A Cutting-Edge Fiber Optic Based Current Sensor for DC Current Measurement in Electrochemical Industry

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Abstract- High DC current measurement of a few tens to many thousand amperes with precession is required in a few electrochemical industries for process control, operation, and equipment protection. Customarily, current estimation in the electrochemical industry has been founded on the Hall Effect. The proposed Fiber optic current sensors use the Faraday Effect, which makes the polarization of light to rotate. Compared with a Hall impact DC current transducer, Fiber Optic Current Sensor (FOCS) isn't just superior as far as its performance and usefulness yet it is likewise littler and lighter. The sensor follows the Faraday Effect in an optical fiber and measures the path integral of the magnetic field along a closed loop around the current conveying conductor. The differential magneto-optic stage movement of energized pivoting light waves propagating in the fiber is utilized to quantify the magneto-optic stage move. Fiber spinner innovation is utilized for signal detection and processing. The sensor can be introduced without removing the current carrying conductor, consequent recalibration is not required. This cutting-edge fiber optic current sensor offers better accuracy, electrical insulation, consumes less power, smaller and lighter in size than conventional current measurement systems used in electrochemical industry.

Keywords – DC Current Measurement, Faraday Effect, Fiber Optic Current Sensor (FOCS), Hall Effect, Polarized Light Waves

I. Introduction

High DC current measurement of several tens to hundreds of thousand amperes with precession is required in several electrochemical industries such as aluminum, copper, zinc, etc. for process control, operation, and equipment protection. In these industries require high precise DC current sensors to measure, control and operational process.

To supply this requirement of higher voltages and high currents in such industries, they are connected to ac grid through several rectifiers. With the optimized process in place, industries will save energy and monitor actual energy consumption, and thus operate and control the process more accurately. This paper presents and compares the traditional method of Hall effect current measurement with a versatile Fiber Optic Current Sensor in electrochemical industry. It is intended to bring out and highlight the superiority of fiber optic current sensor in accurate current measurement of several hundreds of amperes. The FOCS defeats the disadvantages of conventional Hall Effect transducers [1-3]. The proposed Fiber Optic Current Sensor offers better execution over Hall Effect current sensor for the electrochemical industry.

The rest of the paper is organized as follows. Traditional, current measurement in electrochemical industry, based on hall effect are explained in section II. The new fiber optic current sensor for current measurement is presented in section III. Comparison of hall effect and fiber optic current sensor system are given in section IV. Concluding remarks are presented in section V.

II. TRADITIONAL CURRENT MEASUREMENT IN ELECTROCHEMICAL INDUSTRY, BASED ON HALL EFFECT

When a magnetic field (B) exists in the perpendicular direction of current (I) conveying conductor, a difference in potential occurs in between the two fields. This potential is corresponding to the flow of current amplitude. At the point, when there is no magnetic field and current flow, then there is no potential difference. In case, when the flow of current and a magnetic field coexist, the interaction of current charges with the magnetic field creates a current distribution to change and causes the Hall voltage V_H as shown in Fig.1and Fig.2.

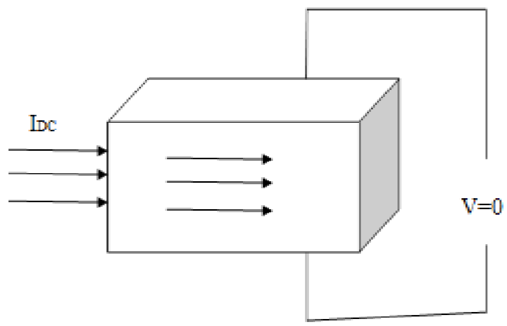

Figure 1. Hall effect generalization, when no magnetic field

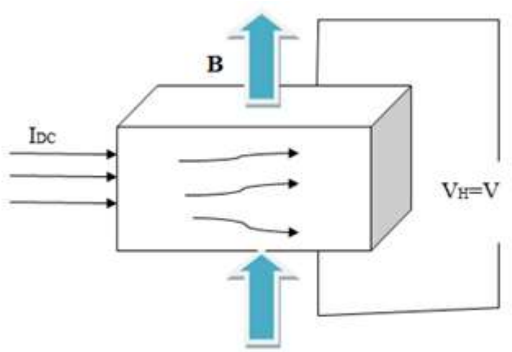

Figure 2. Hall effect generalization, causing Hall voltage V_H with the interaction of the magnetic field and current

The magnetic core of a Hall effect current transducer encompasses a current conveying bus bar. Various semiconductor Hall components, situated in holes inside the center, are utilized to sense the magnetic field. The signals of Hall elements are given to current amplifiers for primary gain, whose outputs move through coils encasing the magnetic core. These coils create a magnetic field that overcompensates the field of the primary current. And so, the secondary current is corresponding to the primary current. Fig. 3 shows the working of Hall effect current transducer. This type of transducer is complex in nature and weighs up to several hundreds of kilograms requiring a larger area. It requires complex setup procedures to avoid the asymmetric field errors and susceptibility to neighboring current carrying bus bars.

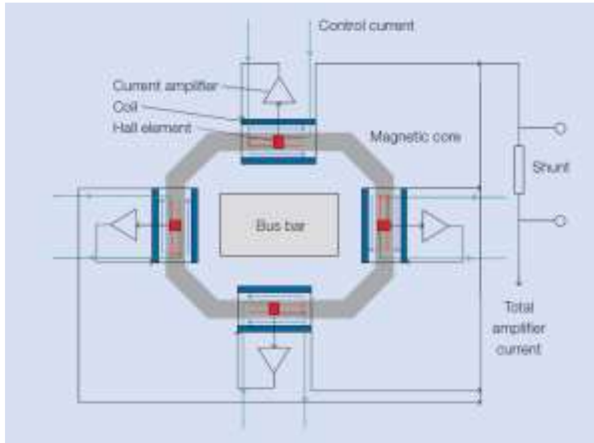

Figure 3. Hall effect current transducer working [15]

III. Fiber Optic Current Sensor For Current Measurement

The new Fiber Optic Current Sensor for high DC current measurement is an advanced cutting-edge sensor for the electrochemical industry. The sensor utilizes the principle of Faraday effect.

3.1 Faraday effect–

The Faraday or magneto-optic effect is the phenomenon that the plane of polarization of a linearly polarized light wave traverse through a medium, for example, a piece of glass, is rotated in the proximity of a magnetic field, as shown in Fig.4.Linear light may also be depicted by a set of co-propagating right and left circularly polarized light waves [4-5].

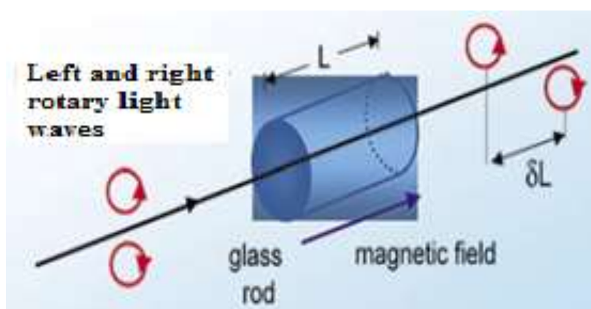

Figure 4. Faraday Effect[15].

In a magnetic field, the two rotary waves proceed with different velocities and thus gather together a path difference of δL or equivalently phase difference of ϕ_F. In a current sensor, the light goes around a closed path defined by the fiber around the conductor. In reflection mode the phase difference is given by:

$$\Delta \phi_F = 4V N\int H \, ds = 4V N I \qquad (1)$$

Where V is the Verdet constant, a material dependent measure for the magnitude of the Faraday effect [6-7]. N is the quantity of turns of light in the region of the conductor carrying the current I. As a consequence of the closed path, the signal depends just on the current and the number of fiber loops, and not on dimensional factors like the diameter or the fiber loop form.

3.2 Fiber optic current sensor–

In this type of sensor configuration, the light is reflected back at the end of a sensing coil and travels back along the same path. The setup is shown in Fig.5. Partially polarized light is launched from a source, passes through a coupler, and then enters a fiber polarizer to achieve completely polarized light. Because of the 45° splice between the axis of the fiber polarizer and the axis of the polarization-maintaining (PM) fiber, the wave is equally split between the PM fiber y- and x- axis [8]. The stage modulator will modulate the phase contrast between these two linearly polarized components. Before entering the detecting coil, the wave passes through a quarter-wave phase retarder. Because of 45° splice just before the retarder, both of the linear orthogonal components will give rise to one circularly polarization component each but with a different sense of rotation. At the end of the sensing coil the wave is reflected and the two components swap positions, i.e. the one component that is right-hand circular will become left-hand circular and vice versa. Upon passing the phase retarder in the backward direction, the circular components are changed over back to linear components [9-12]. Due to the fact that the two components swapped positions when they were reflected the linear components are interchanged, i.e. the one part parallel to the x-axis at the input will be parallel to the y-axis at the output and vice versa. The PM fibers will induce a relative phase difference between the two components since there is one fast axis and one slow axis but since the components are swapped the relative phase difference will become zero after the backward propagation.

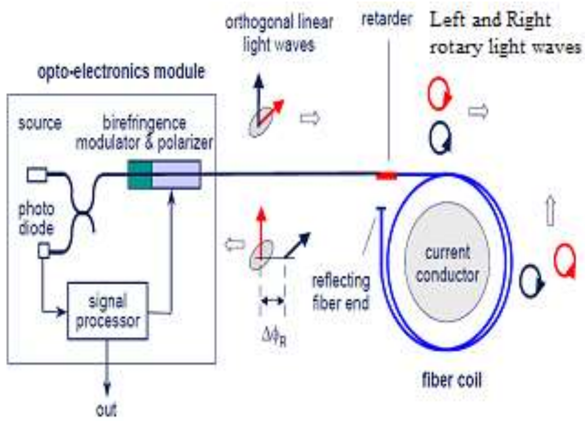

Figure 5. Schematic illustration of a fiber optic current sensor for high DC current measurement [1].

In the event there is a current present in the conductor, i.e. there is a magnetic field encasing the conductor, there will be an induced phase shift between the two components that is four times the Faraday phase shift $\Delta\phi R=4\phi F$.

The reason that the observed phase shift is four times the Faraday phase shift is due to the fact of the non-reciprocity quality of the Faraday effect. Since the wave is transformed into one right-hand rotary component and one left-hand rotary component, there will be a corresponding phase shift two times the Faraday phase shift after the forward pass through the sensing coil. In transit back, with swapped polarization, the wave will once again experience a phase shift that is two times the Faraday phase shift and the total phase shift will result in four times the Faraday phase shift.

Preference of the light reflection arrangement is that it is basically resistant to mechanical vibration and shock [13-14]. Another preferred standpoint is the single finished detecting fiber, which helps in sensor installation, specially under the conditions in the electrochemical industry.

IV. Comparison Of Hall Effect And Fiber Optic Current Sensor System

The Fiber Optic Current Sensor overcomes the limitations of traditional transducers and offers better performance and functionality. Fig. 6 demonstrates a typical Fiber Optic Current Sensor utilized as a part of electrochemical industry [15]. Sensor head constructed with standardized units allowing flexibility, comprising of portions of fiber-fortified epoxy, suits the strip with the sensing fiber. The sensor head can be mounted to the current carrying bus bars easily. The sensing strip is inserted afterward. The sensor head is associated with the sensor electronics by means of a fiber cable link. Some of the key attributes of a traditional Hall effect sensor and FOCS comparison is given in Table I.

The sensor is a turn-off of a present current sensor for applications in the electrochemical industry which provides a diverse performance for users including the following:

- Accuracy is inside ±0.1 % over an extensive range of temperature and currents.
- Superior in terms of performance and functionality.
- The device can be introduced without removing the current carrying conductor. Onsite calibration is not required.

- It is additionally smaller and lighter, weighs only a few tens of kilograms requiring lesser area.
- The sensor is importantly easier to transport and quicker to install.
- No particular structure is compulsory to magnetically center the sensor head. This renders the customer remarkable adaptability with regards to sensor position.
- In comparison to traditional current transducers, incorrectness attributable to asymmetric field system and magnetic overburden are innately wiped-out.
- The device will manage bi-directional magnetic fields. A nearby inversion in the field course, prompted by sturdy neighboring currents, does not bring about an erroneous sensor output. What is more, the sensor signalizes once reversed currents appear.
- The signal processing electronics is fully galvanically disconnected from the bus bars.
- Advanced output signals are accessible to the present modern automation industry.
- Power utilization of the optical device is so small considered with conventional sensors, which expend up to many kilowatts of power.

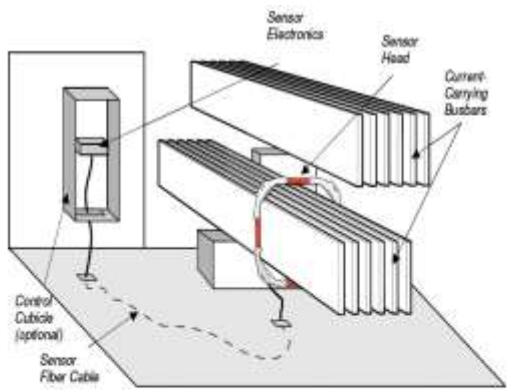

Figure 6. A typical Fiber Optic Current sensor used for high DC current measurement [15].

Table -1 Comparison of Hall effect sensor versus Fiber Optic Current Sensor

Attribute	Hall Effect Sensor	Fiber Optic Current Sensor
Application Flexibility	Poor	Good
Weight	Heavy	Light
Transport and Installation	Difficult	Easy
Magnetic Centering/ on site calibration	Required & is Complex	Not Required
Power Consumption	More	Less

V.CONCLUSION

The Fiber Optic Current Sensor is an important and real advance in the innovation of high current dc measurement. This best in class fiber optic current sensor bring out superior performance and is smaller, lighter and less complicated than conventional Hall effect current measurement system for the electrochemical industry.

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