Operational Management of Grid Transformers – An Experience of POWERGRID

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1.0 Introduction

Power Grid Corporation of India (POWERGRID), the Central Transmission Utility (CTU) of India is engaged in construction and operation of EHV/UHV power transmission system in India and inter-connection with SAARC countries. Presently 154 no of Substations having transformation capacity of 1,31,000 MVA are under operation in POWERGRID which includes about 50 no. of 765kV, 300 no. of 400kV and 50 no. of 220kV/ 132kV grid transformers. As the population of transformers and reactors are going to be doubled in another 5 years due to the rapid growth of Indian power system and specifically with the growth of 765kV system, a well defined transformer management system is required to effectively manage the huge population of the equipments.

The time required for repair/ refurbishment / replacement of transformers and reactors are very high in comparison to any other switchyard equipment. Further in the regulatory regime, the penalty for non availability of the element in service is huge. This throws the challenge for the need of systematic maintenance of transformers and reactors to make advance planning for removing the ailing equipments from service so as to reduce outage time. A scientific maintenance methodology is required to run the equipment trouble free.

2.0 Quality of Manufacturing

Better procurement specifications and better quality standards being followed during procurement process is important in getting trouble free service. POWERGRID starts their quality system from the procurement of raw material used in manufacturing of the transformers. Vendors are approved based on strict quality standards. Manufacturing of transformers is carried out based on laid down strict Manufacturing Quality Plans (MQP) which has a number of customer hold points and they need to be cleared before proceeding further in the manufacturing process. Sweep Frequency Response Analysis (SFRA) is included as part of factory test and the signatures are compared with pre-commissioning SFRA test. Short circuit test is introduced in transformers to improve the capability of the transformers in service. POWERGRID has developed its own oil specification for all its transformers based on the past experience in transformer oil and even impregnation of the transformer windings are done with the same specification oil to avoid mixing.

3.0 Transportation

Transportation of transformers is one of the major concerns. Due to restriction on travel through bridges for bigger transformers, it takes longer time to reach the destination which involves several time manual loading and unloading during transit. POWERGRID specify digital impact recorders to be fitted on every consignment for better analysis. Mostly transformers are transported with Nitrogen gas filled and continuous monitoring is being done that the equipment is always kept under positive pressure. Escorts are also provided for major consignment to speed up the transportation. POWERGRID is also contemplating GPS based tracking system of the consignment movement.

4.0 Equipment Storage, Erection and Commissioning at site

Some of the equipments require long storage as they need to be kept as spares or awaiting site clearance for erection. If the storage period is more than 6 months, the equipments are kept in oil filled condition. For equipments which are meant for long storage as spares are designed with a small conservator to be fitted during storage period as the other accessories are not erected during this period. Special packing procedure has been developed for storage of accessories and is stored in covered storage. For ease of loading the spare transformers and reactors from one Substation to other, spares are stored at raised platform to match the height of the trailer. This helps in saving of time during emergency.

Minimizing outage of transformers is very important to improve grid reliability. Procedures have been worked out and experimented for replacing 315MVA, 400kV transformer in 3 days which normally takes about 10days. Procedures are in place for replacing bushings in shortest possible time. Replacement transformer is normally fully erected and kept for charging before pulling to the plinth. Dry air is continuously passed inside transformer during erection or during internal inspection using a dry air generator and exposure time is kept to the minimum to avoid moisture entry. Before starting erection, internal inspection of the equipment is carried out this includes photography of critical internal areas. Internal photography helps in analysis of internal details in case of any problem after commissioning.

Once the transformer is erected and ready for commissioning, all pre-commissioning tests are carried out and recorded in specified format. The test results are reviewed by experts at central level before clearing for charging. The review includes comparison of pre-commissioning results with that of factory test results, Impact recorder data analysis and oil quality test results and comparison of SFRA results with that of Factory signatures. As per our internal standard, we get charging clearance only when oil moisture content is Ò5ppm and BDV of oil >70kV. Oil samples are collected for DGA before energizing, 24hrs, 7 days, 30 days, 3 months after energizing and further sampling is decided based on the condition of gassing of the equipment.

5.0 Maintenance and Condition Assessment

Transformer being static device, no frequent maintenance is required at site to keep in good condition. The On-Load Tap Changers, cooler fans and pumps, valves and taps, monitoring devices require maintenance. We overhaul OLTC diverter compartment after five years from commissioning and maintenance of other devices annually. Condition Assessment tests are carried out on yearly basis and deterioration trends are monitored. Leakage in Indian transformers is one of the major issues which take much of the time in arresting. New transformers are being procured with on-line Hydrogen and Moisture monitoring devices to give advance information. POWERGRID has developed 6nos. state of the art Oil Testing Laboratories to handle condition assessment of oil filled equipments such as transformers, reactors, CTs, bushings etc. Inter-laboratory validation tests are carried out frequently to keep all the laboratories in same standard. Tests are carried out for new and used oil for oil quality, DGA, Furan and DP of paper in the laboratory. Portable DGA kits are also used for initial scanning and in case of emergency. All transformer test results are periodically reviewed by Regional Transformer Committee once in 3 months and critical cases are reviewed by Central Transformer Committee.

6.0 Failures and investigation

Failures are inevitable when a large fleet of transformers are handled. Normally new transformers do not fail due to poor maintenance. The issues are mostly because of the quality of the equipment, manufacturing defects, transportation related issues and frequent faults in the system. A vigilant monitoring can help in identifying the defects in advance so that catastrophic failures are avoided. It is very much important to identify any latent defect in transformer during warrantee period as manufacturers are responsible for rectification. POWERGRID has standardized design of transformer for interchangeability as in the event of failure, the other make transformer can be installed without losing time.

Normally manufacturers do not show interest in repairing of their own transformers after the warrantee period as they are loaded with new orders. Even if they accept to repair, large time is taken for repair of transformers. POWERGRID tries to repair most of the failed units at site taking all necessary precautions. Now a dedicated site repair bay has been developed with required facilities for repair and refurbishment of transformers with major defects. This will help in availability of transformers in shortest possible time.

Figure-1 Transformer Repair Bay

7.0 Few Case Studies

Few case studies have been presented below indicating problems at different stages, method of investigations carried out and the action taken for rectification.

7.1 Case Study I: Transportation issue

One 160MVA 220/132 kV auto-transformer was received at Site. As per practice, the impact recorder file was downloaded and analysed. It was found that transformer has seen following impact during the transportation:

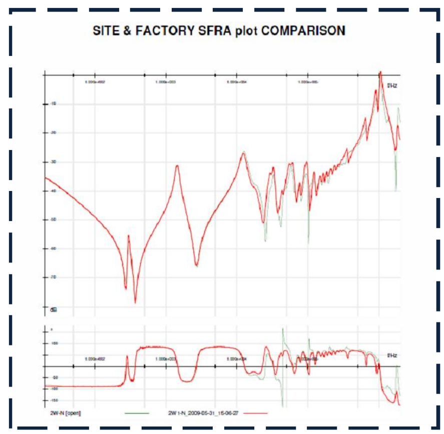

Figure-2- SFRA Signature Comparison

Horizontal X- direction	= 2.3 g
Horizontal Y- direction	= 3.1 g
Vertical Z- direction	= 7.7 g

Normally when the equipment is received at site with such recordings, we insist thorough internal inspection and careful comparison of SFRA test results with that of the factory one. In this case the site and factory SFRA signatures were compared and it has shown variation in mid ï frequency range indicating problem in the winding as shown in graph:

Internal inspection was carried out in association with manufacturer to assess any abnormality in the transformer due to high impacts/ stresses seen by the transformer. Internal inspection revealed shifting of supporting blocks below top yoke above the coil clamping support ring as shown in the photograph below:

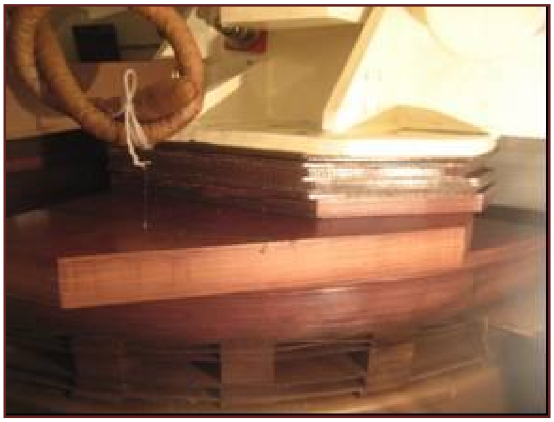

Figure-3- Slip of Support Blocks

As rectification requires lifting of core coil assembly and also requires complete analysis of the winding, the transformer was sent back to works for repair.

7.2 Case study 2: Transformer failure on through fault which has SFRA variations during commissioning

Transformer was commissioned in Oct'06. During commissioning of this Transformer, deformation was observed in R phase SFRA signature. This was referred to the manufacturer and in turn they replied that frequency range of 400 kHz and above may not be harmful as they are due to mechanical shocks/ vibrations during transit.

The shock recorder chart was sent by site to Manufacturer for analysis and manufacturer confirmed that the shocks received by ICT during transit were within limits. Considering that other pre-commissioning results did not indicate any abnormality, the transformer was charged and kept in service. The transformer tripped on through fault (6.5kA) on the same phase. Immediately the oil sample was sent for Dissolved Gas Analysis which revealed increase in all fault gases including Acetylene (C2H2). DGA results are tabulated in Table-1 below:

Sample Date	TGC (%)	N2 (%)	O2 (%)	H2	C H4	C2 H4	C2 H6	C2H2	CO	CO2
28.03.2009	NA	NA	NA	**269**	**46**	**56**	**4**	**55**	**454**	**2018**
07.01.2009	**8.7**	**6.86**	**1.61**	**154**	**27**	**31**	**3**	**33.8**	**374**	**1650**
23.12.2008	**4.63**	**3.67**	**0.74**	**155**	**26**	**31**	**3**	**45**	**369**	**1589**
19.07.2008	3.7	3.01	0.47	26	5	2	1	0	333	1792
18.01.2008	5.38	4.32	0.93	24	3	1	0	0	227	1019
20.07.2007	9.3	7.38	1.81	30	2	1	1	0	166	882
13.12.2006	10.43	7.71	2.48	12	1	0	0	0	50	298
11.10.2006	10.34	7.5	2.56	0	1	0	0	0	23	249

Table-1-DGA Results of Transformer

Suspecting the Short circuit performance of the Transformer, a set of SFRA scans were performed on the Transformer. The response was superimposed on pre-commissioning results to see if SFRA test show any abnormality. SFRA results did indeed clearly show that the R-phase Transformer winding has moved.

Figure-4 Graph-2: FRA scan of R Phase HV to IV winding

With above results, problem in Transformer winding was suspected. Frequency Response Stray Losses (FRSL) and other low voltage electrical tests were carried out on this transformer.

FRSL measurement is basically impedance measurement and consists in supplying low voltage to one winding of the transformer and short-circuiting another one. Unlike the conventional impedance measurement method, the FRSL method is applied on a range of frequencies from 15 to 400 Hz. The rms current (*Irms*), rms voltage (*Erms*) and active power (*P*) are measured for each frequency in order to plot the equivalent resistance and impedance curves as a function of frequency. The FRSL method covers the diagnosis based on the conventional impedance variation measurement since this parameter is measured for each frequency, including industrial frequency.

FRSL results are shown in Graph-I & Graph-II . FRSL results indicated

- Change in the REACTANCE of Common winding (IV-N) of Autotransformer is very significant in R Phase, which is almost 10 % when compared to other two phases as indicated in Graph 4.
- Change in the REACTANCE of Full HV winding (HV-N) of Autotransformer is also significant in Phase A, which is almost 5 % when compared to other two phases.

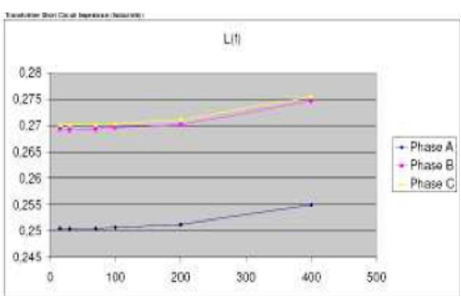

Figure 5: Short circuit Inductance plot of FRSL measurement of Common winding

After carrying out all these tests, it was recommended by the manufacturer to charge the Transformer with increased DGA monitoring (fortnightly basis). The Transformer again tripped after five days on differential protection while feeding fault current in 220 kV systems. The transformer was taken out of service and sent to manufacturer's works for detailed investigation. R phase IV winding (220kV) found badly deformed as shown in the figure below:

Figure-6 Damaged winding of Transformer

The transformer was repaired at manufacturer's works by replacing all the coils in R phase. The transformer is operating satisfactorily.

7.3 Case Study 3: variation in winding resistance

The transformer was charged in March 2009. During commissioning there was small discrepancy in the winding resistance and OLTC connection was suspected and all connections were tightened. Though the resistance mismatch has not improved, it was decided to charge the transformer as the problem was not identified. The transformer was again tested during next annual maintenance period and found that the winding resistance of Y-phase, IV winding increased in comparison to other phases of ICT. The values are given below:

2U1-N: 359mq 2V1-N: 406mq
2W1-N: 356 mq 1U1-2U1: 229.6mq
1V1-2V1: 229.8mq 1W1-2W1: 229.6mq

As internal inspection could not reveal any other abnormality, it was decided by the manufacturer to take back the transformer to their works for detailed investigation and rectification. During investigation it was found that in IV winding, out of 8 conductors, the extreme conductor was open. The fault was located at the bottom and probably due to manufacturing defect. As the burning was inside and there was no oil circulation in that spot, DGA has not indicated appreciable increase in fault gases. Some of the failure pictures are presented below:

Figure-7 Failure of Winding

Copper globules were found and burning marks also noticed on conductors of first disc from bottom and two bays towards the left of IV bottom lead. Flash over mark was also observed on bottom SER (Static End Ring).

7.4 Case study 4: DGA showing abnormality in bushings

Bushings lead to more number of failures of transformers. It has been observed in number of cases that bushing problems have reflected in DGA of main tank oil. The typical pattern observed is steep rise in H_2, CH_4, CO and CO_2 gases. In some of the occasions, with the help of this analysis, defective bushings were removed thus saving Transformers from catastrophic failures. DGA of bushing oil was also carried out as confirmation test and found that those bushings were on the verge of failure.

It is also mentioned here that in some cases of bushing failures, the insulation deterioration was not noticed in the tan ŭ measurement. It has been observed that DGA of bushing oil has indicated fault gasses where in bushing tan ŭ has not increased. Bushing oil samples have been collected at several bushings in POWERGRID and problems identified and rectified. Few cases where bushing deterioration has been indicated in the DGA of main tank oil are presented below:

7.4.1 63 MVAR 400kV Line Reactor

Date of charging:-24-04-2005
Date of Replacement of bushing: 30-01-2010
In the above Reactor, fault gases were rising (H_2, CH_4, CO & CO_2) as shown in the table below:

Sample Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	CO	CO_2
4/4/08	0	0	0	0	0	7	155
11/4/08	9	1	0	0	0	39	722
19/4/08	28	2	1	0	0	50	1821
4/5/08	90	2	1	0	0	74	3496
3/11/08	285	12	3	2	0	205	6770
12/2/09	350	21	3	3	0	223	7474
22/6/09	427	37	3	4	0	255	9755
6/10/09	558	56	3	6	0	351	12708
3/2/10	11	3	0	0	0	16	684

Table-2 Rising Trend of fault gases

Bushing tan delta of the Reactor was measured immediately after taking shut down and repeated at different oil temperature till the temperature stabilized. It was found that the faulty phase bushing was showing varying Tan delta proportional to the temperature with very high values at high temperature and normal reading at ambient temperature. Other two bushings were however showing stable Tan delta values at different temperatures. The bushing was replaced and after oil de-gassing, the reactor was charged. The dissolved gas in main tank has become normal.

7.4.2 315MVA, 400/220/33kV Auto-transformer:

DOC: 28/02/2003
Date of Replacement of Bushing: - 30-07-2009

DGA results of Reactor								Tan δ values of B Ø Bushing	
Sample Date	H2	CH4	C2H4	C2H6	C2H2	CO	CO2	Date of meas.	Tan δ
17/10/08	144	30	3	8	0	123	1266	2006-07	0.0043
26/01/09	176	34	3	8	0	117	1132	2007-08	0.0040
15/06/09	119	34	8	7.64	0	112	1423	14.8.09	**0.0128**
20/08/09	7	19	41	11	0	24	507		
18/3/10	6	5	0	0	0	39	739		

Table-3 Rising Trend of fault gases

In the above case, fault gases (H2 & CH4) were increasing. While measuring Tan delta of bushings, one of the phase was showing higher Tan Delta value. After replacement of bushing, fault gases stabilized.

7.4.3 63 MVAR 400kV Line Reactor

DOC: 17-11-2006
Date of Replacement of bushing:-09-03-2010

In this line reactor, fault gases (H2 & CH4) were increasing. Suspecting bushing problem based on the pattern of the fault gas, Tan delta of bushings were carried out. One of the bushing was showing higher Tan Delta value. After replacement of the defective bushing, fault gases stabilized.

DGA results of Reactor								Tan δ values of R Ø Bushing	
Sample Date	H2	CH4	C2H4	C2H6	C2H2	CO	CO2	Date of meas.	Tan δ
14/05/08	14	8	2	1	0	455	5233	2006-07	0.00352
14/11/08	286	32	11	5	0	310	5548	2007-08	0.0025
23/03/09	352	51	12	6	0	371	6783	09-03-10	**0.0082**
30/09/09	363	73	13	8	1	368	8719		
29/01/10	**579**	**94**	**13**	**10**	**0**	**398**	**7711**		
18/03/10	8	2	1	0	0	17	901		
24/04/10	11	5	2	1	0	68	2655		

Table-4 Rising Trend of fault gases

8.0 Conclusion

The pace with which POWERGIRD is adding the transformers in its network and with ageing transformer fleet, it is a challenging job to maintain these costly equipment. As the outage of these equipment leads to grid reliability issues and also loss of revenue, it is imperative to keep these equipment in service. A constant watch of the performance of the equipment is very important to save catastrophic failures of transformers in service. As brought out in this paper, all the condition assessment test results need thorough analysis with comparison to the earlier results to achieve useful meaning out of that. POWERGRID is now working on equipment health and criticality index which will further help us in identifying the critical equipment and take appropriate action and to better management of the transformers.

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