Working model of optical fiber sensor for estimation of sludge in oil in electrical transformer

T Venkateswara Rao1, V V S S Chakravarthy2 & K Krishna Murthy3

1Department of ECE, Dhanekula Institute of Engineering & Technology, Ganguru, Vijayawada, Andhra Pradesh, India
2Department of ECE, Raghu Engineering College, Vishakhapatnam, Andhra Pradesh, India
3Department of Electronics, P.B.S. College, Vijayawada, Andhra Pradesh, India
E-mail: tumati01@gmail.com; E-mail: sameersree@gmail.com; E-mail: kolla_krishnamurthy@rediffmail.com

Received 9 February 2011; revised 31 May 2011; accepted 6 June 2011

A working model of an optical fiber sensor for estimation of sludge in transformer oil is presented based on evanescent field of absorption. The method proposed consists of a multimode glass fiber of diameter 62.5/125 µm operated at 1100 nm wavelength. The external jacket and cladding of the fiber are removed at different points along the length of the fiber and along with the coils immersed in transformer oil. The two ends of the fiber are taken out from the transformer; one end of it is connected to an ANDO (1100 nm) power source while the other end is connected to an optical power meter coupled with a relay and circuit breaker. The method presented will be of great use for estimating the formation of sludge in transformer surrounding the coils and thereby prevent its damage due to formation of sludge. With little effort, the working of the system can be made on-line and monitored from a central office.

Keywords: Oil sensor, Evanescent sensor, Sludge detector, Optical fiber sensor

1 Introduction
Fiber optic sensors represent a technology base that has revolutionized a multitude of sensing applications.1-5 Their characteristic advantage of being non-electrical, explosion proof, rugged, removable, immune to EMI and RFI, small in size etc make their use attractive for sensing applications. Fiber optic sensors have large applications in science and engineering as is evident from the vast range of physical properties which can be sensed optically, ranging from light intensity, temperature, rotation, radiation, flow, liquid level to chemical analysis, sound, strain, vibration etc. Literature survey has shown the use of an optical fiber for measuring the concentration liquids6 in iodine, the temperature of liquid7,8 estimation of iodine salt solution9 and various other parameters10. The use of a multimode plastic clad silica fiber with 5 mm sections cladding striped 5 mm apart over the length of the fiber was also reported11.

In the recent years, evanescent field absorption fiber optic sensors have become increasingly popular for remote and distributed sensing applications12-14. The main advantage of these sensors is that one can monitor the parameter of interest in real time. These sensors are based on the absorption spectroscopy15-18. When light travels form a denser to rarer medium, evanescent wave propagates parallel to the interface. The amplitude of the wave decreases exponentially in rarer medium with a characteristic penetration depth19.

Power breakdown sometimes causes due to failure of the transformer. There may be many reasons for failure of the transformer but the most common being the oil acting as coolant in the transformer not maintained to optimum level. The line supervisor periodically expected to check the level of the oil in the transformer. If the level of the oil is not maintained the transformer gets heated up and results in bursting. The oil surrounding the transformer acts as a coolant. During continuous operation of high voltage transformers, the transformers get heated up, the oil acting as a coolant gets evaporated resulting in the formation of sludge. Also during summer when the temperature goes beyond 40-45°C the external radiation will also help in bursting the transformers.

2 Experimental Set-up
We are reporting a working model for estimation of sludge formation in transformer oil in an electrical transformer using a multimode glass fiber of diameter 62.5/125 µm of length 10 m (Figs 1-4). The method involves the intensity based fiber optic sensor based on evanescent field absorption, capable of
continuously monitoring the formation of sludge in transformer oil, as and when exceeds the expected level, the system activates a relay and the transformer is cut-off from the mains, thereby preventing its damage. The experimental arrangement of multimode glass optic fiber with a portion of the cladding removed at the specified points, is shown in Fig. 1

Optical fiber of length 5 m is taken and cladding is removed at regular intervals of 2 cm. The fiber is introduced through the vent hole of a 3 phase transformer. The fiber is made to go along the length of the coils in the transformer as shown in Fig. 1 and the photographic representation is shown in Figs 2-4 taken at different angles. The two ends of the multimode glass fiber are taken out; one end of it is connected to a ANDO power source operated at 1100 nm while the other end is connected to an optical power meter with appropriate electronic circuit with a relay to indicate its possible failure for some time and then the ‘cut-off’ the transformer from the mains. Electrical transformers for distribution of power are usually seen on road sides. These transformers are usually known as distribution transformers for LT connections. The details of the transformer and the oil used in experimental set-up are detailed here as Ratings: 11000/433 volts, 63
KVA, 50 Hz, Connections: HV Delta and LV Star connected with neutral. Transformer oil is as per IS: 355 Electrolytic High Voltage (EHV) oil.

The linemen are expected to service and maintain the oil level periodically. Because of continuous operation of the transformer, which usually generates radiation within and outside due to environment, evaporation of oil takes place resulting sludge formation. If sludge is not removed and oil not replaced, the radiation effects are cumulative and results into the breakdown of the costly transformer (few Lakhs of rupees). As of now, based on our consultations with electrical distribution and maintenance engineers of the state electricity board, there appears to be no method to check the oil level in transformer, except to replenish oil which may be done once in a year or two. Hence, the method proposed will be of immense use to save the electrical transformer from its damage. Light from the source is launched into one end of the fiber through an appropriate connector. The light is now guided through the fiber and comes out from the second end of the fiber passing through the various sections of the transformer immersed in oil. This power is termed as power launched or initial power. Due to continuous operation of the transformer, formation of sludge takes place and the sludge (high RI, high viscous and high density) will cover the core of the fiber which results a change in intensity of the guided light through the fiber. The intensity detection scheme is quite good to record the changes in the guided power due to evanescent field absorption. As the content of the sludge further increases beyond certain value, the system takes care to disconnect the transformer from the high tension lines.

3 Results and Discussion

The variation in the normalized power \( P_n \)

\[
P_n = \frac{P'}{P}
\]

where \( P_l \) is the power launched into the fiber without any sludge and \( P' \) is output power.

The variation of normalized power \( P_n \) with increase in the sludge level formation in a transformer is as shown in Fig. 5. As the sludge level in the transformer oil increases surrounding the core of the fiber, change in the output power is recorded. Due to increase in refractive index of the sludge that results in evanescent absorption and a variation in the output power is noticed. As the sludge level increases, light guided through the optical fiber further changes which results into an increase in output power.

The method suggested for detection of sludge in electrical transformer can be easily designed for different types of transformers by suitably choosing the type of fiber, the length of the fiber based on power requirement. The sensor so developed can also be used not only in electric transformers but in other industry where formation of sludge in the liquids may cause problems.

Acknowledgement

We would like to thank Prof T Radha Krishna, Emeritus Professor, JNTU-Hyderabad, India, for his helpful suggestions and discussions.

References