Fiber Optic Current Sensor: A Review

Sonali Narayanrao Wagh
Electronics and Communication,
Parul Institute of Engineering and Technology
Limda, Vaghodia, Vadodara, India
sonalipachghare@gmail.com

Prof. Srushti Soni
Electronics and Communication,
Parul Institute of Engineering and Technology
Limda, Vaghodia, Vadodara, India
spsoni181@gmail.com

Abstract— ***This paper is a review paper of the fiber optic current sensor. Sensor uses the Faraday Effect to measure the current. Faraday Effect states that when two circularly polarized waves pass through the medium like glass, they travel with different velocities in the presence of external magnetic field. Two most popular sensors are presented. They are Sagnac loop interferometer current sensor and in-line interferometer current sensor. Individual configurations and working is studied. Although very advantageous fiber optic current sensor suffers from some undesirable effects that have to be cancel out in order to increase the sensitivity of sensor. Sources of these errors are discussed and some methods to compensate those errors are presented. Applications of the sensor are presented.***

Keywords— ***Fiber-optic current sensor, Faraday Effect, Linear birefringence, Faraday Mirror, Polarization. Verdet constant***

I. INTRODUCTION

In power industry role of sensors is crucial. Sensors are installed to monitor current and voltage. By reliable measurement of these quantities we can diagnose the fault and can protect devices. Conventional sensors like Hall Effect current sensor which uses magnetic flux compensation are precise but suffer from many disadvantages like they are complex, Consumes kilowatts of power, are very bulky and weigh more than 2000kg. Recent development in fiber communication made fiber optic current sensor more popular as it give many advantages over conventional sensors. It can be used for both AC and DC current measurement. It gives immunity against electromagnetic Interferences (EMI), as the sensors are made of dielectric materials they are electrically isolated, no saturation Effects, it consumes low power, it has small weight and relatively low cost.

In this paper two most popular current sensors are presented. Sagnac loop interferometer current sensor and in-line interferometer current sensor. Both the sensors work on the principle of Faraday Effect. Faraday Effect states that when two circularly polarized waves travels with different velocities when the external magnetic field is applied. The phase shift produced by the waves is measured which is a direct measure of current. There are some undesirable effect too that we have to compensate to make FOCS more reliable. Birefringence is the common problem that found in single mode fiber which affects the sensitivity of the sensor if not treated. There are some methods which can be used to supress the birefringence.

II. SENSOR CONFIGURATION

A. Faraday Effect

Fiber optic current sensor works on Faraday Effect. It states that when left and right handed circularly polarized waves travels through a medium like glass, they accumulate a phase shift between them if a magnetic field is applied along the direction of propagation of light. As in the current sensor magnetic field is directly proportional to current to be measured, phase shift is direct measure of current.

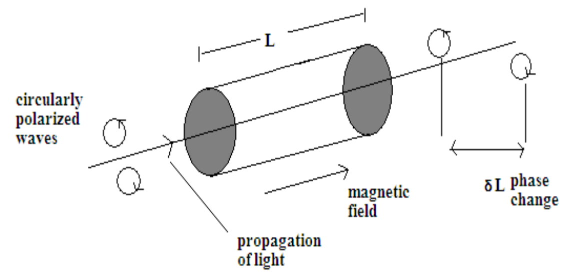

Fig. 1 Faraday Effect

B. Sagnac loop interferometer current sensor

Fig .2 shows the set-up of Sagnac loop interferometer current sensor. Light is emitted by the light source which is a low coherence, broadband semiconductor source like superluminescent diode. Superluminescent diode gives the advantage of both LED and LASER.

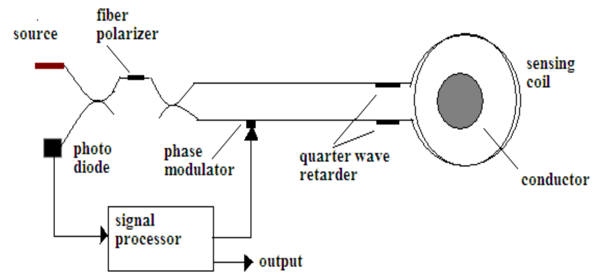

Fig. 2 Sagnac loop interferometer current sensor

Light passes through fiber polarizer which converts the wave in two orthogonal components. These components travel through the polarization maintaining fiber. The two quarter wave plates which are placed before sensing coil converts the linearly polarized waves in to circularly polarized waves which are counter-propagating.

These waves travel with the different velocities through the sagnac loop. Different velocities are due to the magnetic field which is induced due to the applied current. The two circularly waves once again passes through the quarter wave retarder which converts them in to linearly polarized wave. The phase difference accumulated due to Faraday Effect is given by

$\Delta\Phi s=2\Phi F$
(1)

Where ΦF =VNI, V is the verdet constant of the material which represents that how strong is the Faraday Effect in that material. N is the no. of loops of fiber in the loop and I represents the current to be measured. Equation (1) shows that current can be directly measured if we know the phase shift. This method has a disadvantage that its sensitivity is greatly affected by temperature and vibration.

C. in-line interferometer current sensor

The disadvantages faced by sagnac current sensor are eliminated by inline interferometer sensor also known as polarization rotated reflection interferometer. The partially polarized light from the source is completely polarized by the linear polarizer.45˚ spice between the fiber axis and the axis of polarization maintaining (PM) fiber splits the wave equally between the X-axis and Y-axis of PM fiber.

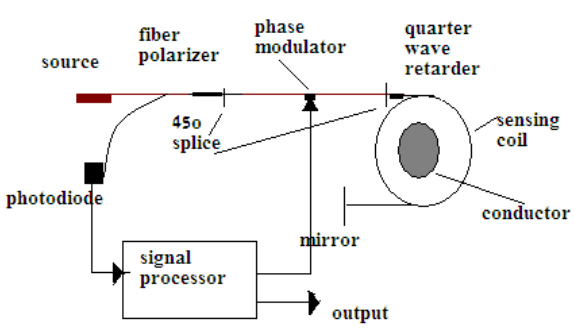

Fig. 3 in-line interferometer current sensor

After crossing the PMF the two orthogonal waves pass through the quarter wave retarder which is oriented at 45˚ with respect to the fiber axis. It transforms the two components in the circularly polarized waves with opposite rotation direction. The waves after passing through the sensing coil are reflected by the mirror which is placed at the end of the coil.

Due to reflection the state of polarization interchanged i.e. left hand circularly polarized wave become left handed and vice a versa. On returning path the waves are once again converted to linearly polarize by quarter wave retarder and pass through the same optical path. As the Faraday Effect is nonreciprocal the phase shift experienced by the waves is double than in the sagnac current sensor as the wave travels the distance twice.

The phase difference accumulated due to Faraday Effect is given by

$\Delta\Phi s=4\Phi F$
(2)

Because of this the sensor doubles the sensitivity compared to previous one.

III. ADVANTAGES

A. Simple Configuration

As the sensor head is only a circular loop of sensing fiber, sensor weight is very low compared to conventional current sensors.

B. Electrical Isolation

Optical sensors are made of dielectric materials like glass so they are electrically insulated.

C. Capable of measuring both AC and DC with high accuracy.

D. Immunity to EMI

Due to long wavelength light transmission with silica fiber, the device is immune to electro-magnetic interference (EMI).

E. Light weight and low power consumption

Conventional current sensors like Hall Effect current sensor with magnetic flux compensation are very bulky and power consuming can weigh more than 2000kg.all these disadvantages are overcome in optical current sensors.

IV. APPLICATIONS

Because of the above mentioned advantages FOCS has many applications in power industry. FOCS can measure both to AC and DC up 500KA. IT is used for distance protection in which it is observed that saturation effect is absent which is there in conventional current sensor device like CT. It can also modify for harmonic measurement in high–voltage electric power systems.

V. BIREFRINGENCE EFFECTS IN OPTICAL FIBERS

Despite of all the advantages fiber optic current sensor suffers from some non- desirable effects that have to be cancel out in order to keep the sensor sensitive to the Faraday Effect. One of the major issue in optical fiber is the presence of birefringence which can result in change of the state of polarization. Unstable polarization is not desirable due to the fact that the state of polarization is the information carrier. As shown in the Fig. 4 Birefringence causes different refractive indices for X and Y axis because of which polarization state changes from linear to elliptical, then circular again to linear but with 180° phase shift. It takes length lb to come in original state. Length lb is called beat length. Effect of birefringence is reduced sensitivity of the sensor. There are two types of birefringence: linear and circular birefringence. In single mode fiber (SMF) both inherent and induced linear birefringence has to be considered whereas inherent circular birefringence can be neglected.

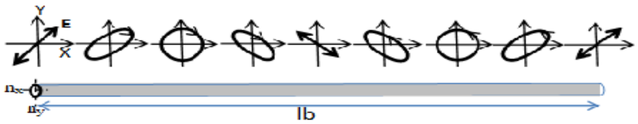

Fig. 4 Transformation of polarization

There are many sources of linear birefringence in SMF includes elliptical cross-section, inner mechanical stress on the core may be due to non-homogeneity of cladding density in area close to the core, outer mechanical stress induced linear birefringence. Some methods for suppression of unwanted linear birefringence are given. They are as follows.

1. Use of polarization maintaining (PM) fibers,
2. Fibers with high circular birefringence,
3. Twisted fiber,
4. Spun low-and high-birefringent fibers,
5. Annealed fibers,
6. Orthogonal conjugation compensation which uses the faraday mirror.

VI. CONCLUSION

Fiber optic current sensors based on Faraday Effect have many advantages over conventional current measuring techniques. Two most popular fiber optic current sensors are presented. Sagnac loop interferometer Sagnac loop interferometer current sensor and in-line interferometer current sensor.

Later one is advantageous in a way that is more insensitive to temperature. Due to their unique properties, fiber optic current sensors have found many applications in the power industry. There are some undesirable effects that have to be cancelled out in order to make these sensors sensitive to the Faraday Effect. Various approaches may be used to compensate these effects.

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