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Polarization Method for Electrical Current Measurement

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Abstract – This paper presents a polarization method for electrical current measurement using optical fiber. Classical polarization method has the advantage of being simple but for getting a good performance the optical components have to be carefully assembled due to their sensitivity to disturbance (temperature, vibration). In the field of power systems the most common sensors are those used for the measurement of electrical quantities and to oversee the electrical equipment under voltage. Many times these sensors are located in hardly accessible places (vacuum spaces, with oil, gas, etc.) or connected at a higher potential than earth potential.

Keywords: Polarization Method, Current Measurement, Optical Fiber, Optical Fiber Sensor, Faraday Effect

I. INTRODUCTION

Regularly, for the measurement of electrical currents are used devices and sensors, which allow galvanic separation from the conductor where the current to measure passes, like current transformers or sensors based on Hall or Faraday effects. Other important requirement is the immunity to the electromagnetic perturbations encountered in electrical power stations.
The research of new sensors called 'unconventional' it was quickly oriented to optical measurement methods and especially for using Faraday effect). This method was first investigated using a glass bar, developed later due to the apparition of optical fibers. Optical fibers sensors can perform all these requirements because galvanic separation and electromagnetic interferences are inherent properties of optical fibers [1].
In the field of power systems the most common sensors are those used for the measurement of electrical quantities and to oversee the electrical equipment under voltage. Many times these sensors are located in hardly accessible places (vacuum spaces, with oil, gas, etc.) or connected at a higher potential than earth potential
The measurement of electrical quantities (current, voltage) using optical fibers is based on the polarization modulation. This phenomenon supposes that the quantity to measure produce modifications of the birefringence at the optical fiber level. The birefringence of the active medium can be realized to bring about his anisotropy, meaning that the refractive index is depending on the polarization plane of light. The effects used are: electrical optical effect (Kerr, Pockels) or magneto-optical effect (Faraday).

II. THE FARADAY EFFECT

The current measuring is based on Faraday effect in a single-mode fiber, which is wrapped around a conductor in a closed loop [2]. The light wave's polarization direction is rotated by the magnetically field's is parallel to the light wave's path (fig. 1).
The Faraday effect is not reciprocal, meaning it doesn't vary with the light propagation distance, while optical activity is a reciprocal phenomenon. This solution led to decrease sensitivity to temperature variations. It must be avoided to establish a fixed point in the fiber and the twist sense changing must be done carefully.
From a macroscopic point of view, the Faraday effect appears like a rotation of the polarization plane of a polarized light. This light is propagating in optical fiber that is the magnetic field. This rotation of the polarization plane, due to Faraday effect is proportional to the magnetic field circulation ds along the luminous trajectory (path) according to the expression:

$$\theta_F = V \int_L \vec{H}(s)\vec{ds} \qquad (1)$$

where:
S – curvilinear abscissa along the luminous trajectory;
L - total length of luminous trajectory;
V – Verdet constant (a property of propagation medium).

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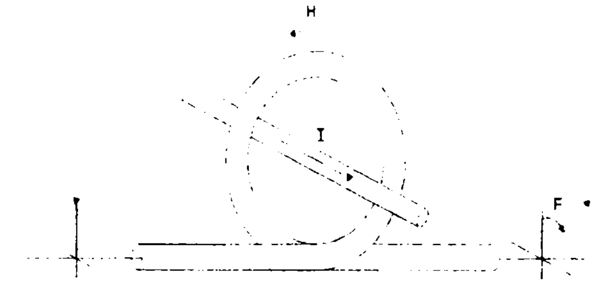

Fig 1 Measure principle

III. THE ELETRO-OPTICAL SYSTEM

In this paper is presented one method through whom the magnetic field has been created namely:

- realization of a coil around the optical fiber;

The used optical fiber is a ,silica' monomode fiber with low birefringence „LoBi". The fiber is the most important part of the sensor. The use of a multi-mode fiber is not recommended, as a linear state of polarization entering a fiber will be quickly destroyed, therefore a single-mode fiber will be used instead. Even in a single mode fiber there is a loss of polarization of the light caused by anisotropy effects (linear intrinsic and extrinsic refractions).

This type of fiber allows the transmission of a linear polarized light beam maintain the polarization plane position. The apparition of a magnetic field produces a rotation of the polarization plane (the essence of the measurement method). The electro-optical source is a laser diode having the wavelength corresponding to the maximum intensity $\lambda_p = 662$ nm. It's properties are: the threshold current intensity $I_{th} = 22$ mA, the intensity for the optimal current $I_{op} = 23$ mA, the optical power output $P_0 = 1$ mW. The Faraday effect being dispersive along the wave length we have to use a monochrome source which has a good coupling efficiency with the single-mode fiber. The wavelength is chosen as short as possible because Verdet constant is proportional to $1/12$. The coupling between the laser diode and the fiber optic is a sensitive part of the system. The electronic power supply for the laser diode realized an adjustment for the current intensity throw the laser diode. It has a block for a slowly start to eliminate the eventually over growths that can appear at connection (this over growths can destroy the diode).

The ORIEL analyzer is used for analyzing the light beam outlet from the sensor. It is positioned between the optical fiber connector and photodiode. It has a rotator calibrate with $0{,}10^0$ resolution and the properly analyzer.

Also, it has been used: one ammeter for alternating current ($I_n = 5A$, $c = 0{,}5$), one inductor coil, one rheostat ($30\Omega / 5A$) that allow a fine adjustment of current intensity and the autotransformer that can assure an adjusting voltage for the serial circuit to induce the measuring current.

IV. THE ANSWER OF OPTICAL FIBER CURRENT SENSOR

The Jones vector is used for characterization the answer of optical fiber sensor and we write this vector like a matrix product for each optical component:

$$J = P_\theta \cdot R_{\theta_F} \cdot J_0 \qquad (2)$$

where:

J_0 – the Jones matrix for linear polarized light;

R_{θ_F} - the matrix of optical fiber core;

P_θ - the matrix of polarizer.

When the light is linear polarized the Jones vector J_0 is:

$$J_0 = \begin{pmatrix} E_{x0} \\ E_{y0} \end{pmatrix} = \sqrt{I_0} \begin{pmatrix} \cos\psi \\ \sin\psi \end{pmatrix} \qquad (3)$$

The Jones matrix of optical fiber core was written when the linear birefringence is 0.

$$R_{\theta_F} = \begin{pmatrix} \cos\theta_F & -\sin\theta_F \\ \sin\theta_F & \cos\theta_F \end{pmatrix} \qquad (4)$$

The matrix of polarizer is:

$$P_\theta = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \cdot J_0 = P_0 \cdot J_0 \qquad (5)$$

So, the Jones vector was completed and the luminous intensity is:

$$I = I_0 \cos^2[(\psi - \theta) + \theta_F] \qquad (6)$$

The answer of optical fiber current sensor has a maximum sensibility when we analyze the light at $\psi - \theta = \pm\pi/4$. For this function point, the luminous intensity is:

$$I = \frac{I_0}{2}(1 \pm \sin 2\theta_F) \qquad (7)$$

The sensibility of the both signals (alternating and direct signals) is:

$$S = \frac{I_1 - I_2}{I_1 + I_2} = \sin 2\theta_F \qquad (8)$$

V. EVALUATION OF LOSSES IN SYSTEM

We have identified the parameters that produce the system losses. These are: reflection of light, fiber optic intrinsic attenuation and the brush-up of both ends of the fiber [6]. The transmittances are:

$$T_{refl} = 1 - \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad (9)$$

where: n_1 and n_2 are the refractive indices in the core and cladding.

The attenuation transmittance is:

$$T_{at} = 10^{\frac{l \cdot A}{10^4}} \qquad (10)$$

The total transmittance for the system without polarizer is:

$$T_{tot} = T_{refl} \cdot T_{at} \cdot T_{fin} \cdot T_{ld-fo} \quad (11)$$

The total transmittance when using a light analyzer in system is:

$$T_{P-tot} = T_{pol} \cdot T_{totala} \quad (12)$$

In this case the losses are: the emission and the reception reflection and the attenuation losses.

VI. EXPERIMENTAL DETERMINATIONS

The two realized systems allowed measuring a current intensity between $0 \div 5$ A (small interval, easy to be done). That signifies that the method sensibility is very good, especially because this sensor is used generally, for hundreds or thousand amperes domains.

Before the beginning of the measures the polarizer characteristic had been traced and using the smallest squares method we can identify his function:

$$U_{pol}(\theta) = 0{,}9074 + 19{,}012 \cdot \cos^2(\theta - 9{,}96) \ [\text{mV}] \quad (13)$$

After that, the minimal and the maximal point of this characteristic was identified. The minimal point is a conventional 0, and its position depending to the connector' position. If the last one is moving, the minimal point is changed. After these two points were determined it was identified the half of the transmission point (fig. 2). This corresponds to a 45^0 angle, after $\cos^2$ law. Any rotation of the polarization plane caused by an electric current produce a linear variation of transmitted luminous intensity

The rotation of the polarization plane depending on the electric current intensity to measure is given by:

$$\theta(t) = V \cdot L_b \cdot H = V \cdot N \cdot i(t) \quad (14)$$

where:

V – the Verdet constant ($24 \cdot 10^{-5}$ degrees/A);

L_b – the length of the optical path in the coil (0,2 m);

N – the turn numbers of the coil (1200);

According the second equation we have obtained the relation between the output voltage of the measurement system U_{out} and the value of the rotation angle of the polarization plane.

$$u(t) = 0{,}9074 + 19{,}012 \cdot \cos^2(\theta(t) - 9{,}96) \ [\text{mV}] \quad (15)$$

Using the optical fiber current sensor it have measured some the values of the direct and alternating currents. The experimental determination had been repeated six times to estimate the trust interval (repeatability).

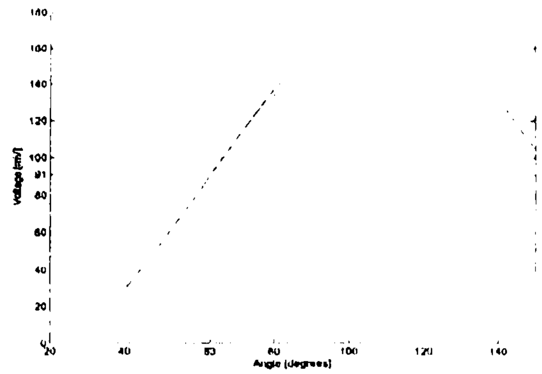

Fig. 2 The analyzer response

Depending on the measured value U it has been measured:

- the medium value of the measurement for each value of the current; the experimental squared deviation (rectified) ; the trust interval (the absolute error of fidelity), where t=1 (t is the Student repartition coefficient for $P = 99{,}73\%$, $n = 6$); the related error corresponding to the studied domains; the regression function, based on the theoretic model (we used the smallest squares method) :

$$U(I) = U_0 + S \cdot I \ [\text{mV}] \quad (16)$$

where: $U_0 = 3.432$ [mV]

- the medium value of the angle corresponding to the medium voltage and to the angle determined on the theoretic value; the absolute true error; the related true error; - the total error.

We observed the values for the total errors. The total error obtained when we measured the direct current is 2.89% and for the alternating current is 1.89% . This values are almost the related true errors.

The solution to increase the useful signal and in fact meaning the sensibility are:

- increasing the current intensity through the laser diode;
- the increasing the photo detector sensibility;
- the extension of the measurement domain for the current intensity as well as the magnetic field intensity;

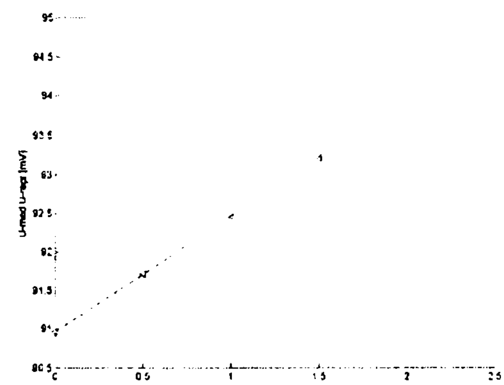

Fig. 3 The transfer function for the direct current

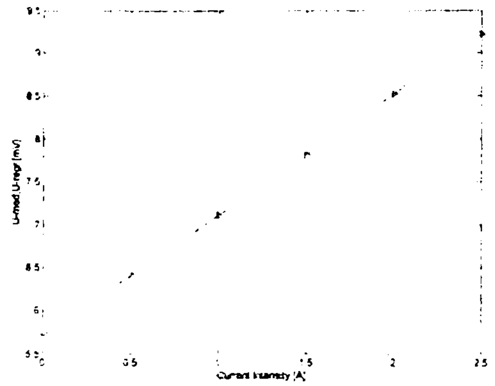

Fig. 4 The transfer function for the alternating current

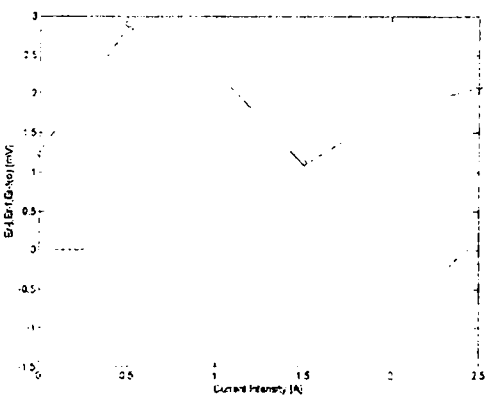

Fig. 4 The error characteristic for the measurement direct current

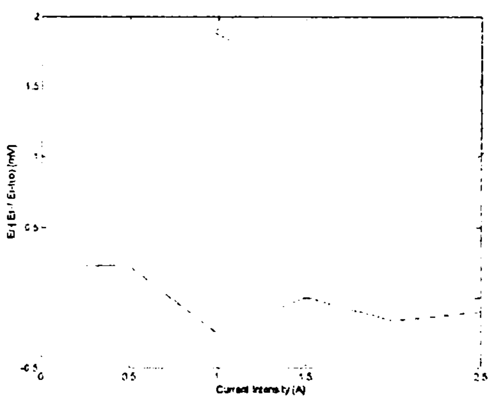

Fig. 4 The error characteristic for the measurement alternanting current

VII. CONCLUSION

The current sensor described above works employing the Faraday effect. The major difficulty in the construction of such a sensor consists of using a classical detection configuration.

The used solution attests the stability and the good linearity of the method and allows the projection for a very large scale of current by a good choosing of the inductor. Our solution confers a good linearity and that will permit the design for a large current domain. When the currents have large values, the sensibility will increase, meaning that the rapport signal vs. noise will be better.

We could use a Wollaston prism instead the analyzer, allowing the compensation of certain influence quantities, but this solution is expensive.

These types of optical current sensor have the small dimensions and it offered the immunity of the electromagnetic perturbations and the galvanic isolation.

REFERENCES

[1] Royer, P., "*Capteur de courant et traitements associes*", SEE Limoges, 14-15 oct 1995;

[1] Dakin, J., Culshaw, B., "*Optical Fiber Sensors: Principles and Components*", Artech House, Boston, London, vol. I, 1988;

[2] Chai, Y.,"*Handbook of Fiber Optics. Theory and Applications*" Academic Press, Inc., San Diego, California, 1980;

[3] www.oxford-electronics.com;

[4] Stanciu, M., "*Senzori cu fibre optice*", Ed Secorex, Bucureşti, 2001,

[5] Ionescu, A., "*Traductoare pentru automatizări industriale*", Ed. Tehnică, Vol. I, Bucureşti, 1985;

[6] Simion, V., Pantelimon, B., Ştefănescu, C., "*Aspecte privind pierderile din sistemele de măsurare cu fibre optic"e*, Proceedings of International Metrology Conference, (ISBN: 973-99385-5-8), vol.3, pag. 855-858, Bucharest, Romania, September 18-20, 2001;