DC CURRENT MEASUREMENT FOR HIGH VOLTAGE EQUIPMENTS BY ELECTRO-OPTIC METHODS

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Topic: High Voltage Techniques

ABSTRACT

In electro-optic measuring methods, Pockels and Kerr effects are widely used for voltage measurement, and Faraday affect is widely used for current measurements. In this study, small currents have been measured experimentally by using Faraday electro-optical effect. Interferometer measurement techniques have been examined and a new sensing system is constructed.

I. INTRODUCTION

Optically active materials rotate the polarization of linearly polarized light. Under the influence of a magnetic field inactive isotropic materials rotate the polarization of a light beam parallel to the field vector. The fact that only the field component parallel to the direction of propagation is rotated is expressed by the scalar vector product Eq. (1),

$$\alpha = V\int \vec{H}\, d\ell \qquad (1)$$

where α is the angle of rotation (in degrees), H is the magnetic field vector, $d\ell$ represents the path of the light in sensor, V is the Verdet constant of the sensor material. Verdet constant is magnitude of rotation in an unit area. Verdet constant is 2.5×10^{-4} deg/A for glass fiber in this experiment.

Two types of Faraday sensors are employed; optical (silicate) fibers and bulk material [1]. In both cases, light from a laser source is polarized before being sent through the sensor. To determine magnetic field (current) one measures the rotation angle at the output of the sensor [2]. In many application this rotation is established by fringes in an interferometric system. Suitable materials for sensors preserve the polarization of the light beam and do not rotate the plane of polarization in the absence of a magnetic field. Isotropic materials are preferred for sensor applications. High sensitive signals are obtained with fiber optics wound several times a conductor carrying current. For maintain the polarization single mode fiber optics generally is used in fiber optic applications.

Some bulk materials have higher Verdet constant than normally used fiber optics. Typical values for fiber sensors are $V=2.5\times10^{-4}$ deg/A and l=1 m. Thus a magnetic field of 2×10^{5} A/m is required to observe a phase shift of about π/4 [3]. If the sensor forms one loop around a conductor that carries a current, $\oint \vec{H}\, \vec{ds} = I$ is used to express the integral in equation Eq. (1) in terms of *I*,

$$\alpha = VI \qquad (2)$$

For a sensor placed inside a coil with N_c turns,

$$\alpha = VN_cI \qquad (3)$$

yields.

The output optical signal after rotation at the measuring arm is,

$$P = (P_0 / 2)(1 + \sin 2\alpha) \qquad (4)$$

P_0 is the optical power from the light source, α is the Faraday rotation angle, P is the optical power received [4].

Non purity of the material and also bends and pressures on it induce variation of linear refractive index. This variation is reduced by using polarization maintaining fiber. Vibration is another failure source. By bending fiber circular refractive index variation is obtained. Verdet constant varies with heat and frequency [5]. Verdet constant changes with;

$$\frac{dV}{dT} = Vx10^{-4} K^{-1}. \qquad (5)$$

II. INSTRUMENTS USED IN EXPERIMENT

Used optical mounts are manufactured by Newport, New Focus and Thorlabs companies. The mirrors, polarizers, focusing lenses, microscope objectives, beamsplitters, detectors and fiber optics were mounted on the setup is as shown in Figure 1.

These optical mounts are; self centering mounts, xyz sliding stages, rotating and sliding stages, mounting posts, adjustable post holders, post holder bases, angle brackets, optical component mounts, swivel clamps, prism holders, ball bearing slides, optical jaws, breadboard mounting plate.

Laser Source: In this study Helium-Neon Laser was used. Its output power is 2.8 mW. It has enough power, well isolated and a stable laser. Output beam is not polarized. Polarization was provided by polarizers in setup. He-Ne laser is fed by a power supply that draws 2.5A, feeds with 12.5 Volt and output voltage level is 1700 VDC. Beam divergence is 1.3 mrad. Wavelength is 632.8 nm.

Polarizer: Ordinary lights produce magnetic and electrical waves perpendicular each other. Polarization occurs at every direction. At a particular angle of incidence at which the electric filed vector is assumed parallel to the plane of incidence, no light would be reflected. This angle is called the polarizing angle, such that the sum of the reflected and refracted angles is 90°. In other words, at the polarizing angle, the reflected and the refracted rays are at right angles to each other. There are two roles of polarizers; the production of polarization (polarizing role) and detection of polarization (analyzing role).

Beamsplitter: Beamsplitters were used for interferometric arms which require the light path to be split. Beamsplitters that are 1.65 mm thick were used with 45 degree in the setup. First surface is coated with a layer which is reflected the red laser without loss. Transmittance of light has 632.8 nm wavelength is about 90 percent on the first place. Back surface is coated with anti coated coating. These coatings provide maximum light gain. Glass material is BK-7 type and its refractive indices is 1.50 [6].

Mirror: Reflection of He-Ne Laser on this mirror is 90 percent at 45 degree incident angle. Coating is high polished metallic. It has diamond turned machined surface. Coating thickness is less than 100 nm. This prevents unwanted scattering light.

Fiber optic: One of the properties of light is the phenomenon of polarization. Light can be described as a transverse wave traveling through a medium such as glass, air or vacuum. The electric and magnetic fields which make up a beam of light always oscillate in the perpendicular to the direction of its traveling. The polarization of a light beam can be affected by many things, including reflection from surfaces, stresses within the transmitting media, magnetic fields and the others. Controlling and manipulating the polarization state of light is also highly desirable. The electric field vector just vibrates up and down in a specific direction. This known as linearly polarized light. The polarization state of light traveling trough a medium can be influenced by stress within the medium. This can present problems with ordinary single mode fiber. When a normal fiber is bent or twisted, stresses are induced in the fiber. To solve this problem, several manufacturers have developed polarization maintaining fibers (PM fibers). Such fibers are also known as polarization preserving fibers or Hi-Bi fibers. This PM fiber used in this study operates by inducing a birefringence (a difference in the propagation constant of light traveling through the fiber for two perpendicular polarizations) within the fiber core. In this study, SM.63-P manufactured by Fujikura was used as polarization maintaining fiber. Core diameter is 125 micrometer.

Focusing Lens Assembly: Fiber optics outputs which are used at Mach-Zehnder type two arms interferometer are guided to beam splitter by focusing lens assembly. This assembly consists of two Plano-convex lenses and one plano-concave lens.

Detector: There are two types of detector, thermal and photonic. Photonic silicon detector was used in this study. Silicon detector visible light response is better than InGaAs detectors. Relative response of silicon detector is 70 percent at 632.8 nm. It gives maximum response at 830 nm.

Coil: Small (leakage) current passes through the 300 turns coil which was wounded on the fiber optic. According to Ampere's current law magnetic field induced inside the coil. Induced magnetic field changes the polarization direction of light guided by fiber optic inside the coil. Magnetic flux density is parallel to the fiber axis. For 300 turns coil, magnetic flux density is,

$$B = \mu_0 nI \qquad (6)$$

where B is the magnetic flux density, I is the current, n is the turns, μ_0 is permeability of air $4\pi x10^{-6}$ H/m. If I equals 35 mA, magnetic flux density is calculated as $13.2x10^{-6}$ A/m.

Microscope objectives: Focusing of microscope objectives is better than other lens assemblies. Two 40X magnification microscope lenses were used to focus the laser input of the fiber optics. The higher the numerical aperture, the closer working distance and smaller the field of view are other advantages of the objectives.

III. PREPARATION OF SETUP

Polarization maintaining single mode fiber optic was preferred because of cheap, widespread use in sensor applications and proper dimension for setup to measure the leakage current on the high voltage equipment with proper sensor. Before starting of this study two kinds of fiber were procured from Fujikura and Fiberguide firms. Because of dimension and quantity of fiber procured from Fujikura is more suitable for experiment, study was started with this fiber, while the one manufactured by Fiberguide has very small diameter and the bulk glass materials which are very expensive and also hard to form.

Room temperature is kept constant during the experiments, in order to prevent the effect of temperature changes on fiber optics. To avoid the vibration and impact, the floating optical table was used. Test setup was constructed on this table and. measurements were conducted in a dark room.

Alignment was one of the main problems during the experiments. Instead of expensive optical alignment tools, available optical components were used. A grooved table was done to locate the fiber. Fiber was correctly located and fixed with plasticizes to avoid bending. Fiber surface was rubbed down with a special emery. This was very difficult matter beside the alignment. Roughness of fiber surfaces were checked by 50X magnification microscope. Mach-Zehnder type interferometer was constructed to measure the leakage current. It is two arms interferometer. In this study, two 300 turns coils were wounded on two single mode polarization maintaining optical fibers (with plastic coatings) both being equal in length as 100 mm. Small (leakage) current was drawn via coils. He-Ne laser was used as a light source. The DC small current was provided from a precision power supply. He-Ne laser light first arrived to the beamsplitter. Laser light splits two parts after beamsplitter. Both parts are almost equal in power. This was verified by a laser power-meter. Passed light from beamsplitter reaches polarizer and this light was polarized. The polarized light travels in the microscope objectives and then arrives to the reference arm of interferometer. Light was focused on the mirror with the collimator (focusing) lens assembly. Reflecting light from mirror via another collimator lens reaches the second beamsplitter. Finally reference light was detected by silicon detector.

Reflecting light from first beamsplitter reaches to mirror in front of the measuring arm. Reflecting light from mirror reaches measurement arm as polarized light passing through the polarizer and microscope objectives. Leaving light from fiber optic is fallen on beamsplitter. After beamsplitter, the measuring light comes on the detector. Reference light and measured light coincides on the beamsplitter. Coincided lights create the interference. Interference produces a fringe pattern. Since detected signal is a cosine function of the detected phase variation, a waveform of oscillation (pattern of fringes) occurs. Interference amplitude varies with current value. Thus, electrical signal output of detector varies with current variation. Measuring setup is shown in Figure 2.

IV. DC ELECTRIC CURRENT MEASUREMENT

300 ohm 11W resistor was connected to the coil in series. Current level was increased starting from 1mA to 50 mA. When the current was 35 mA level, a signal was observed on the scope. Sinus wave changes with current variation. Each 1 mA current increment is caused to 0.25 mV voltage rise on the output signal. The period of the Sine wave was 24 ns. This wave shows the fringe pattern. Obtained waveforms at 36 mA and 37 mA are given in Figure 3 and 4 respectively. While at 36 mA peak to peak voltage level is 6.5 mV, at 37mA peak to peak voltage level was observed as 6.75mV. Average voltage values were measured starting from 35 mA to 50 mA. Measured values were demonstrated at Figure 5. As seen in this figure, system response is 0.25 mV/mA. Linearly results were obtained between 35 and 50 mA current levels.

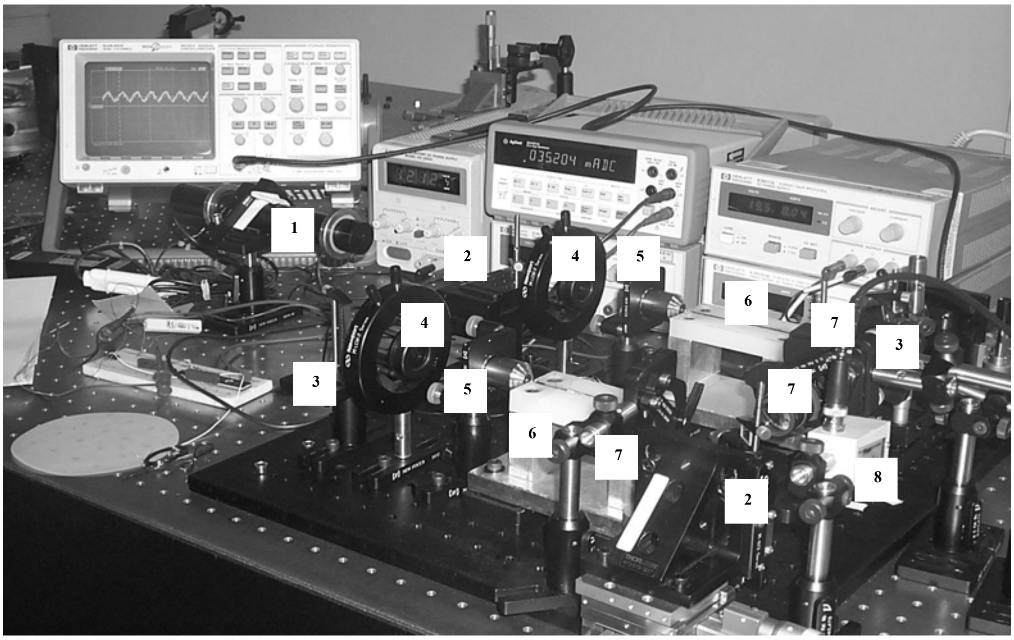

Figure 1. Leakage current experimental setup (1) He-Ne Laser, (2) Beamsplitter, (3) Mirror, (4) Polarizer, (5) Microscope Objective, (6) Optical Fiber, (7) Lens Assembly, (8) Detector

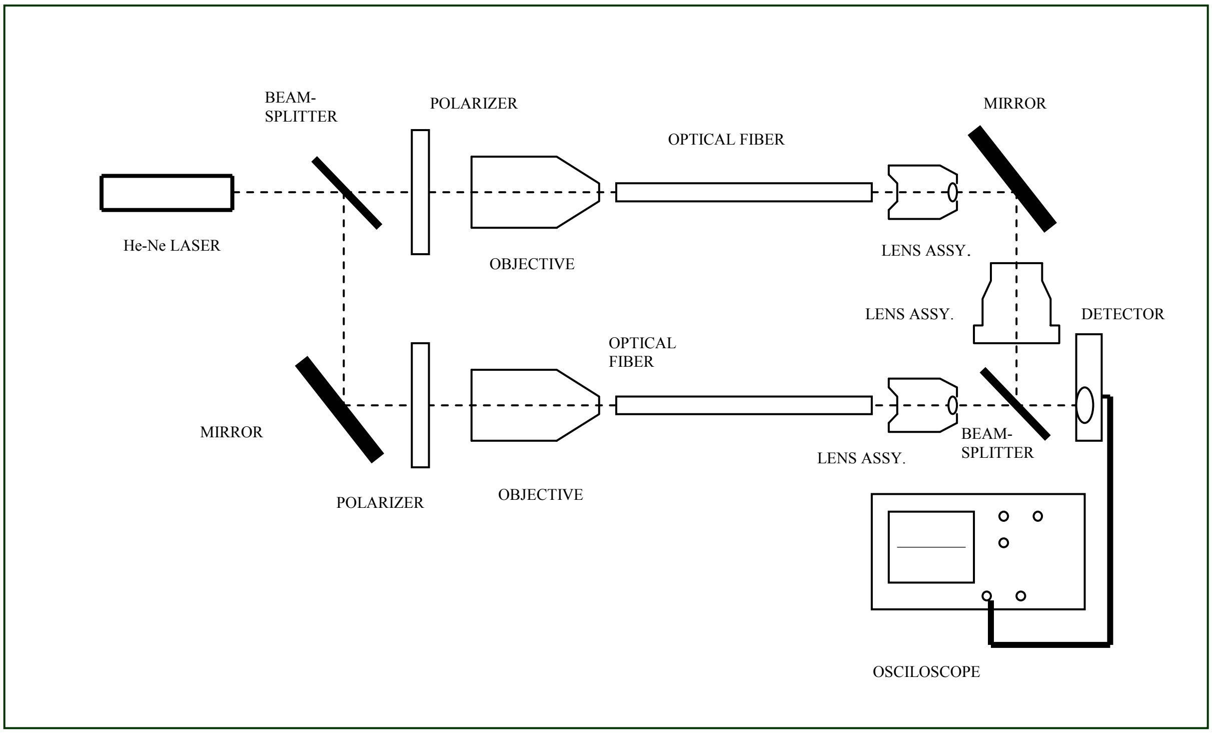

Figure 2. Leakage current measurement experimental setup

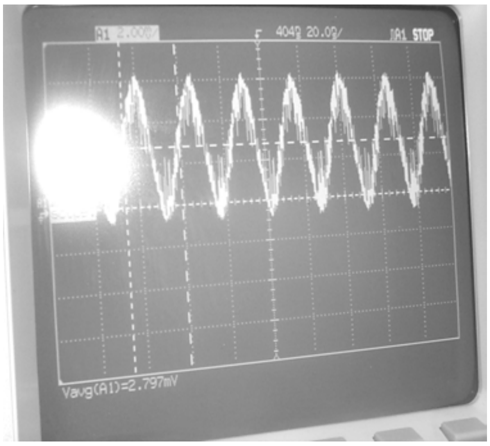

Figure 3. Waveform at 36 mA

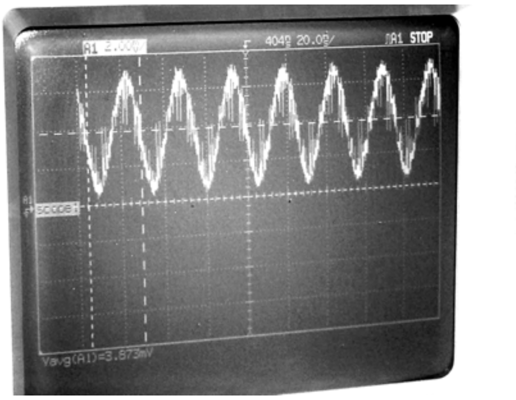

Figure 4. Waveform at 37 mA

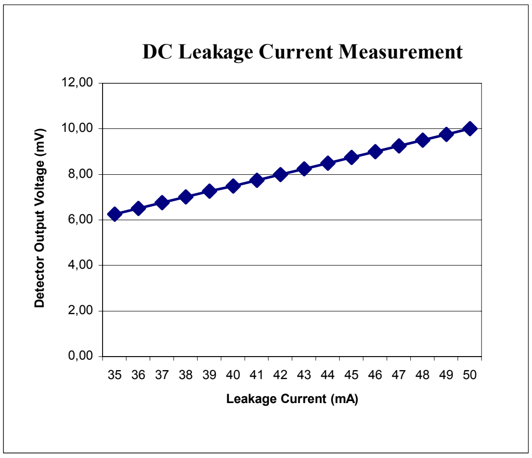

Figure 5. Leakage current versus detector output voltage

V. CONCLUSION

The experimental results showed that a possibility of measuring the small electric current sensitively using by a new electro-optical method. In this proposed method, the interference phase variations are detected by an optical interferometric sensing device. Using Faraday electro-optic effect, small currents can be measured linearly changing voltage levels. The coil generates magnetic field which excite the single mode PM fiber. The leakage current has driven by a coil that is wounded on the optical fiber. Magnetic field was obtained by that coil and generates the Faraday effect. Under the influence of magnetic field polarization, the maintaining optical fiber rotates the polarization of linearly polarized light. This rotated polarized light and reference light have been coincided and fringe pattern has been obtained in two armed interferometer of Mach-Zehnder type. The output optical signal has been detected by a photo-detector with the intensity of light rather than orientation of polarization. The waveform of detected signal has been observed by a digital oscilloscope. By using this interferometer set-up, d.c. leakage currents have been successfully measured in the range of 35-50 mA. A.c and impulse current measurements will be the subject of the future work.

VI. REFERENCES

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