Transformer Monitoring by using Vibration Analysis

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Abstract: Since power transformer is a complex and critical component of the power transmission and distribution system, their reliability is crucially important for the energy system operation. So, there is an increasing interest in applying monitoring systems and line diagnosis methods to transformers, as these are one of the most expensive and critical apparatus of a power system. Detecting failures in an incipient stage can avoid major damages of power transformer, allowing important savings in investing, and giving time enough to plan transformer outages. In recent years, a great number of monitoring systems have been suggested. In this paper the use of a vibration model to be applied to transformer monitoring is proposed. The paper deals with the introduction of the comparative method of the state estimation of transformers using continuous monitoring of transformer vibration.

Key words: Transformer, vibration, Monitoring, Harmonics.

INTRODUCTION

Power transformer asset management has been generally considered to be one of the most important power system apparatus asset managements (Nafar et al 2004- Nafar et al 2011). This is due to the substantial investments in the transformers and the importance of the transformers as one of the major factors that affect the system reliability. Since large power transformers are the most expensive and strategically important components of any power generator and transmission system, their reliability is crucially important for the energy system operation. Thus the number of maintenances should be the possible minimal over its lifetime. It is highly desirable to develop methods that allow diagnosis failures in the transformers when they are in an incipient stage, that’s the reason why in the last years power transformer monitoring and diagnosis techniques have increased their popularity (Nafar et al 2004- Nafar et al 2011- Young 1998- Myers1998 – Wang et al 2002 –Sokolov2001).

This paper describes methods of transformer asset management as one of the important power system assets. Condition monitoring techniques are illustrated in this paper and then the transformer oil-tank vibration is investigated as a main technique for transformer condition monitoring. There are known methods to measure transformer oil-tank vibration, but without measuring the current simultaneously with vibration, the decision can be false. To reach this goal two main parts must be examined (windings and core) by making tests on the site. Vibration analysis extended with the measurement of currents and voltages offers a robust method to plan maintenance. The aim is to find correlation between current and vibration which represents correctly the state of the transformer winding. While vibration is caused by the windings the electrodynamic forces, the magnetostriction effect makes the core to vibrate. Separation of these sources would be advantageous, but it is essential to find out if they are correlated or not? This method hopefully gives an important benefit, after an accurate state estimation the transformer may be repaired on site if it is needed. With more than one accelerometer, it is possible to predict which winding should be repaired in case of three phase transformer. In this case repair on the site is enough.

2. Condition Monitoring Techniques:

Utilities need to reduce costs associated to operation and maintenance of installed equipment. Main ways to achieve this cost reduction are the use of on-line condition monitoring, and a shift from time-based to condition based maintenance.

• Improve transformer reliability and minimize downtime
• Maximize transformer life with maintenance activity to address abnormal operation
• Safely maximize normal loading without damaging insulation or reducing transformer life
• Provides true dynamic loading capability
• Perform aging analysis of insulation Minimize condition monitoring costs through unified monitoring of various parameters for the entire transformer

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Several condition monitoring system have been suggested to diagnosis fault in the power transformer (Nafar et al 2004- Nafar et al 2011- Young 1998). In this section, the most important technique are investigated in the following text.

2.1. Condition Monitoring by Thermal Analysis:

Thermal analysis of the power transformers can provide useful information about its condition and can be used to detect the inception of any fault. Most of the faults cause change in the thermal behavior of the transformer. Abnormal conditions could be detected by analyzing the HST. The most famous abnormal condition of the transformer that could be detected by thermal analysis is the overload (Young 1998).

2.2. Condition Monitoring by Partial Discharge Analysis:

Most serious failures of a large power transformer are due to the insulation breakdown. The Partial discharge (PD) which damages insulation because of the gradual erosion is the major source of the insulation failure. Techniques for locating a PD source are of the major importance in both the maintenance and repair of a transformer (Nafar et al 2004- Nafar et al 2011- Young 1998). Although because of complicated structure of transformers, exact location of PD is very difficult, recognition of fault region reduces the reparation costs. Considering the importance of this theme, many researches are done in this domain. Location methods are classified to acoustic and electrical method.

Generally, the advantages of acoustic method are cheaper, simpler and on-line measurement method. Acoustic PD method employs a sensor that converts sound signals into electrical pulses. Sound being emitted by partial discharge inside the transformer is picked up by the sensor and is converted into electrical sensor, which is further amplified by in the main equipment. The equipment amplifier is tuned to the normal acoustic discharge frequency, hence the unwanted signals due to core vibration, noise produced by cooling system etc are eliminated. The number of peaks in the signal available for one second is stored as counts per second. In electrical method the neutral current and the top current of coil are measured and analyzed by different way.

2.3. Condition Monitoring by Furan Analysis:

Insulating material (mainly cellulose paper) in a transformer is subjected to different type of stresses, depending upon the service conditions. The ageing of cellulose is influenced by overloads, lightning surges, and internal faults leading to thermal stresses. Ageing of insulation result in de-polymerization of insulating material and Furan and other compounds are produced. These compounds are extracted from oil and their concentration is analyzed using High performance Liquid Chromatography (HPLC). Rate of change of furan concentration indicates the rate of ageing paper.

2.4. Condition Monitoring by Dissolved Gas Analysis (DGA):

DGA was the first most effective diagnostic test, which was applied to transformers in service for condition monitoring. Lot of significant data and expertise has been accumulated over the past 25 years and considerable standardization in methods of analysis and interpretation has been achieved. Gases dissolved in oil are analyzed by gas Chromatography. The technique helps in detecting incipient faults developing in transformers. DGA is supplemented by other tests to confirm diagnosis (Young 1998- Myers1998 – Wang et al 2002).

2.5 Condition Monitoring by Frequency Response Analysis (FRA):

During its life transformer is subjected to several short circuits with high fault currents, which consequently, may cause deformations / displacements of windings as well as changes to winding inductance or capacitances in transformers. Such small movements may not be detected through the conventional condition monitoring techniques, such as DGA, winding resistance measurements, capacitance and tan delta measurements et. However, Frequency Response measurement has proved to be an effective off-line tool to detect these changes and is widely being used world over. The test is repeatable and immune to electro magnetic interference and is not influenced by weather. Following inferences can be drawn from the test results.

- Transformer is healthy and there is no movement of windings.
- Transformer is damaged and requires immediate repairs.
- Minor winding movement has occurred but the transformer can be run under close monitoring.
- Internal inspection of transformer can be avoided after it had met heavy short/circuit inter turn faults.

2.6. Condition Monitoring by Recovery Voltage Measurement (RVM):

Moisture in transformer has an adverse effect on the dielectric strength of oil and paper. It reduces mechanical strength of paper and accelerates the aging process.

In addition to conventional tests viz. capacitance, tan delta and insulation resistance measurement for assessing the moisture in transformer. DC recovery voltage measurement is another off-line diagnostic tool for
the condition monitoring of the oil, paper insulation of transformer. It detects the content of water (in percentage) present in insulation system.

2.7. Condition Monitoring by Vibration Analysis:

The most common cause of power transformer failures is mechanical defect brought about by excessive vibration. The usage of the vibration signals in monitoring and diagnosis fault in the transformer is a relatively new technique compared with other techniques of transformer condition assessment methods. The transformer vibration consists of core vibrations, winding vibrations, and on load tap changer vibrations (Antipov et al 1996 - Patel 1973 – Holm et al 1985-Hiraishi et al 1971- Shengchang et al 2001- Kang & Birtwhistle 2001 ). These generated vibrations propagate through the transformer oil until they reach the transformer walls, at which they could be collected by using vibration sensors. The health condition of the core and windings can be assessed by using the vibration signature of transformer tank (Holm et al 1985). Also, vibration analysis is a very powerful tool for assessing the health of the on load tap changer (Hiraishi et al 1971- Shengchang et al 2001).

3. Transformer Vibrations:

Vibrations in the power transformer are generated by the several forces appearing in the core and in the windings during transformer operation. In this section, the most important reasons are investigated (Patel 1973 – Holm et al 1985-Hiraishi et al 1971- Shengchang et al 2001- Kang & Birtwhistle 2001).

3.1. Winding Vibrations:

The vibration of winding is due to the electrodynamic forces caused by the interaction of the current circulating by a winding with the leakage flux. These forces are proportional to the current squared and have components in axial and radial directions. Axial forces tend to compress vertically the winding. In the simple case of a two winding transformer, radial forces tend to compress the internal winding and to expand the external one, since currents in the windings have opposite senses. Since vibration depends on current squared, and taken into account that current is almost sinusoidal (50 Hz in Iran), winding vibration main harmonic is that of 100 Hz. Nevertheless some harmonics multiple 50 Hz can appear due to magnetizing current or some residual harmonic currents.

3.2. Core Vibration:

The core vibration is caused by magnetostriction and magnetic forces. Magnetic materials suffer a change in its dimensions of about few parts per million when they are submitted to a magnetic field. This phenomena is called magnetostriction (Shengchang et al 2001- Kang & Birtwhistle 2001). Taken into account the relationship between applied voltage and magnetic induction (Eq. (1)) and admitting the elongation proportional to the force, results that the magnetostriction forces are proportional to the voltage squared.

\[ U = 4.44fNB_s \]  \hspace{1cm} (1)

Magnetostriction main harmonics have frequencies even multiplex of 50Hz (in Iran). Higher frequencies harmonics are due to the non linear character of the magnetostriction phenomena. Moreover if the core was an iron homogeneous mass, magnetostriction would only cause vibrations in the plane of the core. In practice the core is composed of magnetic sheets and the joints between legs and yokes are overlapped. In these conditions an irregular flux density distribution appears because of the little variations of the gap between the legs and the yokes sheets and the interlaminar flux in the joints. This aspect causes magnetostriction forces in a plane perpendicular to the core. Moreover, the sheets have little irregularities and friction between core sheets excites other core vibration modes in a direction perpendicular to sheet plane. Another kind of forces appear tending to minimize the air-gap length between legs and yokes and so the energy in the magnetic circuit. The forces are sinusoidal with 100 Hz frequency.

4. Measurement:

In Fig. 1 a sample power transformer could be seen. There are four points which indicate where to place the accelerometers to capture the vibrations. The vibration measurement requires special equipment, and a remote unit, because the vibration can be captured only in the vicinity of the transformer, but currents and voltages are measured in the control room. The system used to capture the vibration signals at each measurement position of the transformer is shown in figure 2.
In order to test above mentioned method, the vibration signals of a testing transformer were measured. The transformer under study was characteristic of the following nominal data:

- Power: 2MVA
- Turn ratio: 20/0.4kV
- Thyristor switched static VAR compensation exist in substation

The compensation serves 3rd, 5th, 7th harmonic filter as well. Fig 3 shows the time function of the primary current in which more than 80A current changes can be observed. These changes are sudden and rapid according the railway’s demand.

The switching transient and the corresponding vibration-time function are shown in Fig. 5. There are three relevant peaks in the vibration RMS time function, which is correlated with the current of secondary side. This means that the amplitude of vibration is mostly determined by the electrodynamics force.

The time function of vibration and the harmonics of vibration are shown in figures 6 and 7. It could be seen that the most significant harmonic of the vibration is the 200Hz component.
In Fig. 8 harmonics of primary voltage is shown. Also, the time function of primary current and the harmonics of current are shown in figures 9 and 10.
It could be seen in these figures that the even order harmonics must originate from the core because the exciting current has no such kind order of component (just odd order) only primary voltage has 200Hz component in the frequency spectrum. One approach may be if the correlation ratio changes test by test is should mean that some kind of problem has begun to develop. So, one idea for transformer monitoring is the checked the changes of these pattern.

5. Conclusion:

In this paper several kind of monitoring methods which are suitable to predict time to the next maintenance for power transformers have been introduced. It has been shown that vibration analysis is a very powerful tool for assessing the health of the power transformer. It could be seen that state estimation is a very difficult and complex task. It is shown that the tank vibration of transformers has very important information about health of transformer. Measurement results show an interesting correlation between current and vibration harmonics.

REFERENCES


