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Literature Survey of Distribution Transformer Failure Reasons and Methods

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ABSTRACT

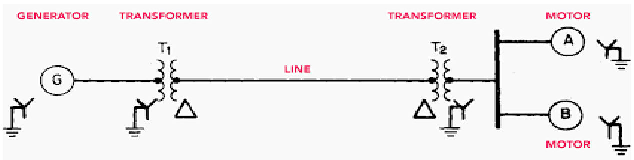
The transformers are essential equipment of the power system. Transformers internal state deteriorates over age, increasing the chance of risk. A critical concern for utilities is preventing this risk and maintaining transformers in excellent operational order. The object of this paper to clarify the transformer failure reason and effects of poor power quality on Transformer efficiency rate of failure of transformer and Operation of transformer with respect to linear and non- linear load. Power quality includes Voltage, current, power factor, shape of wave form etc. In this paper we compare and analyse the transformer failure data of Rajasthan with Punjab states.

Keywords— Transformer insulation failure, Transformer failure, power quality, harmonics, , distribution transformers.

I. INTRODUCTION

Transformer is a static device thus the efficiency of transformer is very high because there is no friction loss. Transformer is a main device in power system because it transfers electrical energy from one place to another place at constant frequency. It steps down or step up the level of voltage according to requirement. Failure rate of distribution transformers in India is very high (11-18/%) as compared to developed countries (3%). This high failure rate is major problem for all the Discoms in the country. A lot of money is wasted in repair and replacement of transformer [1]. Thus, the failure of of transformer interrupt the power supply reliability.

The role of transformer starts at generating station power is generated at maximum value of 11 KV in generating stations in India. This power needs stepping up to extra high voltages(66kv) for reduction of current and the losses during transmission. After that it is stepped down to 66/11KV at substations for primary distribution and further stepped down to 11KV/400V using step down distribution transformers for secondary distribution system to feed consumers of different categories e.g. commercial, domestic, etc. The distribution transformer is a very important equipment of the distribution system to provide uninterrupted power supply to the consumers. So it should be highly reliable and efficient.



The risk of failure is defined as the product of probability of failur [2]. To improve the reliability and to reduce the risk of failure of the system, it is important to bring down the rate of failure. This requires a systematic study of distribution transformer failures.

There are many international standards [9-15] formulated to incorporate above concern about transformer failures.

The aim of this paper is to find the reasons of transformer failure in distribution system so that in future these problems may be avoided. Huge money loss of the Discoms along with improvement in quality and reliability of the distribution system saved. The paper is divided in six main sections, namely introduction, main components of a Transformer prone to failure, cause of transformer failures, Transformer failure check, Remedial measurement and conclusion.

II. MAIN COMPONENT OF TRANSFORMER PRONE TO FAILURE

A distribution transformer consists of Magnetic component (Core, yoke). Magnetic component responsible for iron loss. Electrical circuit consist of (windings and insulation), Terminals, bushings, oil, tank, radiator, conservator and breather as main parts. The transformer can fail due to fault or defective in any of the component as discussed below.

A. Magnetic Core

The core of transformer provides mechanical strength and carries magnetic flux. The core fails due to DC magnetization or displacement of the core steel during the construction of transformer.

B. Winding

This carry current in the transformer and they are arranged as cylindrical shells around the core limb where each strand is wrapped with paper insulation. The main reason of winding failure is short circuit or we can say transient over voltage. By over voltage insulation of winding burn and come indirect contact with supply. The main reason of short circuit in transformer-Mechanical fault in the winding during the manufacturing, low oil level, faulty insulation material, Transient over voltage due to lightening surge.

C. Tank

Transformer core and windings are enclosed in the tank. It performs as a physical protection as well as serves as container for oil used as coolant. It has to withstand environmental stresses such as high humidity, corrosive atmosphere and sun radiations. The tank is checked for oil leakage, excessive corrosion, dents and other signs of rough handling.

D. Insulation

Solid insulation, made of cellulose base products press board and paper, is used between the windings for electrical isolation or separation. Cellulose consists of long chain of glucose rings which degrades with time leading to shorter chains. Solid insulation may get damage due to movement of transformer or force generated by short circuit. This solid insulation is the weakest link in the transformer insulation system.

Main cause of Faults in insulating material :- generation of $CuSO_4$ or hot spots created due to low quantity of oil or overloading of transformer.

E. Transformer Oil

The main function of oil in transformer is to provide insulation and cooling. Transformer oil is a highly refined product from mineral crude oil. It consists of hydrocarbon composition such as paraffin, naphthalene and aromatic oils [8].

The failure of cooling oil causes due to two reasons malfunction of the oil circulation and poor heat transfer to secondary cooling circuit. Moisture coupled with heat are the major cause of oil contamination leading to generation of conducting particles. Thereby temperature inside the transformer will rise and insulation may fail.

F. Bushings

Winding terminals are taken out side with the help of bushing. Bushing made up of porcelain. used are generally Two types of bushings are generally slid bushings and capacitance graded bushing. In solid bushing there is a central conductor and porcelain or epoxy insulation around it.

The main reason of failure of bushing is short circuit. It may be due to faults in the insulation or due to damage. The damage can occur due to flying parts from other failed equipment or sabotage, during shipping. Cracks, Damages, in the porcelain and bad gaskets provide ingress of water inside insulation of the bushing leading to its failure.

III. TRANSFORMER FAILURE FACTORS

Three factors involves in the failure of transformer Electrical, mechanical and thermal. Here we are going to study about each and every factor .To study about each and every factor we have to performs some tests on transformer It is very difficult to find out a particular factor of failure.

A Electrical Factors

Electrical factors classified into three categories-Transient or overvoltage, Lightening and switching surges. All the failure due to short circuit and over voltage are considered in electrical factor

B. *Mechanical factors*

Mechanical factors involve damage done by electromechanical force. Due to mechanical factors winding insulation may get damaged. Some important mechanical factors are

- Damage during shipping
- Crack in bushing
- Oil leakage
- Electromagnetic force
- Tripping of conductor
- Damage in breather

C. Thermal Factors

This involves the damage done due to heat generated in winding. Due to overload a large amount of heat is produced. Insulation of transformer get damaged due to this heat. Other factors:-

- Non linear load
- Failure of cooling system

- Oil circulation problem
- Over excited condition
- Temperature
- Operation of transformer in high ambient temperature.

CI. TRANSFORMER FAILURE CHECK

To conduct failure test on distribution transformers IEEE standard C57.125 “Guide for Failure Investigation, Documentation, and Analysis for Power Transformer and Shunt Reactors [9] is used. It provides a procedure to perform failure test on transformers to find out the most probable cause of transformer failure.

A failure test is generally starts with no supply complaints from the affected area where the distribution transformer has failed. Failure test require all historical data related to transformer. To find the cause of failure external check of transformer require. When failure is confirmed, then onsite investigation and testing is conducted to collect data from site. Before conducting the failure test all historical data related to transformer must be gathered. The failed transformer is checked internally, externally and finally teardown is performed so that study analysis to be done to find out the cause of failure of transformer.

Procedure for information collecting

Before conducting the onsite failure test we should have all the historical data related to transformer.

During the onsite inspection all data related to transformer require which may include-

- Rating of transformer
- Routine test report
- Preventive maintenance record
- Oil filling and test report
- Load detail at the time of failure
- All breakdown record
- List of any fault or switching event in the system

Site Inspection

An inspection of failed transformer is require to find out the reason of failure of transformer.

This inspection must be quick because the data may be destroy during restoration of supply.

This inspection consists:

- External condition check of transformer
- Visual check of site
- Temperature and environment at the site

External Conditions: On arriving at site investigator should ask people about any abnormality they saw. Investigator has to look for any unusual sound, odors any dead animal in area. After all this investigator should check the sign of overload any leakage in oil tank, check for any crack in bushing. If everything seems ok than next step is to conduct diagnostic testing of transformer.

Transformer conditions: Investigator has to look for following visible abnormalities in the transformer main tank cracks , leaks, sign of overheating, oil spill or fire, oil level in main tank, conservator oil level, radiators

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damage, conservator damage and bushings for leaks, broken porcelain, holes in caps and tracking. If no visible damage is found by inspection externally, now next step is to conduct diagnostic test of failed transformer.

a. Diagnostic Testing

When there is no visible damage the next step is external examination of transformer. Then diagnostic tests are conducted to find out fault and to give instruction of repair. Test data should be recorded and several tests may be interpreted together to diagnose a problem. Samples of insulating oil for testing must be taken first to opening the transformer for test. Following tests can be conducted on transformer for failure check.

Insulation Resistance test: The device used for this purpose is megger resistance between winding to winding, winding to ground, core to ground is checked .

Other tests: Transformer Turn ratio; Winding DC Resistance; Oil dielectric breakdown; Excitation (low voltage)

Before performing field tests, safety precautions should be taken to ensure that the transformer is disconnected from power and auxiliary sources and has been properly earthed(which is very important)

b. Internal Check

When the results of diagnosis test confirm the failure of transformer, an internal test is performed on site to determine the location of fault and amount of damage. Transformer oil is removed for test, the exposure time must be kept to a minimum to reduce moisture entrance into the tank. Internal abnormalities may include the following

The color of oil, odor of burnt insulation, burnt oil, indication of moisture and its location and free water in tank and amount.

- Evidence of burns, discoloration, or deposits due to arc or stray flux overheating on tank walls, copper connectors, bushing terminals,.
- Loose connection or splices to bushings, collar, spacers etc.
- Displacement of winding .
- Condition of core and core damage evidence.

Tear down Inspection

If the internal inspection do not provide any exact cause of failure of transformer, then it is necessary to perform de tank the transformer to find the cause of failure. The core is bring out of tank for check which can provide following proof of failure.

Damage to core or breakdown of core insulation.

- Proof of tracking results from dielectric breakdown.
- Radial and axial failure.
- Mechanical failure.
- Proof of thermal failure.

CII. FAILURE STUDY

After collecting on-site and off-site data. It must be theoretically studied before reaching any conclusion. The

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energy from the power system is disturbed due to this failure. So care must be taken while reporting cause and effects.

A. Study of Mechanical Failure of Windings

To thoroughly analyze distribution transformer failure, it is important to an understand the axial and radial forces causing mechanical deformation to winding. The direction of forces and mechanism of failure in core type transformer is different from the shell type transformer. Different winding type has different strengths to resist conductor moment under short circuit forces. The rigidity of the winding clamping system ,stiffness of the insulation system, , the strength of the conductors and the elasticity of the coil play an important role in determining the winding response to electromagnetic forces.

1) Core Type Transformers winding Failure Modes

i) Failure due to Radial Tension

Forces acting radially outward can cause conductors to stretch. Moderate deformation can cause to axial instability and collapse of the coil. It can also cause the conductor insulation to tear. In extreme cases, the stretched conductors break down when the elastic limit is exceeded.

ii) Failure due to Radial Compression

Forces directed radially inward can cause conductor mechanical failure of the winding(Breaking of conductor).

iii) Axial Expansion Failure

Forces directed axially towards clamping plates can cause these plates to bend or break, or can cause jack bolts to bend or break. These forces can also cause conductors to tilt, Improper clamping , may allow winding conductors to shift axially. This force can cause collapse of the winding and winding become unstable.

iv) Axial Telescoping Failure

This term is used to describe the moment of individual winding relative to one another winding(i.e. outer winding moving upward or downward relative to inner winding.) or to describe the axial instability of winding (i.e. outer turns moving upward or downward relative to inner turns). Any mechanical failure of the clamping system would allow winding to move in opposite direction relative to one another, thereby telescoping. The axial instability of an individual winding could result from radial compression failure, radial tension failure, radial or from axial collapse. The result of these failure might cause conductors to slip and collapse inward, thereby telescoping.

v) Failure of End Turn

End turn experiences both radial and axial forces. The resultant of these forces tends to tilt the outside turns and twist the ends inward towards the core leg.

Spiral Tightening Combined axial and radial forces can cause the entire inner winding to tighten and spiral, leading to circumferential displacement of the live conductors

2) Shell Type Transformers winding Failure Modes

i) Radial Forces

Small radial components of force develop on the edges of the coil. When coil heights are tapped to obtain

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graded insulation level, the amplitude of radial forces are greater than usual. Forces directed radially outward can cause conductors to break

ii) Axial Forces

Within the same coil group, the axial forces are attractive, thus placing the conductors, insulation and spacer block under compression. These forces exert beam stresses on the conductors surface, which try to bend or break the conductors between the spacer blocks. The axial forces between the different windings are forces of repulsion and try to force the coils against the ends of the core window laminations. These forces are responsible for stress on insulation between winding and the core, and are extended through the core to the transformer tank.

Study of Electrical Failure

Transformer failure can be caused by transient surges. In such failures, the transformer insulation withstand capacity should be checked, with arrestor discharge voltage to ensure proper insulation coordination. Lightening, switching surges over-excitation, winding resonance, layer to layer short circuit, insulation tracking, partial discharges, static electrification of oil and flashovers are all forms of electrical failure modes. Once internal electrical failure occurs, all fields are abnormal . Stresses are on insulation in this ways which are not anticipated. Under these circumstances, fault

analysis becomes very difficult. . Often, the sequence of events, first causes, and original weaknesses may not be determined by from test of the internal damage. External evidences and transformer accessories typically provide the clues to study the fault sequences. Various types of voltages that can exist in the transformer windings (primary and secondary) and associated parts discussed here for purpose of analysis.

Normal low frequency system operating voltages

These are generated ac system voltage or system voltage appearing at the transformer terminals. These voltages can be expressed in rms(route mean square) value and depends upon the transformer connections (delta or star) for phase to phase or phase to neutral voltages. Voltage between neutral to any one phase is called as phase voltage and voltage between any two phase(Phase R and Phase Y) is called line voltage.

i) Normal low frequency induced voltages

These are induced voltage at secondary side of the transformer. Voltages induced in the winding by faraday's law Currents flowing in adjacent windings and conducting parts within the transformer .

ii) Abnormal low frequency system operating voltages

Short term ac voltages caused by over excitation, un balance loading or fault conditions that are typically removed from the system by operation of protective relay. And circuit breaker.

iii) Abnormal high frequency system voltages

These are transient voltages typically caused by lightening, system switching or winding resonance. High frequency voltages generally produce greater dielectric stress than low frequency voltages in the winding turns nearest to the transformer terminal connections which may puncher the insulation of winding.

iv) Other causes of Abnormal high frequency and low frequency voltages

These voltages arise from external solar or DC disturbances or internal fluid phenomenon such as possibility of

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charge separation on insulating surfaces, progressive winding failure from developing turn to turn faults or changes in electric field distribution due to particle initiated discharge.

CIII. RESULTS AND DISCUSSIONS

Rajasthan State electricity board (RSEB) Generation company is responsible for Generation and Distribution of Power in the state of Rajasthan. It has a very large consumer base consisting of commercial, domestic industrial and agriculture loads divided in four zones. It has large number of distribution transformers feeding the consumers. The transformer failure rate is above 15% which is a huge loss to the organization. According to IEEE Std. 57.100 [10] the life of liquid immersed transformer is 20.55 years. So large number of distribution transformers are failing prematurely. In this paper a city base sub division is selected and a failure analysis in conducted on failed transformers from 2010 to 2015 to find out the cause of failure of distribution transformers. Data on Transformer failure has been collected for a one zone of RSEB including four circles named as C1, C2, C3 and C4 for the year 2010 to 2015 given hereunder.

Table 1: Transformers failed during 2010-2015

Transformer Failure in West Zone					
Year	C1	C2	C3	C4	Total
2010	1992	3017	3424	1425	9858
2011	2259	3402	4019	2367	12047
2012	2474	3184	3589	3774	13021
2013	2589	3418	4133	5717	15857
2014	2645	3615	4189	5792	16241
2015	2512	3602	4286	5855	16255

Table No. 1 gives yearly number of failures of distribution transformers of west zone consisting of four main circles indicating increasing order of failure. Which indicate huge loss to the organization per year, is worth of laks of rupees. To find out the main reason of such a high failure of transformer. One city sub division is selected and failure study is conducted continuously from 2010 to 2015 on transformers of various KVA rating shown in table no. 2. Onsite check, external check, diagnostic testing, internal check and tear down analysis are performed as per IEEE standard C57.125 to find out main reason of failure of distribution transformer.

Table 2: Year wise and capacity wise failure of transformer

Transformer Failure in City Sub Division						
Capacity	2010	2011	2012	2013	2014	2015
6.3 kVA	2	2	1	3	1	8
10 kVA	5	4	0	3	5	10
16 kVA	2	3	11	0	12	8
25 kVA	12	16	15	17	16	19
63 kVA	9	9	11	15	18	12
100 kVA	11	13	12	19	16	17

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200 kVA	0	0	0	8	1	0
300 kVA	0	0	0	1	0	0
500 kVA	0	0	0	0	0	1
Total	41	47	50	66	69	75

On the basis of the failure study done, the causes of failure of transformer are listed in Table 3. The most common cause of failure of transformer is insulation failure in all the transformer; it deteriorates due to heat(due to short circuit), acidity oxidation and moisture. Line surges such as voltage spikes, switching surges, line faults, short circuit and distribution abnormalities, Nonlinear load, overloading, improper maintenance, moisture in oil contamination are also the main causes of failure.

During failure study a large number of transformers reported in other category, whose cause of failure is different than the listed in Table 3. It is suspected that most of the transformers are failed due to nonlinear loading of the transformer. The change in the electric load profile has created power quality problems like harmonics and poor power factor issue. The most important contributor to power quality problems is the use of nonlinear load in all sectors. Nonlinear type loads responsible for degradation in the electric supply nonlinear load also responsible for harmonics generation in power system. Harmonics results in increased losses (iron and copper loss) in transformer hence more heating is resulted which derates the capacity which may result in failure of transformer. Study in progress to find out no of transformer failures due to power quality problems.

Table 3: Causes of transformer Failure

Cause of Failure	No of Failure
Insulation failure	92
Manufacturing Defects	22
Overloading	30
Line surge	70
Improper Maintenance	19
Lightening	14
Sabotage	2
Moisture	21
Oil Contamination	20
Other	58

CIV. CONCLUSION

In this paper failure modes of transformer are discussed and failure study of distribution transformer carried out on one sub division of RSEB. Failure analysis is carried out on transformers of various KVA capacity failed between 2010-2015. Onsite check, external check, diagnostic testing, internal check and tear down analysis are performed as per IEEE standard C57.125 to find out reason of failure of distribution transformer. This analysis reveals that insulation failure (due to short circuit or over voltage), and line surges are the major cause of the failure of transformer. Large no of transformers are also failing due to manufacturing defects, poor maintenance, moisture and oil contamination.

REFERENCES

[1] Singh, R. and Singh, A, "Causes of failure of distribution transformers in India," in *Proc. 9th International Conference on Environment and Electrical Engineering (EEEIC),* Prague, Czech Republic ,2010.

ISBN : 978-93-91535-29-2

[2] Mohsen Akbari, P. Khazaee, I. Sabetghadam and P. Karimifard "Failure Modes and Effects Analysis (FMEA) for Power Transformers," in *Proc.* 28th International Conference on Power System, Tehran, Iran, 4-6, November 2013.

[3] D. Linhjell T. J. Painter L. E. Lundgaard, W. Hansen, "Aging of oil impregnated paper in power transformers," IEEE transactions on power delivery, 19(1), January 2004.

[4] William H. Bartley, HSB, "*Analysis of Transformer Failures*," Proceedings of the Thirty Six Annual Conference, Stockholm, 2003..

[5] S.S.Rajurkar and Amit R. Kulkarni, "Analysis of Power Transformer failure in Transmission utilities" in *Proc. 16th National Power Systems Conference*, 15th-17th December, 2010.

[6] A.K. Lokhanin G.Y. Shneider V.V. Sokolov V.M. Chornogostsky, "Internal insulation failure mechanisms of HV equipment under service conditions", 15-201 CIGRE Session 2002.

[7] George Eduful1 and Godfred Mensah, "An Investigation into Protection Integrity of Distribution Transformers - A Case Study," in *Proc. of the World Congress on Engineering 2010 Vol IIWCE 2010*, June 30 - July 2, 2010, London, U.K.

[8] N. A. Muhamad, B. T. Phung, T. R. Blackburn, K. X. Lai,"Comparative Study and Analysis of DGA Methods for Transformer Mineral Oil," *IEEE Power Tech*, Lausanne, pp 45-50, July 2007.

[9] IEEE Guide for Failure Investigation, Documentation and Analysis for Power Transformers and Shunt Reactors, IEEE Standard C57.125-1991.

[10] IEEE Standard Test Procedure for Thermal Evaluation of Oil-Immersed Distribution Transformers ANSI/IEEE Standard, C57.100-1986

[11] IEEE Guide for Interpretation of Gases generated in Oil filled Transformers, IEEE standard C57.104-1991,.

[12] IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment, IEEE standard C57.106-2002.

[13] IEEE Guide for Diagnostic field testing of Power Apparatus- Part I: Oil filled Power Transformers, Regulators, and Reactors, IEEE standard 62-1995.

[14] IEEE Guide for loading Mineral – Oil – Immersed Transformers, IEEE C57.911995.

[15] ANSI/IEEE C57.117 - 1986, "IEEE guide for reporting failure data for power transformers and shunt reactors on electric utility power systems," 5