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Sludge Detection in The Oil Of An Electrical Transformer Using OM4 Optical Fiber

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Abstract

Based on the evanescent field of absorption, a model for estimating the sludge in the oil of an electrical transformer using optical multimode OM4 fibers is presented. The model proposes the use of OM4 optical fiber, which is a laser optimized multimode optical fibre operating at 850nm wavelength. The multimode optical fiber is inserted through the transformer coil which is immersed in the oil, after removing the cladding and the external jacket at various points along the length of the fiber. The one end of the fiber is connected to the laser while the other end is connected to an optical power meter. With this method, the amount of the sludge formation in the transformer oil can be determined, thereby preventing the bursting of transformers.

1. Introduction

The optical fiber is extensively used for high data rate transmission. It also bears the property of ruggedness, durability and more importantly, the immunity against the radiation and electromagnetic interferences. All the above mentioned properties enable the optical fiber to be used as an optical sensor that can revolutionize the sensing application. The optical fibers have been extensively used as a sensor for determining the physical quantities like the temperature, pressure [1], vibration and liquid level etc. Several authors have shown the use of optical fibers as sensors for estimating the iodine in the salt solution [2], the temperature of the liquids [3], [4] as well as the measurement of stress and strain in several remote areas.

The workings of the sensors are based on the absorption spectroscopy. Scenarios like sudden breakdown of the power or the bursting of the transformers are most common and occur more frequently in summer seasons. These hazards occur due to the improper maintenance of the oil up to the optimum level and the formation of the sludge. To reduce such hazards, a working model was proposed for sludge detection using multimode fiber using ANDO power source at 1100nm [5]. Here an improved detection model is proposed by using the OM4 optical fibers as a sensor for estimating the sludge in the transformers with better output power, so as to monitor the oil quality followed by oil replacement in transformer, thereby avoiding the hazards.

Nowadays, the evanescent field absorption optical fiber sensors are increasingly used in remote and wide area distributed sensing applications[6]. All the physical parameters can be measured in the real time with the help of the optical fibers. In the proposed model, the OM4 optical fibers are used as optical sensors for the sludge detection. The vertical cavity surface emitting lasers (VCSEL) are used as the power source operating at 850 nm. The absorption and fiber losses occur least at this particular wavelength.

2. Oil Deterioration in Transformers

The transformer is a static device which transfers the AC electrical energy from one energy level to another energy level. During this continuous conversion of the energy level in high voltage transformers, the core of the high voltage transformer gets heated up. The oil used in the transformer acts as a coolant as well as an insulator. During the continuous operation of the transformer, the moisture in the oil as well as the oxidation process leads to the formation of the semi solid hydrocarbon termed as sludge.

In free-breathing transformers, the oxidative deterioration is faster as compared to that of the sealed transformers. Atmospheric oxygen and moisture serve as a source of oxygen. The rate of oxidation also depends on the oil temperature. As the temperature goes higher, the oxidative breakdown becomes faster. This very process of oxidation process results in the formation of sludge.

In the transformers, the surfaces through which heat is generally dissipated, gets smeared with sludge. The sludge acts as a barrier to the heat transfer from the core and coils to the coolant. For the longer duration of operation, the sludge blocks off the flow of oil through the cooling ducts. As a result, the transformer insulation gets heated and consequently gets damaged, particularly between the turns of the transformer windings. Due to the deterioration of the turns' insulation, short circuits occur between the turns, resulting in the breakdown of the transformer.

3. Optical Multimode Fiber

Generally, OM4 multimode fibers have cores with graded index profiles and large numerical aperture (NA).The refractive index of the core is gradually changing, thus helps to reduce the modal dispersion. The NA is defined as the maximum angle at which a fiber can accept the light that can propagate through it. This phenomenon allows them to work with low-cost optical components and light sources such as VCSEL. OM4 optical fiber is considered to be "laser optimized," i.e. optimized for use with VCSEL light sources. OM4 fiber has a precise refractive index profile, virtually free of defects. The current applications primarily use 850 nm VCSEL lasers. The use of 850 nm wavelength is particularly used as the fiber losses and the attenuation is least in this particular window. This in turn helps to receive the optical power overcoming the losses, thus with better output power. OM4 optical fibers are compatible for applications operating at 1300nm wavelength. This particular wavelength is useful for operation as the losses due to the attenuation and fiber losses are quite minimum as compared to other wavelengths put in use.

Light propagates in the optical fiber by means of total internal reflection. For this, two conditions are required. Firstly, the light should travel from denser to the rarer medium and secondly, the light incident on the core and cladding surface should hit beyond the critical angle [7], which is given by

$$\phi_c = \sin^{-1}(n_2 / n_1) \qquad (1)$$

where n_2 and n_1 are the refractive indices of cladding and core respectively. The launching angle is the angle by which the light from the source is launched in the fiber such that the light propagates by total internal reflection, which is given by

$$\phi_i = \sin^{-1}(\sqrt{(n_2 - n_1)} / n_0) \qquad (2)$$

where n_0 is the refractive index of the medium through which the light is launched.

4. Model for Sludge Estimation.

Figure 1 presents a model for estimating the sludge formed in the oil of the electrical transformer using OM4 optical fibers. Here the power transformer is to be used for the setup model. Ratings of the power transformer used in the model are as follows: 33/0.4KV, S13 Series three Phase, 160KVA connections: high voltage delta and low voltage star connected with neutral. The transformer oil is generally an electrolytic high voltage oil generally an ethylene chloride with refractive index as 1.486.

Specifications of OM4 optical fibers: OM4 fiber is a 50 micron (μm) laser-optimized multimode fiber with graded index core profile.

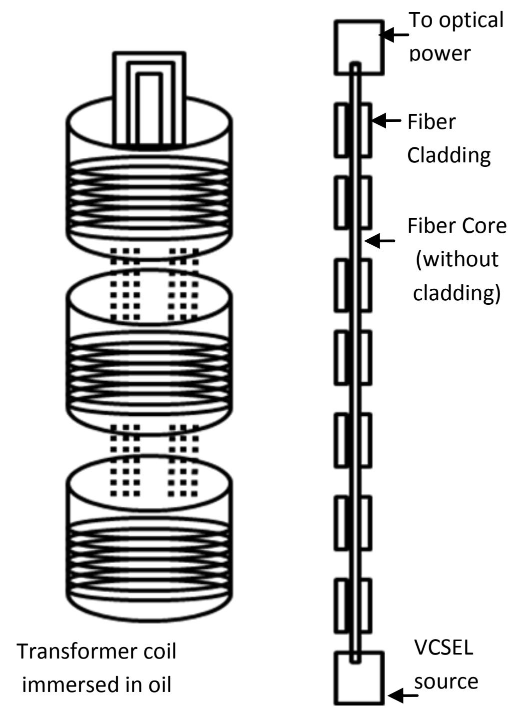

Figure 1. Estimating the sludge formed in the oil of the electrical transformer using OM4 optical fibers

In this model, an OM4 optical fiber of 10 m length is taken. Then the external jacket and the claddings are removed at a regular interval of 3cm. Then the fiber is passed through the entire length of the coils of the transformer which are immersed in the oil. The one end of the fiber is connected with VCSEL operating at 850 nm and the other end is connected to the optical power meter with relay circuit to indicate the amount of the sludge by means of displaying increasing intensity power and the circuit breaker to isolate the transformer from the main supply.

5. Working of the Model

The light is launched into the fiber which is immersed in the oil through VCSEL at a particular launching angle, using an appropriate coupler. As the critical angle is maintained for the cladded portion of the fiber, the light propagates. Some of the light modes striking at the points where the claddings are removed get leaked out of the fiber. This occurs because at those points, now the transformer oil i.e. ethylene chloride acts as the cladding but of different refractive index. Due to the change in the refractive index of the core and the virtual cladding (transformer oil), the critical angle as well as the launching angle (from the cladded to uncladded portion and again from the uncladded to the cladded portion) gets changed. The condition of the critical angle is not achieved, in the uncladded portion as the refractive index of the oil is smaller than the cladding refractive index. As a result, some of the light modes get leaked out of the fiber core. This process continues at every point of the fiber core where the cladding is removed. As a result, a small amount of the light modes reaches the fiber end and thus less power is displayed at the power meter. This is the condition when no sludge is present in the fiber.

When the transformer works for a longer period of time, the sludge begins to form in the oil due to the above explained factors. This sludge begins to deposit on the optical fiber which is passing through the windings. Now the uncladded portions of the fiber are covered by the sludge and so the refractive index of the sludge and the oil get added. As the refractive index increases in the uncladded portion i.e. level of sludge in the oil increases, the launching angle as well as the critical angle increases due to which the previously leaking light modes are now concentrated in the core. As a result, more optical power is obtained at the receiver. Thus, as the level of the sludge increases, more is the optical power recorded. The lineman can periodically take the record of the optical power through the optical power meter and can thus estimate the sludge level, thereby properly servicing and maintaining the oil level.

6. Results and Discussion

An optical beam of power P_{in}, is launched in the periodically cladding stripped OM4 optical fiber, which is immersed in the transformer oil. When there is no sludge in the oil, P_{out} is the power obtained at the output of the optical fiber. The normalized power P_n is given by

$$P_n = P_{in} / P_{out} \quad (3)$$

The normalised power is observed to be varying with an increase in the sludge level formation in the transformer oil as shown in Figure 2. The power obtained at the output of the OM4 graded index fiber operating at 850 nm is enhanced as against the power obtained at the output of the multimode optical fiber [5]. As the level of the sludge increases, the combined refractive indices of the virtual cladding (i.e. transformer oil and the sludge) around the cladding stripped regions of the OM4 optical fibers increases. As a result the leaky modes are now mostly internally reflected through the core, due to which the power at the output of the fiber increases.

Thus, a threshold optical power can be maintained for the maximum sludge formed in the transformer oil. The lineman can periodically monitor the optical power meter readings and accordingly can change the oil, thereby avoiding the hazards of transformer bursting.

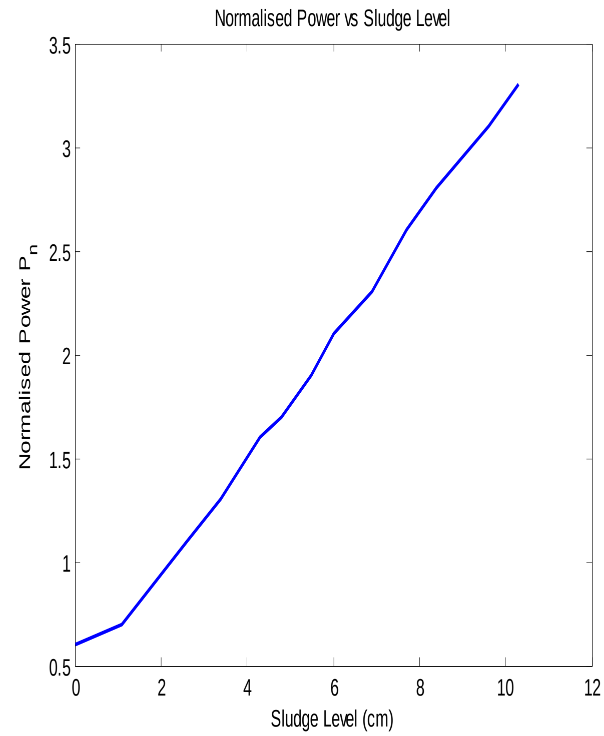

Figure 2. Plot showing the variation of the normalised power versus the sludge level

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