Root-Cause Analysis of Transformer Failure Scenario at Power Sub-Station

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Abstract – Power transformers are vital equipment in power sub-station to establish reliable electrical power transformation throughout different area concerned to that sub-station. With growing nature of deregulation in electrical markets, the scope of failure of power transformer increases simultaneously. Hence rigorous maintenance program should be adapted in order to maintain the failure rate of power transformer.
In this paper, efforts are made to analyze the root-cause effects contributed to power transformers failure. Different failures events are taken from different sub-station throughout Delhi and Gujarat state of India. Explained studies had been done throughout sub-stations to prepare accurate failure scenario.

Key-Words: - Sub-Station, transformer, manufacturer records, SFRA, C & Tan Delta, oil test/DGA.

1 Introduction

Power transformer manufacturers are increasing the capacity (rating) to full fill the demands of power markets. With increasing capacity of transformer a well-planned maintenance program are needed. A rigorous preventive maintenance program should be acquired by sub-station authority for trouble free operation of power transformers. There are different modes of failure of transformer as listed below:

- failure due to electrical breakdown
- failure due to mechanically breakdown
- failure due to thermal breakdown

All the three modes of failure contribute significant ally in transformer failure reason but in these three modes the third one thermal breakdown should be given priority for failure cause.

2 Failure Investigations

Failure investigation consists of many steps in accurate sequence to conclude a significant outcome for transformer failure. For investigation purpose, we accept IEEE standard C57.125 “guide for failure investigation, deformation, and analysis for power transformer and shunt reactors. Failure investigation starts with failure of transformers. Safety should be maintained when investigation is to be carried [6, 7].Investigation process consists of following major component:

- Preparation/information gathering
- Testing
- Inspection (externally & internally)

- While preparing information data base we should always take reference as factory test result or commissioned test result. We should make a trend analysis for available data. With variation in particular data, we have to go for that particular condition monitoring only. If possible take manufacturer reference for investigation process especially in internal inspection. Manufacturers have their own process for internal inspection as inspection is done with camera probe or by drilling inside transformer within required area.

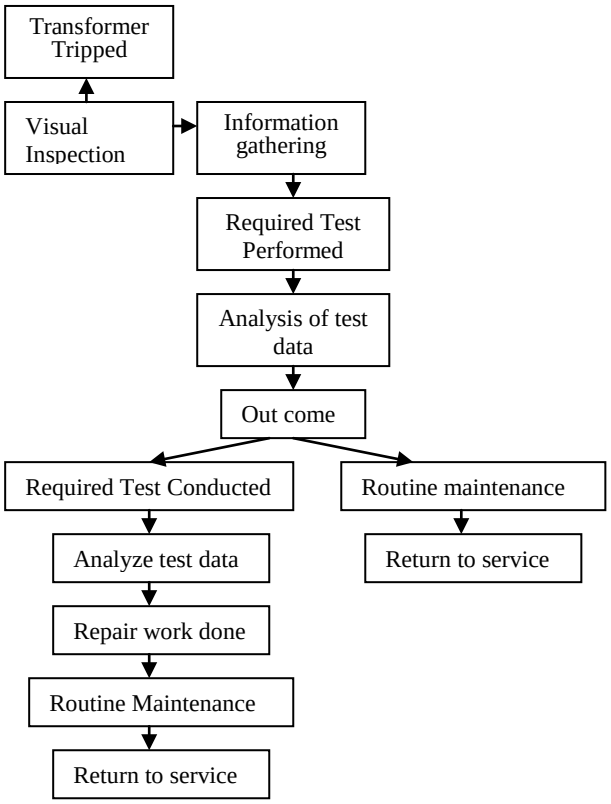

Fig.1 Flow chart of Transformer Maintenance.

3 Case Study

Field study had been done on different transformer of DTL sub-station in year 2013.

Transformer no	1	2	3
Make	BHEL	NGEF	Crompton Greaves
Rating	315 MVA	100 MVA	100 MVA
HV/LV ratings	400/220/66 KV	220/66 KV	220/66 KV
Phase	3	3	3
Substation rating	400/220 KV	220/132/66 KV	220/66 KV
Location	DELHI	WAZIRABAD(DELHI)	LODHI ROAD(DELHI)
Year of failure	2013	2013	2013
nsulation evel	HV(400): 1300 KVP, HV,NEUTRAL :110KVP, IV(220KV): 950 KVP, IV-NEUTRAL: 95KVP, LV(11KV): 250 KVP	HV(220): 1050 KVP, HV,NEUTRAL :95KVP, IV(66KV): 325 KVP, IV-NEUTRAL: 95KVP, LV(11KV): 170 KVP	HV(220KV):1050KVP, HV-NEUTRAL: 95KVP, IV(66KV): 325KVP, IV-NEUTRAL: 95KVP,LV(11 KV): 170 KVP
% impedance	HV-LV: 71.41%, HV-IV: 11.60, IV-LV: 57.04%	HV-LV: 30.09%, HV-IV: 14.60, IV-LV: 19.88%	HV-LV: 25.33%, HV-IV: 14.60, IV-LV: 11.95%

Table 1

4 Transformer no- 1

The 400/220 sub-station has been commissioned near about 1998 with the transformation capacity of 1260 MVA. Among the three transformers operating in sub-station, one with rating of 315 MVA failed in year of 2013.

Fig.2 damaged transformer.

4.1 Failure event sequence

On two day prior to failure, the transformer is loaded with 85 MW and that only time buchhloz relay give an alarm. A shut down was taken for analysis and all the test was performed such as capacitance and tan delta, insulation resistance, DC resistance, turn ratio, magnetic balance and magnetic reluctance conducted. Oil sample was taken for different oil quality test such as DGA, breakdown voltage, interfacial tension. All the result taken from test was found to be normal. Transformer was put on no load. After some more hours again buchhloz alarm, differential alarm, OLTC buchhloz, REF relays trip and consequently a fire alarm also trip and there was a fire in transformer leading to brunt of transformer[5,7].
Simultaneously there was a tripping of all 400 KV feeders. The fire prevention system installed at substation could not control the fire [5]. With the oil spillage and tank explosion leads to heavy fire and fire tenders were informed and takes almost a full day to control fire. Due to heavy fire other equipments also got burnt such as:

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Surge arresters of rating 390 Kv (3 no), surge arrester of rating 216 Kv (3 no), and isolator 400 Kv (1 no).

Fig.3 brunt transformer

4.2 Initial visual inspection

In initial inspection, we had seen brunt transformers. Different parts of transformers consisting of bushing, tank, winding got damaged due to fire. Along with transformer parts surge arresters, isolator, current transformer and many other equipments of sub-station got damaged. Relays affected due to failure are listed below:

Buchhloz relay, OLTC buchhloz, differential relay, and REF relay etc.

4.3 Transformer history (operation and maintenance)

The transformer is manufactured in 1993 and commissioned in 2000. The transformer is kept out of service for consistently for seven year. After commissioned of transformer following test was done periodically as listed below apart from routine check up:

Test conducted	Year of conduction	Status of test
Capacitance and tan delta on winding and bushings	14-05-2004, 9-12-2006, 21-12-2006, 10-04-2008, 2009,2011,2013	Normal
Oil test/DGA	2005, 2006, 2007, 2008,2009,2010,2011,2013	Gradually increasing nature for gas contains for DGA
Thermo vision scanning	2007, 10- 02- 2008,2010, 2011,2013	Normal
SFRA	2005,2010	normal

Table 2

Only maintenance work done on transformer was replacing of bushing of centre phase having rating 52 Kv.

4.4 Observation

1. Data related to testing and maintenance during 2000 to 2005 is not available. No record is available for these periods.
2. Periodicity of different test conducted during service of transformer is not accordance to standard such as FIST, IEEE, and CPRI manual.

4.4.1 Dissolved gas analysis report

As per standard manual, DGA test should be done on half yearly basis. But here DGA test was conducted on yearly basis which is violation of recommended standard [4]. The result of DGA conducted during different periods is found to be not consistent and gradually increasing nature of gas found.

4.4.2 C & Tan Delta report

C & Tan Delta test should be conducted on yearly basis but here this test was done only once in two year [2].

With previous record of bushing failure, it was recommended to conduct this test twice in year but not followed by the authority.

3. Differential Relay tripping indicates to internal fault in transformer which may be related to insulation failure of winding.

4.5 Analysis

As per available data records, no clear picture appears for failure cause. But as concerned to data history, transformer is kept out of services for almost seven years during 1993 to 2000. The transformer at site is generally filled with nitrogen under prescribed limit of pressure for not more than 5 to 6 month. If long storage cases occur transformer should be filled with oil and oil to be filtered at regular interval. Here long storage of transformer may result in ingress of moisture throughout insulation of winding and hence result in insulation failure of transformer.

4.6 Restoration of failed transformer

Restoration is not possible as transformer is completely brunt and has to be replaced.

5 Transformer- 2

The 220/66/11 KV sub-station is commissioned in 1997 with transformation capacity of 240 MVA.

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Among the four transformers operating in sub-station, one with 100 MVA fails on 2013.

5.1 Failure sequence event

Before tripping transformer is running parallel with another 100 MVA transformer with loading rating of 78 A. The three damaged oil pump and related fuses were replaced on 27-08-2013 during a shut down. All feeders were under test and after test transformer was re energized. On that same day in evening again transformer failed with tripping of following equipments:

Transformer differential (Y & B Phase), Buchhloz, pressure relief device (PRD), Buchhloz of OLTC, Sudden pressure relay, low oil level alarm, low oil flow alarm, fan and pump fail indication.

5.2 Initial visual inspection

- Axial displacement of parceling housing of all the phase of HV bushing was clearly visible at bottom gasket location.
- No external deformation was seen because of successful operation of PRD device.
- Clear indication of flashover marks on clamping rod and base of core of oil.
- No oil spillage and external fire.
- No sign of arcing mark on test tap.
- At the time of site visit, different maintenance activities were going on.

5.3 Transformer history (operation and maintenance)

The transformer is manufacture in year1997 and commissioned in year 1999. After commissioned of transformer various test conducted periodically as a maintenance programs.

Test conducted	Year of conduction	Status of conduction test
Oil test/ DGA	As in standard manual all the routine work was done	Normal during service time
C & Tan Delta	2005, 2007, 2010	Normal during service time
SFRA	2005,2010	Normal during service time
Thermo vision scanning	2005, 2011	Normal during service time

Table 3

Only repair work on transformer was done by replacement of damaged pump and filtration of oil.

5.4 Observation

1. Transformer is kept out of service at sub-station for almost two year which is not recommended as per standard.
2. Test conducted periodically during its life time service and their effect

a) SFRA and C & Tan Delta test was not conducted as per standard [2]. During its service year of 14 year, SFRA was conducted only twice time where as C & Tan Delta was conducted thrice times.

b) The DGA was conducted as per standard and no significant variation was seen during service time. But after the failure of transformer, DGA test response indicates large variation in the percentage of gas contains [4]. High percentage of acetylene (C_2H_2) supports the arcing on clamping rod and also insulation failure between winding or between coils or between coils and earth.

c) Magnetizing current test and magnetic balance test and turn ratio test conducted after failure does not show any abnormality.

d) Insulation resistance test result conducted after tripping show the Dielectric absorption ratio for LV-E, ME-LV and HV-LV are 1.0, 1.2, and 1.2 respectively which are below the normal requirement of at least 1.3.

3. Tertiary winding is the potential cause of failure of many transformers. In failed transformer, external reactor was used in series with the tertiary winding of transformer and this external reactor got failed. The burning of cellulose insulation over copper conductor leading to exposure of copper conductor of one of the coils of B- phase of external reactor was clearly seen.
4. The fault gas developed inside transformer leads to operation of PRD device.
5. The tripping of differential protection supports internal faults. So there is chance of insulation failure inside transformer

5.5 Analysis

As seen from observation, the root- cause effect of failure of power transformer is unloaded tertiary winding with a chance of insulation failure also. Here also we had seen that transformer was kept out of service for long duration of almost two year which is avoidable.

5.6 Restoration of failed transformer

Transformer oil breakdown voltage was recorded as 49 Kv. Hence filtration of oil and replacement of

damaged reactor of tertiary winding had been done and transformer has been reenergized.

6 Transformer- 3

The 220/66/11 Kv sub-station is operating with total transformation capacity of 340 MVA. Among five transformers at sub-station, the one with rating of 100 MVA FAILED IN THE YEAR 2013.

6.1 Failure sequence event

Before tripping, the transformer was running in parallel with another 100 MVA transformer. At 14:30 hrs on 9-11-2013, 100 MVA transformer tripped along with 33 Kv outgoing feeder. Along with transformer tripping, 220 Kv as well as 33 Kv CB associated with it also got tripped. The tripping of different equipment was shown by different protection system equipments such as:

Transformer differentials, buchhloz OLTC, Buchhloz relay e.t.c

6.2 Initial visual inspection

No oil leakage from OIP Bushings was observed. No external deformation was observed within transformer tank and winding system. The nearby line has been tapped and feeding directly to two transformers through surge arrester, CVT, CT, isolators, and circuit breakers.

6.3 Transformer history (Operation & Maintenance)

The transformer was manufactured in the year 2003 and commissioned in the year 2004. After commissioned of transformer various routine maintenance works had been done but no records are available regarding maintenance work[1].

6.4 Observation

1. Transformer is kept out of service for almost one year with no records of storage at sub-station.
2. Test conducted periodically during its life time service and their effect

a) SFRA and Tan Delta were conducted in year 2005 and 2007 respectively[2].

b) DGA/oil test were conducted as per standard manual in the year starting from 2005 and continued throughout service life of transformer. Percentage of CO2 increases regularly with each test[4]. Prior to failure, the response obtained through DGA indicates large value of acetylene, hydrogen, CO & CO2.

c) Low value of insulation resistance observed for HV to Earth and LV to Earth.

d) Magnetizing current in lateral Y- phase of HV and LV winding were found to be abnormal as current in Y- phase of HV winding was 417Ma where as R-Phase and Y- Phase current values were recorded as 4.98mA & 5.05Ma respectively. Similarly for low voltage winding, the currents values were recorded as 10Amp, 94.9Ma &94.3Ma respectively for R, Y & B phase.

e) SFRA test conducted after the failure of transformer indicates large deformation in winding.

6.5 Analysis

Short circuit and inter-turn insulation failure could be the reason of failure. Large value of deformation indicates heavy rush of short circuit current throughout windings. DGA result also support the heavy arcing story.

6.6 Restoration of failed transformer

The transformer is kept out of service for repair work and healthy transformer is likely to replace the faulty one.

Conclusion

- Manufacturer records for transformer and violation limit of each related process should be at sub- station and followed strictly.
- Transformer should not be kept out of service for long duration. It is recommended to kept transformer out of service only for 6 to 7 month. During this period transformer should be kept nitrogen filled under prescribed limit. If long duration is there, regular oil filtration should be done regularly.
- Factory test report and pre-commissioning test report of transformer should be at sub-station.
- All the test and maintenance work should be done as per standard manual.
- Complete data base records of routine maintenance and periodical checkup should be at sub-station.
- Considering the failure rate of bushing, it is recommended that the test related to bushing should be done twice in a year instead of single test in a year.
- Design with tertiary winding for external reactor should be change as per modern design.

Acknowledgment

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Appendix (FIST)

S. no	Transformer parts	Condition based routine maintenance
1.	Transformer winding	1. Dc resistance 2. Turns ratio test 3. Percentage impedance/leakage reactance 4. Sweep frequency response analysis 5. Capacitance test 6. Excitation current and watt loss 7. Power factor/dissipation factor
2.	Bushings and arresters	1. Capacitance test 2. Dielectric loss test 3. Power factor test 4. Temperature test 5. Oil level(bushings level) 6. Visual inspection for cracks and chips
3.	Insulating oil	1. Dissolved gas analysis 2. Dielectric strength 3. Metal particle count(if transformer has pump problems) 4. Moisture 5. Power factor/dissipation factor 6. Interfacial tension 7. Acid number 8. Furans 9. Oxygen inhibitor test
4.	Conservator	1. Visual (oil leaks and leaks in diaphragm) 2. Inert air system(desiccant color) 3. Level gauge calibration
5.	Core	1. Insulation resistance 2. Ground test
6.	Tank and auxiliaries system	1. Fault pressure relay 2. Pressure relief device 3. Buchholz relay 4. Top oil temperature indicator 5. Winding temperature indicator 6. Infrared temperature scan 7. Sound analysis(sonic) 8. Vibration analyzer
7.	Cooling system	1. Clean(fan blades and radiators) 2. Fans and controls(check fan rotation) 3. Oil pumps(check flow indicator, check rotation) 4. Pump bearings(vibration, sound, and temperature) 5. Check radiator(valve open)