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Review of AC (Small) Current Measurement Techniques

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Abstract: This study presents, a review of some techniques for Alternating Current (AC) measurement. It is an overview to acquaint the researcher a spot check of which best method to be chosen for small current measurement. In this review, introduction of current measurement chronology, principles, methods, advantages, disadvantages and some applications are discussed. The techniques considered includes Rogowski coil, Hall effect, Shunt resistor current, optical current, Optical current transformer, current transformer and mechanical current measurement method. Rogowski coil, inductive current measurement method, current could be measured without disturbing or interrupting the electric power system. Hall effect current measurement could be entirely integrated on a single silicon chip, resulting into low-cost, high-volume application in current measurement. Shunt resistor current measurement with ground referenced output voltage, easy single supply design, straight forward, easy and rarely requires more than an operational amplify to implement, inexpensive and precise in current measurement. These will result to low cost, better insulation, safety of personnel and equipment and quality of electric power system production and usage. So, depending on the desired electrical parameters needed, advantages and disadvantages from each or combination of these methods could be use to achieve efficient and effective current measurement, resulting to better control and regulation of electric power system.

Key words: Current mearsurement techniques, small current mearsurement, equipment, electric power system, alternating current

INTRODUTION

The benefit of electric current in the contemporary society cannot be over emphasized. The researches of men like Sir Isaac Newton (1643-1727), Michael Faraday (1791-1867), Andre-Marie Ampere (1775-1836), Heinrich Lenz, etc., in sciences and technologies have vividly exposed these hidden talents of nature. The methods of current measurement which depend on the situation and safety factor. The techniques are sort for to gain effective usage and control of current measurement. The application of fundamentals techniques will guard the researcher to choose the best method that satisfies the need in the research. With these it becomes necessary to review various ways of current detections. The most commonly used methods applicable in the industries are Rogowski Coil, Hall Effect, Shunt Resistor and Current Transformer Method. Optical based Current Sensor Methods have been used experimentally but have not been deployed in real engineering applications.

TYPES OF CURRENT MEASUREMENT TECHNIQUES

Rogowski coil method

Introduction: Rogowski coils perform passive current measurement and are used in testing, measurement devices and power monitoring activities. Calibration is required to account for manufacturing variations in the coil and provide uniform device-to-device sensitivity. Traditionally coils are compensated with an amplifier making both the coil and the amplifier a matched pair. Rejustors provide a passive compensation solution for Rogowski coils, enabling coil manufacturers to produce devices with uniform performance increasing interchange ability while reducing manufacturing complexity (Ward, 1993).

Background of Rogowski coil: Rogowski coil, named after Walter Rogowski is an electrical device for measuring Alternating Current (AC) or high speed current pulses. The device use a helical coil sensor which is uniformly wound onto a relatively long non-magnetic circular or rectangular strip, usually flexible (Fig. 1). The helical coil of wire has the lead from one end returning, through the centre of the coil to the other end so that both terminals are at the same end of the coil. The whole assembly is then wrapped around the straight conductor whose current is to be measured. The first description was given by Rogowski and Steinhaus (1912) and Tumanski (2002). Sometimes, this coil arrangement is called a Chattock coil (Rogowski-Chattock potentiometer). Indeed, the operating principle of such a coil sensor was first described by Chattock (1887) (it is not clear if Rogowski

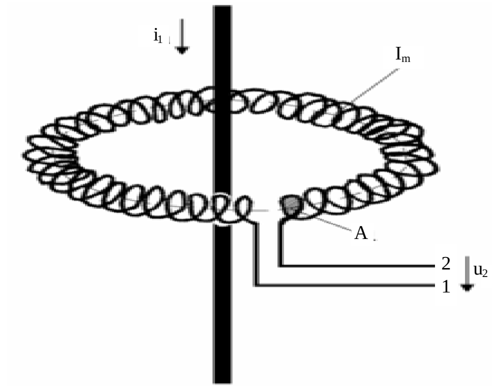

Fig. 1: Rogowski coil wrapped round current carrying conductor

knewof the disclosure by Chattock because in Rogowski's study Chattock was not cited). However, Chattock used it to measure magnetic fields rather than currents (Rogowski and Steinhaus, 1912; Shirkoohi and Kontopoulos, 1994).

Theory of Rogowski coil: The principle of operation of this sensor is based on Ampere's law rather than Faraday's law. If the coil of length l is inserted into a magnetic field then the output voltage is the sum of voltages induced in each turn (all turns are connected in series). The output signal of the Rogowski coil depends on the number of turns per unit length (N/l) and the cross section area A of the coil (Fig. 1) (Murgatroyd *et al.*, 1991).

Since, the voltage that is induced in the coil is proportional to the rate of change of current in the straight conductor, the output of the Rogowski coil is usually connected to an electronic integrator circuit in order to provide an output signal that is proportional to current. The voltage drop by Rogowski coil is expressed as:

$$V = \frac{-AN\mu_o}{l}\frac{di}{dt} = M\frac{di}{dt} \quad (1)$$

Where:

μ_o = $4\pi\times10^{-7}$ is the magnetic constant
A = πR^2 is the cross section area of the toroidal
N = The number of turns
l_m = $2\pi R$ is the length of the winding
$\frac{di}{dt}$ = The rate of change of the current threading the loop
M = Mutual inductance of Rogowski coil

Equation 1 assumes the turns are evenly spaced and that these turns are small relative to the radius of the coil itself. At high frequencies, the impedance of Rogowski coil's inductance will increase and so decrease the output. The inductance L of a toroidal coil is expressed as:

$$L = \mu_o (R - \sqrt{R^2 - a^2}) \quad (2)$$

Where:

R = The major radius of the toroidal and
a = Its minor radius

Several methods in measuring the low amplitude current by Rogowski coil are discussed in studies of Rogowski coil current transducer for low amplitude current (100 A) measurement in which the mutual inductance M of Rogowski coil need to be improved by Liao *et al.* (2003).

Advantages of Rogowski coil: Rogowski coil has many features which give it advantages over other methods of current measurement (including current transformers) in several applications. These advantages includes: Flexibility in usage, Rogowski coil is made open-ended and flexible, allowing it to be wrapped around a live conductor without disturbing it. Secondly, unlike conventional transformers that have an iron core, the transformer in a Rogowski coil uses an air core which provides both low impedance and there is no danger of saturating the core (as can occur in iron core transformers). Rogowski coil does not suffer from magnetic saturation under transient condition and therefore, it has high measuring accuracy in transient state. It is linear this means that the same transducer can be used to measure a wide range of currents. For example, metering, test and protection functions could be combined. This feature is also very useful in installations where there is some uncertainty as to the level of current which will flow, as the sensitivity of the measuring system can be adjusted after the measuring coil has been installed without the need to change the coil. Rogowski coil transducers are highly suitable for protection applications because they do not saturate in the early stages of a transient even when asymmetric components (DC offsets) are present. This feature is also useful for measuring ripple components in DC systems, such as battery chargers and alternator rotor supplies. It has wide bandwidth, this can range from <1 Hz to several 100 kHz depending on the coil type. Transducers are useful for harmonic analysis. Since, they are linear they do not create harmonics. It is accurate, the systems can be made with an uncertainty better than 0.1%, this accuracy can be maintained even with a split coil. Rogowski coil can be used for on-site calibration of other current measuring devices. Rogowski coil is compacted and lightweight, the flexible coil can be fitted in confined spaces. It can often be tucked behind cables which are mounted on trays or clipped to walls. It is light enough to be suspended on the cabling if necessary. Flexible coils are also useful for measuring large conductors or cable bundles. Rogowski coil is typically made from air core coil so in theory there is no hysteresis, saturation or non-linearity.

Disadvantages of Rogowski coil: One disadvantage of the coil is that the Rogowski coil produces output voltage proportional to di/dt. Therefore, at connecting or disconnecting moments, the emf goes infinite. Transient Voltage Suppressors (TVS) or other protection has to be considered to prevent overloading the downstream electronics. The difficulty of building an analogue integrator which is stable over a long period of time has kept Rogowski coil from being used in metering applications (Dickinson and Friedrich, 2005). Voltage drop is only generated when there are changes in the magnetic field, therefore Rogowski coil cannot be used to measure dc component in the current. Rogowski coil relies on measuring magnetic field, it makes this type of current sensor susceptible to external magnetic field interference compared to CT (Koon, 2002).

Applications of Rogowski coil: The numbers of applications where Rogowski coils have been used are very large and only a selection is included here. Earth resistance of transmission towers, this is a difficult measurement to make because of the other towers which are earthed in parallel. With flexible coils it is possible to make a direct measurement of the current flowing down the legs to ground and hence obtain a reliable measurement. In current sharing, Rogowski coils have negligible insertion impedance and are thus useful for studying the current sharing between groups of parallel conductors. Iron-cored measuring devices, particularly current transformers, reflect impedance into the cables and can distort the current sharing. Energy management studies in industrial premises are becoming increasingly important in helping consumers to select the best supply tariff for their purposes.

Flexible current transducers are useful in simplifying the installation process and in coping with large conductors. Current transformer calibration with careful construction, coils wound on rigid formers can be made to be extremely accurate and stable and a bridge technique has been developed which uses Rogowski coils to calibrate metering CT's on site. Since the coils are linear, the same equipment can cope with any current level and any CT ratio. In Protection, Rogowski coils are useful in protection systems because of their good transient performance and high-current capability. As the coils are compact they are easier to fit on existing installations without the need for expensive modifications. Finally, Rogowski coil current transducers can offer a useful contribution to the art of measuring electric currents under difficult or unusual circumstances, as well as for more normal situations. A wider understanding of what they are and what they can do is obviously essential if their full potential is to be exploited. Rogowski coil has long been used for high current measurement, such as in sub-station transformers and arc wielding machines (Dickinson and Friedrich, 2005).

HALL EFFECT CURRENT METHOD

Introduction: In power systems, safety and reliability are the most important considerations. To meet the safety and reliability requirements, appropriate current monitoring devices are being sort for used to measure currents for metering and fault protection. Hall effect could be entirely integrated on a single silicon chip is becoming popularly in use. This has resulted in low-cost, high-volume application of the Hall effect (Chen and Chen, 2011).

Background of Hall effect: In his study wrote that Hall effect was discovered by Edwin Hall in 1879 while he was a doctoral candidate at Johns Hopkins University in Baltimore (Chen and Chen, 2011). Hall was attempting to verify the theory of electron flow proposed by Kelvin some 30 years earlier. Hall found when a magnet was placed so that its field was perpendicular to one face of a thin rectangle of gold through which current was flowing, a difference in potential appeared at the opposite edges. He found that this voltage was proportional to the current flowing through the conductor and the flux density or magnetic induction perpendicular to the conductor. Although, Hall's experiments were successful and well received at the time, no applications outside of the realm of theoretical physics were found for over 70 years. With the advent of semiconducting materials in the 1950s, the Hall effect found its first applications. However, these were severely limited by cost. In 1965, Everett Vorthmann and Joe Maupin, MICRO SWITCH sensing and control senior development engineers, teamed up to find a practical, low-cost solid state sensor. Many different concepts, were examined but they chose the Hall effect for the basic reason that it could be entirely integrated on a single silicon chip. This breakthrough resulted in the first low-cost, high-volume application of the Hall effect, truly solid state current monitoring devices and other applications.

Theory of Hall effect: When a current carrying conductor is placed into a magnetic field, a voltage will be generated perpendicular to both the current and the field. This principle is known as the Hall effect. Figure 2-3 shows the basic principle of the Hall effect. It shows a thin sheet of semiconducting material (Hall element) through which a current is passed.

The output connections are perpendicular to the direction of current. When no magnetic field is present as shown in Fig. 2 and 3 current distribution is uniform and no potential difference is seen across the output. When a perpendicular magnetic field is present as shown in Fig. 3, a Lorentz force is exerted on the current. This force disturbs the current distribution, resulting in a potential difference (voltage) across the output. This voltage is the Hall voltage (V_H). The interaction of the magnetic field and the current is shown in equation form as Eq. 3.

$$V_H \alpha I \times B \quad (3)$$

Hall effect sensors can be applied in many types of sensing devices. If the quantity (parameter) to be sensed incorporates or can incorporate a magnetic field, a Hall sensor will perform the task.

Advantages of Hall effect: They can be totally isolated from another high voltage electrical system which eliminates many safety concerns. The resolution can be improved by looping the wire through the current clamp as many times as to double, triple or quadruple the sensitivity or resolution of the sensor. The Hall effect current sensor does not get hot (Chen and Chen, 2011).

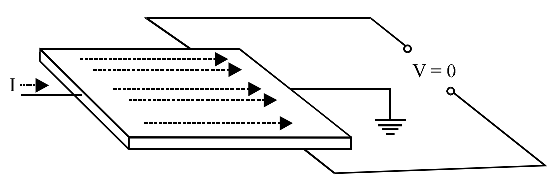

Fig. 2: Hall effect principle with no magnetic field

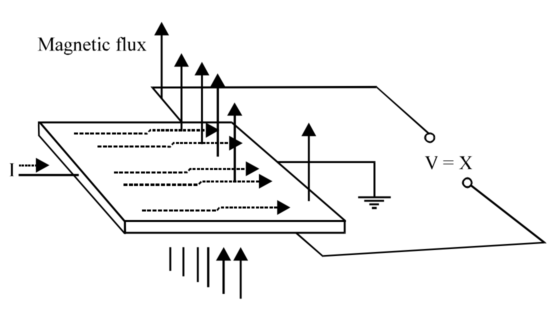

Fig. 3: Hall effect principle under magnetic field influence

Hall effect magnetic detector has inherent voltage isolation from the current path. It can be integrated into Hall element and interface electronics on single silicon chip (Popovic, 2004). The use of a Hall effect device increase the accuracy of current in both high current path and a low current path measurements, provides more signal than the shunt solution over the measurement range. Hall effect devices are readily apparent with the low insertion loss of the device. The device improves current measurement accuracy over a wider current range and reducing power consumption by significantly reducing the 1^2R loss. The obvious benefit for a small form-factor, Hall effect solution is that the volume required is a fraction of the equivalent CT solution and in addition there is an elimination of gain and additional protection components. It has nice advantage over safeguards to protect data acquisitions. Current measurement accuracy is essential with low power dissipation and size solution as compared to the traditional method of measuring this current (Cummings *et al*., 2006).

Disadvantages of Hall effect method: The drawback of this technology is that the output from Hall effect sensor has a large temperature drift and it usually requires a stable external current source. Hall effect sensors are somewhat less common comparing with the CT (Koon, 2002). The device output voltage is very small requires high amplification. The sensitivity is temperature dependent and requires adequate compensation. There is an inevitable offset, i.e., a small DC voltage at zero current, the offset amplitude and temperature coefficient are subject to significant fluctuations. Also, noted is sensitivity to short current peaks in the circuit; according to the hysteresis properties of the core material, these peaks can cause a static magnetization in the core that result in a permanent reminisce and finally to an offset alteration of the Hall element (Friedrich and Lemme, 2000).

Applications of Hall effect method: The use of Hall effect devices in battery systems will help to reduce the Printed Circuit Board (PCB) area required for a shunt sensing solution and enable high-side sensing which does not interrupt the ground path. The use of either Hall effect devices or Current Transformers (CT) is common in UPS systems while CTs are seen as low-cost solutions, they actually require more support components than a Hall effect solution and are strictly limited to AC applications. More so cost attributed to using CTs to monitor the AC line voltage is the additional circuitry to manage the effects of in rush and possible core saturation during an in rush event. UPS solutions require using the line voltage to charge a battery that is used to supply line voltage for a system in the event of a power failure. When powering the inverter stage at high loads, the optimal place to have the Hall effect IC is at the line voltage itself to monitor the load currents directly. By using Hall effect devices in the battery charging system and inverter power train, the efficiency of the converters can be optimized, this can help to reduce the overall size of the system and save costs (Cummings *et al*., 2006; Dickinson and Friedrich, 2005).

SHUNT RESISTOR METHOD

Introduction: Shunt current measurement techniques are found to be in wider spread use since they have been the first possible method for current detection, monitoring and measurement. Measuring current requires careful consideration when setting up measurement system. It should be understood that two factors needed to be consider in ensuring accurate measurement, i.e., the device measurement method and impact of measurement on the circuit.

Background Shunt resistor current method: With its importance in electric power control and stability many studies and implementation had been carried out to improved techniques of Shunt resistor current measurement methods (Johnson and Palmer, 1994; Liao *et al*., 2003). This method was applied and used in post arc detection and measurement (Barrault *et al*., 1993).

Theory of Shunt resistor method: The Shunt resistor current measurement method adopts the Ohms law principle of current measurement. A known resistance of shunt is placed in series with the load so that all of the current to be measured will flow through it. The voltage drop across the shunt is proportional to the current flowing through it and since its resistance is known, a milli-voltmeter connected across the shunt can be scaled to directly display the current value Fig. 4. In the Shunt method, low value of R_{shunt} is chosen to minimize the power dissipation of the shunt. If the Shunt resistor of the device is too large versus the resistance of the circuit under test, the voltage burden causes large errors (Matthaei *et al*., 1964). In order not to disrupt the circuit, the resistance of the shunt is normally very small. Shunts are rated by maximum current and voltage drop at that current. All shunts have a derating factor for continuous use, 66% being the most common. Current shunt measurement techniques have two methods of measurements which are low side current sensing and high side current sensing methods. The low-side refers to the return path from the load and the low-side is usually at a low voltage to ground. Figure 5 depicts circuits of low

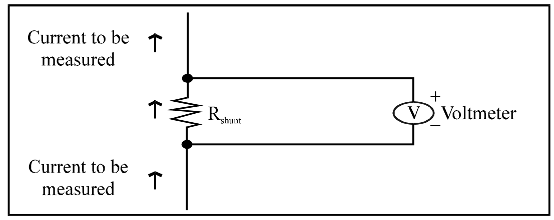

Fig. 4: Voltmeter measuring a voltage drops across a resistor

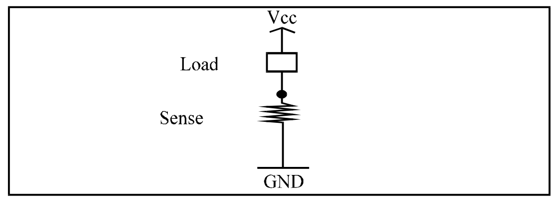

Fig. 5: Low side current sensing, sense resistor between load and ground

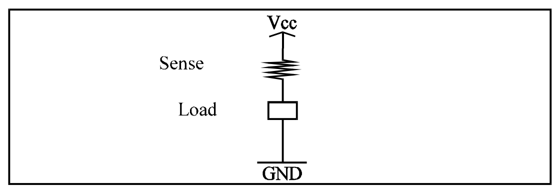

Fig. 6: High side current, sense resistor between supply and load current shunt monitor

side sensing technique. Similarly, the high-side refers to the supply path to the load and the high-side is usually at a high voltage to ground. Figure 6 depicts circuits of high side sensing technique. The decision to place a current shunt in either position has advantages and disadvantages that must be accounted for and assessed based on the particular application.

Advantages of Shunt resistor current method: Current shunts are considered more accurate and cheaper devices due to current shunt low side advantages which includes Shunt resistor current measurement low input common mode voltage, ground referenced output voltage, easy single supply design, straight forward, easy and rarely requires more than an operational amplify to implement, inexpensive and precise. Other are high side advantages, such as load is grounded, load not activated by accidental short at power connection, high load current caused by short circuit is detected are easy to use provide a ground-referenced current or voltage-source output that is proportional to the current of interest, provide high common-mode rejection without the difficulty of resistor matching can sense high-side currents in the presence of common-mode voltages have a pair of differential inputs that can be connected to shunts which are at voltages well in excess of the voltage that the amplifier is powered from and power management.

Disadvantages of Shunt resistor method: Some alternatives to shunts can provide isolation from the high voltage by not directly connecting the meter (Hall effect current sensors and current transformers) to the high voltage circuit. Although the voltage drop is small, this can have a negative impact on the circuit under test and the measurement. This voltage is known, as the voltage burden and is a series voltage error introduced by the device. There are thermal limits where a shunt will no longer operate correctly. At 80°C thermal drift begins to occur at 120°C thermal drift is a significant problem where error, depending on the design of the shunt can be several percent and at 140°C the resistor (usually manganin alloy) used becomes permanently damaged due to annealing resulting in the resistance value drifting up or down. If the current being measured is also at a high voltage potential this voltage will be present in the connecting leads to and in the reading instrument itself. Sometimes, the shunt is inserted in the return leg (grounded side) to avoid this problem (Matthaei *et al*., 1964). Low side disadvantages are enumerated as load lifted from direct ground connection, load activated by accidental short at ground end load switch, high load current caused by short is not detected adds undesirable resistance in the ground path may require an additional wire to the load that could otherwise be omitted. High side disadvantages are listed as high input common mode voltages (often very high), output needs to be level shifted down to system operating voltage levels. It requires very careful resistor matching in order to obtain an acceptable Common Mode Rejection Ratio (CMMR) and must withstand very high and often dynamic, common-mode voltages (often outside the limits of the supply rails of the amplifiers used).

Applications Shunt resistor method: It used for over current-protection and supervising circuits could measure as much as 4-20 mA system current used for programmable current sources. Linear and switch-mode power supplies used in battery operated circuits for which you need to know the ratio of current flow into and out of a rechargeable battery and used in proportional solenoid control, linear systems Matthaei *et al*., 1964).

OPTICAL CURRENT (OC) METHOD

Introduction: Optical Current Sensors (OCS), also known as Magneto-Optic Current Transducers (MOCT's) are achieving increased acceptance and use in high voltage substations due to their superior accuracy, bandwidth, dynamic range and inherent isolation. Once deemed specialized devices intended for novel applications, optical sensors have risen to a performance level exceeding conventional magnetic devices. With this new technology (i.e., magneto-optical current transducer base on Faraday effect), there is enthusiasm and excitement about how the development will revolutionize older technology and most people to embrace the fundamental concept of the new technology (Hrabliuk, 2001).

Background of Optical Current (OC) method: The Magneto-optic or Faraday Effect was first reported by Michael Faraday in 1845. Serious research and development to implement the Faraday effect into highly accurate current measuring applications was begun in the late 1970s. These efforts resulted in a number of successful field trials using optical current sensor based metering systems that date back to 1986. These installations utilized porcelain columns and also had data acquisition capabilities. However, the earlier data acquisition systems did not lend themselves to the analysis of waveform quality and performance as required for the present installation (Maffetone and McClelland, 1991). Since Faraday's early discovery, this phenomenon has been observed in many solids, liquids and gases.

Theory of Optical Current (OC) method: Optical based current measurement device are known as magneto-optic current transducer whose principle is base on Faraday effect. Faraday effect states that when polarises light passing through a glass material (Faraday material) that is parallel to a strong magnetic field, the plane of the light rotates.

Figure 7 shows the polarized light. The amount of rotation α for the given material is proportional to the strength of the applied magnetic field and the distance travelled by the light through the medium. The rotation α, mathematically is expressed as:

$$\alpha = \mu \ VnI \quad (4)$$

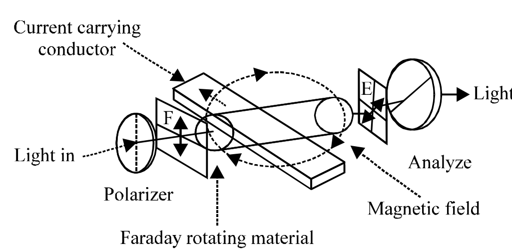

Fig. 7: Rotation of the plane of polarization of the light path (Li, 1997)

Where:

- I = The current in amperes
- n = The number of loops around the conductor
- μ_o = The constant of permeability which equals unity in air
- V = The Verdet constant (0.31×10^{-5} rad/amp-turn) (Day *et at.*, 1987) which is defined as the rotation/unit path/unit field strength
- α = The angle of rotation in radian

To examine this principle closer the following definitions are offered: The rotation of the plane of polarization of the light path with respect to the length of that path is proportional to the magnetic field intensity and can be expressed as:

$$\frac{\Delta\theta}{\Delta L}\approx\vec{H} \tag{5}$$

Therefore:

$$\frac{\Delta\theta}{\Delta L}\approx\mu_o VN\vec{H} \tag{6}$$

From Ampere's law:

$$\oint\vec{H}dL = I \tag{7}$$

It follows that:

$$\theta = \mu_o VNI \tag{8}$$

Solving for single turn or loop of bulk glass, then N = 1 and μ_o = 1. Researchers have:

$$\theta = VI \tag{9}$$

Electronic signal processing circuitry is then utilized to precisely evaluate this low level 60 Hz intensity variation and output a calibrated signal that is exactly in phase with respect to the primary current sine wave.

Advantages of OCS: Major benefit of optical current sensor based on metering and relaying systems is immunity to geomagnetic effects and EMI. Magneto Optic Current Transducers (MOCT's) is utilised to improve performance, reliability and solve problems in substation protective relaying and transient recording. Each one of these areas has several difficulties that engineers have endured with conventional current transformers measurement. MOCT's will not saturate under heavy fault current and eliminate burden concerns, offer an increased frequency response and the power interface is entirely optical. It affords total isolation which increases the safety to both personnel and equipment. Substation revenue metering accuracy and eliminates the low-end meter accuracy. MOCT has very high bandwidth and extremely wide dynamic range, freedom from saturation effects and DC operation. With temperature compensating controls incorporated into the MOCT electronics it come intent to observe the long term seasonal performance of the device.

Disadvantages of Optical Current (OC) method: The problem with this approach is the relative movement between the core and the glass. The conductor encircled with a number of glass blocks, forming a closed path, this method renders the sensor insensitive to interfering magnetic fields. This method has complex optical sensor assembly resulting to inadequate sensitivity. Although, the glass block sensor offers some significant advantages compared with the coiled fibre sensor. The additional problems includes in most designs, the sensors are sensitive to interfering magnetic fields as closed optical paths are not normally formed round the conductors. Secondly, in common with the coiled fibre type, these sensors are sensitive to fibre down lead vibration. Mechanical perturbations of the optical fibres connecting the sensor to the optoelectronic processing system result in optical intensity changes which are manifest as noise (Pilling *et al.*, 1994). Faraday rotation depends on the Verdet coefficient of the optical sensing material. However, materials with high Verdet coefficients have temperature and stress dependent birefringence properties. Since, the Verdet constant of dielectric material varies with temperature and wavelength of the optical source (Fowles, 1968) the measurement may be affected by environmental perturbations, such as temperature fluctuations and wavelength noise of the light source (Chu *et al.*, 1993).

Applications of Optical Current (OC) method: The sensors have many applications in the power distribution industry as both absolute and differential AC and DC measurements up to very high currents are possible. Optical sensors are used in substations for the electrical isolations. With optical sensor applications, increase in the maximum allowed distance between the transmitter and the receiver to several kilometres are achieved. Its compatibility with new electronic relay equipment currently being developed, there is no need for equipment to be incorporate with secondary isolation.

OPTICAL CURRENT TRANSFORMER (OCT)

Introduction: Optical Current Transformer (OCT) is gaining credibility in power engineering with advantages of high resistance to electro-magnetic interference, magnetic-saturation-free, hysteresis-free and no need for extra power supply in primary side. Furthermore, as one type of Electric Current Transformers (ECT), OCT can interface with digital relay protection device easily and meet the real-time demands of substation automation (Chen *et al.*, 2006).

Background of OCT: As the name implies, Optical Current Transformer (OCT) is a combination of optical sensor and optical current transformer made of optical fibre hence utilizes Faraday's effect in current measurement (Kumai *et al.*, 2002). In electrical industries, OCT is commonly employed for high accuracy in the steady state applications.

Theory of OCT: On the high voltage side, high current signal is changed to small electric signal, converted to data electric signal by electronic circuit and then is changed to data optical signal. The signal is transmitted to low voltage side by optical fibre and is demodulated to weak electric signal which is proportional with heavy current at high voltage side. The amplitude value and phase information of heavy current is obtained (Shang *et al.*, 2005; Liu *et al.*, 2007). OCT also utilizes Faraday effect to measure primary current.

Advantages of OCT: OCT is use in protection and metering systems used for currents flowing in the high voltage conductors. It utilizes Faraday effect to measure primary current, excellent electrical isolation and comes in small size. OCT has high resistance to electro-magnetic interference. It is magnetic-saturation-free, hysteresis-free and no need for extra power supply in primary side. It can interface with digital relay protection device easily and meet the real-time demands of substation automation. The optical electric current transformer is light in weight and costs low. Based on virtual instrument and digital signal processing technology, error measuring system is designed by using LabView Software and DAQ-2006 data acquisition card. Also on virtual instrument, optical electric current transformer error measuring system could be designed easily. OCT is in principle, be a suitable replacement for a conventional device for power system protection purposes without loss of system quality or reliability. It adopts high precision iron core coil and has an outstanding insulation and simple.

Disadvantages of OCT: The OCT is subject to the problem of linear birefringence (or double refraction is the decomposition of a ray of light into 2 rays when it passes through certain anisotropic materials, such as crystals of calcite or boron nitride) due to stress of bending fibres and change of temperature. These problems are solved by using double-coated twisted fibres.

Applications of OCT: OCT is used to measure exact amplitude value and phase information of analogue signal of power system. It is able to measure phase error and ratio error of optical electric current transformer. In electrical industries, OCT is employed for high accuracy in the steady state while Rogowski coil's is employed for high accuracy in transient state applications (Chen *et al.*, 2006).

CURRENT TRANSFORMER CT METHOD

Introduction: Current Transformer (CT) is one and most basic measuring element in electric power system. Current transformers (CT), together with Voltage Transformer (VT) or Potential Transformer (PT) are known as instrument transformers. When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit which can be conveniently connected to measuring and recording instruments. A current transformer also isolates the measuring instruments from what may be very high voltage in the monitored circuit.

Background CT: Power quality assessment relies on the accurate measurement of current and voltage. Current transformers exhibit a good frequency response under distorted conditions, although this is only valid for a low impedance load on the secondary of the current transformer. Measuring accuracy of electromagnetic CT is high in steady state (Ackermann, 1999). After long-term applied researched, the accuracy of measuring steady state current is able to reach several ten thousands. In fact, the primary objective of current transformer design is to ensure that the primary and secondary circuits are efficiently coupled so that the secondary current bears an accurate relationship to the primary current. The primary winding is connected in series with the source current to be measured and the secondary winding is normally connected to a meter, relay or a burden resistor to develop a low level voltage that is amplified for control purposes.

Theory of CT: Current transformers operate on the same principles as other transformers with magnetic cores. The transformer consists of a primary and one or more secondary winding around a closed magnetic path formed by the magnetic core. Current in the primary winding sets up a change of flux in the core. Ignoring losses, the secondary winding sets up a change of flux, equal in magnitude but reversed in direction to oppose this change in flux. This simplified (and ideal) description can be refined to account for secondary effects due the materials and construction methods used (Ackermann, 1999; Makky *et al*., 2008). The voltages are proportional to the numbers of turns in the coils; the coils with most turns have the higher voltage (Warnes, 2003). High permeability and low core loss materials in toroidal shapes are recommended to reduce errors due to leakage flux and high magnetizing currents. Materials selection for a current transformer depends on the operating frequency, accuracy and cost (Magnetics, 2000). High permeability materials in toroidal shapes afford close core coupling and link both windings to minimize leakage flux. Coupling is increased if the primary winding has several turns however satisfactory results can be obtained with only a single turn. For best results, the secondary winding should be evenly spaced completely around the core. The exciting current determines the maximum accuracy that can be achieved with a current transformer.

Advantages of current transformer: The main purpose of the instrument current transformer is to produce from the primary current, a proportional secondary current which can easily be measured or used to control various circuits. Current transformers are commonly used in metering and protective relaying in the electrical power industry. They facilitate the safe measurement of large currents, often in the presence of high voltages. The primary winding is connected in series with the source current to be measured while the secondary winding is normally connected to a meter, relay or a burden resistor to develop a low level voltage that is amplified for control purposes (Makky *et al*., 2008).

Disadvantages of CT: Substation revenue metering accuracy has been attainable using conventional CT's, however there has always been a concern about the low-end meter accuracy. With increase of electric system capacity and the voltage class, electromagnetic CT is hard to fit the development of electric system gradually. In short circuit fault occasions, serious magnetic saturation occurs resulting secondary to current output waveform distortion, hence is not able to reflect the transition process accurately in short circuit occasion and bring about relay protection mistake action and refuse action. It does not allow the measurement of DC signals. Isolation between primary and secondary sides is implicitly given and has limited frequency range problem. The main error in a measurement-type Current Transformer (CT) is magnetizing current that causes ratio and phase displacement errors. Commonly, cores with high effective permeability are used in current transformers in order to minimize magnetizing current and reduce errors (Magnetics, 2000; Rashtchi *et al*., 2008).

Applications of CT: Current Transformer is used in measurements of distorted current waveforms with Secondary Load Impedance. It is commonly used in metering and protective relays in the electrical power industry (Ackermann, 1999). Current transformer is best performed in steady state current measurement.

MECHANICAL METHOD

Introduction: Mechanical methods of current sensors could be inferred to as electromechanical transducers which have been the bases of present technological emancipations. It cuts across all endeavours of engineering, particularly in electrical engineering.

Background: With search of new and improved methods of current measurement and control of electric current various possible methods and approaches have been invented, developed, improved and adopted for use, just as narrated earliar.

CONCLUSION

Sourcing for means of improved methods of current measurements in handling (generation, transmission, distribution and control) of electrical power has led to the search and discoveries of different techniques of electric current measurements, such as Optical Current (OC) method, current transformer method, Shunt resistor current method, Hall effect current measurement method, Rogowski coil inductive method as narrated earlier. So, depending on the desired electrical parameters needed, advantages and disadvantages from each or combination of these methods could be use to achieve efficient and effective current measurement, resulting to better control and regulation of electric power system. The techniques show that it is possible in reproducing replication of its types in their ratios but the constrain surrounding its productions and safety factors are most paramount parameters to be considered.

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