ISSN No:-2456-2165

AC DC Current Measurements Using Indirect Non Contact Methods

Sharva Salelker
Department of Microelectronics,
Goa college of engineering
Ponda, Goa, India

Pavan Prasad
Siemens, EM, DG PRO R&D Unit
Verna, Goa, India

Nitesh Guinde
Department of Electronics and telecommunication
Goa college of engineering
Ponda, Goa, India

Abstract:- A reliable supply of electricity free from power outages is important for the stability and economic development of any country. Power outages are caused due to various reasons such as faults in power systems, damages in various parts of the power network, overload currents etc. While some power outages are unavoidable such as those occurring due to natural weather conditions, at least twenty five percent of all industrial outages can be managed. In order to reduce power outages, the continuous monitoring of electrical parameters such as current, voltage, temperature etc is essential. In case of current monitoring, conventionally current transformers (CTs) are used in AC substations and zero flux dc current transformers are used in HVDC substations. CT technology is reliable and accurate. Zero flux dc current transformers also feature high accuracy. However, CTs can only be used for alternating current measurements. Also, they are very bulky, costly and require a lot of maintenance. Zero flux current transformers also have a large volume and heavy weight. Hence this paper presents a current measurement IOT module using TMR technology. This module will be self-powered, compact and capable of measuring AC as well as DC currents in HVAC and HVDC substations.

Keywords:- *HVAC, HVDC, Power Outages, Current Monitoring, TMR.*

I. INTRODUCTION

Electrical power, in the short span of two centuries, has become an indispensable part of modern-day life. The lack of a proper and stable supply of electricity could create havoc in our lives. It can lead to dire consequences in places such as hospitals, railways, airports etc. But fortunately, in most cases these have a backup power source which takes over automatically in case the main power source fails. Businesses, retail stores, and even residential homes have increasingly started using backup power sources. Power losses in smaller scale settings may not be life threatening but can still result in undesirable events such as loss of important information, delay in the completion of important tasks and hence decrease in overall productivity. Power failures can occur due to various reasons such as faults at power stations, overloading mains, short circuits, damage to transmission lines or other power equipment, wildlife interference, human error and weather problems to mention a few. Natural calamities have been a major cause of the world’s most severe power outages. Wildfires, mudslides, cyclones, avalanches, blizzards and other such weather conditions can lead to the destruction of power infrastructure resulting in power failures leaving large areas without electricity for a very long time. While some of these power outages may be unavoidable, by using proper prevention techniques, some power outages may be managed. This can be done by ensuring that high quality fuses, circuit breakers and other overload protection devices are installed in the power system to enable the immediate disconnection of power during the occurrence of faults such as short circuits or overload currents which can otherwise leave thousands of people without electricity. For the proper detection of faults, the continuous monitoring of electrical parameters is very important. In case of current monitoring, HVAC substations normally use current transformers (CTs). Similarly, zero-flux dc current transformers are used in case of HVDC substations. Both these current measuring technologies have their advantages of providing good accuracies. But they also have their disadvantages of having large volumes and weights. Hence, this paper presents a current measurement IOT module using TMR current measurement technology. This module is aimed at replacing the conventionally used measurement devices in both HVAC as well as HVDC substations.

II. BLOCK DIAGRAM

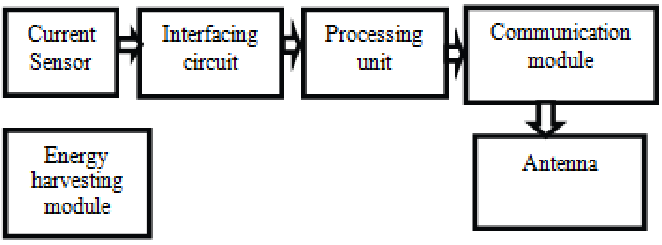

Fig. 1 Proposed current measurement IOT module

The above figure shows the layout of the proposed device, which includes a current sensor of TMR technology, interfacing part, processing unit where the input line current value will be converted to rms value, communication module, antenna and an energy harvesting module which will serve as the power source for this IOT module.

III. CURRENT MEASUREMENT METHODS

1. Current transformers (CTs)

Current transformers rely upon Faraday's law which states that an electromotive force is generated in a coil when it is placed in a time-varying electromagnetic field. They comprise of a primary winding, core and secondary winding. The primary winding has a few turns and carries the current which is to be measured. The secondary winding has a large number of turns and carries the current proportional to the current to be measured. The secondary side is connected to the current windings of the meters or the instruments. The alternating current in the primary produces an alternating magnetic field in the core, which then induces an alternating current in the secondary. Current transformers have a large current handling capacity and are capable of measuring very high currents while consuming low power. They are very commonly used for metering and protection purposes in the electrical power system. However, they are bulky and can only be used for ac current measurements since they require a changing magnetic field.

2. Rogowski coil

Rogowski coils work on Faraday's law of induction. They consist of a helical coil of wire with the lead from one end returning through the center of the coil to the other end so that both terminals are at the same end of the coil. They are wrapped around the current carrying conductor. The alternating current flowing through the conductor induces a voltage in the coil. The output of the coil is further connected to an integrator circuit which gives an integrated output voltage proportional to the current flowing through the conductor. Rogowski coils unlike current transformers are air cored due to which they can measure large currents without experiencing magnetic saturation. Also, the air core design has a lower inductance thus providing a faster signal response and very linear signal voltage. There is no heating, saturation or hysteresis caused by magnetic loss. However, like CTs Rogowski coils can be only used for measuring ac currents. Also, it requires an additional integrator circuitry which typically requires 3 to 24V dc and is obtained by most commercial sensors from batteries.

3. Hall effect

Hall effect current sensing method is based on the Hall effect principle which states that when a current-carrying conductor or a semiconductor is placed in a perpendicular magnetic field, a voltage termed as the hall voltage can be measured at the right angle to the current path. A hall sensor comprises of a thin piece of p-type semiconductor material passing a continuous current through itself. Semiconductor materials such as gallium arsenide, indium antimonide or indium arsenide can be used. When the sensor is placed near a current carrying conductor, the magnetic field of the conductor produces a Lorentz force on the semiconductor material which deflects the electrons and holes to either side of the semiconductor. This results in a potential difference across the two sides of the semiconductor material termed as Hall voltage. This Hall voltage is directly proportional to the strength of the magnetic field passing through the semiconductor material. Hall Effect sensors are used in many automotive and industrial current sensing applications. They can measure both ac as well as dc currents and are available at low costs. However, they can be prone to thermal drift due to changes in environmental conditions and are not capable of measuring currents at a distance of more than 10 cm.

4. Magnetoresistive sensors

Magnetoresistive current sensors are based on the principle of magnetoresistance which is the change in the electrical resistance of a current carrying ferromagnetic material when an external magnetic field is applied to it. They have mid-range magnetic field detection and are made from thin-film material. They respond to the horizontal components of the magnetic field. MR sensors are generally capable of responding to very high frequency fields due to the inherent property of the magnetoresistive elements. They have higher sensitivity as compared to Hall effect sensors and can be used for measuring both ac as well as dc currents. They have a small size and can be used in harsh environments. However, their drawbacks include limited linear range and poor temperature characteristics. Also, a very strong magnetic field can damage the sensor. Popular magneto resistance-based sensor types are: Anisotropic Magneto Resistance (AMR), Giant Magneto Resistance (GMR) and Tunnel Magneto Resistance (TMR). The difference between the different types of magnetoresistive sensors lies predominantly in their sensitivity to the magnetic field and the linearity of their response.

A. Anisotropic magnetoresistive sensors (AMR)

The Anisotropic magnetoresistive effect is the magnetoresistive effect occurring in ferromagnetic materials such as transition metals. In AMR sensors, the orientation of magnetization with respect to the direction of current determines the resistivity of the sensor. They are made of a silicon wafer which is a thin film of permalloy (which comprises of Nickel and iron) fixed on the board. Upon the application of a magnetic field at an angle β to the direction of current, the resistance value of the sensor varies depending on the β value. This change in resistance value will be highest when the direction of the magnetic field is perpendicular to the direction of the current and lowest when the direction of magnetic field is parallel to the direction of current. AMR sensors have lower sensitivity than GMR and TMR sensors, however they are easier to fabricate, offer flexibility in device shape and resistance and have better signal-to-noise ratio at low frequencies. The MR ratio (which is the rate of change in the resistance of an element) of an AMR element is about 3%. AMR sensors find applications in rotation, position and open close detection operation. They are also mostly used in automotive applications.

B. Giant magnetoresistive sensors (GMR)

GMR sensors are based on the giant magnetoresistive effect which is a quantum mechanical magnetoresistance effect observed in multilayers composed of alternating ferromagnetic and non-magnetic conductive layers. A GMR element consists of two or more layers of ferromagnetic metal (typically NiFe, CoFe or related transition metal alloy) separated by ultra-thin non-magnetic metal spacer layers (Cu, Au or Ru). An external magnetic field causes a change in the orientations of the magnetizations of the ferromagnetic layers thereby changing the resistance. A parallel orientation indicates a low resistance value whereas an anti-parallel orientation indicates a high resistance. Compared to AMR and hall effect sensors, GMR sensors possess the advantages of higher sensitivity, wider frequency range, smaller size, lower power consumption and relatively low cost. GMR sensors are used in the automotive industry for applications such as sensing position, angle and rotational speed. They find application in the field of information technology in hard disk read heads. They are also used in current monitoring purposes and in developing magnetic biosensors for life science applications.

C. Tunneling magnetoresistance sensors (TMR)

A TMR sensor also called Magnetic tunnel junction comprises of a barrier layer sandwiched between two ferromagnetic layers. The top ferromagnetic layer is free (not pinned to any layer) and the bottom ferromagnetic layer is pinned. The bottom ferromagnetic layer is a composite of a ferromagnetic pinned layer and antiferromagnetic layer. The tunnel barrier layer comprises of Magnesium oxide or Aluminium oxide. Soft ferromagnetic alloys such as NiFe, CoFe, CoFeB etc are used for making the two ferromagnetic layers. The resistance change in a TMR sensor depends on the angle between the magnetisation directions of the pinned and free layers. When the magnetisation directions of the pinned and free layers are antiparallel to each other, the resistance has maximum value (Rh) whereas as the angle between the magnetisation directions are brought towards zero, the resistance starts to decrease and has the least value (Rl) when the angle is reduced to zero. The operating point of the sensor is considered to be the value halfway between Rh and Rl since it has linear behavior at that point. TMR sensors have an MR ratio of 100%. They have higher sensitivity as compared to AMR and GMR sensors and have advantages such as high accuracy, high stability with less temperature drift, small size and less aging deterioration. TMR sensors are used for contactless current measurement. They can also be used for different biological applications since they have a small size, high sensitivity and are relatively easy to measure with.

5. Fluxgate

Fluxgate sensors or Saturable inductor current sensors are based on the detection of an inductance change. The main component used for this sensing technique is a saturable inductor due to which fluxgate sensors are also called as saturable inductor current sensors. The saturable inductor comprises of a small and thin magnetic core wound with a coil around it and is designed such that its saturation level will be affected by external and internal flux densities. The saturation level is directly proportional to the permeability of the core. Thus a change in the saturation level of the saturable inductor will alter the permeability of the core thereby altering its inductance. The fluxgate sensor analyses this change in inductor value for sensing the current. If the current value is low, the inductance becomes higher whereas if the current value is high, the inductance becomes lower. Fluxgate sensors have high sensitivity, high accuracy, high resolution and low noise. They can be used in different kinds of environment and even hostile environments. However, they have a complex and expensive fabrication method. Fluxgate sensors are widely used in geophysics and astro-observations due to their high sensitivity and resolution. They are important in detecting weak magnetic fields.

6. Zero flux current transformers

Zero flux current transformers typically comprise of two windings (detection and feedback windings), a magnetic core and an operational amplifier. They are capable of measuring both AC as well as DC currents. The detection winding senses the magnetic flux in the core. In this method, a secondary current is generated by a closed control loop with a feedback winding and an amplifier that nullifies the flux value generated by the primary current. Hence this method is called zero flux method. A voltage signal that is proportional to the primary current is generated by the secondary current flowing through a precision burden resistor. The flux value does not get nullified at DC or low frequencies since at those frequencies, the detection winding is not able to measure the residual flux. A dc flux sensor is incorporated (either a flux gate circuit with a few more windings or a hall probe embedded in the core). Zero flux current transformers have a high linearity and precision. They also have high accuracy and are robust regarding electromagnetic interference. However, they need a power supply and an amplifier and have a large volume. Also, hazardous voltages can be produced by improper secondary circuits.

IV. COMPARISON OF THE CURRENT METHODS

The proposed IOT module should be able to measure both AC as well as DC currents. Hence, from the above eight methods, the CT and Rogowski methods were eliminated. Out of the remaining six methods, fluxgate sensors have a high accuracy, sensitivity and resolution. However, they have a high volume and price. Zero flux DC current transformers have high accuracy. However, these are heavy and have a large volume. Hall effect current sensors have a low price and are moderate in size. However, they have low sensitivity. The magnetoresistive sensors have small volumes and are more sensitive as compared to Hall effect sensors. Out of the three MR sensors, the TMR has the highest sensitivity followed by the GMR and AMR sensors. Also, in terms of power consumption, the TMR sensors consume the least amount of power out of the three. Comparing all the current sensing methods mentioned above, the TMR current sensing method has advantages of high sensitivity, small volume, low cost and good accuracy which makes it the most suitable for this proposed device.

V. CONCLUSION

In this paper, a compact current monitoring IOT module to be used in HVAC and HVDC substations has been proposed. The various current measurement methods have been studied and compared and the TMR current measuring technology was selected as the most suitable for this particular application.

REFERENCES

[1]. https://cdn.tmi.yokogawa.com/1/7978/files/High_Current_Measurement_Guide.pdf
[2]. https://en.wikipedia.org/wiki/Giant_magnetoresistance
[3]. https://hiokiusa.com/6-current-sensing-methods/
[4]. https://www.electronics-tutorials.ws/electromagnetism/hall-effect.html
[5]. Qi Huang; Arsalan Habib Khawaja; Yafeng Chen; Jian Li, "State of the art magnetoresistance based magnetic field measurement technologies," in *Magnetic Field Measurement with Applications to Modern Power Grids* , IEEE, 2019, pp.25-51, doi: 10.1002/9781119494485.ch2.
[6]. Mohammed Asadullah Khan, Jian Sun, Bodong Li, Alexander Przybysz and Jürgen Kosel, "Magnetic sensors-a review and recent technologies," Published 15 June 2021, Engineering Research Express, Volume 3, Number 2**,** *Eng. Res. Express* **3** 022005
[7]. Ennen I, Kappe D, Rempel T, Glenske C, Hütten A," Giant magnetoresistance: basic concepts, microstructure, magnetic interactions and applications," *Sensors (Basel).* 2016;16(6):904. Published 2016 Jun 17. doi:10.3390/s16060904
[8]. https://circuitdigest.com/article/how-to-measure-current-in-a-circuit-with-different-current-sensing-techniques
[9]. https://en.wikipedia.org/wiki/Current_sensing#Fluxgate_sensors
[10]. Wei S, Liao X, Zhang H, Pang J, Zhou Y," Recent progress of fluxgate magnetic sensors: basic research and application," *Sensors (Basel).* 2021;21(4):1500. Published 2021 Feb 22. doi:10.3390/s21041500
[11]. https://solareis.anl.gov/documents/docs/APT_61117_EVS_TM_08_4.pdf
[12]. https://en.wikipedia.org/wiki/Power_outage
[13]. H. Li, Q. Li, S.Zhang, M Lei, " Development of a zero-flux dc current transformer for hvdc projects," DOI:10.3969/j.issn.1003-6520.2012.11.028
[14]. Z. Li, W. Jiang, A. Abu-Siada, Z. Li, Y. Xu and S. Liu, "Research on a Composite Voltage and Current Measurement Device for HVDC Networks," in *IEEE Transactions on Industrial Electronics*, vol. 68, no. 9, pp. 8930-8941, Sept. 2021, doi: 10.1109/TIE.2020.3013772.
[15]. https://switchgearcontent.com/2020/10/12/2336/current-measurment-by-zero-flux-current-transformers-in-gas-insulated-switchgeargis/
[16]. https://www.generatorsource.com/Causes_of_Power_Failures.aspx
[17]. https://www.techopedia.com/definition/13085/power-outage