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ABSTRACT

Among the various type of equipments of power system, power transformers are considered as the most critical one. Fundamentally, the significant component of a transformer is its insulation system, which primarily consists of hydrocarbon oil and cellulose paper. Generally, during its service life the transformer insulation undergoes normal stresses. In particular, the paper insulation life is defined by a chemical process normally called aging, which depends mostly on high operating temperature and time. Moisture and the presence of oxygen are the other factors that accelerate the insulating paper aging process.

The main objectives of this work are to assess the condition of oil-immersed power transformers on the basis of different aging by-products (Furanic derivatives, Carbon oxides and Degree of polymerization (DP)) of the paper insulation. With this motivation, firstly a novel capacitive sensor, to detect 2-Furfuraldehyde in transformer oil is developed. 2-FAL is released in transformer oil from degradation of insulating paper and is considered as promising indicator of remaining useful life of the paper insulation. The proposed sensor is fabricated by coating a molecularly imprinted polymer (MIP), sensitive to 2-FAL, on a simple copper electrode. Different test samples are prepared in 100 ml of transformer oil containing 0-20 ppm of 2-FAL for testing the developed sensor. When the proposed sensor is dipped in the test samples, the 2-FAL molecules adsorbed over the cavities of the MIP, which results in a change in the fringing field capacitance of the sensor. The capacitance measured for the test samples decreases linearly with the average sensitivity of 0.087 pF/ppm at 1 kHz.

Next, the sensor's performance is enhanced by changing its electrode design and tested in similar condition. To improve the sensitivity, the electrode is shaped into a novel comb structure with five similar fingers. These fingers increase the total edge length and hence the

fringing capacitance responsible for sensing the 2-FAL molecules in the transformer oil. The comb sensor is tested using the same test samples containing 0-20 ppm of 2-FAL. The comb sensor shows the average sensitivity of 0.184 pF/ppm at 1 kHz. In addition, to automate the insulation diagnosis, the 2-FAL sensor is connected to an electronic circuit based on the instrumentation amplifier to obtain an electrical signal. The sensitivity of the circuit is found to be 0.35 V/ppm in the 0-20 ppm range of 2-FAL concentration.

Further, the physical state of the paper insulation has been determined using a two-stage intelligent insulation health assessment technique. The intelligent technique is mainly based on the estimation of failure indicators (2-FAL, CO_2, CO and DP) of the paper insulation. The essence of this intelligent technique is that it identifies the concentrations of 2-FAL, CO_2 and CO without involving the detailed DGA procedures. Hence, the complexity in the parameter estimation arising due to sophisticated instruments can be avoided. The intelligent technique uses the application of artificial neural network (ANN) followed by the smart life prediction approach (SLPA). In the first stage, the degrading by-products (2-FAL, CO_2 and CO) are predicted as the function of temperature, moisture along with aging time. The model has been tested and found to have least mean square error 1.51×10^{-09}. The second stage of SLPA uses the first stage output and process them to obtain the final output. In SLPA, the concentrations of 2-FAL, CO_2 and CO are correlated to DP values. These concentrations are classified into four intervals as per IEEE standard to obtain four specific ranges of DP, which ultimately represents the physical status of the insulating paper.

Lastly, FIS and ANFIS models haven proposed and developed to predict the DP values of the paper insulation as the function of amount of 2-FAL, CO_2 and CO. The current physical state of the paper insulation can be identified with DP values. Both the models take the three inputs of 2-FAL, CO_2 and CO and processed to estimate the value of DP. The inputs and output are assigned to four linguistic variables in order to develop the FIS model. The FIS model processes the input linguistic variables using a set of fuzzy if-then rules to obtain the output. The ANFIS model is trained with the dataset comprised of 630 points. The training data is prepared following IEEE standards to train the model with least MSE. The performances of the FL and ANFIS models developed with trapezoidal and triangular membership functions respectively are found to be more accurate. Both models are tested with common testing data. The models successfully estimate the DP values close to the actual experimental value. The comparison of the two models has also studied in terms of deviations in estimating the DP values. It is found that the DP values estimated by the ANFIS model are approaching closer to the actual experimental data than FL with an average percentage absolute deviation of 1.98 %.