconnection of the frequency filters can be automated. If a geomagnetic storm Bz(t) acts on the system, a quasi-stationary voltage $\gamma \neq 0$ and then a current I_0 is induced in the vhv line. Its magnitude is monitored by sensor 1, Figure 3. As soon as the current I_0 reaches a preselected (adjustable) value, it activates both switches 2 at the beginning and end of the transmission path and connects frequency filters in parallel to the high-voltage windings of both transformers. The current I_0, in whole or in part (depending on the type of frequency filter), does not flow through the high-voltage windings of both transformers, but through frequency filters. As soon as the geomagnetic storm stops, the current I_0 drops and the sensor 1 activates both switches 2, which disconnect both frequency filters from the transformer windings.

In addition to the quasi-stationary current I_0, an alternating current i(t) also flows through the frequency filters, which has an inductive character and the impedance of the filter coil determines its magnitude. If these current increases the reactive power in the system and thus reduce the power factor (cos ø) to undesirable values, it can be compensated in the usual way, ie by connecting a compensator in parallel, which is most often a static capacitor.

The essence of the new method of protection of transformers against the effects of magnetic storms was described here on an elementary models of the transmission system. However, frequency filters can be used in cooperation with transformers that are part of any topologically complex transmission system.

Figure 4 shows a three-phase network with transformer protection by frequency filters at the point of connection to the distribution network. The three-phase superconducting reactor in connection Y is here connected to the high-voltage winding of a step-down power three-phase transformer, connected between the high-voltage transmission line and the distribution network. The transformer winding is connected to the grounded Y-D node. Similarly, at the point of connection of the generator to the step-up transformer, a superconducting reactor is connected in parallel to the vhv winding of the transformer.

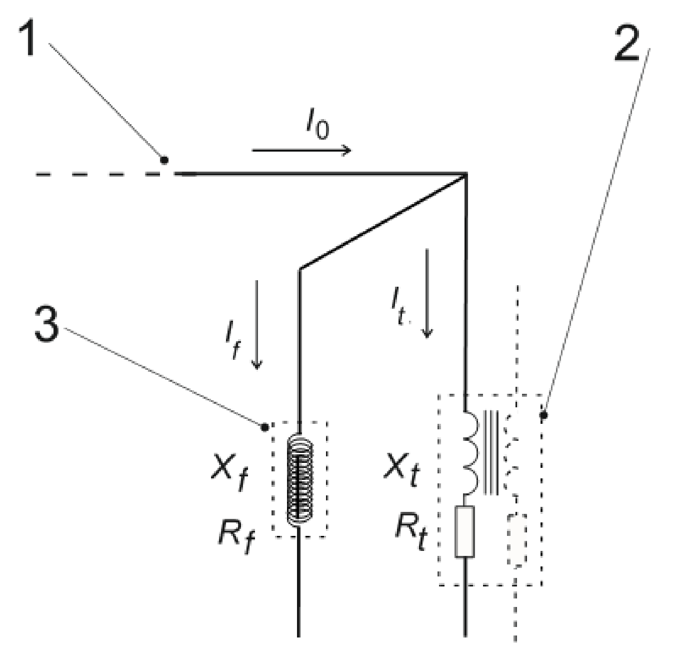

Figure 3: Distribution of the current I0 in vhv line (1) into the current. (2) vhv winding of the transformer (3) Passing through the frequency filter and into the current.

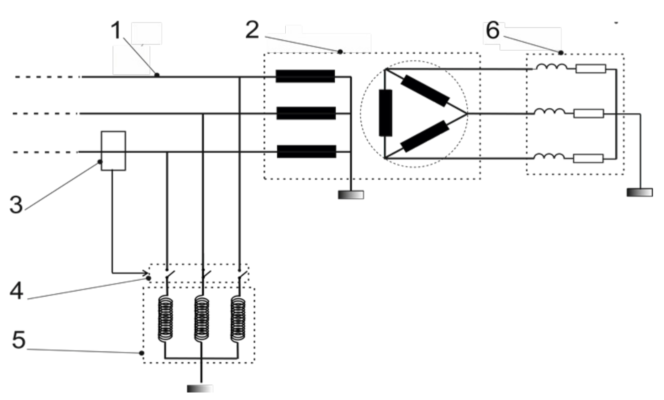

Figure 4: Connection of a three-phase superconducting reactor to the vhv side of a power transformer in a Y-D connection, converting electrical power into the distribution network: (1) vhv transmission line, (2) Three-phase step-down power transformer in Y-D connection with zero output, (3) Indicator of current I0 in vhv transmission line, (4) switch that connects/disconnects superconducting reactor in the transmission system, (5) Three-phase superconducting reactor in connection Y with output zero, (6) Three-phase distribution network simulated by three-phase impedance in connection Y with ground.

INDICATOR OF DIRECT ACTION OF A MAGNETIC STORM ON THE TRANSMISSION SYSTEM

The danger of the Earth's magnetosphere being hit by a magnetic storm is predicted both by direct observation of the Sun's surface and by processing data from satellite networks. Much more accurate (and at the same time incomparably lower costs) information is provided by the indicator described in [3]. The indicator is located in the immediate vicinity of one of the vhv bundle conductors through which the current $I1 \sin \omega_t + I_0$ flows, where the current $I1 \sin \omega_t$ is supplied by the power plant and the quasi-stationary current I_0 is generated by a magnetic storm. The indicator measures the current I_0. It has the following parts (Figure 5).

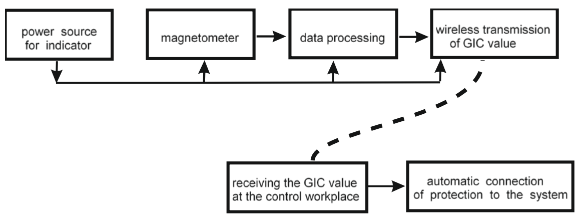

Figure 5: Main parts on indicator.

• Energy converter from the vhv conductor for powering other parts of the indicator.

• A magnetometer with a Hall probe, ie a magnetic field sensor B(t), which is proportional to the current $I1 \sin \omega_t + I_0$.

• A circuits for processing data from a magnetometer. A low-pass filter suppresses the AC component of the current $I1 \sin \omega_t + I_0$ and passes only DC component I_0. The output voltage of the low-pass filter corresponds to the current I_0.

• Transmission system. Sampled current values I_0 are wirelessly transmitted to the operator´s workplace.

• Receiption and interpretation of I_0 values in the control workplace.

The indicator is designed in such a way that Figures 6a and 6b only "hangs" on the vhv line conductor during installation and its position is then automatically locked. Its implementation in the transmission system can be performed on the line in full operation (ie under voltage) using a drone. The indicator can be dismantled in a similar way. The indicator requires no maintenance or service, it works automatically [4,5].

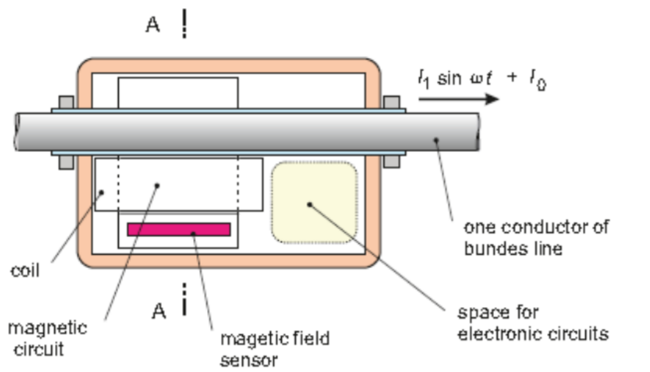

Figure 6A: Overall arrangement of the indicator: longitudinal cut.

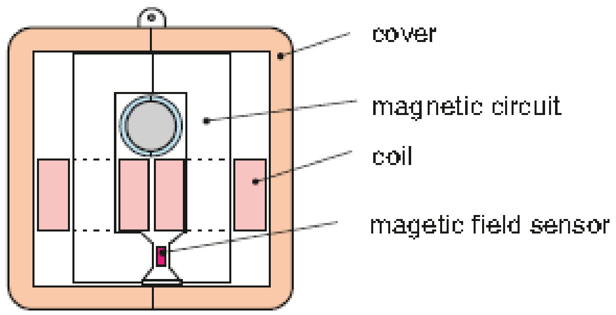

Figure 6B: Overall arrangement of the indicator: cut A–A.

CONCLUSION

The presented work describes a new method of transformer protection, which uses frequency filters. Two types of frequency filters are described: filters with superconductor coils for complete protection, and filters with coils of common materials for partial protection. It is characterized by reliable exclusion, resp. limiting the occurrence of current overload of transformers, low purchase price, the possibility of easy adaptation to existing electrical systems and then automatic, unattended operation. The device is relatively simple and robust, which virtually eliminates its failure rate.

REFERENCES

1. Mayer D.Protection of power transformers against the effect of magnetic storms. Journal of El. Eng.Vol. 72 (2021), No. 4,249-255.
2. Mayer D.Method of protection of power transformers of electrical systems.Czech patent no. 309 130 B6, garanted on 2022.
3. Mayer D., Stork M. Indicator of the influence of a geomagnetic storm on the transmission electric system. Transaction IEEE, currently in print.
4. Stork M, Mayer D.Direct currents in power transformers. J Electr Eng.2019;70(1):69-73.
5. Mayer D. The effect of geomagnetic storms on the electrification system. Cyclonic and Geomagnetic Storms, Predicting factors, formation and enviromental impacts,Inc.New York. 2015:1-18.