Chapter 2

Background

2.1 General

Transformers form a critical link and are often the costliest equipment in a Power system. A transformer outage can cause serious disruption of power to consumers, the extent of which depends on the network configuration. Further, repair of transformer is costly and time consuming and any replacement involving windings can take several months.

For large capital items such as transformers, the direct capital cost of a replacement is usually by far the largest cost element, and for this reason it is often difficult to justify replacement before end of life failure [51]. Hence, replacing transformers on failure is inappropriate except for small distribution units. However, there are sometimes situations, usually when the indirect outage costs are very high, when a replacement can be justified before an end of life failure, if the costs of keeping unreliable equipment in service are sufficiently high [11].

The life of a transformer may be introduced as the change of its condition with time under impact of thermal, electric, electromagnetic and electrodynamics stresses, as well as under the impact of various contamination and aging processes.

A large population of transformers in service are approaching the end of their design lives. It is not unusual to find units more than 40 years old being the backbone of a network or to find typically 50 percent of transformer population in a Utility being more than 20 years old. This kind of performance has been due to the comparatively larger factor of safety in the earlier designs of transformers compounded by average loading well below their thermal ratings. The scenario now has changed. In a global market environment, competition has led to a high degree of design optimization aided by the use of advanced analytical techniques during manufacturing, resulting in the reduction factor of safety applied to transformer designs. The tighter design margins are now compounded by the fact that in a de-regulated environment, Utilities, with low spare capacities, operate transformers at high load factor . In this context, there is need to focus on the real on - site operational issues of Power Transformer due to operational stress and new methods for evaluating the condition of transformers , incipient fault recognition and its location .

2.2 Condition Monitoring and Life Assessment of Transformer

Transformers go through natural ageing under operating stress conditions as well as accelerated ageing, due to contamination and abnormal service conditions such as overloading, short-circuits or over voltages. So, failure can take place well before the design life under such operating conditions unless corrective action [35] is taken as per Figure 2.1.

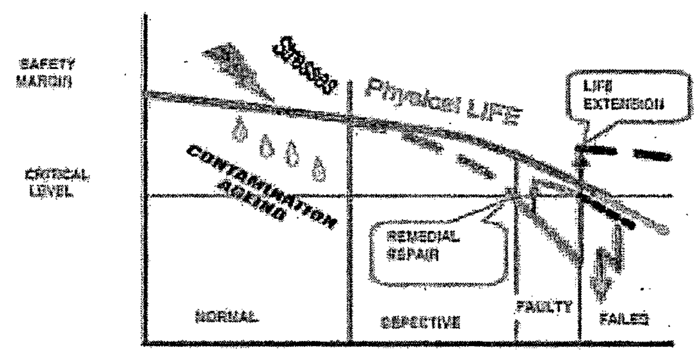

Figure 2.1: Conditions of a transformer in the course of its life cycle

Hence, to ensure reliability of Transformer and avoid unplanned outages, it has become essential to continuously monitor the stresses on transformer and also parameters of transformer that help in the assessment of its condition and take corrective actions [18]. Condition monitoring and Life assessment of a costly and critical asset like transformer aims at:

1. Estimating the extent of contamination to reduce the rate of degradation with preventive action.
2. Detection of faults at incipient stage and avoid catastrophic faults.
3. Reducing maintenance costs by doing condition-based maintenance rather than a time-based one.
4. Developing data base which helps more accurate failure analysis and enable design/process/system improvements to improve reliability in service.

The assessment of transformer condition involves a review of its operational history, design and materials used, as well as: mechanical winding integrity, ageing and water content in solid insulation and oil; condition of the on-load tap changer and its drive, bushings etc.

Results of the condition assessment allow the utility to rank their transformers, and to plan replacement, modernization or scrapping of older units, depending on their critical importance to the network reliability and the scope of required modernization [44].

Monitoring is done in enerzgised as well as de-energised condition , that means it can be done off-line and online. Advancements in micro-electronics, sensors and Signal processing techniques makes the on-line monitoring and diagnostic techniques more advanced.

2.3 Operating stresses on Transformer

Out of the five functional systems, current carrying , magnetic, thermal, packaging and insulation systems, the life of the transformer is essentially decided by the last mentioned. Transformer accessories such as Bushings, Tap changers and cooling fans and oil pumps are also weak links as they finally lead to insulation ageing and failure.

The insulation system consists of cellulose impregnated with resin or oil, mostly, mineral oil. While the liquid insulation can be cleaned or replaced, it is not easy to do that for solid insulation. The degradation of the insulation system of a transformer is irreversible and its life is often the life of the transformer. Further, repair of the solid insulation, particularly of the coils, is very difficult.

Water, oxygen, oil aging products (acids particularly) and particles of different origin are agents of degradation, that can shorten transformer life significantly under impact of thermal, electrical, chemical and mechanical stresses as discussed in next section below.

2.3.1 Thermal stresses

Temperature of the insulation can increase above design levels due to overload, or over fluxing. It can be also due to insufficient cooling due to deposition of sludge on solid insulation or the failure of cooling fans. Beyond temperatures of about 130 deg C, the polymeric chains of cellulose are affected thereby reducing its mechanical strength. The rate of degradation increases with temperature. For every 6 to 8 degree rise in temperature from its designed temperature class can halve the life. Secondary effects of high temperature include decomposition of paper and oil and resulting in the production of water, acids and gases each of which progressively deteriorate the insulation.

2.3.2 Chemical stresses

Chemical deterioration agents could be contaminants in oil such as :

1. Moisture and acids in oil which break cellulose chains and reduce mechanical strength of cellulose and also corrode metal.

2. Corrosive Sulphur in oil, can form copper sulphide deposits on paper.

3. Oxygen forms organic acids and sludge which can impair cooling.

4. Metallic particles is leading to discharges in oil and decompose it.

The combination of moisture, heat and oxygen are the key conditions for degradation of the cellulose.

2.3.3 Electrical stresses

Electrical stresses due to operating voltage and transient over voltages causes ageing under dielectric stress mainly due to partial discharges (PD). Apart from over-voltages, stress enhancement, particularly at insulation surface, may also take place due to the presence of conductive particles and wet fibers. The rate of degradation due to PD depends on its location and energy dissipated there.The cellulose based solid insulation comprises of:

1. Hardboard whose main role is to provide mechanical support,

2. Pressboard that act as insulating barriers and

3. Soft paper as conductor insulation.

Even though the moisture content is lower in conductor insulation than in pressboard, the degradation is high due to high temperature and higher electrical stress and hence should be considered as a weak link.

2.3.4 Mechanical stresses

Under normal operating stresses, the core coil assembly vibrates at double the power frequency, while magnetizing in-rush or short circuit currents can subject the windings to large axial and radial mechanical forces. When the transformer is new, the windings will be well clamped and therefore have a high strength, while the electromagnetic centers of the windings will be aligned to minimize the stresses of electromagnetic forces during short circuits.

As the transformer insulation ages, the paper insulation shrinks resulting in a reduction of clamping pressure, thereby reducing mechanical strength. If now a short circuit occurs and the windings move slightly, magnetic unbalance is created between the windings leading to much higher stresses during subsequent faults.

It is probably through such a process of falling strength and increasing stresses that the mechanical condition of a transformer will degrade rapidly over a few short-circuits immediately preceding the final failure. The mechanical integrity of a transformer winding is challenged by several mechanisms as mentioned below:

1. Excessive short circuit forces due to close-up secondary faults.

2. Excessive mechanical acceleration during transport (accidents).

3. Dynamic forces in service, for instance vibration or seismic forces.

It is assumed that many times dielectric failures are initiated by mechanical movements inside the winding, and these could have been avoided by assessing the mechanical condition of the winding and core at an early stage. Mechanical deformations do not necessarily change the operational characteristics of the transformer. Dielectric failures are a direct results of reduced dielectric strength due to deformations. It is therefore favorable to detect deformations as early as possible, before they lead to problems or failures[33,37]. Hence , Mechanical mode of failure and its assessment techniques will be discussed in detail in following sections of this chapter.

2.4 Mechanical Mode of Failure due Electromagnetic forces

When a system short circuit causes high current to flow through a large power transformer, the windings and internal leads are subjected to extremely high mechanical forces. The total radial force and axial forces on a winding can be multiple of hundreds times of normal forces. The extremely high current during first peak of the fault current is a major source of mechanical displacements and subsequent transformer failures.

The current flowing in transformer winding conductors sets up an electromagnetic field in and around the windings, as shown in the Figure 2.2. Any current-carrying conductor (I) which is linked by the field (B) experiences a mechanical force (F) which is perpendicular to the direction of the current and the field.

The basic equation for the calculation of electromagnetic forces is,

$$\bar{F} = L\bar{I} \times \bar{B} \tag{2.1}$$

Where, B is leakage field density vector, I is the current vector and L is the length of conductor.

Radial force in x-direction due to axial leakage flux density and axial force in y-direction due to radial leakage flux density [1] is acting as shown in the Figure 2.2.

The asymmetric waveform of the short circuit current is shown in Figure 2.3. The Forces experienced by a winding are proportional to square of the winding short-circuit current and are unidirectional and pulsating in nature as shown in Figure 2.4.

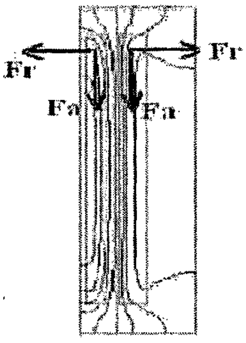

Figure 2.2: Electromagnetic Forces

2.4.1 Core Type Transformer

In a core form transformer, the forces act radially outward on the outer winding and radially inward on the inner winding, but because of the radial fringing at the ends of the windings, there are also axial force components which tend to compress the windings as indicated in Figure 2.5.

When both Winding's are carrying currents and the magnetic centers of the windings are balanced, the distribution of leakage flux is indicated in Figure 2.6. It shows a symmetrical field with a clear indication of how the axial flux is highest at the middle and the radial flux is highest at the ends of the windings [20].

The common failure modes for a core form transformer are as follows:

1. Inward radial hoop buckling
2. Outward radial hoop stretching
3. Conductor beam bending from generated axial force
4. Conductor tilting from cumulative axial force
5. Coil end support instability produced by axial force.

2.4.2 Shell Type Transformer

The main component of the linkage flux density of a shell type transformer is the radial component. This radial component develops axial electromagnetic forces, which tend to

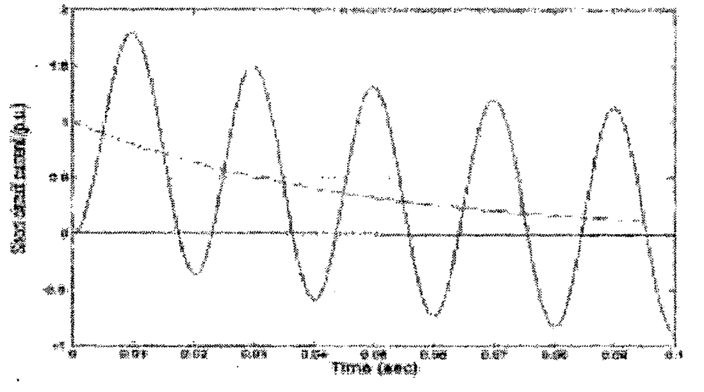

Figure 2.3: Short circuit current

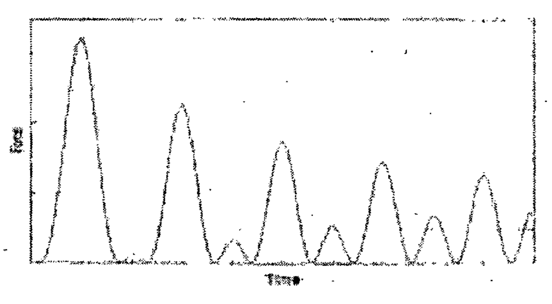

Figure 2.4: Short circuit forces

separate the low voltage windings from the high voltage windings. Whereas the principal forces in the core form design were radially directed, the principal forces in the shell form are axially directed as shown in Figure 2.7. The corresponding magnetic field developed is shown in Figure 2.8.

2.4.3 Radial forces

1. The radial forces are acting outwards on the outer winding tending to stretch the conductor, producing a tensile stress and acting inwards on the inner winding tending to collapse or crush it, producing a compressive stress also called as hoop stress.

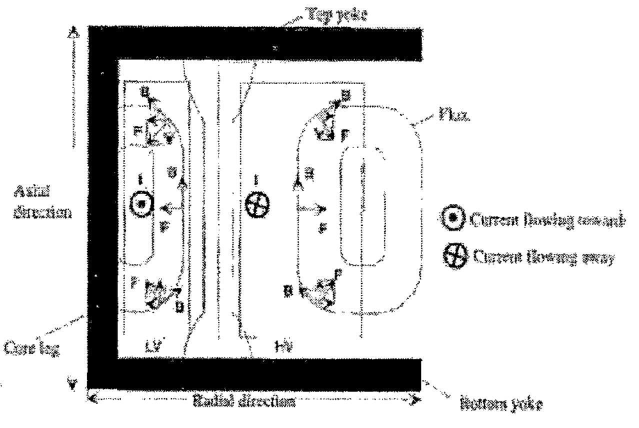

Figure 2.5: Generated Forces in a Core Form Transformer

If a winding is tightly wound, conductors in radial direction can be assumed to have uniform tensile stress.

2. The average hoop stress can be considered as uniform over the entire disk winding. In a layer / helical winding, the average hoop stress is not uniform, i.e., it is highest for the innermost layers and it decreases towards the outer layers. An adequate number of winding supports need to be provided to give strength to the winding against the radial forces.

3. Most of the space in radial direction is occupied with copper (except for the small paper covering on conductors) resulting in high stiffness to mass ratio. The natural frequency is much higher than excitation frequency and hence chances of resonance are remote.

Failure Modes due to Radial Forces:

1. Radial collapse of inner winding is common, whereas outwards bursting of outer winding generally less take place.

2. The chances of winding failing with tensile hoop stress are unlikely if conductor with 0.2 percent yield strength is used.

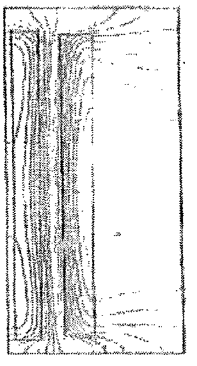

Figure 2.6: Generated Axial and Radial Fluxes in a Core Form Transformer

3. Forced buckling occurs when the winding cylinder has significant stiffness as compared to winding conductors.

4. Free buckling kind of failure occurs mostly with lower thickness of winding cylinders. Conductors bulge inwards as well as outwards at one or more locations along the circumference as indicated in Figure 2.9.

2.4.4 Axial forces

1. The axial forces due to radial fringing leakage field at winding ends are directed towards center of winding from both ends for uniform ampere-turn distribution in windings with equal heights (ideal condition).

2. The compressive force is maximum at the center of the windings.

3. Both the inner and outer windings experience compressive forces as indicated in Figure 2.10. The axial forces are transmitted through the insulation structure. This will give rise to a compressive force in the axial supports or stampings and the insulation must tolerate this compression.

4. For asymmetrical axial winding disposition (winding electromagnetic centres not at same level), axial forces on two windings are in opposite direction and they tend to increase the asymmetry.

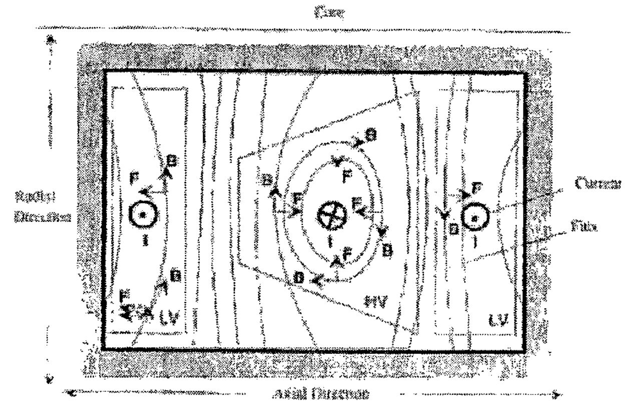

Figure 2.7: Generated Forces in a Shell Form Transformer

5. Strict sizing and dimension control required during processing and assembly of windings.

Failure Modes due to Axial Forces:

1. If a layer winding is not wound tightly, some conductors may just axially pass over the adjacent conductors, which may result into damage to conductor insulation and a eventual turn-to-turn fault.

2. If winding is set into vibration under the action of axial forces, conductor insulation may get damaged due to relative movement between winding and axial insulation spacers.

3. There could be deformation of end clamping structure and windings due to high axial end thrust.

4. To maintain effective pressure on windings a clamping ring made of stiff insulating material (pre-compressed board or permawood) is used.

5. There are two principal types of failures, viz. bending between blocks and tilting.

6. Inner winding conductors, which are subjected to the axial compressive load, may fail due to bending between supports .

Tilting under axial load:

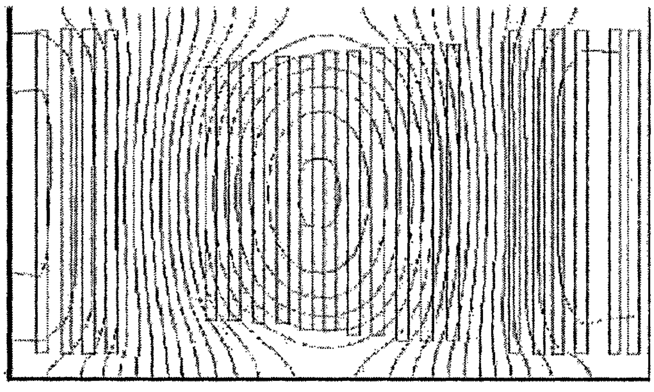

Figure 2.8: Generated Axial and Radial Fluxes in a Shell Type Transformer

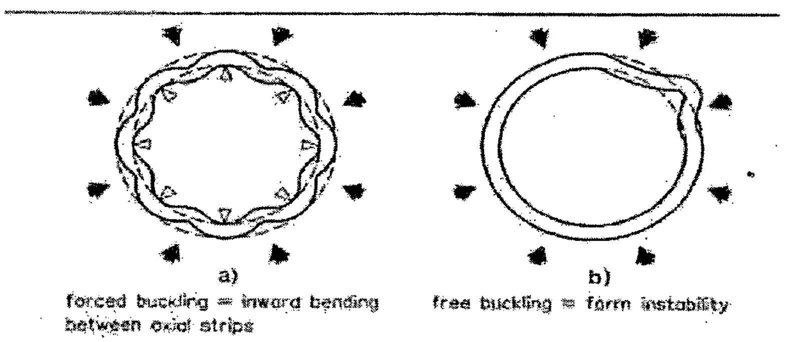

Figure 2.9: Radial forces due to axial field

1. When axial compressive forces exceed certain limit, failure can occur due to tilting of conductors in a zigzag fashion.

2. In this mode of failure there is turning of cross-section of conductors around the perpendicular axis of symmetry.

3. Two kinds of forces that resist the tilting of the conductors: one is due to the conductor material and other is the friction force.

The ability of a transformer to withstand the dynamic forces that are generated due to through fault currents in the windings is described in the specifications IEC 60076-5 and IEC 60076-8. These specifications advise the types, duration and magnitudes of the fault currents that should be considered design review and type test. They also cover

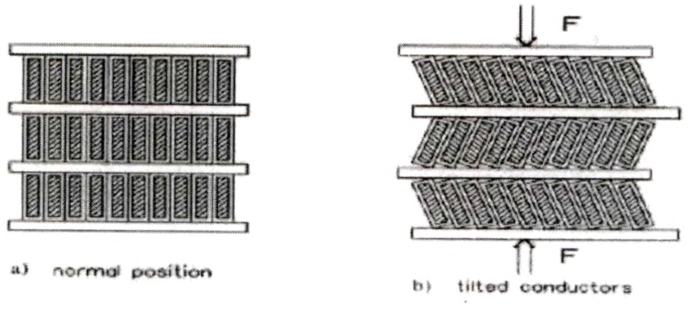

Figure 2.10: Axial forces due to radial field

the calculations required to demonstrate the thermal ability to withstand short circuit. It is known, that at the first dynamic tests approximately 20-30 percent of transformers do not pass the test and more than 50 percent of transformers receive remarks and recommendations on strengthening of dynamic stability at short-circuit current.

The industry has split transformers into three catagory, small, medium and large. Small transformers are normally classified as units that are purchased in bulk, such as pole mounted units and small distribution ¡ 2500 KVA. The design philosophy is usually based on experience and the main parameters for the design are lowest cost and fit for purpose. The proof of short circuit ability is usually by short-circuit testing one or two of units of a bulk order. It is accepted as the quickest and cheapest way to verify conformance, since the units can be un-tanked and modified very quickly and the cost is relatively small compared to the total cost of the bulk order. IEC Category I is up to 2500 KVA.

Medium size transformers up to about 100 MVA are not normally purchased in bulk although there may be several units ordered to the same design. In this case the competitive parameters may also include performance penalties and the lowest first cost may not produce the best optimised design. The cost of short-circuit testing starts to have an influence on the total order charges. The resources required to untank and modify the design are more significant and it calls for more effort to 'get it right first time'. This demands a deeper understanding of the design parameters and the ability to predetermine the short circuit ability of the transformer to ensure that it will pass a short circuit test. IEC Category II is up to 100 MVA.

Large transformers having capacity more than 100 MVA cannot normally be short circuit tested due to either the lack of test facilities or the remoteness of a suitable testing station. It is therefore essential that manufacturers of these large units can predict the short circuit ability accurately. IEC Category III is above 100 MVA. The ability of the transformer to withstand these forces will be assessed by the manufacturer. This assessment may be followed by an internal or external design review.

Therefore reliable calculation methods of axial, radial and tangential forces are important not only at preparation for carrying out of the short circuit tests, but also at transformer design, at development of recommendations on strengthening of dynamic stability [19]. It must be demonstrated that the design strength of the windings and the clamping structure including all external leads and accessories, with regard to the material and type of construction used, exceeds the calculated forces that will exist when the transformer is subjected to a through fault. Every precaution should be taken to ensure the integrity of the unit. It is recommended that such a procedure is adopted whether or not a short circuit test is requested.

The insufficient short-circuit strength of transformer windings, resulting in mechanical deformations of windings, is one of the main causes for putting the transformers out from operation. Short-circuit strength of in- service transformer should be confirmed by various techniques for assessment of mechanical condition of transformer as discussed in next section.

2.5 Techniques for assessment of mechanical condition of transformer

Reliability of the transformer substantially depends on its ability to withstand short circuits due to system faults. The insufficient short-circuit strength of transformer windings, resulting in mechanical deformations of windings, is one of the main causes for putting the transformers out from operation. Short-circuit strength of transformer should be confirmed by design review, electrodynamics calculations, short-circuit tests or comparison to the tested prototypes.

Transformers are specified and designed to withstand the effects of limited duration short circuits at their terminals, but for large transformers short circuit performance is rarely tested. There are also some faults, which the designer cannot easily design against, e.g. tap to tap faults. The technology to ensure that transformers can withstand short circuit faults has improved in recent times, but problems still arise, particularly with older units. Another important factor with older transformers is that significant winding shrinkage can occur with age, leading to a reduction in clamping pressure and short circuit withstand strength.

It is expected that a transformer will experience and survive a number of short circuits during its service life, but sooner or later one such event will cause some slight winding movement, and the ability of the transformer to survive further short circuits will then be severely reduced. It is therefore desirable to be able to check the mechanical condition of transformers periodically during their service life, particularly for older units and after significant short-circuit events, to provide an early warning of an impeding failure. The following methods are very well used to detect winding movement in transformers[29] and assessment of winding condition.

1. Short-circuit impedance or leakage reactance
2. Magnetizing (exciting currents) currents
3. Winding capacitances

2.5.1 Short circuit Impedance or Leakage Reactance

Short-circuit impedance (often referred to as leakage reactance) measurements are probably the most widely accepted method of detecting winding movement, and are prescribed in standard IEC:76-5 [55] for short circuit tests. The technique is simple in principle, and requires relatively standard equipment.

During factory acceptance tests, impedances are measured using three-phase excitation at currents of at least 10 percent of rated value. At site, impedances may be measured using low voltage three phase supplies or using single-phase insulation test sets. If single-phase measurements are made, then separate 'per phase' measurements may be made on each phase in an attempt to facilitate the detection of faults by phase-by-phase comparisons [9].

Leakage reactance measurements are performed by short-circuiting the low voltage winding. During that test, the reluctance encountered by the magnetic flux is determined predominantly by the leakage channel as shown in Figure 2.11.

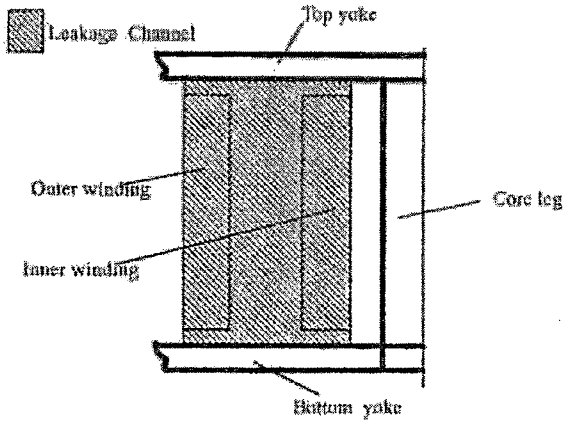

Figure 2.11: Leakage flux path

The leakage channel is the space confined between the inner surface of the inner winding, the outer surface of the outer winding, and the bottom and the top yokes. When winding distortion occurs, it changes the reluctance of the magnetic flux path, resulting in a change of the measured leakage reactance.

The leakage reactance test does not replace the exciting current measurement; the two are complementary. Leakage reactance is influenced by the reluctance in the leakage channel, magnetizing current is influenced by the reluctance in the transformer core and can detect shorted turns in the windings, shorted core laminations, multiple core grounds and problems with the load tap changer.

The windings deformations can affect the leakage flux path, which in turn may result in the change of the measured leakage reactance. The technique suffers the disadvantage that very small changes (of the order of 1 percent) have to be detected . Even so, the main difficulty in making use of the technique appears to lie not with the repeatability of the measurements, but in the natural variation of the measured quantity. Measured per-phase leakage reactance often differ significantly between phases, even for new transformers, and also between transformers of the same design. Agreement with nameplate values is also variable. Therefore, it appears that without reference results from the transformer in question it is very difficult to make a reliable interpretation of results.

2.5.2 Magnetizing or no-load excitation current

The exciting current creates a magnetic flux in the core, and the flux in turn induces a voltage in the energized winding that opposes the applied voltage. Consequently, the exciting current is small, usually only a few percent of the rated load current of the winding. The exciting current of a transformer is made of three components as indicated in Figure 2.12.

1. A magnetizing part (Im), required to build the magnetic field in the transformer core. It is represented in the model by a non-linear inductor.
2. A resistive part (Ir), required to supply all the losses in the transformer at no load. Resistance (R) is associated with losses in the core and in the turn-to-turn insulation.
3. A capacitive part (Ic), required to build the electrical field in the insulation of the transformer. The capacitance (C) accounts for the energy of the electrical field created in the turn-to-turn winding insulation. n the core and in the turn-to-turn insulation.

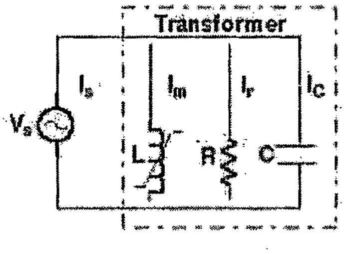

Figure 2.12: Equivalent Circuit for a Transformer at no Load

The relative importance of these three components varies significantly from one transformer to another.

1. Generally, Im and Ir are proportional to the weight of the core. The bigger the core, the more magnetizing current it requires and the more losses it has.

2. The quality of the steel used for the core also plays an important role. The quality of the manufacturing of the core can also influence the magnetizing current and the losses.

3. Ic is independent of the core. It is related to the voltage level and the geometry of the windings themselves. Generally, in low voltage transformers, Ic is negligible. In high voltage transformers, it used to be much smaller than Im and Ir. But in the last 30 years, manufacturers of transformers and of electrical steel have made so many efforts to reduce the losses and magnetizing power of transformer cores that Im and Ic are now the same order of magnitude. If you add high series capacitance windings to these cores like fully interleaved HV windings, the capacitive component of the exciting current might even be greater than the magnetizing one, even at power frequency.

The single-phase exciting-current test is useful in locating probles such as defects in the magnetic core structure, failures in the turn-to-turn insulation, or problems in the tap-changing device. These conditions result in a change of the effective reluctance of the magnetic circuit, which consequently affects the current required to force a given flux through the core.

The exciting current test is comprised of a simple measurement of the single-phase current and watts loss, typically on the high-voltage side of the transformer, with the terminals of the other windings left floating (with the exception of a grounded neutral). The field measurements are performed at rated frequency and usually made at voltages up to 10 kV. Three-phase transformers are tested by applying a single-phase test voltage to one phase at a time. Often a three phase low voltage supply (e.g. 415 V phase to phase) is also used for three phase measurement.

While magnetizing current measurements are usually the easiest way of detecting any shorted turns that may have arisen from winding movement, the technique is of limited sensitivity for other types of faults.

2.5.3 Winding capacitances

The capacitance can be calculated if the geometry of the conductors and the dielectric properties of the insulator between the conductors are known. The capacitance C of a parallel-plate capacitor shown in Figure 2.13 and constructed of two parallel plane electrodes of area A, separated by a distance d is represented by equation:

$$C = \epsilon \frac{A}{d} \tag{2.2}$$

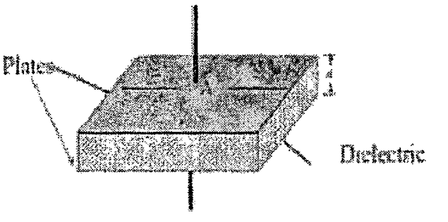

Figure 2.13: Equivalent Circuit for a Capacitor

C- is the capacitance in farads, F e -is the permittivity of the insulator used (or e0 for a vacuum) A- is the area of each plane electrode, measured in square meters d- is the separation between the electrodes, measured in meters

Insulation systems associated with high-voltage power transformer consist of a mix of non-homogeneous component parts. A complete and highly accurate schematic representation of transformer insulation system is quite complex as shown in Figure 2.15and difficult to compose, perhaps consisting of a number of resistor and capacitor elements arranged in many varied ways. For analysis, it is convenient to represent an insulation specimen by a single capacitor combined with a single resistor. The capacitor element represents the fundamental capacitance [5](i.e., its ability to store electrically separated charges), while the resistor element represents the dissipated loss in the insulation when voltage is applied as shown in Figure 2.14.

Transformer insulation is a composite dielectric system, located between the electrodes, i. e., winding conductors, and grounded parts of the transformer. Dielectric measurements allow us to determine the partial conductance of the dielectric system between each accessible pair of electrodes. The most important components of the main two

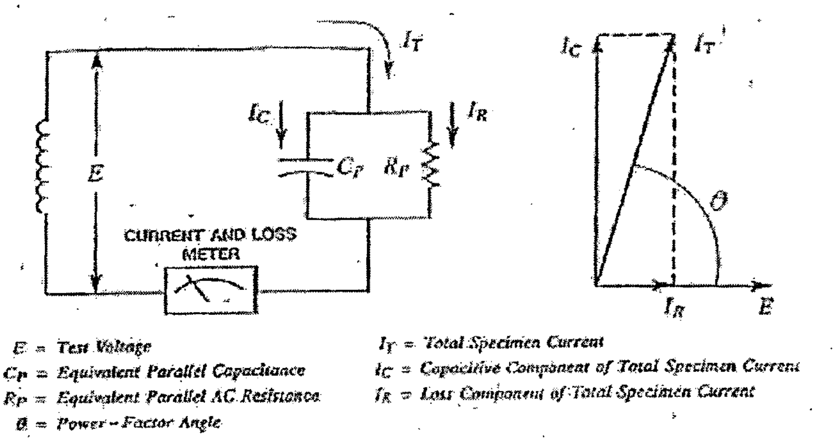

Figure 2.14: Equivalent Circuit for a Capacitance measurement of Transformer

winding transformer insulation are divided into three parts as indicated in Figure 2.16 by CH, CHL and CL as described below:

CH - Insulation between High-Voltage conductors and grounded Tank and Core (H Bushings-Winding Insulation-Structural Insulating Members-Oil):

The typical components of the space HV-TANK are the oil, pressboard space, coil support insulation (situated between the bottom or top turn and the ground), high-voltage bushings and shunting insulation of leads, LTC, etc. and all these parameters are the components of CH. The main part of this insulation space is the oil. This insulation zone presents a good opportunity to identify the condition of the oil. In this space the barrier insulation has the highest probability of absorbing water or being contaminated. However, the influence of the barrier condition on the overall dielectric characteristics of this space is usually minor. The relatively small capacitance of the coil support insulation, bushings and shunting insulation components allows us to detect only severe defects in these components. Thus, the main goal of the measurements in the zone HV-TANK is to determine the condition of the oil and to detect severe defects in the other components like HV winding.

CHL - Insulation between High and Low-Voltage Windings (Winding Insulation-Barriers-Oil):

The interwinding space includes one component: oil-pressboard space. The composition of the space allows us to detect and identify the condition of the pressboard barriers as well as of the oil. This is the only space where one can practically estimate water content in the pressboard.

CL - Insulation between Low-Voltage conductors and grounded Tank and Core (Low voltage Bushings - Winding Insulation- Structural Insulating Members-Oil):

The typical components of the LV-CORE space are: oil-pressboard space, coil support insulation, shunting insulation of the leads, LTC, LV bushings, etc. This space is the least useful in evaluating the condition of the solid insulation. The main goal of the measurements in the space LV-CORE is the detection of severe surface contamination or significant local moisture concentration in the insulation components, etc.

Measurements of winding capacitances is capable of detecting gross winding movement. Power factor and capacitance testing of bushings and winding insulation are, for many utilities, a routine offline method of tracking dielectric deterioration [10]. The power factor will also allow trending of winding moisture content, while the capacitance value will indicate gross movement and loss in core grounds. The technique is very effective in cases when it is possible to make separate measurements for each phase, when phase-by-phase comparisons of results greatly improve the chances of identifying any anomaly, particularly for inter-winding capacitances which should be very similar for each phase [14]. However, in practice the sensitivity of the technique depends on the type of fault involved, and there may be difficulties in interpreting measured values if reference results are not available. Also, in case of autotransformers which is the major population of power transformer in system, the technique is of limited use because it is not possible to measure any main inter-winding capacitances at all.

2.6 Conclusion

There are limitations of existing method for assessment of mechanical condition of transformer as discussed in this chapter. Traditional electrical tests, Short-circuit impedance or leakage reactance, Magnetizing (exciting currents) currents, Winding capacitances and loss factor (tand) provide very little information about transformer insulation since they are limited to a single value results.

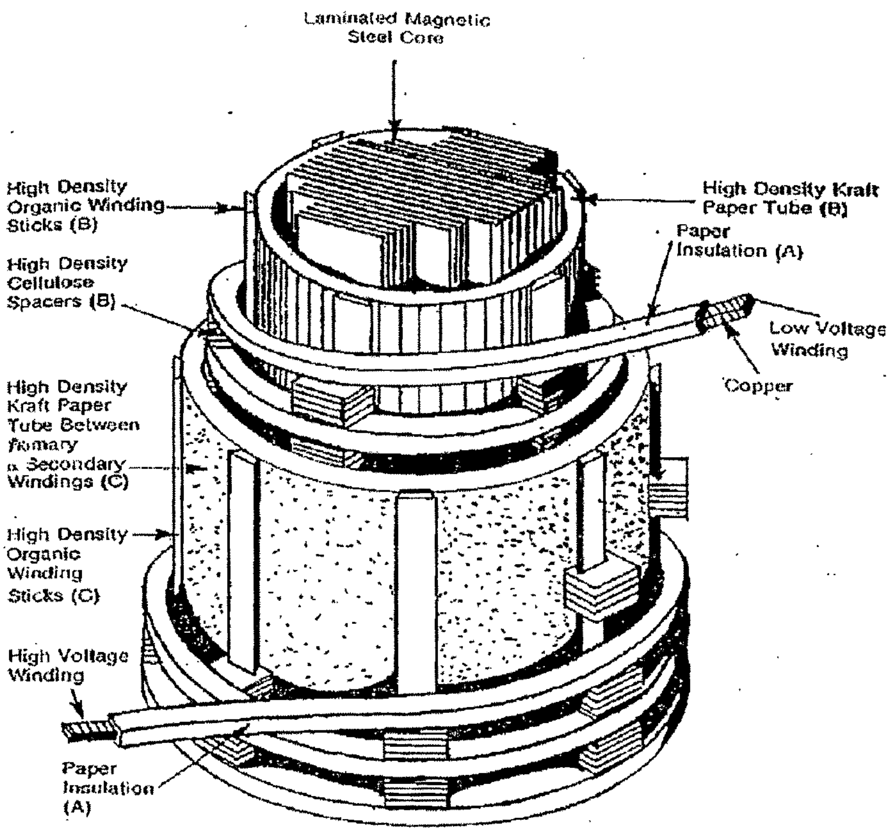

Figure 2.15: Internal layout of Transformer insulation system

These techniques depend on detecting the change in a global quantity, e.g. total leakage flux, that winding movement produces. Method should rely on detecting the effects of the resulting local change produced by a fault so that incipient fault in transformer can be detected.

Development of fast computers and digital signal processing technologies made a major break through in development of new measurement techniques for incipient fault detection in transformers. These new measurement techniques for both in the laboratories and in the field will be discussed in next chapter.

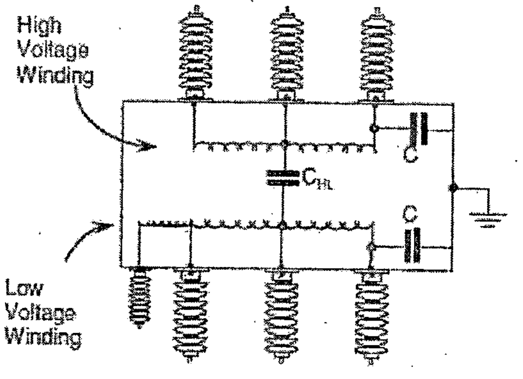

Figure 2.16: Equivalent Circuit for representation of individual capacitance in two winding Transformer