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Condition Monitoring of Transformers Based on Sound Signals- A Review

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Abstract – **Power transformers are important and expensive components in the electric power system. The de-regulation of electric power requires a reduction of the service and maintenance cost of the power utilities. Monitoring systems can help to decrease the transformer life cycle cost and to increase the high level of availability and reliability. On line monitoring is the record of relevant data of a transformer. Diagnosis is the interpretation of these monitored data including the history of the transformer and the statistical judgement of the failure rate. The importance of the monitored transformer and the economic consequences are the basis for the asset management of power transformer together with the risk evaluation. This paper attempts to present the different methodologies adopted for on line monitoring of power transformers.**

Keywords **- Condition monitoring ,Transformer diagnostics, Maintenance.**

I. INTRODUCTION

Power transformers are critical, capital intensive assets for the utility industry. Transformers are extremely reliable; however many of the transformers in use at utilities have already exceeded design life. Extending the useful life of power transformer has become the single most important utility strategy for increasing the life of power transmission and distribution infrastructure. Most power transformer will encounter emergency overloads on occasions, with subsequent loss of life. However, substantial benefits can be obtained by operating power transformer beyond current practices that are based on the name plate ratings. There is an increasing need for electrical utilities to employ transformers to the fullest while maintaining system reliability.

Presently the load and the age of the apparatus is increasing and therefore the monitoring and diagnosis of power transformers becomes more and more important, whereby monitoring is the collection of relevant data during service (on-line) or during maintenance or test periods (off-line) and diagnostic the technical evaluation and Interpretation of the recorded data. This task needs some further information like fingerprints, history, and comparison with other identical apparatus, statistics etc. and acts as basis for the asset management of power transformers.

II. NEED OF MONITORING SYSTEM

Inordinate temperature rise in a power transformer due to load current have known to be the most important factor in causing rapid degradation of its insulation and decides the optimum load carrying ability or the loadability at a transformer. The Top Oil Temperature (TOT) and Hottest Spot Temperature (HST) being natural outcome of this process, an accurate estimation of these parameters is of particular importance. The accuracy of the predictions is not always as good as are desired. Unacceptable temperature rise may occur due to several fault conditions other than overloading, and hence the need of an online monitoring of the transformer becomes more prominent.

III. MAINTENANCE OF TRANSFORMER ARE OF FOUR KINDS

- Breakdown maintenance
- Preventive maintenance
- Condition based maintenance
- Strategic maintenance.

1. Condition based maintenance- Condition monitoring (CM) is nothing but health assessment of equipment. Like human being, the equipments also need a doctor for periodic check up of health in order to keep their health in good condition [1]. Overhauling and retrofitting are another two terms associated with condition based monitoring [1–3]. Using various process parameters, we can get certain indications about the health of the transformer and accordingly necessary actions to be taken to prevent failure and hence increase life time. It is a kind of preventive maintenance.

2. Diagnostics - Diagnostic is a term related to identify disease of human being. The same term is used in industry with respect to find any disorder in any equipment. The data extracted through various processes are grouped intelligently and after that with the help of the properties of the data, a complete knowledge is generated regarding the health condition of the transformer.

3. Overhauling - Overhauling means renovation. Any equipment like transformer, motor, generator , turbine etc are checked with respect to their present performance and possibility of its deterioration in future, and the weak or prone to damage parts are repaired or replaced [1].

4. Retrofitting - It is one is to one replacement of the spares of the equipment with duplicate one instead of original. e.g- previously bulk oil circuit breakers are mostly used in industry, but nowadays BOCB are obsolete and they are retrofitted by Vacuum circuit breakers [1].

IV. LITERATURE REVIEW

Adnan Secic Et Al (2019) It has been over two decades since the publication of pioneerworks about the power transformer diagnostics based on monitoring of their acoustic fingerprints. Since then, there has been great progress in this field and the methods used are as complex as ever. Any unnecessary intervention on a power transformer implies its temporary disconnection from the power grid. The inability to supply electricity to the customer means not only financial loss for the utility but also generates a non-material loss, e.g.,the loss of reputation to the customer. Faster, more accurate, more reliable, and less invasive diagnosis is the main reason behind development and improvement in this _eld. The main goal of this paper is to categorize and review state-of-the art of vibro-acoustic diagnostic methods for power transformers.

Menno van der Veen et al (2012) In this regard an assumption is made: the frequency region of interest appears to be below 10 kHz. The reasoning for this is found in the lower sensitivity of the ear at higher frequencies and in our measurements; they show little sound energy emitted above 10 kHz. Consequently the minimal wave length of the noise equals 3.4 cm (340 m/s divided by 10 kHz). The overall dimensions of the transformers of interest are smaller than 20 cm (2 kW power range and smaller). Therefore, beam forming (lobing) of the emitted sound will occur at high frequencies. One might ask under such conditions whether the emitted sound energy should be measured (reflective sound chamber) or the sound pressure level (only in one predetermined direction in an absorbing sound chamber). Our measurements on many toroidal transformers indicated that acoustical beam forming occurs.

Debi Prasad Das, et al (2015) The core, by which the core vibrates and generates hum noise which consists of frequency 100 Hz, 200Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, when the power line frequency is 50 Hz. The relative magnitude of these frequencies varies transformer to transformer and is also dependant on the transformer load, however, the 100 Hz noise is the dominant among other frequencies. Adjustment of cores and winding at the design and fabrication stage hardly reduces such hum noise with increased cost. Since the transformer noise is a low-frequency noise, its absorption using an enclosure is not feasible. Active noise control (ANC) has been proposed as an alternative to this in which an anti-noise is generated by a signal processing system to combat the transformer noise. ANC has been effective to control such noise in a small area and may not be cost effective to completely nullify the noise in a large area. A feasible application of such methods can be in an active headrest or bed. The active headrest can be used to give a quiet zone near the head of the occupant. The active bed can be used by the occupants of the houses who are exposed to such transformer noise which is predominant during night time and affects sleep.

Md Mominul Islam1 et al (2017) In electric power systems, power transformers are usually considered the most costly item and comprise about 60% investment of high-voltage substations. The huge investment and growing demand of electricity motivate utilities to accurately assess the condition of transformer assets. During operation, transformers regularly experience electrical, thermal, chemical and environmental stresses. Over time, due to these stresses, faults and chemical reactions, different types of catalytic ageing by-products like moisture, acids and gases are produced in transformer oil. The ageing products gradually reduce the dielectric and mechanical strength of insulation. Consequently, as transformers approach the end of their service life, their probability of failure increases. Additionally, regular overloading and short-circuit incidents on aged transformers may lead to unexpected premature failures, resulting in damage to customer relationships due to interruption of power supply. Moreover, failure of transformers can damage the environment through oil leakages and could be dangerous to utility personal by creating fire and explosions, resulting in costly repairs and significant revenue losses.

Yuhang Shi et al (2019) Many detection methods for transformer winding deformation have been proposed such as low voltage impulse method (LVI), short-circuit reactance measurement (SCR), frequency response analysis technique (FRA) and sweep frequency impedance method (SFI) . However, they are off-line methods and require power outages, which are not flexible. The vibration and acoustic signal is closely related to the internal mechanical condition of the transformer which are easy to be implemented in online monitoring and live detection. Therefore, vibro-acoustic signal analysis method has received extensive attention However, the vibration of the core and the winding under the steady operation are difficult to separate, resulting in difficulty in application. When an external short circuit occurs, a large current flows through windings causing strong vibration while the core vibration can be ignored In addition, the ambient noise such as broadband aerodynamic noise from wind or fans and discrete noise from other electrical equipment is also much smaller than the acoustic signal under short-circuit transient. The sound pressure levels of the transformers in service with different capacities range from 60–90 dB. In comparison, it can reach 110 dB or more under short-circuit transient. Different sound sources have different spectral characteristics as well. Therefore, the vibro-acoustic signal under short-circuit transient is more suitable for condition monitoring of transformer winding.

V. CAUSES OF TRANSFORMER VIBRATIONS

Main cause of transformer core vibrations is magnetostrictiona property of ferromagnetic material to change its shape under the infuence of a magnetic eld. Magnetostrictive stress vs. magnetic induction curve of iron can be approximated with a quadratic formula (Fig. 1) since the magnetostrictive stress is proportional to the square of the magnetic induction . Thus, it also correlated to the square of the applied voltage. On the other hand, current through the transformer windings induces axial, radial and combined Lorentz forces which try

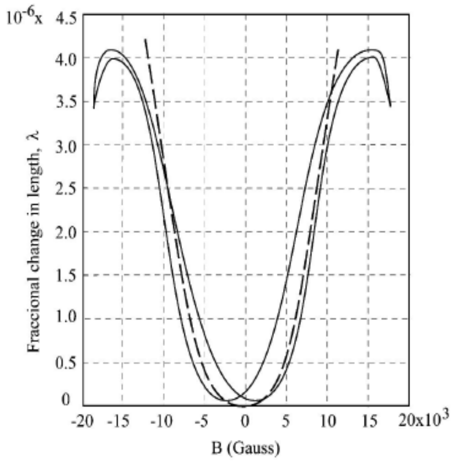

Fig 1. Iron magnetostriction as a function of induction taken from

to compress and stretch the windings, respectively .Lorentz forces are proportional to the square of the current. Voltages and currents are mutually dependent and since they cause transformer core and windings vibrations, respectively, bulk of the works in this field treat the problem of diagnosing these two vibrations simultaneously Transformer core and windings vibrations propagate through the transformer oil and reach the transformer housing which will also, in turn, start vibrating. The viscosity of transformer oil as well as any rigid structures (reflection) affect the propagation of vibrations towards the chassis. Therefore, all these issues must be taken into account when choosing the appropriate sensors and points for sensor placement to perform the measurements.

VI. SOURCES OF POWER TRANSFORMER'S NOISE

Power transformers as fundamental systems for transformation of electricity from one voltage level to another, in the phase of transmission or electricity generation, have several sources of noise. Out of which, the three basic sources of sound generation in power transformer are as shown in Fig.

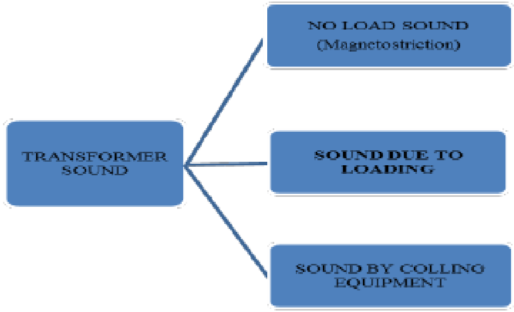

Fig. 1: Transformer Sound.

1. Permitted Noise Level

Transformer's noise is very important operational characteristic of power transformers, which is measured in any final test with methods prescribed by the standards IEC 60076-10 (2001)[4] and IEEE Std C57.12.90 (2006)[5], and at the same time the recommended values of the permitted noise levels by NEMA National Electrical Manufacturers Association Standards TR1 1998 must be met. NEMA Standard TR1 defines noise levels for applicable transformers used by the power industry. This standard includes tables of sound levels as test points, but significant study of the standards will be necessary to apply these values due to the impact of measurement distances. Table I is being provided as "typical" of the kinds of limits defined in this standard at a measuring distance of 2 meter.

Table 1: Audible sound level for liquid immersed distribution transformer

Equivalent two winding kVA	Average sound level in dB
0-50	48
51-100	51
101-300	55
301-500	56
750	57
1000	58
1500	60
2000	61
2500	62

Depending on the requirement of the transformer recommended permitted noise level is also change. With increase in size the permitted noise level is also increased table II showing the permitted noise level of 100MVA & 300MVA power tranformer with oil directed water forced ODWFcooling.

Table 2 Permissible noise level for 100 MVA transformers with ODWF cooling

Test voltage in kV	Permissible Noise dB	
	100MVA	300MVA
350	78	83
450	80	85
750	81	86
900	82	87
1175	83	88
1300	84	89

VII.CONDITION BASED MONITORING METHODOLOGIES

Condition monitoring of transformer is very effective in case of large size power transformers which is having rating in terms of 100,200,300 MVA or even more. A standard 315 MVA transformer costs in terms of crores , may be 5-6 crores with on an average life span 15-20 yrs. Instead of replacing the whole transformer with erection, testing and commissioning costs after the effective life time, it is suggested to do condition monitoring and increase its effective life time up to its optimum usage. Prone to damage spares are needed to be replaced and obsolete spares are needed to be replaced with spares with updated features.

It is seen from the experiences if the user invests just 10% of the transformer’s cost on the account of its condition monitoring the effective life time increment of transformer will be of about 25%, 30% or even more[13]. So, condition monitoring of transformer is a very very important aspect w.r.t its maintenance and it is expected that this article will be very helpful for all industry practitioners to create a general awareness about its different methodologies with practical examples. Fig 1 refers to the flow chart of the proposed work and Fig 2 shows an automatic ratio meter, which is an associated test kit during the testing. The several methodologies used in transformer’s condition monitoring approaches are as follows
1)Tan delta on winding.
2)Test of oil samples.
3)Polarization Index.
4)Dissolved Gas Analysis
5)Furan Analysis
6)Degree of Polymerisation
7) Partial Discharge Test.
8)Frequency Response Analysis
9) Radio Influence Voltage Test .
10) Infra-red Temperature Measurement .
11) Residual Life Assesment etc.

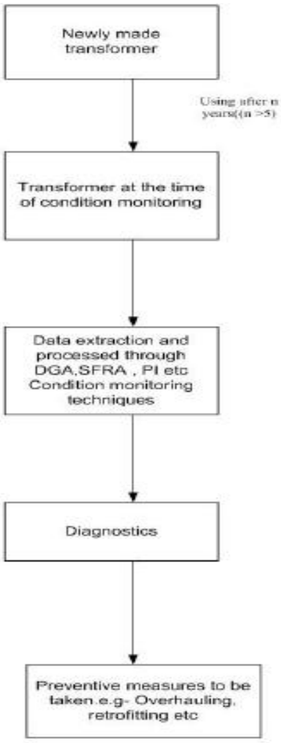

Fig. 2 Flow chart of the proposed work

VIII. CONCLUSION

Transformer cores can make acoustical noise like humming and rattling. The mechanisms that cause this noiseinside the core have been explained. A method has been developed to measure and to scale the acoustic noise of a power transformer under four standardized conditions. They are: nominal mains voltage and mains frequency, 10 % over voltage, 250 mV-DC added and a combination of 10 % over voltage plus 250 mV-DC.

The measured acoustical noise is compared to the widely accepted Balanced Noise Criterion curves, thus enabling world wide comparison of noise levels. A noise test chamber is proposed, based on absorbing all reflections and measuring only at the main axis, where the maximum noise level can be expected due to beam forming at high frequencies. Transformers are always mounted in cases, and a emulation of such a case is proposed by means of a steel plate with standardized dimensions. Distance plays an important role, and the distance relations are given for the "far field" condition, which has been verified in the actual noise test chamber, while a one meter distance is proposed as standard unit distance. Four units have been defined for quantifying the noise levels and the conditions of measurement.

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