

Maintaining large inventory of major components of transformers for a large fleet of transformers in any utility is a very costly and uneconomical affair



ABSTRACT

This article focuses on an original case history of replacement of a leaky 245 kV OIP bushing of a 220/132/33 kV, 160 MVA, transformer on site at the 220 kV Jabalpur substation, in Madhya Pradesh state in India with an available 245 kV OIP bushing having longer L-2.

To retrofit the same turret adopter, an extension piece was fabricated, with an innovative idea of utilizing locally available materials and in-house resources in minimum downtime on site, without relocating or dismantling the transformer, thus giving the Transmission and Distribution Utilities tangible advantages such as large savings of revenue by way of dismantling transportation of the transformer to the

OEM's works for its repairs; repair charges, post-repair transportation to the site followed by erection and commissioning of the transformer on the site etc. and also avoiding dissatisfaction amongst all categories of consumers at large.

KEYWORDS

turret, OIP bushing, draw lead



Retrofitting of 245 kV OIP bushing with longer oil-end

1. Introduction

Maintaining large inventory of major components of transformers for a large fleet of transformers in any transmission utility is a very costly and uneconomical affair. With this in mind, the Bureau of Indian Standards, New Delhi, had issued an Indian Standard IS:12676:1989 titled "Oil Impregnated Paper Insulated Condenser Bushings-Dimensions and Requirements" [1] for the most sensitive and

essential component of the transformer, the OIP Bushings. However, some of the manufacturers do not follow the aforesaid IS and design their transformers at their own convenience and constraints putting the end users/customers into trouble whenever EHV bushings fail or need replacement.

One such incidence took place in June 2016 at the 220 kV Jabalpur substation in India, where the need for replace-

ment of a 245 kV bushing of a 160 MVA, 220/132 kV transformer made by GEC (year of manufacture - 1993) arose. The available 245 kV OIP bushing in the stores of M.P. Power Transmission Utility was with longer length of L-2, Fig. 1 (oil end length from flange to bottom) and to install the same was not possible as it would have fouled with the core coil assembly clamping frame (end frame) of the transformer. The OEM of the transformer was contacted and the extension piece of tur-

Catastrophic failure of a transformer costs the utility a lot

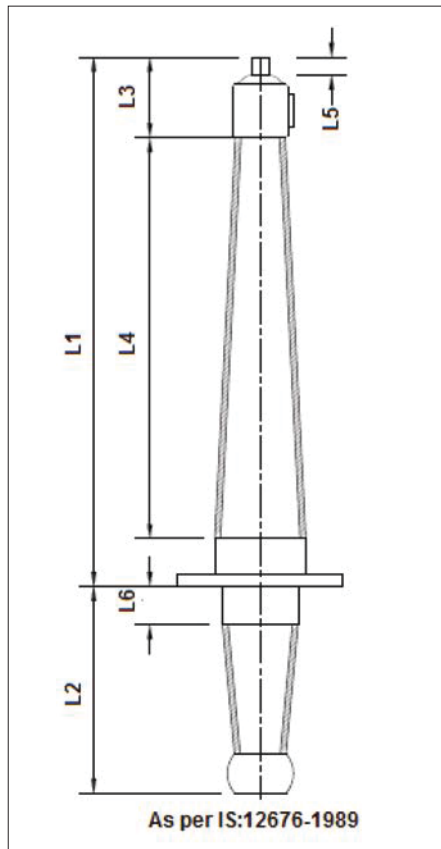


Figure 1. OIP bushing's physical dimensions depicting L2. [1]

ret or a longer turret was requested but they were not able to provide the requested item. The only option left was to accept this challenge. The proverb “necessity is the mother of invention” made us ponder and innovate an idea of fabrication of the extension cylindrical piece to extend the height of the original turret locally with available in-house resources.

2. Power supply arrangement

The power demand of the geographical area of Jabalpur city, towns and the rural areas of Jabalpur district, the neighboring districts, towns and the rural areas are catered through the following transformers/transformer banks installed at the 220 kV Jabalpur substation in India:

- a) 160 MVA, 220/132/33 kV 3 phase transformer made by BHEL.
- b) 160 MVA, 220/132/33 kV 3 phase transformer made by GEC.

c) Three 40 MVA, $\frac{220}{\sqrt{3}} / \frac{132}{\sqrt{3}} / 33\text{kV}$

bank of 1 phase transformers made by Mitsubishi, Japan.

d) Three 40 MVA, $\frac{220}{\sqrt{3}} / \frac{132}{\sqrt{3}} / 33\text{kV}$

bank of 1 phase transformers made by BHEL, India.

3. Occurrence of incidence and observations thereafter

While carrying out the inspection of the substation yard and the equipment, the operational staff had made following observations in June 2016: “The transformer oil was found spread/splashed from the transformer below the 245 kV “1U” OIP bushing, soiling the transformer turret, the body below the said OIP bushing

and an area of ground of the switchyard towards the HV side below the 160 MVA, 220 / 132 / 33 kV, GEC transformer plinth. The same was reported to the maintenance staff responsible for the maintenance of the substation equipment and upkeep of the switchyard.

4. Checking/testing of the transformer

After physically observing the site, the substation maintenance staff performed an emergency shutdown on the said transformer to check the transformer thoroughly and to arrange testing of the same to ascertain its physical and electrical status.

4.1. Observations and checks made by the substation maintenance staff

Following observation/checks carried out by the substation maintenance staff.

Table 1. Observation carried out by the substation maintenance staff

S. No	Observations / Tests	Action taken / Remarks																
1	Profuse leakage of transformer oil from the cemented joint between the porcelain bushing shell and the metallic flange which is fixed onto the turret.	Checked the oil level of the bushing, found that the oil level has reduced.																
2	Insulation resistance and PI (Polarization Index) checked with 5 KV motorized Megger.	Found satisfactory. Insulation resistance converted to 60°C value in MΩ dated 08.06.16.																
		<table border="1"> <thead> <tr> <th>Particular</th> <th>R₆₀</th> <th>R₆₀₀</th> <th>PI</th> </tr> </thead> <tbody> <tr> <td>HV - E</td> <td>510.4</td> <td>725.4</td> <td>1.42</td> </tr> <tr> <td>T - E</td> <td>320.58</td> <td>553.02</td> <td>1.72</td> </tr> <tr> <td>HV -T</td> <td>639.6</td> <td>858.0</td> <td>1.34</td> </tr> </tbody> </table>	Particular	R ₆₀	R ₆₀₀	PI	HV - E	510.4	725.4	1.42	T - E	320.58	553.02	1.72	HV -T	639.6	858.0	1.34
Particular		R ₆₀	R ₆₀₀	PI														
HV - E	510.4	725.4	1.42															
T - E	320.58	553.02	1.72															
HV -T	639.6	858.0	1.34															
3	Checked Buchholz relay.	No accumulation of gas found.																
4	Oil level in the transformer conservator checked.	No change in transformer oil level in the conservator.																
5	Oil and winding temperature checked.	No change in the temperatures recorded as compared to the latest temperatures readings recorded by the operational staff on duty																

4.2. Checks/tests carried out by the testing team

Table 2. Checks/tests carried out by the testing team

S. No	Tests / Checks carried out	Observations / Remarks
1	Tan δ - and capacitance test of the leaky 245 kV OIP bushing.	Found within permissible limits.
2	Tan δ - and capacitance test of the remaining 245 kV OIP bushings and 145 kV OIP bushings.	Found within permissible limits.
3	Magnetizing current test with LT supply.	Found satisfactory
4	Magnetic balance test with LT supply.	Found satisfactory
5	Winding resistance checked.	Found satisfactory
6	Ratio test at each tap of the transformer.	Found satisfactory

Notes:

- Since there was neither accumulation of any gas in the Buchholz relay nor had the DGA results shown any abnormality, the occurrence of partial discharge inside the transformer was also ruled out.
- It was purely a case of profuse leakage of transformer oil from the said bushing only.
- The electrical clearances were neither affected/reduced between phase to phase nor between phases to ground overruling any threat of flash over.
- Considering the above facts, the need for any kind of electric and magnetic field simulation did not arise.

4.3. Status of transformer and leaky bushing

In view of the observations, tests etc. as enlisted in the Table 1 and 2 and the notes, it was concluded that the transformer and also the leaky 245 kV OIP bushing of 1U-phase were in healthy condition. A decision was made to the effect that the said transformer

Some bushing manufacturers do not follow standardized design, which puts the end users into trouble whenever EHV bushings fail or need replacement

could render further service with the leaky 245 kV OIP bushing by topping it up with the transformer oil from time to time, until a substitute arrangement was made.

5. Action taken by substation staff occasionally

The seepage of oil could not be arrested by pasting/application of homogeneous paste made of porcelain powder mixed with Araldite (epoxy adhesive) Fig. 2.

Topping up of the transformer oil into the bushing was done, however, this kind of remedy was short lived and only lasted for about 4-6 months. Threat of failure of the 160 MVA, 220/132/33 kV transformer made by GEC prevailed consequent to threat of failure/bursting of the said leaky 245 kV OIP bushing of '1U' terminal of the subject transformer.

6. Reasons for the replacement of the bushing

- Efforts for arresting the oil leakage from the bushing from the location of jointing between the porcelain shell of the bushing and the metallic portion of the flange were ineffective despite the application of homogeneous paste of Araldite (the fast curing epoxy adhesive) and the powdered porcelain several times, Fig. 2.
- Considering the past experience of catastrophic failure of a couple of EHV transformers due to the failure of bushings, the transmission utility had decided to replace the leaky bushing forthwith. Had this leakage not been noticed timely the bushing would have failed/burst resulting in catastrophic failure of the transformer.
- Catastrophic failure of the transformer would have cost the Power Transmission



Figure 2. Leaky 245 kV OIP bushing of 1U- phase of the transformer with application of homogeneous paste of Araldite (epoxy adhesive) and the powdered porcelain.

In a case of a transformer with a leaky 245 kV OIP bushing, the oil leak could not be stopped by application of homogeneous paste made of porcelain powder mixed with Araldite

Utility and the Power Distribution Utility very dearly by way of the following aspects and constraints:

- a. Catching fire and gutting of the whole transformer.
- b. Spreading of burning transformer oil and porcelain splinters of the damaged porcelain bushing with great thrust would have become the cause of fatal accidents to men and/or damage to the equipment in the vicinity of such transformers.
- c. Downtime of the transformer would have been very, very long.
- d. The power distribution utility would have no option but to resort to load shedding, contrary to the commitment given by the Chief Minister of the State of Madhya Pradesh (India) regarding the supply of uninterrupted power to the farmers during the irrigation season.
- e. Causing many other tangible losses and disadvantages to the Power Transmission Utility as well as to the Power Distribution Utility.

7. Details of the leaky bushing

Relevant details of the original leaky 245 kV OIP bushing are as follows:

- i. Made by: BHEL
- ii. Voltage: 245 kV
- iii. Current rating: 800 Amps
- iv. Length from the flange to the stress ring bottom (L-2): 830 mm
- v. Type: DL (Draw lead type)
- vi. Year of manufacture of the transformer: 1993.

8. Activities and constraints

A thorough search for a substitute bushing with similar physical dimensions and current rating was made in the whole state of M.P. but was in vain.

Following options remained available:

- a. Replace the transformer.
- b. Procure a tailor made OIP bushing with the required physical dimensions.
- c. Manage to use the available OIP bushing of following rating and L-2 dimension:
 - i. Made by: CGL
 - ii. Voltage: 245 kV
 - iii. Current: 1250 Amp
 - iv. Type: DL type.
 - v. L-2: 1130 mm (Conforms to IS: 12676:1989, Reaffirmed in 2001)[1]s

Out of the above mentioned options, the option (c) was found to be appropriate due to the economical reasons, practicability and the minimum downtime.

As noted from the name plate, the year of manufacture of the said transformer was 1993 i.e. 4 years after the IS: 12676:1989 was issued by the Bureau of Indian Standards.

Contrary to the standard IS: 12676:1989 specification pertaining to the physical dimensions of the OIP bushings, the manufacturer M/S GEC Ltd, did not follow the same and designed the transformer with bushing of oil-end length L-2 of 830 mm, jeopardizing and disabling the option of interchangeability of major/main components of 160 MVA transformers putting the M.P. Power Transmission Co. Ltd. in trouble.

Note: Fig. 3 has been specifically depicted for the informing a regular reader as the bushing manufacturers abroad name the

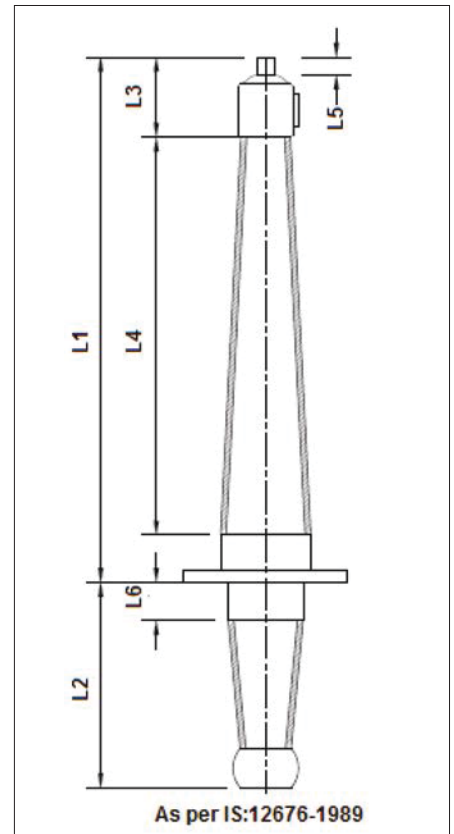


Figure 3. OIP bushing dimensions (in erect position) as per IS: 12676-1989 [1]

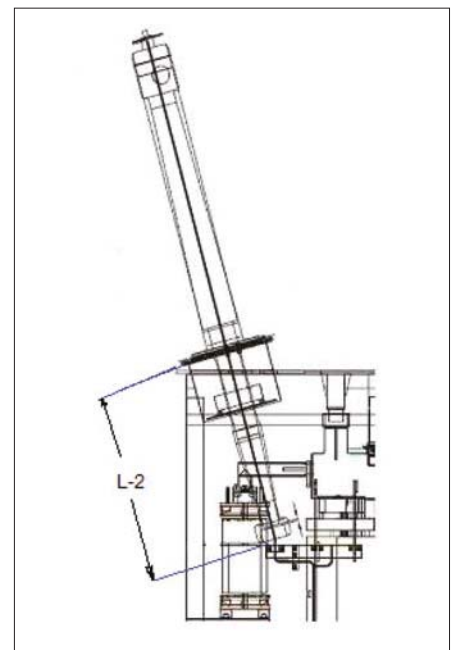


Figure 4. Longer L-2 fouling with core coil assembly clamping frame.

portion– L2 (Oil end length from flange to bottom) differently e.g.:

- ABB has designated it as L-1
- TRENCH, China (THVS) has designated it as L-3
- CGL as - H2

Since there was neither accumulation of any gas in the Buchholz relay nor had the DGA results shown any abnormality, the occurrence of partial discharge was ruled out

The transformer could render further service by topping it up with the oil from time to time, until a substitute arrangement was made

- Alstom as – L5
- MGC (Moser Glaser), Switzerland as L

9. The challenge

The challenge was: “How to use the available bushing?”

Since the length L-2 of the new OIP bushing was 300 mm longer than the original bushing (1130 mm vs 830 mm), it was obvious that the oil end portion of the new bushing would foul with the core coil assembly clamping frame (end frame) of the transformer, Fig. 4.

As the saying goes “Necessity is the mother of invention”, such a challenge has led us to explore/innovate some ideas keeping in mind the feasibility/practicability without ousting the transformer from the system

in minimum possible time, shut downs and downtimes.

10. Innovative idea

- To fabricate an adopter on the turret in a manner that would allow enough clearance to be achieved from the clamping frame of the core coil assembly and to seat the bushing flange thereon
- To extend the HV lead length of draw lead type bushing
- To extend the equalizer pipes

11. Action required

- To design
 - A turret adopter (Turret extension piece)

- An extension piece for the lead for DL type bushing
 - Extension of equalizing pipes
- To plan the number of shut downs for related activities
- To measure the physical dimensions of the turret such as internal and external diameters, measurement of the turret wall, PCD, number of bolting holes, etc.
- To fabricate turret adopter, DL extension piece and equalizer pipe extension
- Final installation, checking and pre-energizing testing, etc.

12. Designing of turret adopter (turret extension piece)

- Turret adopter should be designed that it should withstand vacuum at 0.0133 mbar (10 millitor) while filling of the transformer oil in the transformer is done with all fittings in place minus the radiators.
- It should withstand continuous internal pressure of 35 KN/m² over the normal hydrostatic pressure of oil.

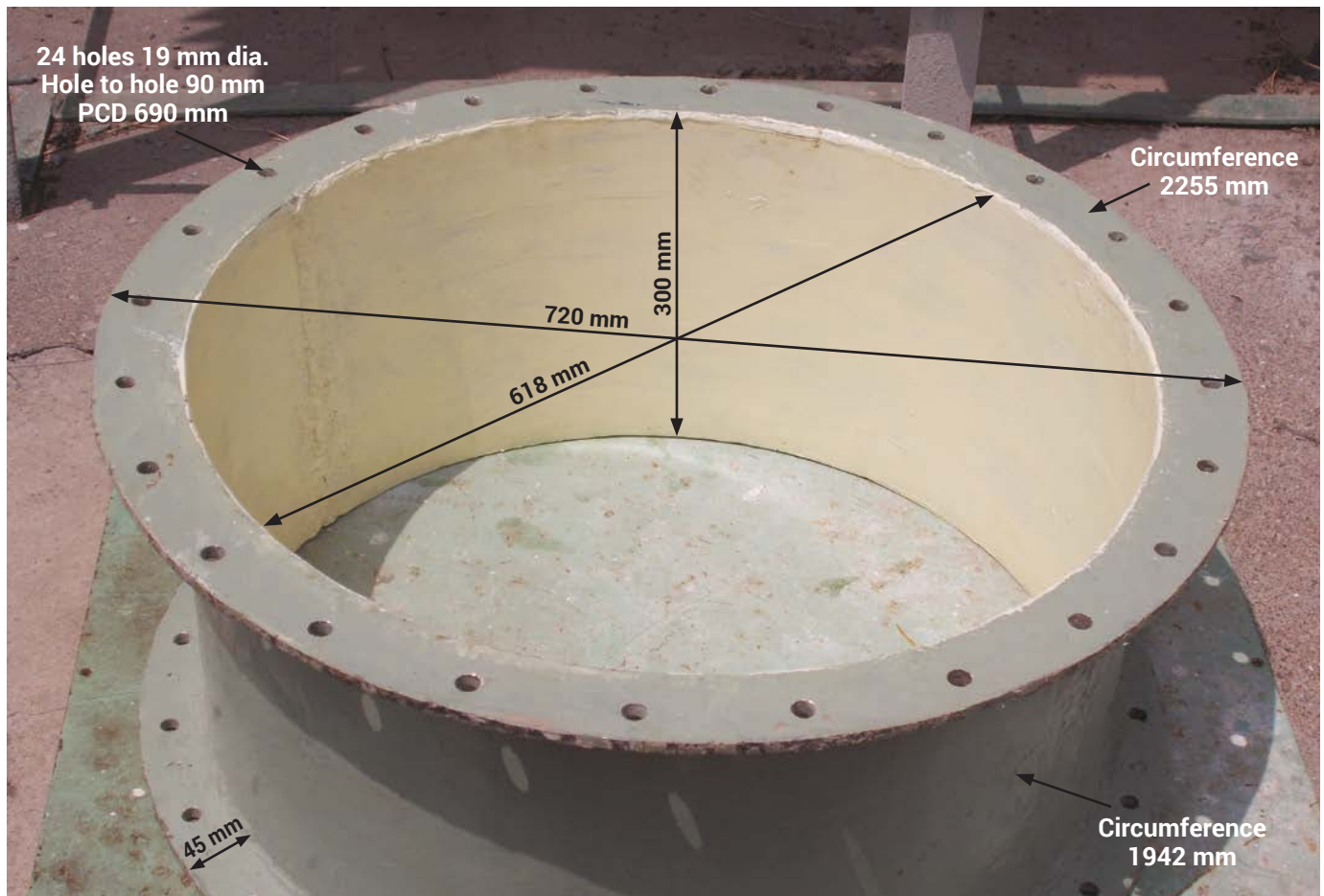


Figure 5. In-house fabricated turret adopter.



Figure 6. Copper extension piece showing suitably turned threads at both ends.

Topping up of the transformer oil into the bushing was done, however, this kind of remedy was short lived and only lasted for about 4-6 months

To fulfill the conditions mentioned above, the wall thickness and the flange collar of wrought iron should be such that they should be equivalent to the original turret wall thickness and the flange collar.

12.1. Fabrication of the turret adopter

A cylindrical extension piece was locally fabricated with a 8 mm thick wrought iron plate with dimensions: 618 mm diameter, 300 mm length and 8 mm thickness with flange on both ends fabricated with 8 mm thick wrought iron plate with internal diameter of 618 mm and external diameter of 720 mm; they have 24 bolting holes of 19 mm diameter at diameter of 690 mm (PCD) and hole to hole distance of 90 mm. The turret adopter fabricated is shown in Fig. 5.



Figure 7. Fitting of extended turret adopter and extension of draw lead.

12.2. Extension of the draw lead

The length of the draw lead was extended by 300 mm using a 360 mm copper rod available in the substation of a draw rod type bushing by suitably turning the threads on either ends for fixing the lead-end and the terminal-end thimble, Fig. 6. The fabricated copper rod extension piece for elongation of the connecting draw lead was screwed to the original draw lead stud of the bushing and on the other end to the terminal to the thimble. The extended turret adopter is depicted in Fig. 7.

12.3. Extension of the equalizer pipe

The equalizer pipe was extended and connected to the main pipe connected to the conservator.

12.4. Final installation of bushing on the turret adopter

The new 245 kV OIP bushing was finally installed on the turret adopter with Neoprene rubberized gasket of ½” thickness, Fig. 8. After completion of installation of the new bushing with L2 1130 mm over the fabricated turret adopter, the oil topping up with filtered transformer oil was done.

13. Pre-energization tests

Following tests were performed to satisfaction prior to energization of the transformer by the testing team.

- i. Insulation resistance values taken with the 5 kV Megger and converted value in MΩ at 60°C (Table 3.)
- ii. Tanδ and capacitance of the bushing Tanδ – 0.0043 and capacitance - 362.79 pf
- iii. Transformer magnetizing current test with the LT supply IR – 1.56 mA, IY – 1.25 mA, and IB – 1.60 mA
- iv. Magnetic balance test with the LT supply (Table 4.)
- v. Winding resistance test on normal tap.

Only tap number 9 (normal) R phase - 290.1, Y phase - 297.6 and B phase - 297.2

Table 3. Results of insulation resistance test

Particular	R ₆₀	R ₆₀₀	P I
HV - E	510.4	725.4	1.42
T - E	320.58	553.02	1.72
HV -T	639.6	858.0	1.34

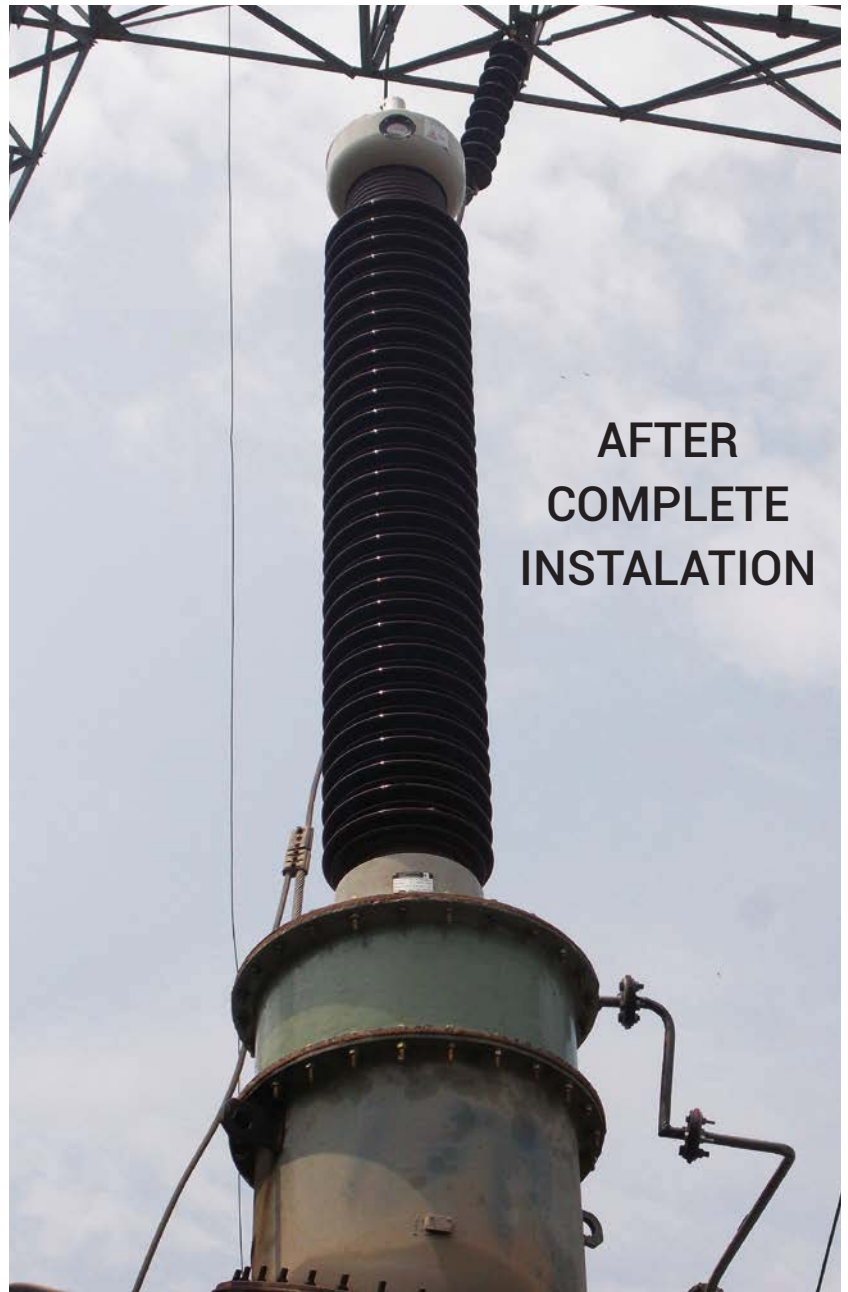


Figure 8. Completion of the installation of the new bushing with L2 1130 mm on the fabricated bushing turret adopter.

Had this leakage not been noticed timely, the bushing would have failed resulting in catastrophic failure of the transformer

Table 4. Results of magnetic balance test

RN	YN	BN	rn	yn	bn
230	215	17	139	130	10
128	230	103	77	139	61
20	211	230	12	128	139

Table 5. Downtime details
The said transformer was re-energized successfully at 14:33 h on 13.09.2016.

S. No	Activity/Work executed	Time taken / Shut down availed	Downtime in h.
1	Measurement of dimensions of turret wall and other dimensions of the collar including number of holes, chordal distance, etc. on the collar.	1:30 h	1:30 h
2	For disconnection of jumpers and preparation etc.	1 day	24 h
3	For final removal of old bushing and installation of turret adopter, lead extension, new bushing fitting and piping	1 day	24 h
4	Offline filtration of the transformer carried out with: Liters: 6000 l per h Filter machine 10 h from the 07.09 2016 to 11.09.2016	3 days + 10 h	96 h
5	Settling time after filtration job plus release of trapped air from strategic location like Buchholz relay, oil-surge relay, turrets of all the OIP bushings and all the locations near PRV on the top cover etc. carried out on the transformer including checking BDV of the transformer oil and IR and PI values on 12.09.2016 till 10:00 h on 12.09.2016	30 h	30 h
6	Pre-energizing/charging tests by the testing team emphasizing on tan delta and capacitances of the 245 kV and 145 kV OIP bushings with 10 kV portable test kit, measurement of winding resistance, measurement of IR values and PI values apart from the routine pre-commissioning tests with LT supply carried out on 12.09.2016 from 10:00 to 18:00 h	10:00 to 18:00 h on 12.09.2016	8 h
7	Transformer was kept idle from 18:00 h on 12.09.2016 until the transformer was energized after ascertaining and following precautions like removal of earthing/discharging rod from 220 kV, 132 kV bays and 33 kV bushings etc., verifying the earth resistance of earth pit and integrity of earthing system carried out by the substation maintenance staff and the testing team prior to the review thereof by the executive engineer testing (division 1), Jabalpur	18:00 h on 12.09.2016 to 14:33 h on 13.09.2016	26:33 h
8	At 14:33 h on 13.09.2016 the transformer was successfully energized/charged on no-load	14:33 h on 13.09.2016	-
9	Total down time		210:03 h

14. Preparation and execution of works prior to each shut down

Note: During every shutdown for transformer maintenance following precautions were implemented/ observed:

- i. Safety tools and safety precautions for men and the transformer were arranged near the 220 kV and 132 kV bays of the transformer such as:
 - a. Adequate quantity/volume of transformer mineral oil conforming to Indian standards-IS: 335 (1993), reaffirmed in 2003 [2] duly tested for all the parameters to ascertain its health
 - b. Safety belts and rubber hand gloves for workers
 - c. Workers' helmets
 - d. Nylon rope of 22 mm or 24 mm in diameter of adequate length
 - e. Adequate numbers of discharged rods (with screw able bimetallic

Considering the past experience of catastrophic failure of a couple of EHV transformers due to the failure of bushings, the utility had decided to replace the leaky bushing forthwith

- G-clamps) for earthing/discharging the residual induction voltage from the 220 kV side and from the 132 kV side effectively
- f. Red colored cloth strips of 30.48 cm in width to encircle and indicate the safe working zone in 220 kV and 132 kV transformer bays during shutdown
 - g. Chain pulley block and tirlfor (a machine with manual handle to pull or lift any load/equipment), etc.
- ii. The assistant engineer/junior engineer at the 220 kV Jabalpur substation applied for a shutdown of the transformer for working thereon on a prescribed application form to the control room operator on duty.
 - iii. The load of this transformer used to be managed by shifting to other two remaining 220/132 kV transformers at 220 kV Jabalpur substation and also to the 220/132 kV transformers in the neighboring 220 kV substations.
 - iv. The transformer's SF6 circuit breakers of 220 kV side and 132 kV side are switched off remotely from their respective control panels from the control room by the operator after ascertaining the load management of the said transformer is implemented as stated in (iii).
 - v. The NIFPS (Nitrogen Injection Fire Protection System) is switched off from the control panel of the NIFPS in the substation control room the supervisor in charge on duty in the control room.
 - vi. An operating artisan on duty from the operating staff is deputed from the control room for jointly inserting the locking pin of the NIFP system of the said transformer manually in the switchyard.
 - vii. An operating artisan on duty from the operating staff is deputed from the control room to manually operate and open:
 - a. The 220 kV transformer isolator towards the 220 kV main bus number 1, 220 kV main bus number 2 and the 220 kV auxiliary bus (also known as transfer bus) isolator and the 220 kV transformer's main isolator manually. [Note:

- (a) An isolator is also called an isolating switch and (b) The 220 kV and 132 kV isolators do not have motorized arrangement for operating the same. They are manually operated].
- b. The 132 kV transformer isolator, 132 kV main bus and the 132 kV auxiliary bus isolators

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- [2] IS: 335 -1993 (Reaffirmed 2003), *Indian Standard for transformer mineral oil*.

Authors



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