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Quality Analysis of Transformer Oil using Novel Approach in Image Processing Technique

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ABSTRACT: Transformers play a critical role to meet the nation's demand of reliable and proficient power system. The performance of the transformer depends on the quality of the insulating oil. The conventional methods used were expensive and time consuming. The proposed work uses a fast and reliable image processing technique. This involves preprocessing of the taken image of transformer through which noises are removed using Average and Gaussian filter. Now, entropy which is the statistical measure of randomness is calculated which depends mainly on the deterioration of the taken oil sample. The neutralization number, acidity and tanδ (Dissipation factor) values are computed and eventually, we classify the oil as good or poor for usage through Support Vector Machines based on these properties.

KEYWORDS: Entropy(E), Oil Age, Acidity Constant, tanδ (Dissipation factor), Neutralization Number(NN), Non Linear Support Vector Machine classifier

I. Introduction

Electrical energy plays an important role in a nation's development. A reliable and proficient power system is needed to meet large demand for electricity. Transformer is an integral part of power system whose role is critical for a reliable power system. Periodically the health of transformer has to be checked which primarily depends on the type of insulation used. Out of different insulators used in transformer, mineral oil so as to say transformer oil is used as an insulation material in almost all transformers. Transformer oil not is only used for insulation purpose, but also for cooling purpose.

Oil serves as both cooling and insulating agent in transformer, so health of the oil is very important. Oil degrades because of gases dissolved in it due to the occurrence of various faults and deterioration with respect to age. Increase in dissolved fault gases concentration in oil, results in oil losing its effectiveness; this will influence the transformer performance. Variation in transformer performance will ultimately effect on power supplying company's revenue and consumers. Hence, to prevent the transformer failure, oil analysis is very essential and there are several methods to diagnose the health of the oil. Currently, in the practice of chemical diagnostic criteria, it has the following significant observation such as, dangerous to operate during oil transaction, time consuming and expensive. As per the literature and practice of electrical system, oil changes have been modifying the colour as time varies. Here, the prominent oil characteristics are Acidity, Interfacial Tension (IFT), power factor and tanδ. They are quite interrelated to each other. Due to the ageing of the oil, these two properties values also remarks through the change. Increasing of acidity will raise the tanδ of the oil. In view of the overcoming the pitfalls of conventional practice, the most convenient strategy through appearance based automation with the help of Image Processing concept. An explorative experiment has been conducted with image processing technique namely Texture Entropy, subsequently compared the performance with conventional methods [1].

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Its dielectric strength, different chemical properties determine the type of insulator it is which in turn determines the health state of a transformer. Thus, it is very important to perform oil analysis periodically to check transformer health. There are a number of traditional methods available. But these methods are very time consuming and expensive. The method of image processing is a quick simple method to analyze transformer oil and thus to check transformer health from the image of a transformer oil sample.

SVM(Support Vector Machines) is one of the most used and accurate classifiers in many machine learning tasks.Power transformers play an important role in both the transmission and distribution of electrical power. Since a fault in a transformer can have a huge repercussion when failures occur, and as the number of old transformers and of those that are difficult to operate in overload conditions is on the rise, it is important to detect incipient faults in a transformer and forecast and prevent failures. In operation, transformers are subject to electrical and thermal stresses, which can cause the degradation of the insulating materials. Generally the degradation products are gases, which will get dissolved in the oil entirely or partially. The gases dissolved in the oil are easily detected through dissolved gas analysis as the ppm level changes[3].

The image processing technique involves preprocessing of the taken image of transformer oil in which first the noises are removed using median and gaussian filter and histogram enhancement technique is used for better visibility. Now entropy which is the statistical measure of randomness is calculated which depends mainly on the deterioration of the taken oil sample. Thus using regression methodfrom the knowledge of entropy and learned data the state properties of oil can be predicted.

This analytic method is useful to detect the fault caused by presence of a single gas predominantly. Noise is the presence of any unwanted signal which degrades the image signal and are removed through filters. In the microscopic images the majority of pixels possess a luminescence less than average which results into poor visual effect. Histogram modification is a tool which pixels will be rescaled to values where there is a well distinguish between their pixel values and thus better to analyze it[1].

Acidity and tanδ are the most important properties of the oil. It indicates whether the quality of the oil has deteriorated or not. The amount of Acidic or alkaline material present in oil is measured from Neutralization Number (NN). As oil gets aged, acidity increases therefore NN also increases. If oil NN is high, that indicates oil is more contaminated with materials, such as varnish foreign matter or oxidization.

Usually there is no acid content in new oil, oxidation of insulation forms the sludge's and impulse out of transformer metal in side tank forms the soaps from acid assault and also increase the insulation degradation.The conventional diagnostic methods are devouring much time to estimate the oil properties. To overcome the disadvantages of traditional method, an image processing technique of Entropy method is proposed in this work.

II. RELATED WORK

A. *Dissolved Gas Analysis:*

The main causes of transformer insulation break down are thermal and electrical disturbances. When the mineral oil is subjected to high thermal and electrical stress, gases are generated from the decomposition of the mineral oil[11]. There are mainly two types of insulation; paper insulation which consists of cellulose and oil which is a mixture of hydrocarbons. Due to excessive thermal and electrical stress cellulose and hydrocarbon undergoes various chemical reaction to form different gases as byproduct. These gases are hydrogen, ethane, methane, ethane, ethyne, nitrogen dioxide, carbon dioxide, carbon monoxide. The DGA will require the removal of an oil sample from the transformer and this can be done without de-energization of the transformer. The oil sample is analyzed in the laboratory using gas chromatography technique. In Dissolved Gas-in-Oil Analysis (DGA) method these gases are analyzed quantitatively to inferexistence of any fault mainly incipient faults. The concentrations of gases in the transformer oil can be used to diagnose faults in the transformer. The evaluation of the measuring results can be performed according to different standards and methods[12]. The most important standards are IEEE C57.104-1991, IEC 60599, MSS-Schema, Dornenburg, Rogers and Duval.

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B. *Electrical Diagnostics:*

Winding Power Factor is due to thermal and electrical stress windings are deformed (e.g. buckling of transformer winding), insulation get deteriorated etc. This results into increase in the power loss in insulations and thus the winding power factor varies. Thus winding power factor is a parameter for diagnostics of transformer oil. Bushing Power Factor provide insulations to electrically separate conductors from transformer tank. Bushing insulations also get deteriorated due to thermal and electrical stress and thus bushing power factor has been used over years to save transformers from faults by detection of bushing power factor[4]. Leakage Reactance, in adverse cases the coil displaces from their original position and this causes a change in the flux linked and there is a change in the leakage reactance[9]. Thus leakage reactance is taken into consideration in diagnosing the transformer oil analysis. Transformer Turns Ratio gets changed when there is a short circuit of windings and thus TTR is included in the diagnostics of transformer oil. DC Winding Resistance due weak contact of windings, weak joints and short circuit of winding the dc resistance of the winding get changed. Thus dc winding resistance is a required oil diagnostic tool[7]. Core Excitation Current the current which is required to excite the core of transformer changes with core deformation, core damage and winding shorting. Thus this factor also added in diagnostics of transformer oil[4]. The common electrical diagnostics tests are briefly described as follows:

- Winding Power Factor
- Bushing Power Factor
- Leakage Reactance
- Transformer Turns Ratio
- DC Winding Resistance
- Core Excitation Current

C. *Thermal and Optical Diagnostic Method:*

Both thermal and optical diagnostic methods using the electromagnetic spectrum between 104 Hz up to 1016 Hz as information source. Either the transformer produces a signal which get detected (for instance heat produces infrared signals) or the transformer reflect signal (for instance surface temperature sensors which reflect high frequency impulses in dependence of the transformer temperature). Temperature monitoring can be performed with the help of PT-100 elements, by using fiber optics or thermography. The best optical diagnostic method is the human optical inspection for inner inspection with the help of the endoscopy [13].

D. *Mechanical Diagnostic Method:*

The tension force of the transformer windings is important for the avoidance of deformation in the case of short-circuit. This tension force decrease during operation so a monitoring is useful for transformer where the risk of short-circuit is high. A possibility for determination of the existing tension force is the measuring of the transient oil pressure after applying of a current surge. The lower the tension force the higher transient oil pressure. Another mechanical diagnostic method is the stream analysis for controlling the cooling system. With this method also mechanical deformation in case of a short-circuit which influence the cooling system can be detected [13].

E. *Taguchi-Artificial Neural Network Approach:*

Taguchi-Artificial Neural Network can be used to detect incipient faults in oil-immersed power transformer. It involved the development of Artificial Neural Network (ANN) designs and embedding Taguchi methodology to fine tune the parameters of a backpropagation feed-forward ANN[8]. Dissolved gas analysis technique was used as it has been found as a reliable technique to detect incipient faults as it provides wealth of information in analyzing transformer condition. This study is based on IEC 60599 (2007) standard and historical data were used in the training and testing processes. Taguchi proposed eight standard procedures for optimizing any process:

- Identify noise factors, testing conditions and quality characteristics
- Identify the objective function to be optimized
- Identify the control factors (CF) and their levels
- Select the orthogonal array matrix experiment
- Conduct the matrix experiment
- Analyze the data, predict the optimum levels and performance
- Perform the verification experiment and plan future action

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ANN with Taguchi method application produced better results in terms of its R value. The most important advantage of using Taguchi method is that it can reduce the number of computational effort and time consumed and provides the optimal combination of the CF. The two major tools used in Taguchi method are orthogonal array and signal-to-noise ratio (SNR) [15].

III. PROPOSED SYSTEM

The first step is of image processing. The microscopic image obtained from oil sample contains noises which can interrupt in image processing detection and may leads to erroneous results. Noise is nothing presence of any unwanted signal which degrades the image signal. Noises can be generated from apparatus or from environment.

The main types of noises in microscopic images of oil sample are:

- Gaussian white noise and
- Salt and pepper noise

Image Enhancement is an important preprocessing tool which results in appreciate visual conception and helps in further processing of image. This is subjective i.e. the different methods to be applied is application dependent.The key functions are:

Step 1: Deblurring of an image
Step 2: Sharpening of an image
Step 3: Improving brightness and contrast of an image
Step 4: Proper edge highlighting etc.

A. *Entropy Technique for Oil Property Determination:*

As oil gets aged color and texture of the oil changes, at the same time some of the properties related to oil also change. In this work Acidity and tanδ of oil is calculated from image processing approach called Entropy[1]. Entropy can be described from equation (1)

$\sum a log_2 a (1)$

Where 'a' contains the histogram counts

Entropy measures the randomness statistically. Entropy accounts for indicating the texture of an input image.

Acidity calculation is done on the basis of straight line formula, because when the samples Ageing v/s Acidity graph is drawn, a slope exists.

The NN values can be estimated from equation (2)

$$NN = A_c * y + c \quad (2)$$

Where, NN = Neutralization Number; c = constant = 0.013; y = years A_c = Acid constant

Acid constant value can be obtained from equation (3)

$$A_c = (F_{nn} - I_{nn})/T_y \quad (3)$$

Where, F_{nn} = Final neutralization number from standard test I_{nn} = Initial neutralization number from standard test T_y = Total number of years A_c = {0.013 for $0 \leq T_y \geq 14$, 0.0159 for $15 \leq T_y \geq 25$}

Two Ac values are taken to acquire the NN, the reason behind this is that the acidity is not constantly enhancing.

tanδ or Dissipation factor can be calculated from equation (4)

$$tan\delta = y * k \quad (4)$$

Where, $y \neq 0$ (fresh oil ageing is taken as 1), k = constant,

k = {0.0021 for $0 \leq T_y \geq 14$

{0.00719 for $15 \leq T_y \geq 25$

Power factor of the oil can be calculated from equation (5)

$$power\ factor = \sqrt{\frac{tan\delta^2}{1+tan\delta^2}} \quad (5)$$

To acquire both NN and tanδ of transformer oil, ageing year of oil is essential. Equation (6) is used to calculate y value from Entropy of the image

$$y = \frac{E_1 - E_0}{k_1} \quad (6)$$

E_0= Entropy of the fresh oil, E_1 = Entropy of the oil sample (old), k_1 = 0.046

The percentage degradation of the oil can be calculated as :

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$$\% \, Degradation = \frac{NN}{0.169} * 100\% \quad (7)$$

The life left for the oil can be calculated as follow:

$$Life\ Left = \frac{0.169 - NN}{Scale} \quad (8)$$

First year neutralization NN = 0.13, 25 years neutralization NN = 0.3

$$Scale = \frac{0.3 - 0.13}{25} = 0.01148\% \quad (9)$$

B. *Algorithm For Proposed System:*

Evaluation of NN and tanδ of Transformer oil by Entropy method

Step 1: Load the image
Step 2: To remove noise use median and gaussian filters.
Step 3: Enhance the image using histogram modification technique.
Step 4: Find the Entropy(E).
Step 5: Declare k_1 and determine y.
Step 6: Check for $y \geq 14$.
Step 7: If y is less than 14 years, set $A_c = 0.013$ for NN and set $k_2 = 0.0021$ for tanδ calculations.
Step 8: If $15 < y < 25$, set $A_c = 0.0159$ and $k_2 = 0.00716$ to compute tanδ and acidity.
Step 9: If $y > 25$, result will show error.

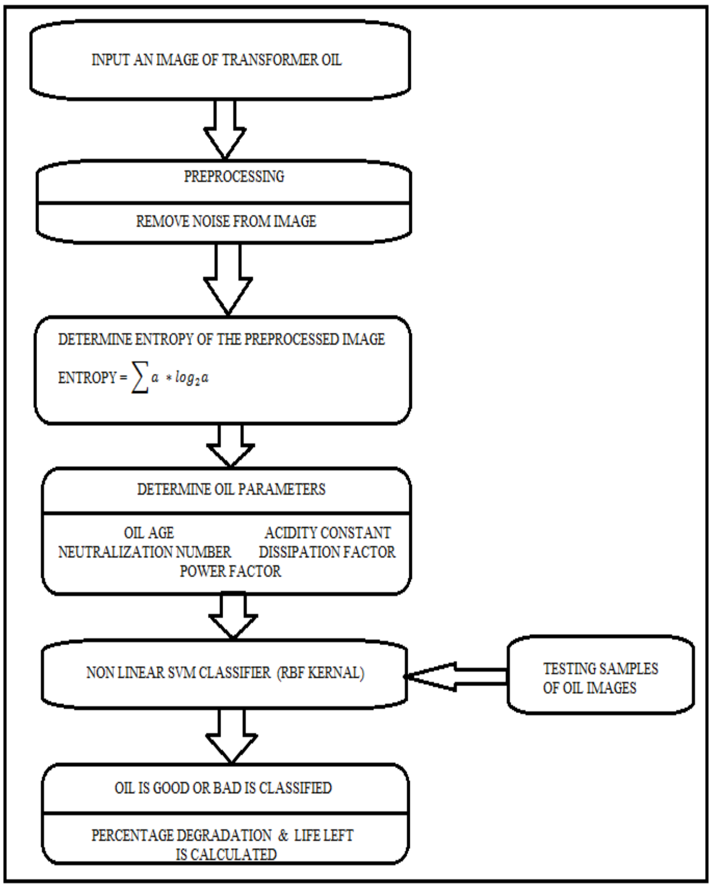

Figure 1.Flowchart of Proposed System

The figure 1 shows the architecture of proposed system.

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C. *Support Vector Machine:*

For Linear Support Vector Machine Given some training data D, a set of n points of the form

$$D = \{(x_i, y_i | x_i \in R^p, y_i \in \{1, -1\})\}_{i=1}^{n} \quad (10)$$

y_i is either 1 or -1, signifying the class to which the point x_i belongs. Each x_i is a p-dimensional real(R) vector.The aim is to find the maximum-margin hyperplane thatdivides the points having $y_i = 1$ from those having $y_i = -1$. The hyperplane can be written as the set of points x satisfying Maximum-margin hyperplane. Examples on the margin are called the support vectors.

$$w.x - b = 0 \quad (11)$$

where .denotes dot product and w the normal vector to the hyperplane. The parameter $\frac{b}{||w||}$ regulates the offsetof the hyperplane from the origin along the normal vector w. If the training data are linearly separate, then two hyperplanes is selected in a way that they distinctthe data and there are no points between them, andthen attempt to exploit their distance. The area boundedby them is called the margin. The hyperplanes can bedescribed by the equations

$$w.x - b = 1 \quad (12)$$

and

$$w.x - b = -1 \quad (13)$$

By using geometry, find the distance between these two hyperplanes is $\frac{2}{||w||}$, so minimize $||w||$. To prevent datapoints from falling into the margin, add the followingconstraint: for each i either

$$w.x_i - b \geq 1 \text{ for } x_i \text{ of first class} \quad (14)$$

or

$$w.x_i - b \leq -1 \text{ for } x_i \text{ of second class} \quad (15)$$

Using a Lagrangian, this optimization problem can be converted into a dual form can be expressed as

$$argmin_{w,b} max_{\alpha \geq 0} \{\frac{1}{2} ||w||^2 - \sum_{i=1}^{n} \alpha_i [y_i (w.x_i - b) - 1]\} \quad (16)$$

The Karush-Kuhn-Tucker (KKT) conditions are necessaryand sufficient conditions for an optimal point. TheKarush-Kuhn-Tucker condition implies that the solutioncan be expressed as a linear combination of the trainingvectors

$$w = \sum_{i=1}^{n} \alpha_i y_i x_i \quad (17)$$

Only a few α_i will be greater than zero. The corresponding x_i are exactly the support vectors, which lie on the margin and satisfy $y_i (w.x_i - b) = 1$.

For non linear support vector machine the resulting algorithm is formally similar, exceptthat every dot product is replaced by a nonlinear kernel function. This allows thealgorithm to fit the maximum-margin hyperplane in a transformed feature space.The transformation may be nonlinear and the transformed space high dimensional;thus though the classifier is a hyperplane in the high-dimensional feature space, itmay be nonlinear in the original input space. The (Gaussian) radial basis function kernel, or RBF kernel, is a popular kernel function used in various kernelized learning algorithms. In particular,it is commonly used in support vector machine classification. The RBF kernel on two samples x and x' represented as feature vectors in some input space, is defined as

$$K(x, x') = \exp\left(-\frac{||x - x'||^2}{2\sigma^2}\right) \quad (18)$$

$||x - x'||^2$ may be recognized as the squared Euclidean distance between the two feature vectors.σ is a free parameter. An equivalent, but simpler, definition involvesa parameter $\gamma = -\frac{1}{2\sigma^2}$.

$$K(x, x') = \exp(\gamma ||x - x'||^2) \quad (19)$$

Since the value of the RBF kernel decreases with distance and ranges between zero (in the limit) and one (when x = x'), it has a ready interpretation as a similaritymeasure. The feature space of the kernel has an in finite number of dimensions;for $\sigma = 1$ its expansion is

$$\exp\left(-\frac{1}{2}||x - x'||^2\right) = \sum_{j=0}^{\infty} \frac{(x^T x\prime)^j}{j!} \exp\left(-\frac{1}{2}||x||^2\right) \exp\left(-\frac{1}{2}||x'||^2\right) \quad (20)$$

A radial basis function (RBF) is a real-valued function whose value depends onlyon the distance from the origin, so that $\emptyset(x) = \emptyset(||x||)$ or alternatively on thedistance from some other point c, called a center, so that $\emptyset(x, c) = \emptyset(||x - c||)$. Any function $\emptyset$ that satisfies the property $\emptyset(x) = \emptyset(||x||)$ is a radial function. The normis usually Euclidean distance, although other distance functions are also possible.Radial basis functions are typically used to build up function approximations of theform

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$$y(x) = \sum_{i=1}^{N} w_i \emptyset(||x - x_i||) \qquad (21)$$

where the approximating function $y(x)$ is represented as a sum of N radial basis functions, each associated with a different center x_i and weighted by an appropriate coefficient w_i. The weights w_i can be estimated using the matrix methods of linearleast squares, because the approximating function is linear in the weights.

IV. Experimental Results Analysis

The five oil image samples are taken and various oil properties such as entropy, age, acidity constant, neutralization number(NN), Dissipation factor are tabulated. The SVM classifier for which RBF kernel function is used to classify the oil. The class labels are taken as good or poor for the classification of oil.

Testing Oil Image Samples	Oil Image 1	Oil Image 2	Oil Image 3	Oil Image 4	Oil Image 5
Entropy	3.2144	3.2816	3.3257	3.6018	3.7884
Age	4.6509	6.1092	7.0644	13.0533	17.1015
Acidity Constant (A_c)	0.013	0.013	0.013	0.013	0.0159
NN	0.060462	0.079419	0.091837	0.16969	0.27191
Dissipation factor ($tan\delta$)	0.0097669	0.012829	0.014835	0.027412	0.12296
Power Factor	0.0097664	0.012828	0.014834	0.027402	0.12204
% Degradation	35.7762%	46.9936%	54.3413%	-	-
Life Left (years)	9.4545 years	7.8032 years	6.7215 years	-	-
Test Quality using SVM Classifier	Good	Good	Good	Poor	Poor

Table 1. Simulation Result of Oil Image Samples

V. Conclusion and Future Work

Image processing technique for transformer oil analysis is software based analytic technique which is fast, reliable and user friendly. Median and gaussian filters were used to filter out the white Gaussian and salt and pepper noise (if any). Entropy technique was used to find out different oil properties like NN, dissipation factor, power factor etc. to determine the performance of transformer. Using regression model was used to establish the relation between different entropy extracted from the image and NN, dissipation factor, power factor and to find the NN, power factor, dissipation factor (tan δ) etc. of the sample.In the proposed work, SVM RBF kernel successfully classifies the oil as good or poor based on the oil characteristics. Furthermore, percentage degradation and life left for the oil sample is also calculated. Thus, this project provides an easy and fast method to check the transformer health from the image of transformer oil.

It reveals the change in acidity, power factor and tanδ properties of the transformer oil. Further, it emphasizes the inference as the outcome of experimentation. It enhances the acidity with respect to increase of tanδ. In the sequence, it notices as quick and viable criteria as compared with conventional practices. Here, the proposed strategy works through statistical parameter such as entropy features of oil image. Subsequently, image processing complete procedure is employed for analysis of transformer oil quality.

Future work defines that proposed work can be built in an android, java and windows platform to be run in a mobile which will be quiet reliable and user friendly. More number of experiment data can be used to validate this practically fit enough to replace the other methods of analysis. Data from different types, ratings of transformers can be used to standardize the process for a class of transformers.

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