

Retrofitting of a 420 kV draw-lead type bushing with a draw-rod type - Part II

ABSTRACT

On observation of deterioration of $\tan\delta$ value to 1.02%, i.e., surpassing the limiting value of 0.7 %, as defined in IEC 60137, of the 420 kV OIP bushing of BHEL's design installed on the Y phase (RYB convention, i.e., 1V in UVW convention) of the 315 MVA, 400 / 220 / 33 kV transformer No. 1 located at the 400 kV substation Katni of the Madhya Pradesh Power Transmission Co. Ltd (India), a decision was taken to replace the said bushing in order to eliminate the threat of its failing. This in turn would have caused a catastrophic failure of the transformer. Such catastrophic failure would result in a colossal loss, causing

system disturbance, loss of equipment and structures, as well as a loss of revenue to the utility.

In the absence of a BHEL's design 420 kV draw-lead type bushing, as was the existing one, there was no other option but to use the available 420 kV draw-rod type TELK bushing at the site. Since the manufacturers had shown their inability to depute any service personnel due to the Covid-19 pandemic in May 2020, the challenge was accepted by the engineers of the MP Power Transmission Company Ltd., who successfully completed the job with limited resources and in record time, and put the transformer back into service.

KEYWORDS:

bushings, draw lead, draw rod, retrofitting, DGA, $\tan \delta$

ACRONYMS:

BHEL (Bharat Heavy Electricals Limited), DGA (Dissolved Gas Analysis), MPPTCL (Madhya Pradesh Power Transmission Company Limited), NIFPS (Nitrogen injection fire prevention system), OEM (Original Equipment Manufacturer), OIP (oil impregnated paper), $\tan \delta$ (tangent delta), TELK (Transformers and Electricals Kerala Limited)



The OIP bushing is designed with multiple layers of grading condensers wound concentrically over the central tube of the bushing, using alternate layers of aluminium foil and the kraft paper

restrain setting of 12 % after taking static winding resistances (a DC test), the decision was taken to lower down the 2nd harmonic restrain setting from 12 % to 10 %, and then the 315 MVA, 400/220/33 kV transformer No. 1 (BHEL's design) was successfully energised. This decision was

taken to avoid any confusion of mal tripping attributed to retrofitting of the OIP bushing.

Fig. 1 shows the removal of the 420 kV BHEL bushing with the help of a Hydra crane.

1. In-house bushing replacement - addressed challenges

The essentiality of grid constraints had called for retrofitting of the 420 kV bushing and expeditious putting the transformer back into service.

There was no other option but to insert a TELK's design bushing through the turret with a stress shield of a different shape very accurately and precisely without damaging the bushing stress shield and the turret current transformer, contrary to the procedure laid down by the OEM [6].

Keeping in view our previous experiences of the transformer tripping on a harmonic



Figure 1. The process of removing the 420 kV BHEL bushing with the Hydra crane.

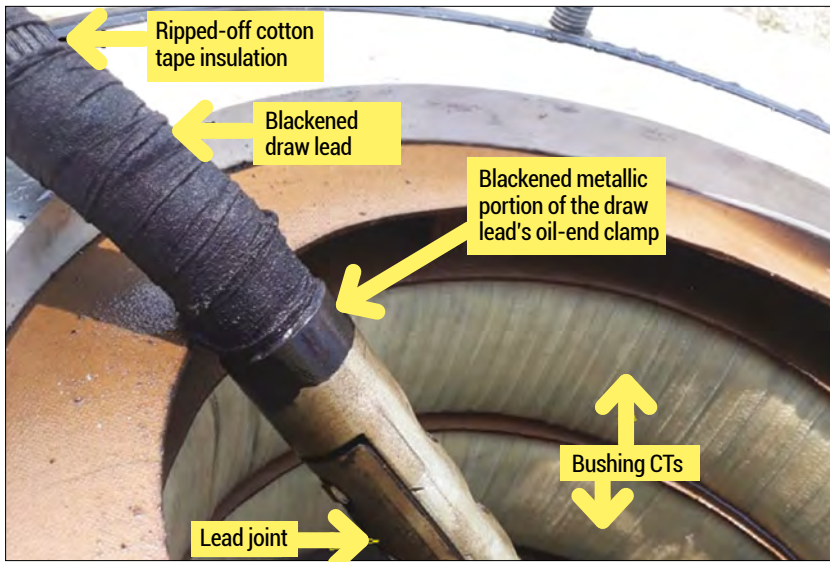


Figure 2. 420 kV BHEL bushing's draw lead after being detached from the OIP bushing's hollow shell is held at the turret edge of 1 V phase of 315 MVA, 400/220 kV/33 kV transformer no. 2.

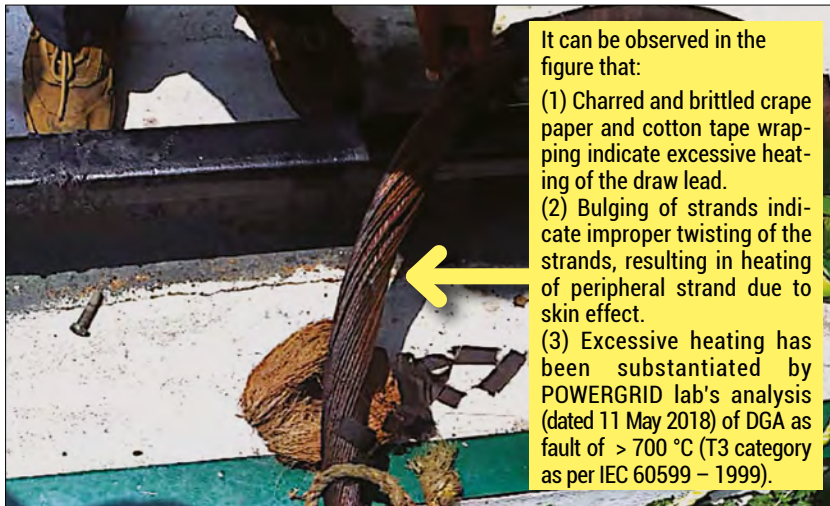


Figure 3. Charred and brittle crepe paper and cotton tape, and bulged strands of draw-lead of 1 V phase of 420 kV OIP BHEL bushing removed from the 1 V phase of BHEL design 315 MVA, 400/220/33 kV transformer No. 2.

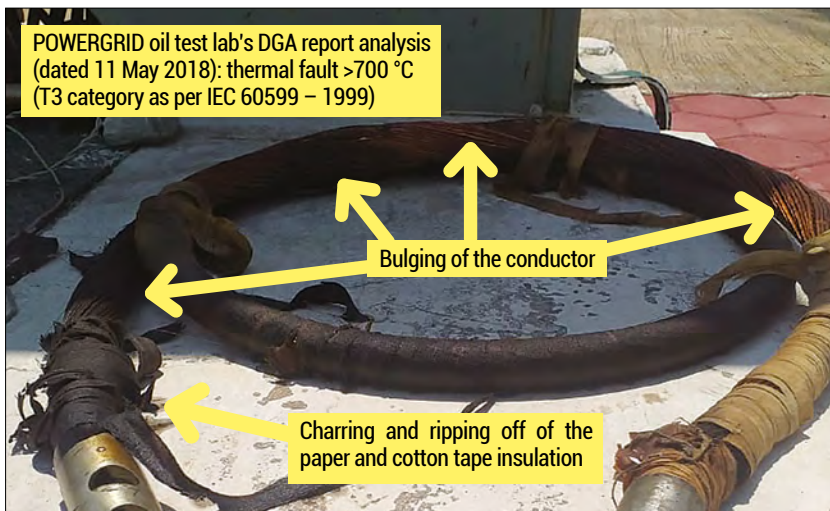


Figure 4. Depicts bulging of the strands, charred and ripped-off condition of cotton tape and the crepe paper strips of the draw-lead of 1V phase 420 kV OIP BHEL bushing of the BHEL 315 MVA, 400/220/33 kV transformer No. 1.

Measurement of the $\tan \delta$ of the bushing showed 1.02 %, while the maximum allowed value as per IEC 60137 is 0.7 %, and there was no significant change in its capacitance value

2. Probable cause of deterioration in $\tan \delta$ value in the instant case

In this bushing, a higher $\tan \delta$ value (1.02 %) was measured without significant change in its capacitance value. IR value recorded on 15 May 2020 of primary to $\tan \delta$ point was recorded on the lower side (11.2 G Ω) as compared to its initial IR value of 56 G Ω recorded on 25 March 2010. These results indicated deterioration, ageing or contamination of insulation.

After removal of the draw-lead type conductor of the deteriorated 420 kV BHEL bushing, a careful examination was carried out. A thermal heating was confirmed on the following grounds:

- a. DGA test reports of the oil samples of the main tank are tabulated in the Table 1 and Table 2, which depicts key gas ratios and existence of CO and CO₂ in ppm. Analyses of these parameters have been used as diagnostic tools.
- b. Looking at the Fig. 2, 3 and 4, the root cause appears to be heating of the bulged peripheral strands due to a skin effect over a certain period. It appears that the bulging of strands must have taken place during erection / installation of the 420 kV OIP bushing of 1 V phase of 315 MVA 400/220/33 kV BHEL transformer No. 1.
- c. Thermal fault of > 700 °C (T3), IEC: 60599 [2], as per DGA analysis by POWERGRID's oil test lab, Itarsi, report dated 11 May 2018 [3] on transformer main tank oil, substantiates the overheating of the draw lead.

Note: Considering the arguments stated above from (a) to (c), it is firmly inferred that the value of $\tan \delta$ has deteriorated due to the heating of the draw-lead of the 420 kV OIP bushing of 1 V phase of the BHEL transformer no. 1.

Table 1. DGA test reports

Dissolved gas analysis				
Test method IEC 60567; test lab: POWERGRID, Itarsi, (M.P.)				
Reference standard: IEEE C57.104-2008				
Gas contents	Unit	Measured value		
		19. 4. 2018	8. 5. 2018	16. 6. 2018
Total gas content	%	8.50	8.57	10.37
Nitrogen (N ₂)	%	6.37	6.46	7.91
Oxygen (O ₂)	%	1.44	1.36	1.68
Hydrogen (H ₂)	ppm	21	24	25
Methane (CH ₄)	ppm	73	77	76
Ethylene (C ₂ H ₄)	ppm	257	265	270
Ethane (C ₂ H ₆)	ppm	29	29	31
Acetylene (C ₂ H ₂)	ppm	2.1	2.3	1.3
Carbon monoxide (CO)	ppm	586	630	673
Carbon dioxide (CO ₂)	ppm	6116	6392	6719

Table 2. Following ratios of key gases, CO and CO₂ are used as diagnostic tools [4]

Date of sample	Ratios of key gases and CO and CO ₂		Remarks
	CH ₄ /H ₂	C ₂ H ₄ /C ₂ H ₆	
19. 4. 2018	73/21	257/29	High ratios of CH ₄ to H ₂ and C ₂ H ₄ to C ₂ H ₆ indicate a developing thermal fault.
8. 5. 2018	77/24	265/29	
16. 6. 2018	76/25	270/31	
	C ₂ H ₂ /C ₂ H ₄		
19. 4. 2018	2.1/257	Approaching a very low value	Suggests the possibility of a high-temperature thermal fault.
8. 5. 2018	2.3/265	-do-	
16. 6. 2018	1.3/270	-do-	
	CO	CO ₂	
19. 4. 2018	586 ppm	6116 ppm	High levels of carbon oxides (636 ppm of CO and 6392 ppm of CO ₂) indicate that the thermal fault in the paper is causing its pyrolysis.*
8. 5. 2018	636 ppm	6392 ppm	
16. 6. 2018	673 ppm	6719 ppm	

*Note: Pyrolysis is defined as a thermo-chemical decomposition of organic matter into non-condensable gases, condensable liquids and solid residual co-products, biochar or charcoal in an inert environment (i.e., in the absence of oxygen). The amount of non-condensable gas (CO₂, CO, H₂ & CH₄) increases with temperature.

Previous test results were verified from the records and it was found that the tan δ value of the bushing was showing an increasing trend

3. Retrofitting / replacement activities

3.1 Process carried out prior to declaring the bushing defective

During periodic maintenance on 15 May 2020, tan δ value on 400 kV Y-phase (1 V) bushing of 315 MVA BHEL's transformer was found to have increased to 1.02 %, which is higher than the maximum limit value of 0.7 %.

Previous test results were verified from the record and it was found that tan δ value of the said bushing was showing an increasing trend, as stated in Table 3.

Thorough cleaning of porcelain was done and the test-tap (tan δ) point was also cleaned with acetone solvent. After that, tan δ measurement was carried out again, but no improvement in the value thereof was observed.

In order to rule out any possibility of deterioration in the test socket epoxy insulation, attributing to deterioration of the insulation of the OIP bushing insulation, the test socket was subjected to uniform heat produced by a conventional 100 W filament bulb hung near the test socket for about 16 hours. Also, despite this process, no improvement was found in the tan δ value.

Measurement of IR value, from the 400 kV terminal to the tan δ point (test terminal) was carried out and found remarkably low on 15 March 2020: 11.2 GΩ as compared to the IR value of 56 GΩ recorded on the 25 March 2010, whereas IR value of tan δ point to earth was found in order.

It was therefore obvious that the defect was in the C1 part of the bushing insulation, which was very hazardous if ignored. Therefore, the issue was reported to higher authorities of our Power Transmission Utility.

3.2 Decision for replacement

Looking to the alarming deterioration of the tan δ value to 1.02 % of the 1 V phase, 420 kV OIP bushing of 315 MVA BHEL's transformer, much beyond the limiting value of 0.7 % (as per IEC:60137), the decision to replace it was taken by the Chief Engineer (Testing & Communication), MPPTCL.

3.3 Non-availability of a BHEL bushing

Spare 420 kV OIP draw lead type bushing of BHEL's design was neither available at the site nor in any of the stores of the Transmission Utility. However, in lieu thereof it was decided to use a spare 420 kV OIP draw-rod type bushing of TELK's design that was available at the site.

3.4 Verification of dimensions of the available 420 kV OIP bushing designed by TELK

With reference to the Fig. 5, relevant dimensions of TELK's design OIP bushing were compared with the defective 420 kV BHEL OIP bushing.

It is worth mentioning here that both 420 kV OIP bushings had 12 tightening holes.

Table 3. Tan δ and capacitance values

Date of measurement	Test voltage	Value of tan δ recorded	Capacitance recorded	Oil temperature	Remarks
25 Mar 2010	5 kV	0.20 %	423.78 pF	40.0 °C	During commissioning
13 Mar 2016	10 kV	0.15 %	426.3 pF	42.2 °C	Routine maintenance
15 Sep 2016	10 kV	0.23 %	421.71 pF	30.9 °C	Routine maintenance
20 Sep 2018	10 kV	0.42 %	420.87 pF	32.6 °C	Routine maintenance
2019	Not available	Not available	Not available	Not available	Non-availability of shut down
15 May 2020	10 kV	1.02 %	419.67 pF	35.0 °C	Routine maintenance

*Note: Due to non-availability of the shutdown in 2019, tan δ could not be measured.

Spare 420 kV OIP draw lead type bushing was neither available at the site nor in any of the stores of the Transmission Utility, so the decision was taken to use the available 420 kV OIP draw-rod type bushing

3.5 Challenges

It is evident from Table 5 that there are some differences in the dimensions, such as in the BCT diameter D2, physical size and physical shape of the stress shield.

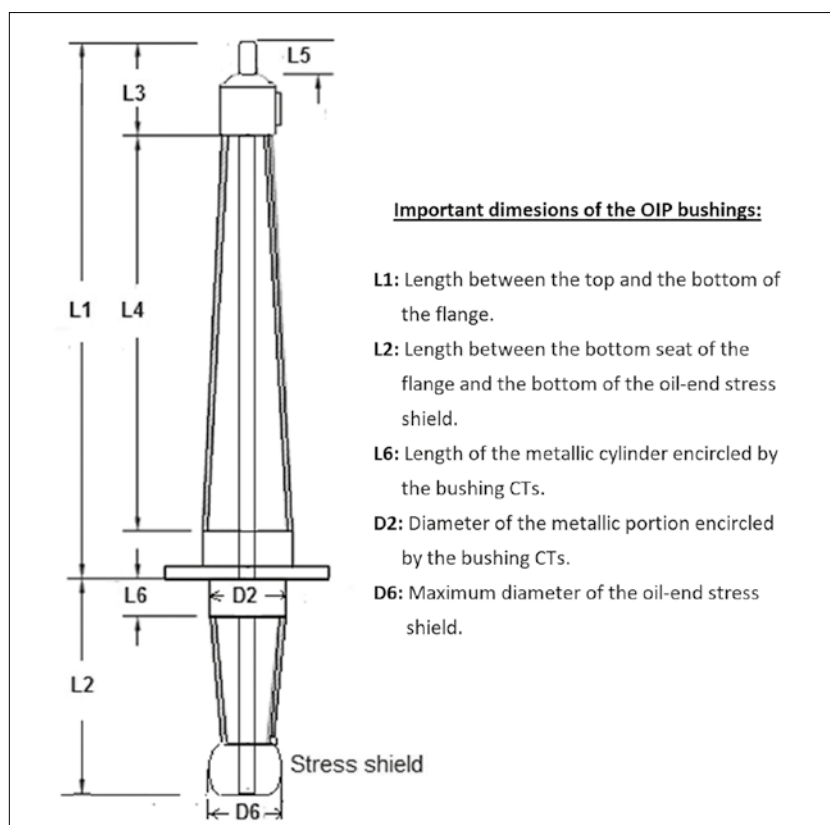


Figure 5. OIP bushing dimensions (in erect position) as per IS: 12676-1989 [5]

The installation of a draw-rod type bushing compared with the installation of a draw-lead type bushing is more complicated, especially in an oil-filled tank

Table 4. The dimensions of 420 kV bushings

Manufacturer	BHEL	TELK
Type	Draw-lead type	Draw-rod type
L1	4050 +/- 10 mm	4195 +/- 15 mm
L2	1640 +/- 5 mm	1640 +/- 10 mm
Flange diameter	720 mm	720 mm
PCD*	660 mm	660 mm
BCT diameter D2**	340 mm	350 mm
Space for BCT (length) L6	400 mm	400 mm
Stress shield physical size	Small	Larger
Stress shield physical shape	Oval	Cylindrical

Note:

*PCD is abbreviation of pitch centre diameter.

**BCT is the abbreviation of the bushing current transformer. The location of the bushing CTs may be seen in Fig. 2.

Table 5. Differences in the dimensions of 420 kV bushings

BCT diameter D2	340 mm	350 mm
Stress shield physical size	small	larger
Stress shield physical shape	oval	cylindrical

Looking to the differences in vital dimensions, it was a challenge to use the 420 kV OIP bushing (draw-rod type bushing) of TELK's design in place of the 420 kV OIP bushing (draw lead type bushing) made by BHEL. It may be worth mentioning that the installation of a draw-rod type

The installation of a draw-rod type bushing compared with the installation of a draw-lead type bushing is more complicated, especially in an oil-filled tank

bushing compared with the installation of a draw-lead type bushing is more complicated, especially in an oil-filled tank. The challenge was accepted by the engineers of MPPTCL under the leadership of R. K. Agrawal, E. E. (Testing Dn-II), MPPTCL Jabalpur, to guide R. K. Gupta, E. E., Testing Division Katni, and his team, without the help or support of either the transformer OEMs or the bushing OEMs.

As the same type / make bushing was not available in the field and we had to replace

the bushing without completely draining the oil from the transformer tank, thus shortening the outage period. Luckily, the stress shield diameter of the available bushing was the same as that of the existing bushing. It greatly helped us in replacing the bushing without completely draining the tank oil and without damaging the turret CT or stress shield itself. Fig. 7 shows the draw-rod of the 420 kV TELK OIP bushing.

- i. The draw-rod was thoroughly cleaned with acetone.
- ii. Thorough cleaning of the existing TELK's design spare bushing was done and was held in vertical position for a period of 24 hours with the support of a locally fabricated structure facilitating the settling down of oil in the bushing. Then the measurements of $\tan \delta$, capacitance and IR values were carried out and found to be in order. The test results were as shown below: At an ambient temp of 37 °C; $\tan \delta = 0.2739 \%$, Cap = 386.11 pF and IR value = 3.197 G Ω
- iii. For replacing the 420 kV BHEL's design draw-lead type bushing by with a TELK's design draw-rod type bushing, a 10,000-litre oil storage tank, oil filtration plant, two Hydra cranes (with long booms), and all tools and plants were arranged.
- iv. All gate valves of cooling banks' header pipes and conservator were closed and approximately 2,000 L of oil in the storage tank was drained up to the turret level.
- v. The BHEL's design 420 kV OIP draw-lead type bushing was dismantled with the help of a long boom Hydra crane.
- vi. Then the 420 kV draw-rod type TELK bushing was vertically lifted over the turret of 1 V phase of the BHEL's design 315 MVA transformer and the draw-rod thimble's round nut was opened with the help of locally fabricated pin spanner and lowered down to establish a joint between the draw-rod half-lap joint connector and the 420 kV wind-

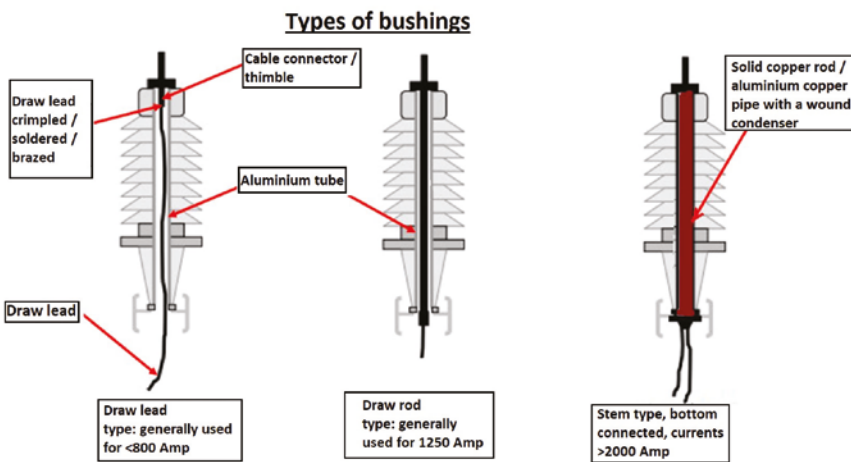


Figure 6. Types of bushings used in conventional transformers



Figure 7. Draw-rod of the 420 kV TELK OIP bushing

ing lead of 1 V phase half-lap joint connector of 315 MVA BHEL transformer. Draw-rod of the TELK bushing was successfully joined with the transformer lead by retrofitting the mismatch of the half-lap joint.

vii. After properly tightening the half-lap joint of the winding lead connector with the half-lap joint of the 420 kV draw-rod end and grinding the larger portion of the draw-rod half-lap connector to size, the whole exposed winding lead and the terminal connector (two halves of half-lap joint connector) were wrapped with a crape tape and then with a cotton tape over that (Fig. 9).

viii. The draw rod was pulled up and the thimble was fitted.

ix. Since the 1 V turret is tilted towards the outer side by about 15 degrees, an appropriate angle of the bushing was established with the second Hydra crane such that the TELK bushing (Fig. 10) assumed a tilted position of about 15 degrees to the vertical plane and then it was gradually lowered down through the turret CT (bushing CT), keeping all precautions since that the portion of the bushing CT area diameter of the TELK bushing was 10.0 mm larger than that of the BHEL bushing. There was hardly any play between the inner diameter of the turret CT (installed in the groove of the turret) and the diameter of the metallic portion of the bushing (diameter D2 in Fig. 5), which was encircled by the bushing CTs. The bushing was lowered down through the turret with utmost precision, maintaining an accurate angle with the successfully fitted stress shield, with the help of two Hydra cranes (Fig. 10).

x. Contrary to the TELK's procedure [6] of lowering down the bushing without a stress shield and fixing the stress shield by entering the transformer tank after decanting all of the oil, we performed the activity / procedure as narrated in (ix).

The following advantages were foreseen with the adoption of this procedure:

- a) The procedure not only saved time by decanting the complete amount of the oil, but also
- b) Averted the possibility of an accident involving the person entering a soiled and slippery transformer tank in order to fix the stress shield.

xi. After the oil filtration was done in a storage tank, the transformer oil was poured back into the transformer.

The measurements of $\tan \delta$, capacitance and IR values of the draw-rod type bushing were carried out and found to be in order

xii. As per TELK's guidelines [6], the settle-down time after the bushing is installed is 72 hours. Accordingly, the 420 kV OIP draw rod-type bushing was installed at around 16.00 hours on 18 May 2020.

xiii. The test results of the retrofitted 420 kV TELK draw rod-type OIP bushing after its installation through the 1 V phase turret, prior to energising of the 315 MVA BHEL transformer No. 2, were as follows:



Figure 8. A 420 kV OIP TELK's design bushing being inserted through the turret with a stress shield



Figure 9. Cotton tape wrapped over the half-lap joints of 1 V phase winding lead and the draw-rod type bushing, tightened

The next challenging task was to avoid mal-tripping of this 315 MVA transformer during the first energising due to the 2nd harmonic restraint component



Figure 10. Manoeuvring and lowering down of the TELK’s design 420 kV OIP bushing through 1 V turret of the BHEL’s design 315 MVA transformer with utmost care and precision using two long boom Hydra cranes.

- xiv. IR value of the 420 kV draw-rod type TELK OIP bushing:
 - a) Top terminal to tan δ point C1 after removing of the test tap cover = 440 G Ω with a 5 kV Megger
 - b) C2 point to earth = 33.5 G Ω with a 500 V Megger
- xv. Final tan δ and capacitance test of the 1 V phase 420 kV draw-rod type TELK OIP bushing at oil temperature of 35 °C and ambient temperature of 38 °C: tan δ = 0.2689 %, capacitance = 391.735 pF, and IR value = 3.86 G Ω , after the completion of 72 hours of settling time.

Table 7. Total downtime

Transformer switched off	11 May 2020	9.22 hrs
Charged	21 May 2020	16.50 hrs
Taken load	22 May 2020	11.30 hrs
Total downtime		11 days, 2 hrs, 8 min

Total downtime of the transformer was 11 days and 2 hours, which included removing of the existing draw-lead type bushing and retrofitting a new draw-rod type bushing

(Note: 10 kV kit designed by Omicron was used.)

4. Transformer energising strategy after the bushing replacement

Our next challenging task was to avoid mal-tripping of this 315 MVA transformer during the first energising due to the 2nd harmonic restraint component (12 % was the existing setting of the 2nd harmonic restraining in the numerical differential relay). To avoid this, we had reduced the 2nd harmonic restraining setting to 10 % from 12 % of the fundamental component and successfully charged the transformer after the replacement of the bushing. In the instant case, we did not want any unwanted tripping during the first charging of the transformer after the bushing was replaced. Since the DC tests were carried out, thus avoiding any complications, the 2nd harmonic restraining setting was lowered from 12 % to 10 % in the numerical differential relay.

The 315 MVA BHEL transformer No. 1 was successfully energised at 16.50 hrs on 21st May 2020.

Had this 2nd harmonic setting not been reduced, there would have been every possibility of the transformer tripping due to inrush current, which would have confused us to think that the tripping must have taken place due to some lacuna in retrofitting job of the bushing. Immediately after the successfully energising of the transformer, the 2nd harmonic restrain setting was restored to 12 %.

5. Total downtime

6. Benefits to transmission utility and the grid network

- i. A system disturbance due to tripping of the transformer or catastrophic failure of the transformer was avoided.
- ii. Had there been failure of 420 kV bushing and operation of NIFP (nitrogen injection fire prevention system), the downtime of the transformer would have been much longer as filtration of the drained oil into the underground sump due to operation of NIFPS would have taken a lot of time or would have called for topping-up of the transformer with new oil.
- iii. Savings in revenue since the job was carried out with available resources and without any support from the OEMs.
- iv. Shorter downtime, facilitating grid stability.
- v. Loss of revenue avoided.

7. Acknowledgements

The principal author would like to express his gratitude to the Managing Director and the Chief Engineer (Testing and Communication), Madhya Pradesh Power Transmission Co. Ltd. (India), for granting permission to him for using relevant data of 315 MVA 420/220/33 kV BHEL transformer No. 1 of the 400 kV substation, MPPTCL, Katni (India) and to associate the serving officers as his co-authors.

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- [6] Instruction manual of TELK OIP condenser type bushings up to 400 kV, publication No. T 9007 D (copy enclosed for reference)

Authors



K. K. Murty (Principal Author) is B.E. (Hons) El. Engg, FIE (India) and CE (India), member of CIGRE India. He is former Chief Engineer and HOD (Testing & Commun.), M.P. Power Transmission Co. Ltd. Jabalpur, having served in MPSEB & MPPTCL, Jabalpur for 33 years at different levels from the Assistant Engineer to the Chief Engineer. He was empanelled as an expert professional on the panel of CPRI, Bangalore and carried out TPI of Power equipment on behalf of CPRI, Bangalore / Bhopal (from 2008 until 2012). Mr. Murty also worked from 2004 until 2006 as an Advisor (Testing) in SOUTHCO, Berhampur, Odisha (a DISCOM in Odisha of Anil Dhirubhai Ambani group). He worked as Metering Consultant to M. P. Electricity Regulatory Commission, Bhopal, for a year in 2005 and as the Course Director for the Graduate Electrical Engineering Trainees, in the Training Institute of MPPTCL, Jabalpur (for two semesters in 2006 and 2007). He is a recipient of plaque in recognition of eminence and contribution to the profession of electrical engineering at the national level by Institute of Engineers India, Kolkata in October 2015.



R. K. Agrawal is a BE Electrical (Hons.) and his present post is that of the Executive Engineer of Testing Division I MPPTCL Jabalpur (India). He has 32 years of extensive experience in construction, testing and commissioning of EHV substations up to 400 kV class. He has presented a paper as co-author at 14th International conference on transformer (TRAFOSEM-2017) organised by ITMA Delhi (Refurbishment of old transformer in MPPTCL) and paper presented at a national seminar on testing and certification of transformer at CPRI Bhopal in 2020 (Hot spot temperature as defined in the IS: 2026-2/IEC 60076-2; Importance thereof as diagnostic tool in conjunction with DGA - citing a case-study). He has successfully performed retrofitting and replacement of bushing of 400 kV, 220 kV and 132 kV voltage class of EHV transformers. He has vast experience in erection and commissioning of EHV substations.



R. K. Gupta holds a diploma in Electrical Engineering & AMIE. His present post is that of the Executive Engineer of Testing Division, Katni. He has 32 years of extensive experience in operation and maintenance of EHV substations from 132 to 400 kV. Mr. Gupta was felicitated by MD, MPPTCL for promptly arresting the flow of oil consequent to failure of tertiary bushing of 315 MVA transformer at 400 kV S/S Bina and putting the transformer back into service after replacing the tertiary bushing, testing, and replacing the oil in 2005. He was also felicitated by MD, MPPTCL for attending to the OLTC of 63 MVA, 132/33 kV transformer, in the 132 kV S/S Sagar, without the help of OEMs service personnel. Testing Division Katni was awarded the third best performing Testing Division in MP in the 2019-2020 under his able leadership.



S. K. Chaturvedi holds a diploma in Electrical Engineering and bachelor's degree in Technology. He presently works as Assistant Engineer (maintenance) 400 kV S/s Katni, since October 2013 in a 950 MVA, 400/220/132 kV /33 kV AIS he is managing the maintenance and erection / installation jobs independently and successfully of EHV equipment up to 400 kV level. He was felicitated by MD MPPTCL for on spot repairing and installation of EMR make diverter switch on a 24-year-old 160 MVA, 220/132 kV TELK make transformer at 400 kV S/s Katni. He successfully assembled a 400 kV, 125 MVAR bus reactor and all associated equipment for the bay at 400 kV S/s Katni, within minimal time. He obtained ISO 9001-2008 certificate in 2015, for 50-year-old 132/33 kV AIS Kymore, for complete renovation. He successfully performed retrofitting and replacement of 220 kV, 132 kV, 33 kV, 22 old pneumatic circuit breakers / VCBs within minimal time and reconditioning of two 40-year-old 132/33 kV transformers.