Condition Monitoring and Life Extension of Transformer

Introduction

Reliable and quality power is need of the hour for the economic development of a country. For providing reliable electrical energy, it is very necessary to have highly reliable associated electrical equipment. The transformer, being a key element in the transmission and distribution of electrical energy, improving its reliability is of utmost importance. System abnormalities, loading, switching and ambient condition normally contributes towards accelerated aging and sudden failure, Hence, it is, all the more essential, to employ continuous monitoring techniques and on-site diagnostics followed by quality maintenance for having trouble-free and reliable operation with minimum outages.

The article, being submitted, shall present a survey of new monitoring and diagnostic technologies in power transformer for the purpose of condition assessment. Also, life assessment and extension programme for transformer in service will be highlighted. Case studies citing site experiences of problem faced on transformer in service and various diagnostic tools employed for finding solutions will be cited.

Types of Major Failures

Following are the major components, which have a direct bearing on reliability of the transformers

- Winding and electrical circuit,
- Core and clamping structure,
- Bushings and external connections,
- Tap chargers,
- Coolers and cooling medium,
- Control and supervisory equipment

The types of failure which occur on transformer are many, one with serious concerns to condition monitoring techniques are listed below

Core

Breakdown in core bolt insulation, core plate insulation or insulation between core and core clamps leads to circulating currents and usually sparking at the fault. Gases are evolved, which dissolve in oil. These can be monitored by Dissolved Gas Analysis (DGA).

Windings and Inter-winding Insulation

Overheating due to poor joints is a common fault in any part of the electrical circuit. Breakdown of inter-strand insulation results in circulating current causing overheating of insulation and hot spots at point of fault. This can be a result of winding movement. A turn-to-turn fault produces a similar effect but with much more energy and can usually be detected and identified. Partial discharge faults can develop between various parts of the insulation structure as a result of contamination (including moisture) or due to poor impregnation or overstressing. Overheating of stress shields results in breakdown and circulating current. A fault between windings and a fault from line-to-ground usually results in serious damage.

Tanks, Flux shields and Fittings

The breakdown of insulation between portions of the tank shields or between the shields and tank can lead to circulating current, which is a function of load current. Circulating current in the tank due to proximity of heavy current conductors can produce hot spots in the tank and across gasket joints.

Bushings

Ingress of moisture, loosed/bad joints may lead to failure of bushings

Deterioration and Failure Factors

The factors responsible for failures and accelerated deterioration are categorized as:

Operating Environment (Electrical)

Transient over-voltages, load current, short circuits (fault currents), lightening and switching surges.

Operating environment (Physical)

Temperature (operating full load with high ambient temperature-humidity index), wind, rain, seismic and pollution

Operating Time

Time in service and time under abnormal conditions or extreme condition (load variation, change in thermal stresses).

Number of Operations of Tap-changer

Number of on-load tap-changer operation.

Vibration Effect

Sound and material fatigue.

Contaminants

Moisture (water content in oil), presence of oxygen and particles in oil.

Condition Monitoring and Online/Off-line Diagnostics

There is an increasing need for power utilities to use assets to their fullest while maintaining system reliability. Transformers, which have exceeded their design life or are approaching the end of their operating life, require all the more attention as compared to new transformers. Due to increasing failure of large power transformers, the maintenance engineers are seriously reviewing their O&M procedure in order to prevent forced outages, incur less maintenance cost, and to have longer life of equipment. To assess the extent of deterioration within the transformer, it is necessary to employ the appropriate diagnostic tool.

A few decades ago, Tan delta/Insulation Resistance measurement of winding/bushing, monitoring of oil/winding temperature, checking of BDV of oil and fault gas analysis, formed the part of condition monitoring strategy

Later on, Dissolved Gas Analysis (DGA) and Furan analysis of oil were added and proved to be effective tools in the condition monitoring of transformers.

However, presently, due to the marked improvement of technology, following additional diagnostic tests have been included for condition assessment of transformers, which have saved power transformers from under going major damages.

- Partial Discharge Measurement,
- Frequency Response Analysis (FRA),
- Recovery Voltage Measurement (RVM),
- Thermo vision Measurements.

Brief description of on-line/off-line diagnostic tests considered for condition assessment of transformers are reproduced below.

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.

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, lighting 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.

Partial Discharge Measurement

Partial discharge occur in oil filled transformers due to the following reasons.

- Voids in the solid insulation,
- Conducting particles in paper or in oil,
- Wet fibers in oil,
- Gas bubbles in the oil,
- Sharp conductor edges.

PD measurement are done in following ways

- Electrical method,
- Accounts method.

Generally, acoustic method is being used at sires since it is cheaper, simpler and on-line measurement. By taking measurements at a number of places on the transformer tank, PD activity region can be identified.

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.
Partial discharges may not cause a failure immediately. However it is a parameter, which shall assess the healthiness of the transformer. PD measurements will also aid in the DGA results.

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.

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.

Thermo vision Measurements

Thermal imaging is one of the most valuable diagnostic tools used for condition monitoring of equipment. Infra red pictures are produced by which temperature measurements can be made. By detecting anomalies often invisible to the naked eye, thermal imaging allows corrective action before costly system failures occur. A thermal vision camera has proven to be an effective on-line condition-monitoring tool of a transformer for determining hot spots on tanks, bushing terminal joints etc. This information is useful in predicting the temperature profiles within the inner surface of transformer tank and would provide approximate details of heating mechanism and deciding the remedial action to be taken well in advance.

Condition Assessment Levels

An accurate condition assessment and appropriate action to the abnormality will restrict the premature failures (catastrophic). Following information shall serve as a useful guide for better and trouble free operation of transformers. For this purpose, following categories are taken.

- Transformer operating within their design life.
- Transformer operating beyond their design life.

Transformer Operating within their Design Life

- Abnormalities Below the limits (Level 1)

Recommended for full load operation with routine monitoring and checks.

- Abnormalities just above normal limits (Level2)

Recommended full load operation with routine monitoring including top oil temperature, winding temperature and DGA.

- Slow DGA Trending with increased Top Oil Winding Temperature (Level 3)

Recommended 75 to 80% of the rated load operation with strict monitoring of top oil temperature, winding temperature, DGA and trending analysis. Perform on/offline diagnostics and develop maintenance strategies accordingly.

- Fast DGA trending with Increased Top Oil and Winding Temperatures (Level 4)

Recommended 50% to 60% of the rated load operation with strict monitoring of top oil and winding temperature, DGA for total combustible dissolved gas and rate of gas evolution (trending). Oil sampling frequency should be at least once a month. Arrange for emergency online as well as offline diagnostics and maintenance accordingly. Keep under strict observation

Transformer Operating Beyond their Design Life

- Abnormalities below the limits (Level1)

Recommended for 80% of the rated load operation with routine monitoring and DGA frequency twice a year.

- Trending Abnormalities (trace) (Level 2)

Recommended 60-70% of the rated load operation with strict monitoring of top oil temperature, winding (hotspot) temperature and Dissolved gas analysis (DGA) frequency once every three months.

- Fast DGA Trending (evaluation rate higher then 0.1 cu ft /day) with Increased top Oil and Winding Temperature.

Recommended 50% of the rated load operation with strict monitoring of top oil temperature, winding temperature and DGA trending. Arrange for emergency on-line as well as off-line diagnostics and maintenance accordingly. Plan to replace the asset.

Life Extension Programme of Transformer in Service

Some of this tips used to improve the life expectancy of transformer in service are highlighted below.

- Strictly adhere to the routine maintenance schedule, which include hourly, daily, quarterly, half-yearly, yearly inspections, as prescribed by the OEM.

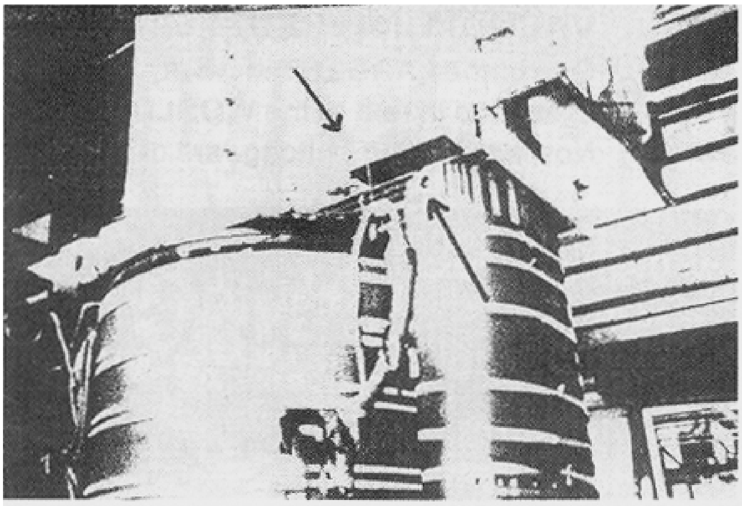

Fig 1 Arc Marck on End Frame and Clamp Plate

- Transformer oil, being hygroscopic, absorbs moisture from the surrounding air. Oxidation and contamination of oil can be avoided by adopting proper oil preservation system. The most effective way is by using air-cell in conservator. By this technique, transformer oil does not come in contact with air directly but through oil resistant nitrile rubber membrane. Air-cell can be retrofitted on old transformer also.

- Thermosyphon is an online oil filtration system having adsorbents viz activated alumina, silica gel etc for continuously removing moisture and acid from transformer oil. This system is installed at the manufacturing stage and has proven to be very effective.
- Employing condition-monitoring tools viz. DGA, Furan analysis and other online/offline tests as explained above for assessing health of transformer and accordingly deciding the maintenance strategy.
- Over the years, utility system has grown resulting in an increase in the available short circuit MVA. Transformers, which have aged, and also, having lower percentage impendence than required by the system, are likely to get damaged if installed in such high fault current areas. Hence, while shifting old transformers to new areas, this precaution may be kept in mind.

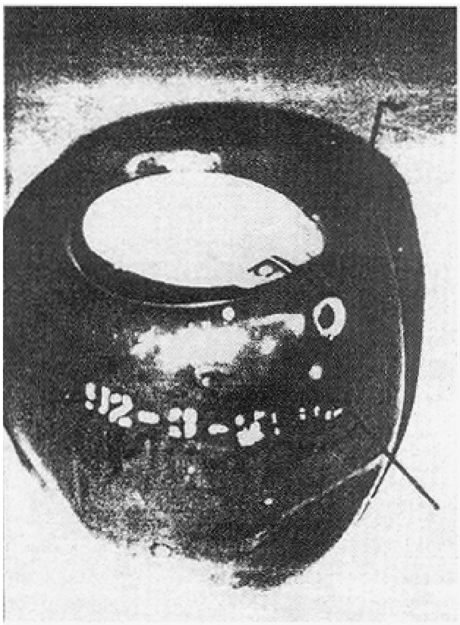

Fig 2 Puncture Mark in the Bushing Shield

- Reducing the fault currents for the more frequent line-to-ground faults by installing neutral reactors can protect many old transformers. Also, it will be worthwhile to use metal oxide gap-less surge arrestors for better protection and having higher safety margins.

Case Study

Failure of 400kV, 200MVA Generator Transformer

A number of failures of generator Transformer were being reported from one Thermal Power Station. To find out the root cause of problem on-line Partial Discharge measurement was done on all the three single-phase transformers by acoustic method. The measurements were carried out by placing the sensor at various locations on the tank wall. It was confirmed that high PD activity is persistent in R&Y phase of the three-phase bank. Higher values recorded were in the range 2500 to 3500 counts. Due to the power demand the transformer could not be taken out for inspection and eventually the failure occurred.

After opening the transformer, it was found that there were puncture marks on surface of the shields and erosion of material on end-frame. Failure occurred due to flash over between the oil end-shield of 400kV bushing to end frame.

The reason was attributed to inadequate clearance between the shield and the end frame, giving rise to high partial discharge (PD).

Since, it appeared to be a generic problem, the design was analysed for electric field. The electric stress near the shield was found to be towards the upper limit. It was decided to increase the clearance by changing turret angle by 0.5 degree. The shield design was also modified, manufactured and replaced in all transformers. Since then such failures had been reported

The PD values were again recorded after rectification and were found to have substantially reduced, being in the range of 100-150 counts.

Problem of hydrogen gas generation in single-phase, 35 MVA, 220/11 Kv, Generator-Transformer

This is case of one of single-phase units of generator transformer, which had been re-commissioned after oil replacement. It was observed that after a period of four months of operation when DGA analysis was done, hydrogen gas had increased from non-detected level (before oil replacement) to 1653ppm and DGA analysis of new oil taken out from drums also showed higher level of hydrogen gas.

Partial discharge measurement was done on the transformer by acoustic method. The measurements were carried out by placing the sensor at various locations on the tank wall very high level of PD values of the order of 10,000 counts was recorded near forced oil outlet confirming gas bubble formation. Recovery voltage measurement indicated a level of moisture content in winding as 2.5%.

After opening the transformer a detailed inspection of core coil assembly was done and no abnormality was observed. Electrical tests indicated that transformer is healthy. The whole lot of oil was replaced with new supply. Subsequently, there was no generation of hydrogen gas.

It was concluded that oil was getting disintegrated due to poor quality

Reference Book:

IEEMA journal
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