REVIEW OF VARIOUS TECHNIQUES FOR POWER TRANSFORMER FAULT ANALYSIS

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Abstract

Transformers are integral part of the power system. They are responsible for transmission of power to long distances with high efficiency. Hence, it is very important to protect the transformers from faults and to analyse the faults. Power engineers need to analyse the fault whether to ascertain its severity. It helps them to decide whether to continue with the operation of the transformer, do minor repair work or to replace the transformer completely and also in doing Periodic preventive maintenance. Many techniques are devised to understand the intensity of the fault.

Keywords

Dissolved gas analysis, Optical Spectrum, Health Index of Transformer Oil, fault diagnosis, Membership Degree, SSA-MDS Pretreatment, Thermodynamic Estimation.

Introduction

The transformers are used to step up transmission voltage right from the generating station, where the power, in India is generated at 11 KV far off the load centres. The stepping up of voltage results in stepping down of current which in turn reduces the transmission losses. After reaching near the load centres this voltage is stepped down in different stages again using the transformers for different consumers like industrial, commercial and domestic. Hence it is very important to analyse the transformer fault. The transformer breakdowns result in loss on account of repair and replacement of failed transformer as well as the income loss to the electricity supplier because of power outage to the consumers. Further disadvantages include decreased reliability and stability of the system, because of frequent failure of power supply. To increase the reliability of the system, it is essential to reduce the failure rates. In order to do so we need to analyse the fault on the transformer. Most of the core faults are thermal faults which do not cause failure in most cases [1]. If the fault results in minor repairs are parts replacement the transformer engineers can repair them. If the fault requires complete replacement of the transformer, then a new transformer can be brought into service.

Various techniques to analyze faults

1. Interpretation of Turn-to-Turn Insulation Fault by Dissolved Gas Analysis

When Dissolved Gas Analysis **(**DGA) method is used to analyse faults in transformers, it is essential to estimate the fault depending on the gases produced and to decide whether or not to execute internal inspection. In case, faults cannot be estimated by internal inspection, the transformer engineers need to come to a conclusion whether still the transformer continued to be operated, or it needs to be replaced by a new one. Important gases according to fault types as suggested by authors in [1] are as shown in table 1 below.

Fault Types	Key Gases
Thermal-oil	C_2H_6, CH_4, and C_2H_4
Discharge-oil	H_2, C_2H_2 and C_2H_4
Thermal-paper	CO and CO_2

Table 1. Important gases according to fault types

The fault locations in transformers given in percentages are, winding at 20%, OLTC at 10%, bushing at 3%, accessories at 22%, and others at 45%. The fig. 1 below shows the thermal fault at tap selector of On-load Tap changing transformer (OLTC) as discussed in [1].

Fig. 1 Arc traces at OLTC tap selector

2. Fault Prediction for Power Transformer Using Optical Spectrum of Transformer Oil and Data Mining Analysis

Conduction of periodic preventive maintenance of power transformer is essential for its health monitoring and detection of fault at early stage. For this, transformer oil is an important element and its contents and properties need to be monitored during the service life of a power transformer. In this technique, The Agilent Cary5000 spectrophotometer is used to conduct optical spectroscopy measurement. The UV-Vis-NIR light is transmitted through 1 cm path-length cuvettes comprising the sampled transformer oil and the reference oil sequentially, and the respective optical transmittance is recorded. For data analysis Rapid Miner, a data mining analytic tool is used which helps in various methods of data mining. It is a web-based tool. A sample search tool is devised for transformer oil sample by means of Rapid Miner server. The optical spectra files are extracted using the Rapid Miner and stored in the database. The Rapid miner searches for transformer oil sample optical spectrum that matches the search criteria within the research limitation and facilitates in identifying the accuracy of this scrutinising method when applied on other optical spectrum of transformer oil. This is illustrated as block diagram as suggested in [2].

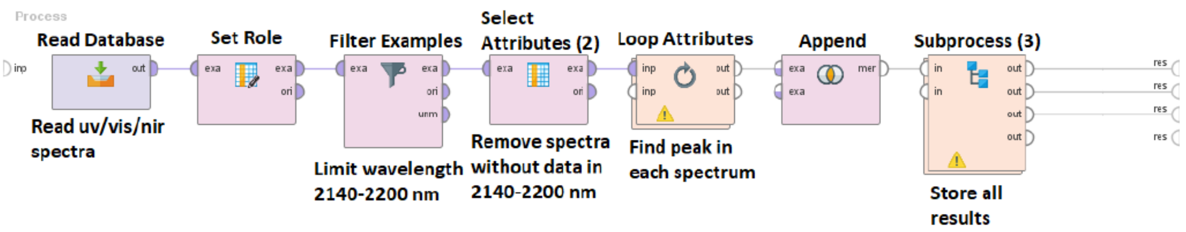

Fig. 2 Algorithm for extracting spectrum files and storing in database.

This method uses Duval's triangle interpretation applied to Dissolved Gas Analysis (DGA) using the transformer oil optical characterization in relation to the fault conditions. The results suggest that large optical absorbance reaches the highest level near 2172 nm for samples with D1 (Low energy discharge) and D2 (High energy discharge) fault conditions. In contrast, T3 fault condition (temperature > 700^0 C) in the power transformer is indicated with an absorbance peak near 2160 nm. Furthermore, the data mining analytic technique applied in the research offers a fast-complementing analysis to obtain the absorbance threshold limit and the range of the detection wavelength, which is used for the classification of power transformer conditions using the transformer oil spectrum with optical spectroscopy. The implementation of optical spectroscopy tool combined with data analytic technique is examined and it is found that this method provides a high accuracy of 98.1% in predicting the fault.

3. Reliable Estimation for Health Index of Transformer Oil Based on Novel Combined Predictive Maintenance Techniques

Because of thermal and electrical stress, the transformer oil insulation quality may deteriorate, which results in transformer faults and supply interruption. To overcome the above problems, this paper presented a comprehensive maintenance of power transformers with the aim to detect transformer faults with more accuracy. In particular, it is designed to recognize incipient faults in power transformers by applying technique called as dissolved gas analysis (DGA) along with a novel proposed method integrated. This method suggested for DGA is implemented based on the combination among the results of five different DGA techniques: 1) conditional probability, 2) clustering, 3) Duval triangle, 4) Roger's four ratios refined, and 5) artificial neural network. As a result, this proposed integrated DGA method improves the overall accuracy by 93.6% compared to the traditional DGA techniques.

The second part, on other hand, used for predictive maintenance, is designed based on finding out the health index for five new transformers and an aged power transformer (66/11 kV, 40 MVA) filled with NYTRO 10XN oil by gauging the breakdown voltage, DGA, moisture content, and acidity for the oil. As part of the breakdown voltage test, two practical types of transformer oils namely NYTRO 10XN and HyVolt III together with their mixtures are assessed and evaluated. Furthermore, oil samples from aged transformer are obtained from a real working, in-service transformer during operation with different aged durations; 9, 10, 11, 12, and 13 years, are examined for breakdown voltage and compared with the samples of fresh oil. The parameters of two oils used is shown in table below as suggested in [3].

Properties	Nytro 10XN			HyVolt III		
	Specified limits		Typical	Specified limits		Typical
	Min	Max		Min	Max	
Viscosity -30°C 40°C	 - -	 600 8.0	 730 7.6	 - -	 1800 12.0	 924 9.2
Density 20°C	-	0.895	0.877	-	0.895	0.875
Acidity mg KOH/g	-	0.01	<0.01		0.01	<0.01
Water Content mg/kg	-	30	<20	-	30	13
Flash Point °C	140	-	144	135	-	141
Pour Point °C	-	- 45	- 63	-	-40	-65
Dielectric Strength kV Before treatment After treatment	 30 70	 - -	 40-60 >70	 30 70	 - -	 57 73
Dielectric Dissipation factor at 90°C	-	0.005	<0.001	-	0.005	0.001

Table 2. Characteristics of oil types used

4. Transformer Oil Diagnosis Based on a Capacitive Sensor Frequency Response Analysis

It is utmost important to do Condition monitoring of big Power transformers in power systems. Measuring the moisture content in transformer oil gives an accurate estimate of transformer aging. The authors in [4] proposed a technique where a capacitive sensor is able to monitor the content of moisture online. A Frequency response analysis (FRA) device is used to record the output of the sensor. The moisture content can be calculated by comparing the FRA readings of the tested oil with a reference FRA test.

A capacitive sensor is kept inside the transformer tank which measures the moisture content online in power transformer. It consists of 24 aluminium plates kept in vertical plane and are 1 mm spaced. This whole set acts as a capacitor. Initially, the authors used steel plates but due to their rapid oxidation they were replaced with aluminium material and the performance improved. The dimensions of the aluminium plates are 120 X 30 X 2 mm supported by plastic bases on the top and bottom. This way the device has enough strength. This entire set is immersed in the transformer tank as shown in fig.3 and connected to FRA device with characteristics show in table 3 as suggested in [4].

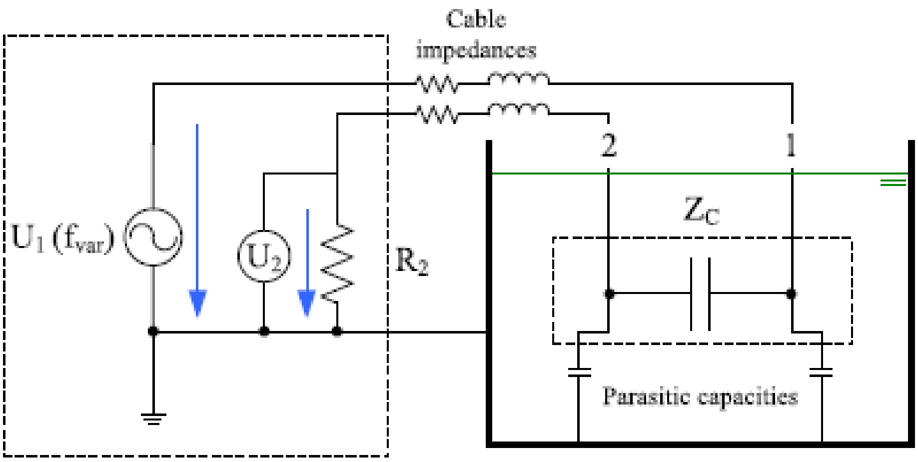

Fig. 3 FRA device connected to capacitive sensor.

Parameter	Value
Frequency range	10 Hz–20 MHz
Output Impedance	50 Ω
Accuracy (down to −80 dB)	< 0.1 dB
Accuracy (down to −100 dB)	< 0.3 dB

Table 3. The characteristics required for FRA device

This article suggested a new online technique to estimate oil aging. It is based on changes in relative permittivity of transformer oil affected by change in its water content. This method uses a capacitive sensor dived in transformer oil. The transformer can be in operation during the tests.

5. Thermodynamic Estimation of Transformer Fault Severity

Conservative practice in transformer fault analysis involves transformer dissolved gas analysis (DGA) technique for concentrations of several fault gases, with or without total dissolved combustible gas, for assessing apparent fault intensity. The authors in [5] suggest a simple method based on normalized energy intensity (NEI), a quantity associated straight to fault energy released within the transformer. When NEI based DGA fault severity scoring is done it is proved to be more sensitive to all IEC fault types and is more responsive to changes in the relative concentrations of the fault gases compared to scores based on fault gas concentrations.

Though it is judicious to expect that in place of gas concentration, the total fault energy might be an appropriate quantity for severity valuation, the respective enthalpies and concentrations of formation of the hydrocarbon gases can be used to compute a quantity directly related to fault energy dissipated in the transformer which the authors call the normalized energy intensity (NEI). The fault severity assessment done using NEI-based is sensitive to all IEC fault types and is better in response to variations in the composition of the fault gas mixture.

For calculating NEI, the concentration (uL/L—ppm by volume) for each hydrocarbon gas is multiplied by (1 L)/(uL) and then by (1 mol)/ (22.4 L) to convert the numerator to moles, then multiplying by (L/kL) converts the denominator from L to kL. The resulting quantity (mol/kL) is multiplied by the enthalpy of formation (kJ/mol) to obtain kJ/kL for that gas. The sum of the kJ/kL quantities for the four hydrocarbon gases is the NEI.

A testing of a 90 MVA nitrogen-covered 138/69 kV transformer exemplifies the purpose of NEI scoring. Hydrocarbon gas scores, calculated on the low-oxygen gas concentration limits in are used for comparison. Oil sample 1 (new oil) contained no detectable amounts of combustible gas. After five years (1748 days) later, the methane, ethane, and ethylene levels, consistent with a T3 (high-range thermal) fault type, raised the NEI to 0.577 with a score of 2.12. That is sufficient to encourage investigative sampling to find whether the transformer is still generating combustible gases. The table below shows the NEI score for different samples taken at different time intervals and is given in [5].

Sample No.	1	2	3	4	5
Days	0	1748	2170	2483	2563
Hydrogen	0	0	0	33	111
Methane	0	35	99	162	275
Ethane	0	38	75	88	128
Ethylene	0	64	169	277	451
Acetylene	0	0	0	0	56
CO	0	4	7	5	40
CO_2	57	996	1185	1437	1403
TDCG	0	141	350	565	1061
Oxygen	12456	326	1800	1200	263
Nitrogen	66326	86823	64715	73327	71006
NEI	0.000	0.577	1.442	2.217	4.280
Fault Type	(none)	T3	T3	T3	T3
NEI Score	**1.00**	**2.12**	**3.50**	**4.00**	**4.00**
HC Gas Score	1.00	2.43	3.38	3.91	4.00

Table 4. DGA values calculated using NEI score

6. Fault Diagnosis of Power Transformers with Membership Degree

The conventional methods involving DGA method are susceptible to misunderstanding the gas data close to the limits and the success rate of getting correct value is low. Although smart methods such as artificial neural network, support vector machines, etc ensure a high success rate, they are typically more complicated to implement practically over a wide range. The authors in [6] propose a new technique based on clustering techniques, for diagnosing faults of transformers with the DGA. A membership degree is given to DGA value by comparing to reference fault set. Test with reliable DGA dataset proves that the success rate of the proposed method is 89%, whereas the David triangle method gives 79% and the IEC ratio method achieves 59% success rate, which establishes the advantage of the proposed method over the conventional methods.

Fuzzy c-means clustering (FCM) is a well-known unsupervised learning type machine learning algorithm. The basic principle of the FCM algorithm is "birds of a feather flock together" and the data is classified accordingly that is similar data is grouped together. Using the fuzzy set theory, FCM algorithm converts the classification problem into a mathematical optimization problem with constraints. It achieves the fuzzy partitioning and classification of the data by looking for the minimum value of the objective function.

Conclusion

Various techniques have been studied for fault analysis of power transformer. Dissolved Gas Analysis (DGA) is a well known and widely used method to estimate the severity of the fault and the power engineers can take a decision as to go for a minor repair or replace the transformer with a healthy one. Research work is being done to add new techniques. Optical Spectrum is used along with data mining to analyse the fault condition. A capacitive sensor along with Frequency response Analysis (FRA) device is used in another method. Thermodynamic estimation of fault is done to understand the fault severity.

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