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Novel Method for Current Measurement using Single Mode Fiber

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Abstract

This paper presents a Fiber optic current sensor (FOCS) which employs selected cut-off single mode fiber. It is all-glass fiber supporting single mode light propagation for operating wavelength of 633 nm from the HeNe laser. A simple and modified practical setup to measure the current, based on the Faraday's Effect is proposed. Experimental results are analyzed and a new formula has been obtained to measure the current using this practical setup.

Keywords: Fiber Optic Current Sensor, Faraday Effect, Single mode fiber, current measurement.

Introduction

Fiber-optic current sensors (FOCS) have been widely investigated during the last years because of their increased acceptance and use due to their superior accuracy, bandwidth, dynamic range and inherent isolation [5-11]. Current sensors employing the Faraday Effect in a coil of optical fiber are very attractive for metering, control and protection in high voltage substations. Advantages include the inherent electric separation of the sensor electronics at ground potential from the sensing fiber coil at high voltage as well as the small size and weight. As a result, the sensors can be integrated into existing high voltage equipment such as circuit breakers and bushings. This eliminates the need for bulky stand-alone devices for current measurement. Furthermore, the output signals in contrast to the power outputs of conventional inductive current transformers are compatible with modern digital control and protection systems [1]. The use of optical fibers as sensing elements for electric current measurements has been developed by several methods such as those utilizing magnetic field to generate the Faraday effect, magneto motive force to make fibers bend, magnetostrictive material bonded on a fiber to constrict or lengthen the fiber, and heating effect to change the fiber's length and refractive index. In all the above methods, perturbations such as magnetic field, pressure, strain and temperature as induced by the measurand i.e.,electric current, accordingly resulting in change of the optical fiber characteristics and then modulation of light within the fiber.[2].

In past several years there is more research and development of FOCS. Because of many advantages such as galvanic isolation, immunity to electromagnetic interference, intrinsic safety, less weight, small in size [3] and also occupies less space. The main principle behind the FOCS is to convert the polarization modulation of the light induced by the Faraday Effect into intensity modulation. The ultimate choice for making use of fiber sensors to measure current is due to its accuracy and because of the fact that it is free from electromagnetic interference [5-11].

In this paper, we have proposed a simple and modified fiber optic current sensor and the current sensor are calibrated according to the experimental values. Magnetic stress effect is employed to sense the current.

Principle of Operation

A scheme of practical FOCS is shown in Fig.1. Light from the He-Ne laser passes through the polarizer and is coupled to the selected cut-off single-mode all glass fiber by a single mode fiber coupler. Sub-micron resolution and stability are required when coupling laser light into the core of a single-mode fiber. F 1015 Newport precision single mode fiber coupler use a steering lens to achieve 0.1 micron resolution in a compact package.

An input iris assists in centering the laser beam. The beam passes through a steering lens which is mounted in a precision x-y translation assembly with 100 pitch adjustment screws. An objective lens focuses the

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beam on the fiber core. Translating the steering lens causes a second-order translation of the focused beam across the fiber end-face providing 0.1 micron beam positioning resolution with negligible changes of incident angle of the fiber face. For use with free space lens operating in the visible wave length range, F1015 has a steering lens with a multilayer dielectric AR coating and a M-20X microscope objective. The effective focal length is 9 mm.

The fiber is placed on the soft magnetic material (SMM) plate and a SMM cylinder is placed on it i.e., the fiber is neatly sandwiched between the two SMM pieces. To distribute the mechanical load properly on the fiber, two dummy fibers are also placed between the SMM pieces.

For the current sensor the force that the two SMM pieces exert on the fiber (Fig.1), if we assume that there is a uniform field in the region of the fiber, can be expressed as [4],

$$f_i = (a_1 \mu_o \mu_r^2 N^2 i^2) / (2 l_m^2)$$

Where, a_1 = area of the SMM cylinder face
μ_r = relative permeability of the SMM cylinder
N = number of turns of wire
l_m = length of the magnetic path
i = applied current

The output of the fiber is then detected by the optical power meter through an analyzer. In our proposed scheme, we have employed the magnetic stress effect to sense the current and the sensor calibration is done by curve fitting technique.

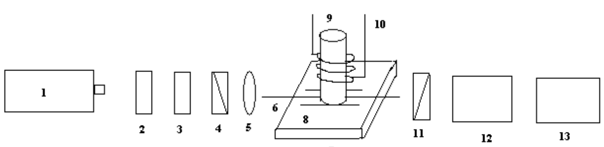

Fig.1 Experimental Setup for FOCS

1. He-Ne Laser; 2 & 3.Mirrors; 4. Polarizer; 5. Lens; 6. Fiber ; 7. Metal plate; 8. Dummy fiber ; 9. Metal Rod ; 10.Coil carrying current to be measured ; 11. Analyser 12. Optical Power Meter; 13. Signal Analyser

Experimental Setup and Measurement Procedure

The block diagram of the experimental setup is shown in Fig.1.Light from the He-Ne laser is polarized and coupled to the fiber by a single mode coupler. After conducting preliminary tests on different coils, we found that the 20 turns coil suits our requirement. The results of the different coils are shown in Table 1. A sufficient magnetic field is produced by a winding of 20 turns of flexible insulated wire, in the form of a coil. When the current passes through the coil, the magnetic field causes the two pieces of SMM to attract each other with the force that is proportional to the square of the field. The fiber is placed between the SMM pieces and so this force exerts lateral stresses on the fiber, resulting in stress induced birefringence. The output of the fiber is detected by the optical power meter through the analyzer. Then the optical power meter output is converted to electrical signal by the signal analyzer and is measured in volts. The results are shown in Table.2.

In one of the earlier studies [4], a coil with 100 turns is used to measure the current. The limitation is that, the measurement can be made for the current in the range between 4 A and 11 A. The other limitation is the current cannot be measured between 0 A and 4 A. These limitations are overcome in the present work which uses a 20 turn coil. In order to increase the range of current under measurement, a modified approach has been proposed in this paper. In our approach the current can be measured from 0A to 18 A by employing a coil with 20 turns. Also, the level of complexity is reduced in this present approach.

TABLE 1

	no.of turns=100		no.of turns=52		no.of turns=33		no of turns = 25		no of turns = 20	
current	mmf	o/p in volts	mmf	o/p in volts	mmf	o/p in volts	mmf	o/p in volts	mmf	o/p in volts
0	0	0.08	0	0.005	0	0.005	0	0.08	0	0.08
1	100	0.147	52	0.012	33	0.008	25	0.08	20	0.08
2	200	0.335	104	0.04	66	0.012	50	0.1	40	0.1
3	300	0.723	156	0.127	99	0.023	75	0.12	60	0.12
4	400	1.08	208	0.243	132	0.039	100	0.16	80	0.14
5	500	1.08	260	0.382	165	0.07	125	0.2	100	0.18
6	600	1.18	312	0.47	198	0.11	150	0.28	120	0.22
7	700	1.2	364	0.507	231	0.169	175	0.38	140	0.28

8	800	1.23	416	0.491	264	0.24	200	0.48	160	0.38
9	900	1.19	468	0.474	297	0.32	225	0.62	180	0.48
10	1000	1.21	520	0.46	330	0.404	250	0.74	200	0.58
11	1100	1.25	572	0.452	363	0.49	275	0.86	220	0.68
12					396	0.554	300	0.96	240	0.78
13					429	0.58	325	1.06	260	0.9
14					462	0.548	350	1.1	280	1
15					495	0.477	375	1.14	300	1.06
16					528	0.471	400	1.14	320	1.12
17					561	0.497	425	1.14	340	1.16
18					594	0.486	450	1.14	360	1.2
19					627	0.446	475	1.14	380	1.2
20					660	0.465	500	1.14	400	1.2

TABLE 2

Input current in Amps	Output in volts	Curve fitting value
0	0.08	0.0804
1	0.12	0.0954
2	0.12	0.1134
3	0.12	0.1347
4	0.16	0.1599
5	0.16	0.1899
6	0.2	0.2255
7	0.24	0.2678
8	0.32	0.318
9	0.36	0.3778
10	0.44	0.4485
11	0.52	0.5327
12	0.64	0.6326
13	0.76	0.7512
14	0.92	0.8921
15	1.08	1.0593
16	1.28	1.2581
17	1.52	1.4941
18	1.72	1.7743

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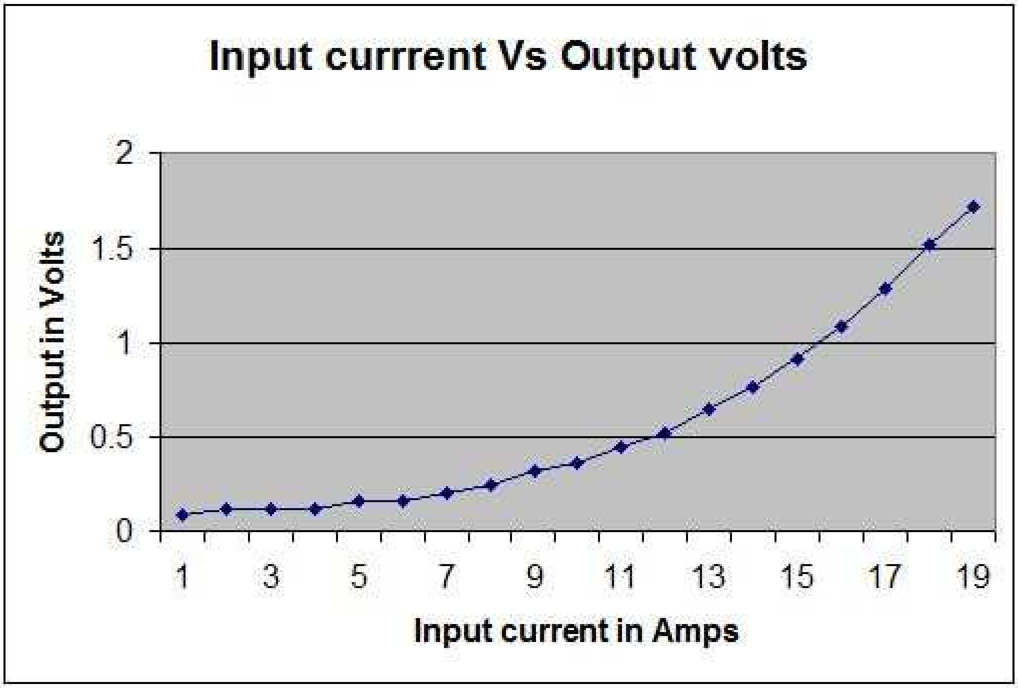

Fig. 2: Plot of the output of the fiber vs. input current

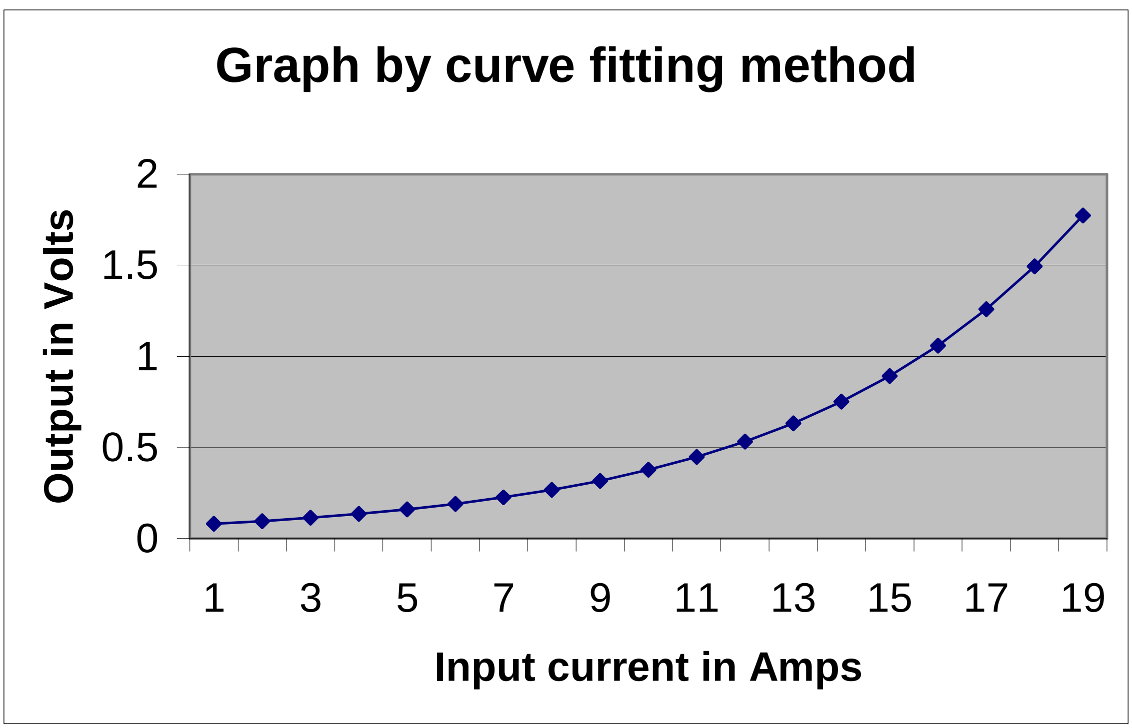

Fig.3: Plot of the output of the fiber vs. input current for theoretical values.

Researchers have reported sensors that are linear or square law behaviors. In the present case from the results it is observed that the output of fiber is neither linear nor exact square law variation. Figure (1) shows the exact variation of the output of the fiber. Hence to obtain a characteristic relation for the sensor, curve fitting technique is used. Figure (2) shows the output of the fiber using curve fitting technique.

The final relation obtained by using sigma plot software is given as

$$I = 0.0804\, e^{0.1719v}$$

Where, I = current flowing through the sensor
V = voltage reading in the output meter

With input polarization at 130 degrees, output polarization at 160 degrees, the output of the FOCS is experimentally measured and calculated using the above relation. The curves are plotted in Figure 3. It is found that there is good agreement between the formula calculated and actual values.

Conclusion

A novel method is proposed using single mode fiber. This FOCS is performed experimentally to measure the current in an energy system. We have proposed a simple system to measure an ac current ranging from 0 – 18 Amps. In other methods, they have the limitations of measuring currents 0.5 Amps to 10 Amps and 4 Amps to 11 Amps whereas in our method, the variation of current measurement is from 0 to 18 Amps which can be varied linearly. The sensor has good characteristics response to measure the current and it shows that it can be a potential application to the FOCS for the practical current measurement. Perhaps, a proper casing must be designed for the coil and soft magneto material. Also necessary care should be taken to avoid the vibration of the optical system. Finally, there is a good agreement between the calculated values from the derived formula and the actual values.

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