REPORT

ON
FAILURE OF TRNSFORMERS
AT
WAZIRABAD, MEHRAULI AND LODHI ROAD SUBSTATIONS
OF
DELHI TRANSMISSION COMPANY LTD. (DTL)

CENTRAL ELECTRICITY AUTHORITY
MINISTRY OF POWER
GOVERNMENT OF INDIA
NEW DELHI

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Report on failure of 220kV/66kV-33kV/11kV, 100MVA Transformer (NGEF make) at Wazirabad substation; 220kV/66kV/11kV, 100MVA Transformer (CGL make) at Mehrauli substation and 220kV/66kV-33kV/11kV, 100MVA Transformer (CGL make) at Lodhi Road substation of DTL on 25-08-2006, 20-09-2006 and 06-11-2006 respectively

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1.0 INTRODUCTION

The 220kV/66kV/11kV Wazirabad substation of DTL is not an old station commissioned sometimes during 1997. The substation is operating with 240 MVA total transformation capacity [Four transformers: with 2x100MVA, 220kV/66kV - 33kV/11kV; 2x20MVA, 66kV/11kV]. The 220kV/66kV/11kV Maherauli substation of DTL is an old station. The substation is operating with 340MVA total transformation capacity [Five transformers: with 3x100MVA, 220kV/66kV/11kV; 2x20MVA, 66kV/11kV]. The 220kV/66kV/11kV Lodhi Road substation of DTL is operating with 272MVA total transformation capacity [Six transformers: with 2x100MVA, 220kV/66kV/11kV; (2x20MVA + 2x16MVA), 33kV/11kV].

The 220kV/66kV - 33kV/11kV, 100MVA transformer (NGEF make) failed on 25-08-2006 at 13:32 Hrs at Wazirabad substation. The 220kV/66kV/11kV, 100MVA transformer (CGL make) failed on 20-09-2006 at 07:40 Hrs at Meharauli substation. The transformer at Wazirabad substation has been reenergised after rectification of the problem. The 220kV/66kV - 33kV/11kV, 100MVA transformer (CGL make) failed on 06-11-2006 at 14:30 Hrs at Lodhi Road substation.

A Standing Committee has been constituted to assess the cause of failure and rate of failure of various substation equipment of 220kV and above voltage class and to suggest remedial measures so as to minimise / avert such failures in future. As part of such activity, Shri K.K. Arya, Director and S.K.Ray Mohapatra, Dy. Director of SE&TD Division of CEA visited the site of failure of transformer at Wazirabad on September 13, 2006. Dr. S. Mukhopadhyay,Chief Engineeer, K.K. Arya, Director and S.K.Ray Mohapatra, Dy. Director of SE&TD Division of CEA visited the site of failure of transformer at Mehrauli on September 29, 2006. Shri S.K.Ray Mohapatra, Dy. Director and Ashok Kumar, Asstt. Director of SE&TD Division of CEA visited the site of failure of transformer at Lodhi Road on November 28, 2006.

During the visits, the respective teams had meetings with DTL officials and discussed in detail with the operation and maintenance staff of substation about the sequence of events leading to failure of transformer. The results of various tests conducted on the transformer before and after failure including DGA and other relevant information were also collected. The assessment / analysis of failure of transformers is discussed below.

1.1 FAILURE OF TRANSFORMER AT 220kV/66kV WAZIRABAD SUBSTATION

The brief details of the failed transformer are as follows:

Transformer Particulars	Details
Name of Substation	Wazirabad
Make	NGEF
Rating	100 MVA, 220kV/66kV - 33kV/11kV, 3phase (Transformer No. II) Vector Group – Ynyn0d11
Sr.No.	6800000162
Type	Three winding Transformer with unloaded tertiary
Year of Commissioning	1999 (Year of manufacture 1997)
Last routine maintenance work carried out	20-08-2006
Date of Failure	25-08-2006 at 13:32 Hrs
Insulation level	HV(220kV): 1050 kVp, HV-Neutral: 95 kVp IV(66kV): 325 kVp, IV-Neutral: 95kVp LV(11kV): 170kVp,
% Impedance	HV-LV: 30.90%, HV-IV: 14.60% IV-LV: 19.88%

1.1.1 Observations

(a) Axial displacement of porcelain housing of all three phases of HV(220kV) bushing was clearly visible at bottom gasket location. But oil leakage from OIP bushings was not observed. The oil level in all three phases of HV bushing is observed to be normal.

(b) Both Pressure Relieve Device (PRD) had operated

(c) No external deformation was observed with the transformer and main tank was intact probably because of successful operation of PRD.

(d) The test taps were checked and no sign of arcing mark was observed.

(e) 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 visible.

(f) There was clear indication of flashover marks on clamping rods (metallic) and base of the core of coil.

(g) Rest of the external reactor including paper insulation was in tact

(h) One of the terminals of the delta connected tertiary winding was earthed

(i) As reported there was no oil spillage and external fire.

(j) No failure or major repair reported since its commissioning except replacement of cooling pumps in recent past.

(k) Factory test report, pre-commissioning test reports were not available with the operating and maintenance staff.

(l) It was reported that On Load Tap Changer has never been called for operation since its commissioning.

(m) Reading(s) of OTI was 56 deg. C and that of WTI were 58(HV), 62(IV), 56(LV) deg. C at 04:00 hours on the day of failure.

(n) Proper soak pit has been provided for the transformer

(o) At the time of failure the OLTC was at normal tap (No.9)
(p) The 220kVdouble bus bar system was operating with bus coupler closed.
(q) At the time of site visit various repairing activity and fitting of various accessories were going on. All gaskets of transformer tank were replaced.

1.1.2 Consequential Damages

Equaliser pipe of B-phase HV bushing found broken giving way for oil to come out. No other damage to the neighbouring equipment was reported due to the failure of transformer.

1.1.3 Sequence of Events

(a) Normal sunny day on the day of failure
(b) Before tripping, the transformer was running in parallel with another 100MVA transformer (No.-II) of Alstom make. The load on the transformer was only 79A.
(c) The three (3Nos.) damaged oil pumps and associated fuses were replaced by new ones during planned shutdown from 5:50hrs to 11:27 hrs on 25-08-2006 and transformer was re-energised at about 12:02 Hrs on the same day.
(d) On August 25, 2006 at 13:15 Hrs, 220kV bus bar protection system was under test. All feeders connected to Bus-I and Bus-II tripped on bus bar protection as 220kV Double Bus system was operating with Bus coupler closed.
(e) Between 13:25 Hrs to 13:30 Hrs all feeders were put back into service along with transformer –II & III. 66kV incomer I &II were also put back into service.
(f) Transformer failed on same day at 13:32 Hrs after operation for only about 1hour 15 minutes.
(g) At 13:32 Hrs, 100MVA transformer-No. II alongwith 66kV Incomer No.II tripped showing operation of following protections provided for the transformer
- Transformer Differential (Y&B phase)
- Buchholz, Pressure Relieve Device(PRD)
- Buchholz of OLTC
- Sudden Pressure relay

(h) In addition to above following alarm and indication were also observed
- Low oil level alarm
- Low oil flow alarm
- Fan and pump fail indication

(i) Transformer failed without any abnormal noise.
(j) No system fault was reported at the time of failure.
(k) Internal inspection of transformer was carried out by DTL on 27-08-2006.

1.1.4 O & M History of Transformer

The transformer was commissioned in 1999 after about two years of manufacture (1997). The Insulation Resistance(IR) measurement, magnetising current, magnetic balance test, turns ratio test, measurement of BDV & other parameters (water content, neutralisation value, % of sediment & sludge, dielectric dissipation factor, specific resistance, interfacial tension, and flash point) of oil, cleaning of bushings, tightness of clamps, connectors, nuts and bolts, thermal scanning using infrared camera,

checking of oil leakage are being carried out by DTL as part of the routine maintenance checks.

The measurement of capacitance and tandelta of bushings and windings was carried out only once on January 17, 2005 since its commissioning. No major repair work of transformer was carried out except filteration of oil and replacement of damaged pumps.

1.1.5 Assessment / Analysis of Failure of Transformer

(a) The failed autotransformer is of NGEF make with unloaded tertiary winding and was commissioned during 1999 after about two (2) years from date of manufacture (1997). The transformer failed on 25-08-2006 after serving for only about seven years. The average loading on the transformer has rarely exceeded 50% of its rated capacity and has never been overloaded beyond its maximum capacity during its service life. The load current of the transformer prior to failure was only 79A against rated current of 262.4 A.

(b) The DGA was conducted after failure at DTL's laboratory on 26-08-2006 and at New Delhi on 28-08-2006. There is wide variation in both reports. However, presence of high content of Acetylene (C2H2) is observed in both the reports. This implies high energy arcing which could be due to insulation breakdown between windings or between coils or between coils and earth.

(c) Tertiary winding is the potential cause of failure of many transformers. The failed transformer had a peculiar feature. External reactor was used in series with tertiary winding of the transformer. This was an old practice of limiting the short circuit current in the tertiary winding. The external reactor of tertiary winding had 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 visible.

(d) There was clear indication of flashover / arcing marks on clamping rods (metallic) and base of the core of the external reactor of the transformer, which could be between bare conductor and clamping rods (metallic) / base of the core of coil. DGA conducted after failure also supports such arcing.

(e) The reports of Sweep Frequency Response Analysis (SFRA) and exciting current test conducted by PGCIL does not mention any abnormality.

(f) Magnetising current test results and magnetic balance test and ratio tests conducted after failure does not show any abnormality. IR test results conducted after tripping show the Dielectric absorption ratio (IR after 60 secs./IR after 15Sec.) for LV-E,MV-LV and HV-LV are 1.0, 1.2,1.2 respectively which are below normal requirement of at least 1.3. IR after 600 sec. has not been measured.

(g) The reason for low oil level alarm, low oil flow alarm and fan & pump fail indication is not understood.

(h) The fault gases developed inside the transformer due to severe arcing might have resulted in sudden pressure rise leading to operation of PRD.

(i) **The tripping of differential protection further supports internal fault. Therefore, the failure of transformer could be due to failure of winding insulation of external reactor of the tertiary winding.**

1.1.6 Restoration of the failed Transformer

Transformer oil tested after failure indicated low BDV of oil i.e 49kV. The transformer at Wazirabad substation has been reenergised after filteration of oil and replacement of damaged reactor of tertiary winding by another reactor of similar design.

1.2 FAILURE OF TRANSFORMER AT MEHRAULI SUBSTATION

The brief details of the failed transformer are as follows:

Transformer Particulars	Details
Name of Substation	Mehrauli
Make	CGL
Rating	100 MVA, 220kV/66kV/11kV (Transformer No. I)
Sr.No.	24373
Type	Three winding Transformer with unloaded tertiary
Year of Commissioning	1999 (Year of manufacture 1982)
Last routine maintenance work carried out	00-00-2006 Not available
Date of Failure	20-09-2006 at 07:40 Hrs
Insulation level	HV(220kV): kVp, HV-Neutral: kVp IV(66kV): kVp, IV-Neutral: kVp LV(11kV): 170kVp,
% Impedance	HV-LV: 30.90%, HV-IV: 14.60% IV-LV: 19.88%

1.2.1 Observations

(a) Oil leakage from OIP bushings was not observed.
(b) No external deformation was observed with the transformer and main tank was intact probably because of successful operation of PRD.
(c) No failure or major repair reported since its commissioning
(d) Factory test report, site test reports not available with the operating and maintenance staff.
(e) The 220kVdouble bus bar system was operating with bus coupler open and two transformers (No. I&II) connected to Bus-I and third transformer connected to Bus-II (No. III).

1.2.2 Consequential Damages:

No other damage to the neighbouring equipment was reported due to the failure of transformer.

1.2.3 Sequence of Events

(a) Normal sunny day on the day of failure

(b) Before tripping, the transformer was running in parallel with another 100MVA transformer (No.-II) of CGL make. The third transformer(BHEL make) was running independently on Bus-1. The peak load on transformer No.-1&2 was 92MVA on 30-05-2006.

(c) At 07:40 Hrs on 20-09-2006, 100MVA transformer-I tripped alongwith 66kV Palam feeder and Incomer No. I&II showing operation of following protections provided for the transformer

- Transformer Differential (87)
- Buchholz
- Buchholz of OLTC
- Sudden Pressure relay

In addition to above following operation has also taken place

- Tripping of 220kV ABCB
- Operation of O/C &E/F, 67X of 66kV Palam feeder
- Operation of E/F, 64X of Incomer – No. II

(d) After failure of transformer, all LT tests on the transformer were carried out by DTL in presence of CGL Engineer. SFRA test was conducted by PGCIL. DGA was also conducted after failure of transformer.

(e) It is also reported that , physical inspection (after draining of oil) carried out by DTL in presence of service Enginner of CGL shows no abnormality.

1.2.4 O & M History of Transformer

The past Operation and maintenance history is not avialable.

1.2.5 Assessment / Analysis of Failure of Transformer

(a) The failed transformer is of CGL make with unloaded tertiary winding and was commissioned in the substation during 1999. The year of manufacture of transformer is 1982. The transformer failed on 20-09-2006 after serving for about twenty four (24) years.

(b) Magnetising current in Y-phase of HV & IV winding were found abnormal. The Y-phase current of HV winding was 1.12Amp. against R-phase and B-phase currents of 8.13mA & 8.06mA respectively. Similarly the Y-phase current of LV winding was 15.82Amp. against R-phase and B-phase currents of 68.6mA & 68.1mA respectively.

(c) Magnetic balance test also shows abnormality in respect of HV and IV winding. The Y-phase voltage was zero indicating dead short circuit.

(d) After failure of transformer, SFRA test was conducted by PGCIL and it was reported that significant deformation has taken place in Y –phase of IV winding (66kV) and minor deformation in HV and LV(Tertiary) winding.

(e) Dissolved Gas Analysis shows high concentration of Acetylene and Hydrogen which clearly indicate low as well as high enegy discharge.

(f) Furan analysi was conducted for the said transformer on 21-09-2004 by CPRI. The test result shows high content of 2-Furfuraldehyde(2535ppb). Such high level of furan content indicates that significant damage to paper insulation has occurred due to heat.

(g) **Considering the present life of transformer (about 24 years) and Furan analysis, it is obvious that the cellulose insulation of transformer has undergone excessive aging. The complete replacement of winding of transformer might be required. The advice of manufacturer in this regard may sought before going ahead with any major repair work which may not be cost effective considering the condition of insulation of transformer.**

1.2.6 Restoration of the failed Transformer:

The failed transformer at Meharauli substation is out of service and likely to be replaced by another one to meet the load demand.

1.3 FAILURE OF TRANSFORMER AT LODHI ROAD SUBSTATION

The brief details of the failed transformer are as follows:

Transformer Particulars	Details
Name of Substation	Lodhi Road
Make	CGL
Rating	100 MVA, 220kV/66kV/11kV
Sr.No.	BS 8955/2
Type	Three winding Transformer with unloaded tertiary
Year of Commissioning	10-07-2004
Last routine maintenance work carried out	03-11-2006
Date of Failure	06-112006 at 14:30 Hrs
Insulation level	HV(220kV): kVp, HV-Neutral: kVp IV(66kV): kVp, IV-Neutral: kVp LV(11kV): 170kVp,
% Impedance	HV-LV: 25.33%, HV-IV: 14.90% IV-LV: 11.95%

1.3.1 Observations

(a) The substation is fed at 220kV level through tapping from the nearby 220kV line. There is no bus bar system at 220kV level. The nearby line has been tapped and feeding directly to two transformers through Surge arrester, CVT, CT, isolators and Circuit breaker.
(b) No oil leakage from OIP bushings was not observed.
(c) No external deformation was observed with the transformer and main tank was intact.
(d) Factory test report, site test reports not available with the operating and maintenance staff.

1.3.2 Consequential Damages

No other damage to the neighbouring equipment was reported due to the failure of transformer.

1.3.3 Sequence of Events

(a) Normal sunny day on the day of failure

(b) Before tripping, the transformer was running in parallel with another 100MVA transformer. The peak load on transformer No.-1&2 was ~~92MVA on 30-05-2006.~~

(c) At 14:30 Hrs on 06-11-2006, 100MVA transformer tripped alongwith 33kV outgoing Exhibition feeder showing operation of following protections provided for the transformer

- Transformer Differential (87)
- Buchholz

(d) In addition to above following operation has also taken place

- Tripping of 220kV as well as 33kV CB associated with failed transformer
- Operation of E/F of 33kV outgoing Exhibition feeder

(e) The 33kV outgoing feeder tripped with heavy jerk. The 33kV cable of BSES was checked and found dead short circuit between two phases. One such two phase cable fault had also occurred earlier.

(f) After failure of transformer, all LT tests on the transformer were carried out by DTL in presence of CGL Engineer. SFRA test was conducted by PGCIL. DGA was also conducted from NTPC after failure of transformer.

(g) It is also reported that internal inspection of winding (after draining of oil) carried out by DTL in presence of service Enginner of CGL.

1.3.4 O & M History of Transformer

The past Operation and maintenance history is not avialable. The capacitance and tandelta of bushings and windings was carried out during January 2005 as well as on 03-11-2006 prior to failure which did not show any abnormality. DGA for the failed transformer is being carried out by DTL since 2004.

1.3.5 Assessment / Analysis of Failure of Transformer

(a) Since its commissioning in the substation two cable faults have been reported.

(b) Low IR value observed for HV to Earth and LV to earth(i.e ratio of IR value after 60 sec. to IR value after 10 Sec.).

(c) The failed transformer is of CGL make with unloaded tertiary winding and was commissioned in the substation during 2004. The year of manufacture of

transformer is 2003/2004. The transformer failed on 06-11-2006 after serving for about two (2) years.

(d) Magnetising current in Y-phase of HV & IV winding were found abnormal. The Y-phase current of HV winding was 416 mA against R-phase and B-phase currents of 4.97mA & 5.05mA respectively. Similarly the Y-phase current of LV winding was more than 10Amp. against R-phase and B-phase currents of 94.9mA & 94.3mA respectively.

(e) Magnetic balance test also shows abnormality in respect of HV and IV winding. The Y-phase voltage was zero indicating dead short circuit.

(f) After failure of transformer, SFRA test was conducted by PGCIL and it was reported that significant deformation has taken place in Y-phase of HV winding and R & B-phases of IV winding (66kV). Tertiary(LV) winding has also been affected.

(g) The joint internal inspection by DTL and service engineer of CGL has repoted physical damage and distortion to winding. It is also reported that the repair works can not be under taken at site for which transformer has to be transported to manufacturer's works.

(h) Dissolved Gas Analysis is being carried out regularly since 2004. DGA was conducted during September 2004, January 2005, May 2005, October 2005, September 2006 and November 2006. CO2 content is continuosly increasing since 2004. The DGA conducted during November 2006 shows high concentration of Acetylene, Hydrogen, CO and CO2 which clearly indicate low as well as high energy discharge.

(i) Heavy short circuit and interturn insulation failure could be the reason of failure of the transformer. The deformation in winding observed during internal inspcetion might be due to flow of heavy short circuit current for a longer duration.

1.3.6 Restoration of the failed Transformer

The failed transformer is to be moved out of the station for repair and a healthy transformer is likely to replace the faulty one to meet the load demand.

2.0 RECOMMENDATIONS

2.1 Design of transformer with such external reactor in series with tertiary winding of transformer (as in case of NGEF make transformer at Wazirabad) is no more a

conventional practice. Such design of tertiary winding with series reactor may be avoided in future.

2.2 Factory test report and pre-commissioning test reports of each transformer, which are considered to be the base results, should be made available to the operation and maintenance staff of the substation so that subsequent measured results can be compared with the base value to find out any abnormal change. The trend analysis (relative change in test result and rate of change) will provide valuable information to O&M staff for taking early action so that any major failure can be avoided.

2.3 In addition to other tests being conducted by DTL, it is recommended to conduct core to ground insulation resistance measurement, DC resistance measurement and determination of Polarization Index (PI) corresponding to 60secs. and 600 secs., Recovery Voltage measurement, SFRA etc. may also form part of maintenance activity. PI corresponding to 60secs. and 600 secs., might provide additional information and help in assessing condition of transformer. The periodicity of the tests is to be decided.

2.4 Complete data base of previous test results starting from factory test, pre-commissioning tests etc. and history of the transformer may be maintained properly which would help in proper evaluation of results. Periodicity of tests to be conducted on transformer needs to be decided based on condition assessment and relative change in test results with respect to time (trend analysis) rather than conventional scheduled time based.

2.5 DGA is being carried out by DTL since 2003. But the rising trend of various fault gases need to be monitored to plan future action. It is suggested that DTL may procure on line portable DGA equipment which can cater to number of substations for condition monitoring of transformers. In the process dependency on outside agency would not be there and measurements can be carried out as and when required. DGA based on the results of same equipment used at different times would provide better information for analysis / interpretation.

2.6 Non-operation of Pressure Relieve Device (PRD) has caused serious damages to transformers in number of cases as in recent past in DTL's system also. So far no site tests are being conducted to assess healthiness of PRD whose operation is very much required to save transformer from serious damages. Therefore, it is required to check healthiness of PRD at site at regular interval of time. The manufacturer may be consulted to find out the method of checking healthiness of PRD of transformer at site.

2.7 Since oil surge relay, Buchholz of OLTC has also operated, the OLTC assembly may also be checked in case of transformer at Mehrauli substation.

2.8 Considering the failure rate of transformer due to bushing, it is recommended to conduct capacitance and tandelta measurement for bushings as well as winding twice in a year to have fairly close monitoring of bushings.

2.9 Field test results (conducted after failure) may be verified during major repair work at manufacturer works / at site for which the concerned person associated with operation

& maintenance activities may be deputed to manufacturer's works for the purpose to have better insight and understanding of cause of failure which would help in future.

2.10 In all three cases, failure of transformer is attributed to insulation failure (interturn isulation failure) and / deformation in windings. The deformation in winding indicates flow of high short circuit current for longer duration. There is no Disturbance Recorder at 220kV substations to record such system faults and its duration. The replacement of conventional Electro-mechanical / static relay by modern numerical relay could help in getting such valuable information. As such the short circuit withstand level of transformer is being verified by emperical calculations. No short circuit test is being conducted on the transformer due to non-availability of indigenous testing facility. Therefore, such failures raise serious question about the short circuit withstand capability of transformers being manufactured in the country. The fault clearing time of protective system needs to be reviewed. Adequate measures need to be taken to protect the transformer from severe short circuit condition.

2.11 It is observed that SFRA is being carried out by DTL only after failure of transformers. If base / reference signature would have been available, it would have provided better insight into cause of failure. Two out of three failures of transformer reported above shows deformation in winding. Similar observations were also made in case of failure of transformers of DTL in the past. Therfore, it is advisable to conduct SFRA for healthy transformers also as and when required, may be at least once in two years.

Submitted by

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to investigate the failure of equipment
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