Analysis of Power Transformer failure in Transmission utilities

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Abstract—This paper focuses on failure of EHV transformers in transmission utilities along with important reasons for failure of the same in brief. This further covers case study of failure of transformer in one of the region in the state of Maharashtra along with remedial measures to be taken to avoid the same. It also discusses in brief various activities needed to be taken in order to effectively handle the issue of power transformer failure.

Keywords—Transformer, transformer oil, oil insulation, transformer winding, transformer cores

I. INTRODUCTION

Today Indian economy is amongst the fastest growing economy in the world despite of global financial meltdown. It is expected that Indian economy shall continue to grow approximately at the rate of 8-9% in the years to come. India is amongst the leading countries in the world to attract foreign direct investment. India’s manufacturing sector, heavy industries, various global service centres and booming high tech software are all dependent on reliable power supply. This underlines the principle that ‘No Power-No Business’. This makes it utmost important that ‘Transformers’ the heart of substation must function reliably. Ministry of Power’s ambitious initiatives like Rajiv Gandhi Gramin Vidyutikaran Yojana (RGGVY), Power to all by 2012 make it challenging task to maintain reliability of supply. India faces major challenge both today and in the future for the growth and improvement in reliability of its electrical infrastructure including that of transformer. Failures of critical transformer assets not only impact industries, other consumer categories affecting economy of the country but also have social and political ramifications.

II. MSETCL INFRASTRUCTURE

MSETCL is the largest State Transmission Utility (STU) in the country. MSETCL infrastructure is shown in Table I. It is the only state utility operating and maintaining +/- 500kV, 1500MW Chandrapur-Padghe HVDC bipole transmission system for large power haulage of the order of 1500 MW from generation rich eastern part of the state to load rich western part covering a distance of about 750 kms approximately. MSETCL’s transmission system is capable of handling 18,500 MW of electric power. It has transmitted 97,189 MUs in the year 2009-10. MSETCL has ambitious infrastructure development plan of around 11,000 Cr rupees. MSETCL has total EHV transformer population of around 1356 as on 31.03.2010. Out of those 318 numbers are ICTs contributing to 31191 MVA capacity. There are 84 numbers of 400 kV transformers and 234 numbers of 220 kV transformers. Apart from this, MSETCL system also has 16 numbers of HVDC converter transformers including two numbers of spare converter transformers at each location.

<table>
<thead>
<tr>
<th>VOLTAGE LEVEL</th>
<th>EHV SUBSTATION</th>
<th>TRANSFORMATION CAPACITY</th>
<th>EHV LINES (CKT KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500KV HVDC</td>
<td>2</td>
<td>3582</td>
<td>1504</td>
</tr>
<tr>
<td>400KV</td>
<td>21</td>
<td>13165</td>
<td>6562</td>
</tr>
<tr>
<td>220KV</td>
<td>149</td>
<td>31585</td>
<td>12356</td>
</tr>
<tr>
<td>132KV</td>
<td>246</td>
<td>19867</td>
<td>11064</td>
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<tr>
<td>110KV</td>
<td>33</td>
<td>2080</td>
<td>1698</td>
</tr>
<tr>
<td>100KV</td>
<td>35</td>
<td>2373</td>
<td>678</td>
</tr>
<tr>
<td>66KV</td>
<td>34</td>
<td>1139</td>
<td>3270</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>520</strong></td>
<td><strong>73791</strong></td>
<td><strong>37133</strong></td>
</tr>
</tbody>
</table>

TABLE I: MSETCL Infrastructure as on 31.03.2010.

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III. MSETCL TRANSFORMER FAILURE DETAILS IN RECENT YEARS

Table I indicates that total transformation capacity in MSETCL as on 31.03.2010 is 73,791 MVA. This emphasises the fact that reliable operation of these transformers is of utmost importance. To maintain reliability it is essential to know reasons for failure of maintaining reliability and ways to overcome the causes of failure. In order to assess failure of transformers it is essential to know exactly the reasons behind the failure. Following section gives methodology developed by MSETCL based on practical experience to pinpoint the cause of failure for EHV transformers. The risk of a transformer failure is actually two-dimensional, the frequency of failure and the severity of failure. Fig.1 gives details of transformer failure in MSETCL during 2008-09, 09-10 (upto June 2010).

A. Analysis of transformer failure in Nagpur zone of MSETCL

Nagpur zone has total of 72 EHV substations voltage levelwise breakup for those is shown in fig.2.

As MSETCL system is closely knit with MSEDCL system in the state of Maharashtra, fig.3 shows how MSETCL system is interfaced with MSEDCL system as far as transformer distribution in Nagpur zone is concerned along with details of number of EHV substations as per interfacing with voltage level wise category.

There are total of 187 EHV transformers in Nagpur zone 153 of them are EHV transformers and 34 of them are ICTs contributing to about 18% as shown in fig.4.

Transformer failure analysis in Nagpur zone covered under this section considers duration from 2005-06 to 2008-09. There were total of 27 transformer failures during this period. Fig.5 indicates details of number of transformer failures against year.

As MSETCL system has transformers of different MVA capacities, for the purpose of analysis attempt was also made to categorise MVA group wise transformer failure as shown in fig.6. In this three categories of transformers namely transformers having capacities 10 MVA and below, 25 MVA and above and 100 MVA and above are considered.

Fig. 1. Age wise transformer failure details in MSETCL in recent past.

Fig. 2. Details of EHV level wise substations in Nagpur zone of MSETCL.

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It is well known fact that fault level at substation also has impact on proper functioning of transformers, so analytics is also developed to categorise transformers in high, medium and low fault level groups as shown in fig.7.

There can be variety of reasons for failure of transformers, some of the important ones are listed below

i) Insulation failure
ii) Design and Manufacturing default
iii) Oil contamination
iv) Overloading
v) Fire or Explosion
vi) Line surges
vii) Lightning
viii) Moisture ingress

Apart from this Aging, poor O&M practices, loose connection, poor repairs etc can also result in failure of transformers. Fig.8 shows transformer failure classification based on cause of fault.

As major responsibility of transmission utilities is to carry bulk power from generating stations and bringing it to load centres thus transmission utilities work in proximity with distribution network. This may result many times into transformers interfacing distribution network experiencing more number of faults for longer duration further resulting into failure of EHV transformers. This is indicated by fig.9 and fig.10. These figures indicate that EHV transformers of 132/11kV and 66/11kV which are in close proximity with distribution system have more number of failures compared to other categories. Fig.9 indicates that out of 27 number of EHV transformers in Nagpur zone 10 number of transformers are 132/11kV and other 10 are 66/11kV transformers contributing to approximately 62% of the total transformer failures in the zone.

B. Failure of HVDC Converter transformer

The converter transformer are single phase three winding units of 298.6 MVA capacity each and having line winding of $400/\sqrt{3}$ kV and Delta and Star connected valve windings of $211 - 211\sqrt{3}$ kV voltage rating respectively. Out of total of 16 numbers of transformers, 8 numbers are supplied by BHEL-India and 8 numbers by ABB Sweden. After bipolar operation for a few months, failures of converter transformers at Chandrapur and Padghe started from June 2001. Nine transformers have failed, out of nine transformers four...
numbers are from BHEL-India and five numbers are from ABB Sweden. Out of these, failed transformers one transformer each of BHEL and ABB make which has failed, was repaired earlier. In all the cases, transformers connected to star winding have failed [1]. The failure was analysed considering the following:

- Frequent and high amplitude transients.
- Failure occurred in normal operation, however no direct cause for breakdown was identified.
- Turn to turn breakdown in star winding.
- No breakdown paths to earth in the transformer.

C. Detail investigation of converter transformer failure in MSETCL

In process to carry out detail investigation of failure of converter transformer the design was scrutinised with design tools. The voltage transient behaviour of the winding was evaluated by using both calculations and measurements. The strength of the insulation against repetitive transients was also verified and concluded that no design deficiency is causing the breakdowns.

i) Copper Sulphide Deposits

Inspection of the winding when disassembled turn by turn showed that at some locations there was a shiny deposits on spacers and conductor insulation. These deposits were identified as Copper Sulphide (CU$_2$S).

- Influence on Dielectric Strength

The electric conductivity of CU$_2$S is significantly higher than the conductivity of paper and oil. This means that the presence of CU$_2$S may change the electric field distribution. The series of tests were performed on both CU$_2$S contaminated material and unaffected materials. The result of these tests shows that:

- Partial Discharge (PD) initiation voltage and the breakdown voltage of the CU$_2$S coated material are significantly reduced as compared to the uncoated material.
- Uncoated and unaffected insulation has the same strength as brand new insulation.

ii) Impact of Transients

CU$_2$S lowers the PD initiation level Depositions of copper sulphide on the winding alone are not sufficient to create a short circuit or partial discharge between two turns. For either of these two happens the insulation has to be further degraded by frequent repetitive transients. Such transients may occur in HVDC applications, since HVDC transformer is exposed to a commutation process when the current is transferred from one phase to another. A rapid increase in the terminal voltage during this process results in fast transients in the winding which locally stress the insulation.

The converter normally operates at the firing angle ($\alpha$) of 15$^\circ$ but $\alpha = 90^\circ$ operation during line faults though rare, cause very high stresses on the turn-to-turn insulations. This operation occurs during line faults.

iv) Reasons for formation of Copper Sulphide (CU$_2$S)

Formation of CU$_2$S is a very interesting phenomenon. The transformer oil is basically highly refined mineral oil and consists of mainly mixture of hydro-carbons and some other compounds, containing Oxygen, Nitrogen and Sulphur. Most of the compounds containing sulphur can react with copper under extreme conditions and form copper sulphide deposits. After investigation M/s ABB arrived at final conclusion as follows:

- Aggressive oil produces copper sulphide
- Copper Sulphide weakens the insulation
- Transients arising due to $\alpha = 90^\circ$ operation or transients from continuous higher MVAR operation are sufficient to initiate partial discharges. Repetitive transients further degrade the insulation.
- A partial discharge in sufficiently degraded insulation, will not extinguish.
- When the insulation is sufficiently degraded, PD will continue at normal service voltage levels.
- A partial discharge leads to a turn to turn fault and Transformer breakdown.

Finally the detailed investigations revealed that the series failure of HVDC transformer occurred mainly due to insulating oil problem. M/s ABB after studying the problem suggested to use passivated oil for new or repaired unit and to add passivator in the oil of in service converter transformer. After taking remedial measures no converter transformer failure is observed. These measures have resulted into enhancing the availability of HVDC system. Currently HVDC system availability is as per the standards decided by MERC.

IV. MEASURES TAKEN FOR REDUCTION OF TRANSFORMER FAILURES IN MSETCL

A. Measurement of Capacitance and $\tan \delta$

Capacitance and $\tan \delta$ measurement of bushings gives an indication of the quality of insulation in the bushing[2]. In MSETCL practice is followed to replace the bushing if value of $\tan \delta$ is found to be greater than 0.007. If the trend in variation of Capacitance and $\tan \delta$ values monitored is
observed to be abnormal decision of replacing of bushing is taken. The same technique is used to know healthiness of ground and interwinding insulation of transformer. MSETCL has a practice of yearly monitoring of Capacitance and Tanδ measurement.

B. Provision of High set relay for EHV transformers

High set relays are provided on distribution side feeders to avoid unwarranted trippings/failure of transformers. For a closeup fault on distribution feeder, the high set relays are expected to operate to clear the fault and avoid the reflection of the same on transformer. The high set relays being instantaneous helps to isolate the faulty feeder quickly. MSETCL has provided high set relays on distribution side feeders emanating from EHV substations and this has helped to reduce the incidents of transformer tripping/failure due to distribution related faults.

C. Independent operation of EHV transformers

Based on the failure analysis of transformers, it is noticed that the failures of EHV transformers feeding the distribution network are more than that of ICTs. After detailed analysis and studies it has been decided to operate the EHV transformers in independent mode rather than parallel operation as far as possible where the load can be managed. This has helped in reducing inadvertent trippings and failure of transformers also to some extent.

D. Dissolved gas analysis (DGA)

Dissolved Gas Analysis (DGA) is one of the most widely used diagnostic tools for detecting and evaluating faults in electrical equipment. However the interpretation of DGA results is often complex and should always be done with care, involving experienced insulation maintenance personnel. (Ref: IEC 60599:1999). This technique is mainly useful for the transformers filled with mineral insulating oil and insulated with cellulose paper or press-board-based solid insulation. This process mainly involves steps

i) Knowing reasons for generation of gases:
Fault gases are produced by degradation of the transformer oil and other insulating materials such as cellulose. In the presence of an active fault, the rate of oil and cellulose degradation is significantly increased, and the types of degradation products formed will vary with the nature and severity of the fault.

ii) Interpretation of dissolved gas analysis
Interpretation of dissolved gas analysis is generally done based on standards like IS 10593:1992, IEC 60599:1999, ASTM D3612. Apart from this it is also important to see whether the measured values are well above the sensitivity of the analytical methods and equipment and to check whether gas concentration is high enough to consider for further investigation.

Inputs on following historical information is vital in carrying out the DGA interpretation.

1) How old is the transformer?
2) Did a bushing fail at some point?
3) Did the transformer fail at some time?
4) Is the unit heavily loaded as of today or in past?
5) Has the transformer been repaired after a failure?
6) Has the DGA tests been performed in past?
7) Have the fault gases risen suddenly?
8) Has the oil been degassed?

The method in IS 10593:1992 was based on IEC Pub 599: 1978, which has since been modified as IEC 60599. MSETCL has a practice of taking yearly DGA and based on DGA results appropriate action to safeguard the transformer is taken. Portable DGA kit procured by MSETCL works on photo acoustic principle has capable of detecting concentration of 8 fault gases along with the moisture content. MSETCL has also provided online DGA monitoring equipment on experimental basis on some of the units.

Apart from above DC resistance measurement and determination of Polarization Index (PI) corresponding to 60s. and 600 s, SFRA etc. are the other maintenance practices followed at MSETCL in order to minimise transformer failure rate. MSETCL follows the practice of recording SFRA during testing at factory before despatch of the transformers and confirming healthiness of transformer by recording SFRA at site before commissioning of the transformer. Further MSETCL has taken a policy decision to provide Nitrogen injection type fire protection system for all transformers of rating 100 MVA and above to prevent the transformers from catching fire during failure incident. It is observed that with above mentioned measures taken by MSETCL number of instances of EHV transformer failure could be controlled, further helping in improvement in the reliability of supply.

V. CONCLUSIONS

This paper discusses in short, some of the important reasons for the power transformer failure along with methodology to classify transformer failures depending on various factors. Based on the data it can be said that many times transformers interfacing distribution network experience more number of faults for longer duration further resulting into failure of EHV transformers. This paper also discussed some of the preventive methods in brief to minimise the rate of transformer failure.
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REFERENCES


BIOGRAPHIES

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