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A Comparison of Signal Processing Techniques in Optical Current Sensor for GIS

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Abstract

This research is contents about output characteristic of optic current sensor that use faraday effect. optic current sensor used in an experiment is consisted of three parts.① Source of light used laser diode of 1310 [nm].② Sensor section manufactured circularly according to gas insulated switchgear. And 9/125[μm] standard single mode optical fiber for communication was installed winding 20 [turn] on sensor section core surroundings of diameter 31 [cm]. ③ Electrical signal of PD(Photo detector) is collected using NI company's 16bit DAQ board via terminal block.

Collected data analyzed by different three signal processing methods. NI company's Labview™ was used to signal processing software.

As a result, In signal processing of optic current sensor, we could know that noise greatly more influences the error generation than fluctuation of light intensity. also, 1 class CT(current transformer) manufacture that have error rate less than 1[%] was available by removing these

Key Words : Faraday effect, Optical fiber measurement, Current transformer, Polarization analysis

1. Introduction

Increase of supply voltage and setup scale are the trends to be satisfied recently due to rapid increasing demand for power. In this situation, gas insulated switchgear is suitable in miniaturization of setup scale in electrical insulation. Hereupon, correct voltage, current measuring for accident prevention of gas insulated switchgear, and stable operation and partial discharge detection technology were required. Existing current transformers have shortcomings of high weight, residual magnetism, output signals distortion by magnetic saturation etc. Therefore, a necessity of an optical current sensor that use a Laser is augmented. This is because it has advantages of high insulation, less demage, no inductivity, and stability.

Optical current sensor can be divided as bulk type or optic fiber type that uses optic fiber(FOCS, Fiber optic current sensor). Optic current sensor

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that compose by bulk type has big verdet constant[1].

Therefore, It expresses high sensitiveness. However, It is bound to undergo wrong sorting of optic element or temperature drift. On the other hand, FOCS is profitable in big current measuring because use of the optical fiber that have low Verdet constant. It can also improve sensitiveness as that close several times around conductor because it uses optical fiber[1].

However, there are two constituent that influence in FOCS's linearity and sensitiveness. Firstly, it is the noise from the source of the light that change in optical circuit. Secondly, it is the strength of light which shows non-linearity between Faraday turning and current. It appears to depends on light source.

In this study, we compared and analyzed effect that fluctuation of light intensity and noise affect the error rate as process FOCS's output signal.

2. Relation theory

2.1 Faraday Effects

Measurement of current that uses mineral ore obeys Faraday effect. It is the phenomenon where the shaft of polarized light rotates by the effect of a magnetic field when light passes inside of magnetic substance. Fig 1. shows Faraday effect's diagram. It is one of the magneto-optics

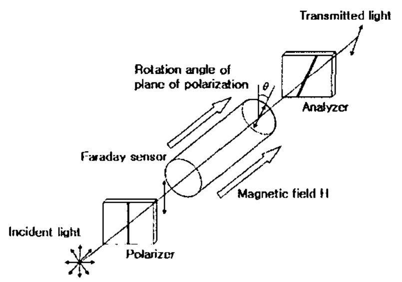

Fig. 1. A schematic diagram of faraday effect

phenomenon. When linear polarization passes Faraday element, a vibration axis of polarized light rotates as θ of Eq. (1).

$$\theta = V \cdot H \cdot L \cdot \cos\phi \qquad (1)$$

Here, V : Verdet constant [rad/A]

H : a magnetic field [A/m]

L : Faraday element's length(optical path length) [m]

Φ : Angle between progress direction of light and magnetic field

The relation that polarization side's rotation angle θ is satisfied in Eq. (1). However, there is a use of Vector value by direction of a magnetic field. Therefore, it is very difficult to measure the rotation angle θ in case we use magnetic substance element. Therefore, a closed loop type sensor section is composed around a conductor using optical fiber by Faraday's element to solve this problem. In this case, sensor section has fixed value, independently of distance between sensor and conductor and it forms a sensor by Ampere's circuit law. Eq.(2), that is not influenced by neighborhood signal source except the measurement of conductor is obtained. In this composition, rotation angle θ is proportional in number to the winds of optical fiber and current[2].

$$\theta = Vn \oint H \cdot dl = Vnl \qquad (2)$$

Here, n : Winding number of optical fiber

I : current

2.2 Polarized light analysis

Maximum sensitiveness and linearity of the measured value are obtained by measuring 45° between Analyzer and an early polarizing plate (I = 0). The signal of light which is measured in

PD(Photo detector) depends on the existing intensity J_0 of light. Henceforth, in spite of comparison of Faraday rotation and input current I, a non-linear relation exists between the measured current. This can be separate by a cast of orthogonal two vector ingredient ($\theta=\pm45[°]$) using PBS(polarization beam splitter). As it does an operation, the state of polarization is produced. Two output signals of PBS are deduced by fluctuation of light intensity that causes AC and DC ingredient and hookup of optic element in optical circuit. These can be illustrated with Eq. (3) and Eq. (4)[3].

$$J_a=\frac{J_1}{2}(1+\sin2\Phi_F)+n_1(t) \quad (3)$$

$$J_b=\frac{J_2}{2}(1-\sin2\Phi_F)+n_2(t) \quad (4)$$

Here, $J_{a,b}$: PBS output signals , $n_{1,2}(t)$: Noise of in optical circuit, $J_{1,2}$: Light intensity

The DC ingredient is given by $\frac{J_{1,2}}{2}$ and AC ingredient can be expressed as $\pm\frac{J_{1,2}}{2}\sin2\Phi_F$. The element that influences FOCS's linearity and sensitiveness is the noise $n_{1,2}(t)$ that happens in optical circuit and intensity the $J_{a,b}$ of light which is shown as non-linear between Faraday rotation and input current being dependent on light source as in Fig 2. Change of source of light in optical circuit affects much FOCS's linearity and sensitiveness. but, these quality can be adjusted by proper signal processing method.

3. Experiment and method

Experimental device, light source section, sensor section, signal measurement section, and signal processing section appeared in Fig 2.

We used 1310[nm] laser diode as the light source and It is available to operate for hours (10^5[h)]. The sensor section that measures the current using the Faraday's effect manufactured to raise sensitiveness by a number of times that wind 20[turn] single mode optical fiber (9/125 [μm]) in a closed loop type. The signal measurement section that change optical signal to electrical signal separates by two orthogonal vector ingredients using PBS. It then changes optical signal to electrical signal using PD that has fast response speed.[4] The signal processing section collects signal on real time and achieves analysis and storage at the same time. This uses 16bit's DAQ board. It composed a signal processing program using Labview™. Data of two signals at optical current sensor is collected through DAQ board at the same time. Each signal processing through programming was composed in Labview™. The detection and comparison of virtual value in each signal processing waveform was done.

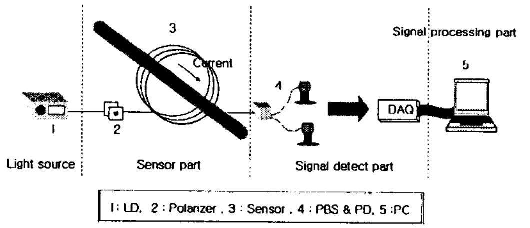

Fig 2. A schematic diagram of the FOCS

4. Result

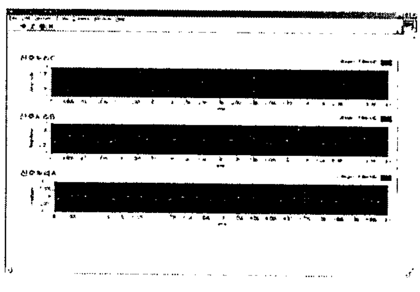

Fig. 3. A display of an experimental measurement

Fig 3. shows A, B, C signal processing methods, at the same time, using Labview™ measured screen. The compare and displayed waveforms of each measured signal processing results.

4.1 Signal processing A

Fig 4. is a signal processing A diagram. It is easy that signal processing A composes electronic circuit part for signal processing by the simplest method. However, the effect by the output fluctuation of light intensity is big. The change by loss of signal that occurs in hookup of each optic element greatens, too. If we use the difference of Eq. (3), Eq. (4) that is obtained in PBS, the results appear as below.

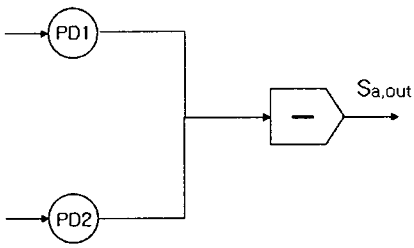

Fig. 4. A schematic diagram of the signal processing A

$$S_{a,out} = J_a - J_b = \frac{J_1 - J_2}{2} + \frac{J_1 + J_2}{2}\sin 2\Phi_F + [n_1(t) - n_2(t)] \quad (5)$$

If we suppose that two signal outputs of PBS have equal special quality, and that they can be approximated as $J_1 \approx J_2 = J_0$. Also, if the source of light changes and the noises of light which pass optical circuit are same, then the output $S_{a,out}$ is expressed as that is approximated by $n_1(t) \approx n_2(t) = n(t)$.

$$S_{a,out} \approx J_0 \sin 2\Phi_F \quad (6)$$

Fig 5. compares output $S_{a,out}$ of signal processing A with the reference values that is been proportional to Faraday rotation angle θ and It can be obtained form Eq. (2). It is considered that by the effect of strength, J_0 of light shows much differences between the reference values and the experimental values.

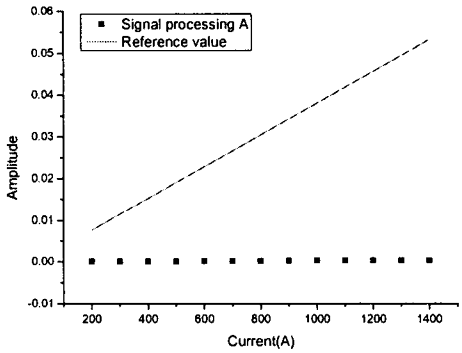

Fig. 5. A comparison between the signal processing A and a reference value

4.2 Signal processing B

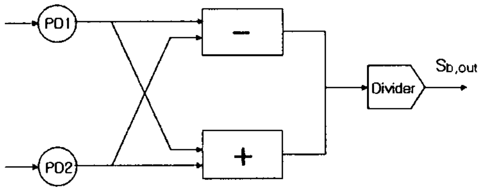

Fig. 6. A schematic diagram of the signal processing B

Fig 6. is a signal processing B diagram. It is a method to produce state of polarization using two x axis and y axis ingredients that are obtained in PBS. The output $S_{b,out}$ appears as in the following Eq. (3) and Eq. (4).

$$S_{b,out} = \frac{J_a - J_b}{J_a + J_b} \quad (7)$$

$$= \frac{\frac{J_1 - J_2}{2} + \frac{J_1 + J_2}{2}\sin 2\Phi_F + [n_1(t) - n_2(t)]}{\frac{J_1 + J_2}{2} + \frac{J_1 - J_2}{2}\sin 2\Phi_F + [n_1(t) + n_2(t)]}$$

The output $S_{b,out}$ that is approximated in $J_1 \approx J_2 = J_0$, $n_1(t) \approx n_2(t) = n(t)$ is expressed as follows.

$$S_{b,out} = \frac{\sin 2\Phi_F}{1 + \frac{4n(t)}{J_0}} \approx \sin 2\Phi_F + \frac{2n(t)}{J_0}\sin 2\Phi_F \qquad (8)$$

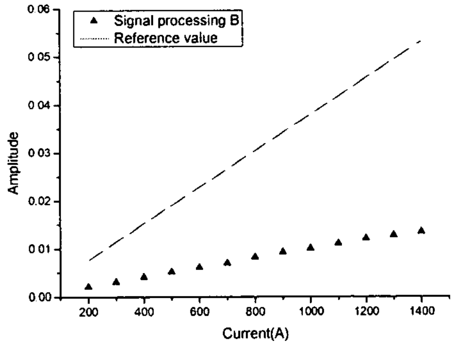

Fig. 7. A comparison between the signal processing B and a reference value

Fig 7. compares the output $S_{b,out}$ in signal processing B with the reference values. As an effect of light intensity J_0 decrease, the output values of signal processing B improved than the output values of signal processing A. However, it shows much differences, yet, from the reference values. This is considered that to be due to noise $n(t)$ effect in optical circuit.

4.3 Signal processings C

Fig 8 is the signal processing C diagram. It detects each AC ingredient and DC ingredient in two signals of PBS. Then it divides each by AC and DC ingredient to remove the state of polarization's change by the fluctuation of light intensity and noise in optical circuit. Then, the function about noise in optical circuit and fluctuation of light intensity is removed to get a stable output signal.

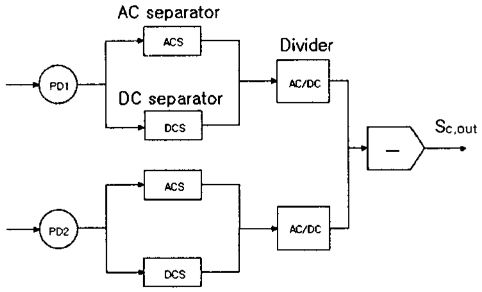

Fig. 8. A schematic diagram of the signal processing C

$$S_{c,out} = \frac{J_{ac1}}{J_{dc1}} - \frac{J_{ac2}}{J_{dc2}} \qquad (9)$$

$$= 2\sin 2\Phi_F + \frac{2[J_2 n_1(t) - J_1 n_2(t)]}{J_1 J_2}$$

The output S_{out} that is approximated in $J_1 \approx J_2 = J_0$, $n_1(t) \approx n_2(t) = n(t)$ is expressed as follows.

$$S_{c,out} \approx 2\sin 2\Phi_F \qquad (10)$$

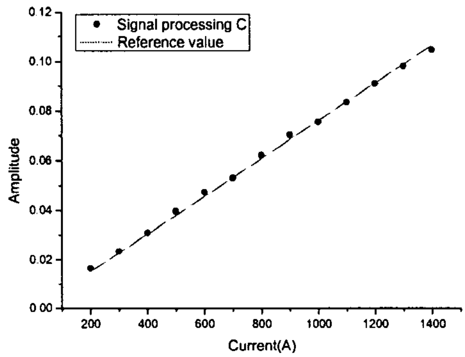

Fig. 9. A comparison between the signal processing C and a reference value

Fig 9. displays the output $S_{c,out}$ of signal processing C where the effect of intensity J_0 of light and optical circuit's noise $n(t)$ is removed. Signal processing C shows higher linearity and sensitiveness than other signal processing methods have. All the three methods show linear increase by input current increase. However, the signal processing C largely reduces the fluctuation of light intensity and noise in optical circuit and shows high responsiveness and linearity than other signal processing methods. It also shows nearly property closer to the reference values.

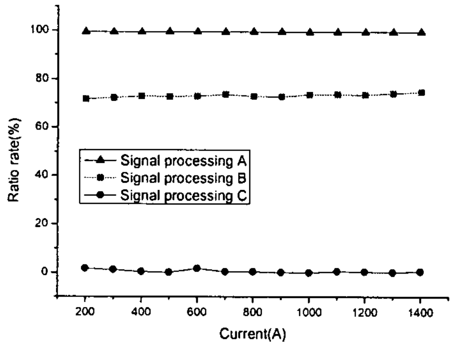

Fig. 10. A comparision of an error rate of the each signal processing

Fig 10. expresses error factor that compares each of the signal processing A, B, and C measurement data with the reference values using Eq. (11). The effect of intensity J_0 of light that highly depends on the source of light in signal processing A, the error factor is the biggest. The decreased J_0 effect on signal processing B including noise $n(t)$ shows approximately 15[%] low error factor than A in optical circuit. Finally, signal processing C that removes two error elements, expresses the best special quality expressing the lowest error factor.

$$E=\frac{I_{out}-I_p}{I_p} \qquad (11)$$

Here, I_{out}: output signal of FOCS, I_p: reference value of FOCS

Specially, The signal processing C shows a stable error property within 1[%] in a current more than 300[A] that compare 1 Class that is used by current measuring standard. It is presented at Fig 11.

Fig 12. displays change of waveform by increase of current in signal processing C. Waveform at 100[A], 500[A], 800[A], 1000[A] were compared while being measured. It shows, in each measurement, the current that amplitude of the output increases lineally.

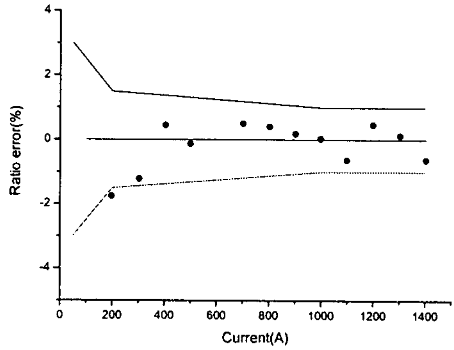

Fig. 11. An error limits of the accuracy class 1 at the signal processing C

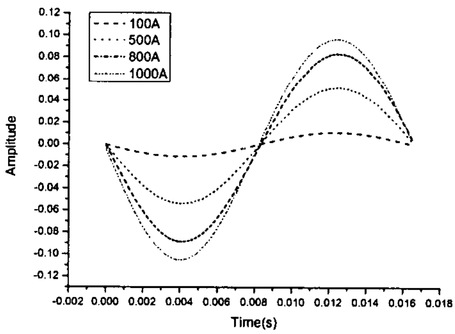

Fig. 12. A waveform of the FOCS signal processing C

5. Conclusion

This research has compared with three signal processing methods that can compensate noise and fluctuation of light source intensity in FOCS.

Firstly, sensitiveness and linearity decrease factor of output signals are noise that generated by fluctuation of light source intensity and noise in optical circuit.

Secondly, It is that noise error in optical circuit bigger than the error what cause by fluctuation of light intensity.

Thirdly, the error factor appeared below 2[%] in case remove all changes of intensity of light that depends on noise and source of light in optical circuit were removed.

Specially, input current area of more than 400[A] error factor by below 1[%] had appeared. Therefore, it shows enough stability to operate by 1 Class CT. Hereupon, FOCS that use signal processing C has shown application possibility of being stable, special quality as gas insulated switchgear current sensor.

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References

[1] J.I.Jeon, C.W.Jung, W.Z.Park, K.S.Lee, J.B.Kim, "Optical current snesor using magneto-optic effects", ICOPS 2003.IEEE Conference Record, 350, June 2003.

[2] A.Papp, H. Harms, "Polarization optics of index-gradient optical waveguide fibers", Appl. Opt 14, No.10, 1975.

[3] Z.P. Wang, Q.B. Li, J.H. Sun, L.B. Zhang, "Comparison of signal processing schemes used in optical current transformers". Electric Power System Research 57, 93-96, 2001.

[4] A.Papp, H. Harms, "Magnetooptical current transformer 1: Principles". Appl. Opt. 19, 3729, 1980.

[5] H. Aulich, W.Beck, N. Doukilas, H. Harms, A. Papp, and H. Schneider, "Magnetooptical current transformer 2: Components", Appl. Opt. 19, 3735, 1980.

[6] H. Harms, E. Feldtkeller, "Automatic recording of faraday rotation and cirecular dichroism", Rev. Sci. Instrum, Vol. 44, No. 6, 1973.

[7] George I. Chandler and Franz C. Jahoda, "Current measurements by faraday rotation in single-mode optical fibers", Rev. Sci. Instrum 56(5), May 1985.

[8] M. Takahashi, H.Noda, K.Terai, S.Ikuta, Y. Mizutani, "Optical current transformer for gas insulated switchgear using silica optical fiber", IEEE Trans, Vol. 12, No. 4, October 1997.

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