General guidelines for safekeeping of high voltage transformers - Part 1

ABSTRACT

Transformers such as HV/EHV (132 kV and above) are the most vital and costly equipment in power systems and large Industries. It is the prime duty of HV/EHV substation managers, asset managers, and substation Operation & Maintenance (O&M) engineers to look after transformers, beginning from receipt on-site through their lifecycle scrupulously with motherly feelings.

Generally, OEM (Original Equipment Manufacturer) guidelines must be followed. This article is a significant and important contribution of experienced engineers in O&M and testing and commissioning up to 400 kV in HV/EHV substations. The authors deliberate all the aspects from receiving the consignment of an EHV Transformer on-site through its lifecycle, including O&M and life expectancy enhancement.

This article serves as a guideline for substation managers, asset managers, and substation engineers in the absence of any guidelines issued by their utilities or in the industry.

KEYWORDS:

N_2 (nitrogen gas), SFRA (Sweep Frequency Response Analysis), FAT (Factory Acceptance Test), TCIV (Transformer Conservator Isolation Valve), OEM (Original Equipment Manufacturer), DGA (Dissolved Gas Analysis), FDS (Frequency Domain Spectroscopy), furan analysis

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Transformers are one of the most expensive equipment in an electrical substation, and care should be taken as soon as they arrive at the site

The transformer should be kept under positive pressure between 0.1 bar and 0.3 bar (1.5psi to 4.4pis) at all times in storage

Figure 1. Transformer received loaded on multi-wheeled low-bed trailer

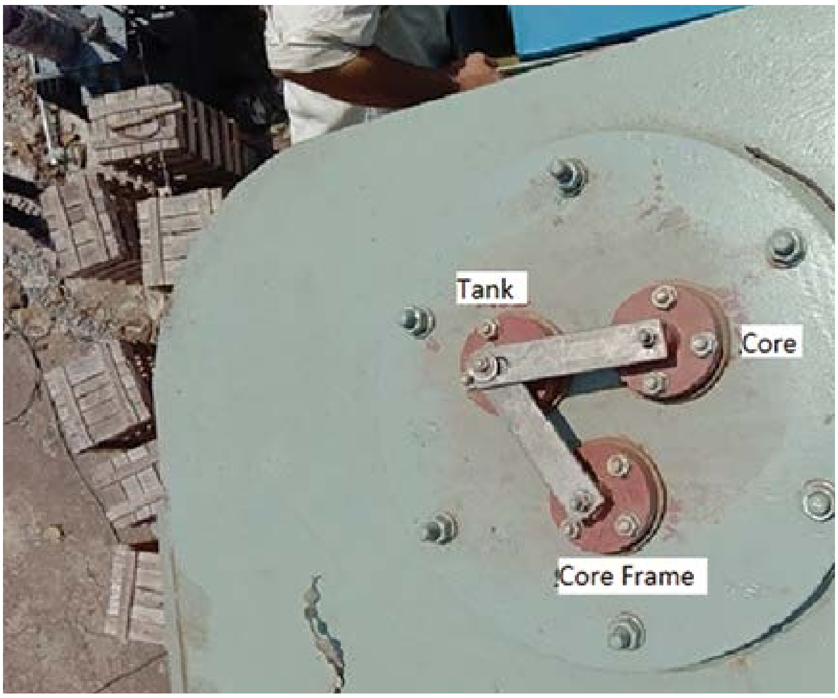

Figure 2. The tank, core, and core frame connections are brought out through individual bars to 2.5 kV* bushings are shorted together on the top cover of the transformer.
*Note: As far as the kV rating of such bushings is concerned, 2.5kV is adequate. However, some customers ask for 10kV AC for one minute as a test voltage. None of the international standards specify this test. These test points are basically for verification of whether the core is earthed at a single point or is earthed through the clamping frame or tank.

1. Introduction

Transformers are one of the most expensive equipment in an electrical substation. Utmost care is required immediately upon receipt of an HV/EHV transformer. Typically, their tanks arrive on a multi-wheeled low-bed trailer. A transformer should only be accepted if all prescribed tests are found satisfactory before unloading the transformer. Subsequently, the transformer may be transported from the trailer to the plinth and installed there. Thereafter, its erection, testing, commissioning, and O&M are carried out, beginning the life cycle. Address all points in sub-clauses, which should be carried out scrupulously in order for transmission utilities to extend the life expectancy of transformers to 35–40 years by adopting good maintenance practices.

Failure of HV/EHV transformers not only causes colossal losses to the utility and disturbances to the electrical grid but also dissatisfaction among consumers at large. In the case of continuous-process industries, owners may suffer enormous losses due to unforeseen failure of HV/EHV transformers.

2. Activities on receipt an HV/EHV transformer

The following checks and tests are performed upon arrival of the consignment of an HV/EHV transformer at the site before unloading it from a multi-wheeled low-bed trailer (Figure 1).

a) Before unloading a transformer from a multi-wheeled low bed trailer, the trailer should be placed in such a way that when it is unloaded, moved, and installed on the plinth, its HV/EHV bushings face toward the HV/EHV busbars.
b) Carry out a visual inspection of the transformer for any sign of physical damage during transportation.
c) Obtain the impact recorder and its data from factory officials.
d) Perform an SFRA test in the presence of OEM personnel and tally with the one taken at the time of dispatch of the transformer from their works through test bushings shown in Figure 3 [1].
e) Check the N_2 (nitrogen gas) pressure. It should have positive pressure in case of dispatch without oil (bulky transformers are transported with

nitrogen gas at positive pressure). In case the main body is shipped with oil, check the oil level and note any leakage.

f) For oil-filled transformers, a sample of oil should be taken from the bottom of the tank and tested for BDV (Breakdown Voltage) and moisture content. If the values do not meet the relevant standards, the matter should be taken up with the manufacturer.

g) Check the dew point of the N_2: it should not be higher than –30 °C (in the case of 400 kV transformers).

h) Check and verify that the transformer core is earthed at a single point only through the test bushings provided at the top of the transformer by removing the shorting links, as shown in Figure 2.

i) Measure the IR value between the core, frame and tank with a 500-2500 V DC insulation tester.

j) Check and verify the isolation of test leads from the transformer tank by testing continuity with a multimeter.

k) Perform the LV (Low voltage) magnetic balance test, magnetizing current test through test bushings as shown in Figure 3 and verify test results with the FAT (Factory Acceptance Test).

l) Verify the vector group of the transformer as per the R&D (Rating & Diagram) plate.

m) Check and confirm that packing case numbers match the packing list. Check contents and tally with the packing list if the packing case is damaged.

2.1. Prepare the transformer's life sketchbook (register) or computerized Excel file as soon as the transformer is received on site.

a) Enter all FAT results of the transformer.

b) Enter all activities of checking and testing mentioned in clause 2.0.

c) Enter all pre-commissioning tests and activities.

d) Enter all test results during semi-annual or annual routine maintenance. Include test reports pertaining to SFRA (Sweep Frequency Response Analysis), DGA (Dissolved Gas Analysis), furan analysis, etc.

e) Enter any other emergency repair or replacement of components.

3. Storage [1]

3.1 Storage—less than 90 days (with dry air or dry nitrogen)

The transformer should be kept under positive pressure between 0.1 bar and 0.3 bar (1.5psi to 4.4pis) at all times in storage. A reserve gas supply > 10 bar (150) must be coupled with a pressure vacuum regulator.

3.2 Storage—up to six months (liquid-filled)

Some OEMs permit storage in dry nitrogen or dry air for up to six months, but liquid-filled storage is preferred.

An unassembled transformer can be vacuum-filled with liquid up to the core level, and the space above is pressurized with dry nitrogen or dry air. An elevated pressure should be applied for several hours, and the tank should be checked for leaks. Both the cylinder pressure and the tank pressure should be monitored and recorded.

3.3 Storage—more than six months (as a spare for emergencies)

The spare transformer should be installed on its plinth. It should be fully assembled, vacuum-filled with liquid, tested and stored at the proper liquid level in the conservators. The silica-gel breather should be monitored from time to time so that the spare transformer is kept ready for replacement of a faulty transformer in case of emergency.

i. If the spare transformer has an OFAF (Oil-Flow Air-Forced) cooling system equipped with pumps, one-half of

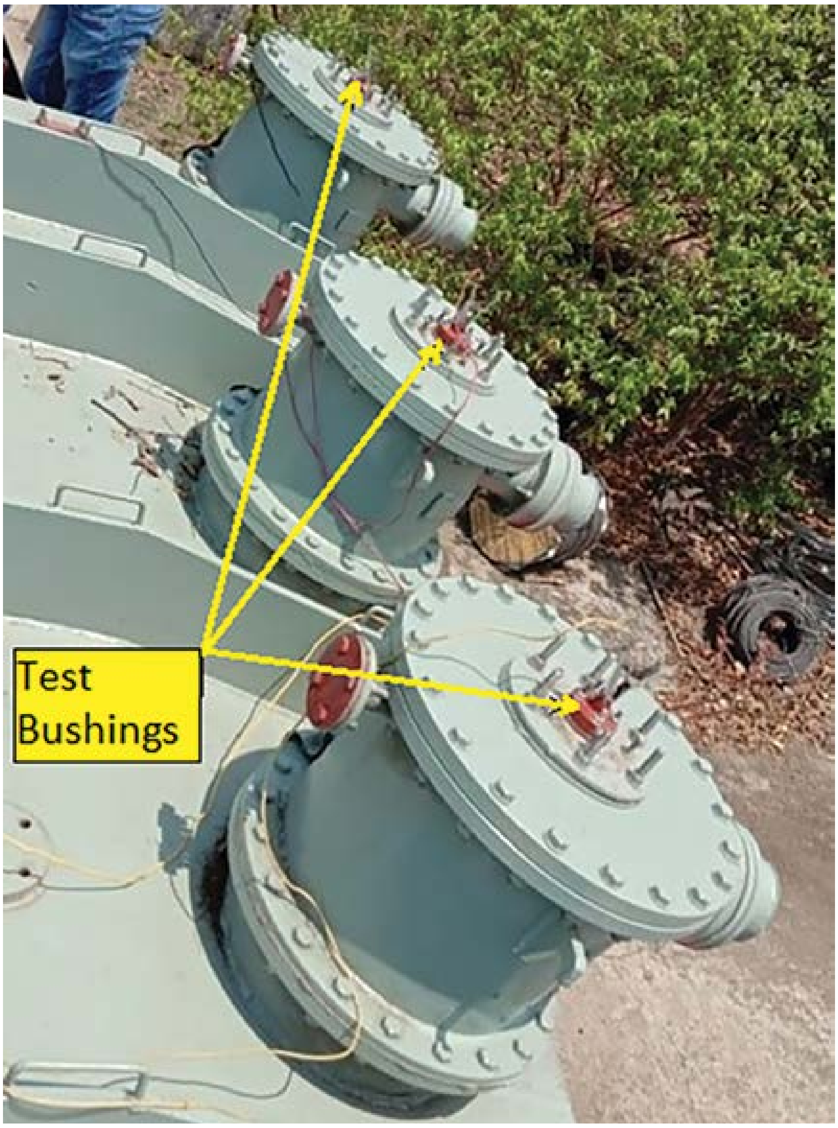

Figure 3. Epoxy test bushings on blanking plates of the transformer turrets. Test leads are connected to them for LV (Low voltage) tests of the transformer on the low-bed trailer.

Upon transformer arrival and after passing the initial tests, the transformer can be unloaded by means of wooden sleepers and hydraulic jacks with an adequate load-bearing capacity

the pumps should be run for 30 min, followed by operation of the other half periodically (3–6 months). The fans should be run for approximately 10 min monthly, and the control cabinet heaters should be checked.

ii. If the spare transformer has an ONAF (Oil-Natural Air-Forced) cooling system

Note: Where the transformer bank is comprised of 3+1 single phase units, all control cables at the top of the transformer pertaining to Buchholz, PRV (Pressure Relief Valve)/PRD (Pressure Relief Device), OSR (Oil Surge Relay), etc., should be brought into a marshalling box for quick change of control cable connections.

4. Erection, installation, and assembly

4.1 Shifting the transformer to the plinth and placing thereon transportation of the transformer and installation on the plinth

Unload the transformer by means of wooden sleepers and hydraulic jacks with adequate load-bearing capacity. Lower it down onto MS 'C' channels placed upside down on a pair of rail poles properly greased (Figure 4). Drag the transformer to the plinth on the rail centre with a manual Tirfor-winch or motorized geared winch machine of appropriate capacity. Fix the wheels and lock all wheels with rails on the plinth (Figure 5).

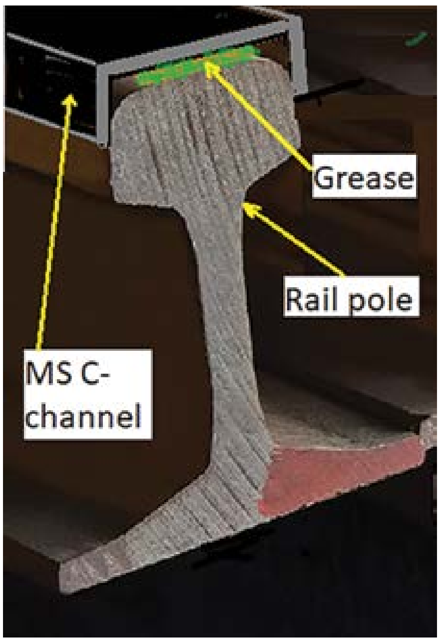

Figure 4. MS- C: Channel placed on a greased rail pole

4.2 Internal inspection

a) Preparation and precautions

i. For internal inspection of large transformers, dry compressed air / oxygen cylinders (4–5) are kept on site. There is always a threat of insufficient oxygen inside the tank, which may cause suffocation of personnel who enter the tank for internal inspection. Dry compressed air / oxygen is injected through the bottom valve, keeping one blank plate open on the top of the transformer tank on the opposite end for proper ventilation. Ensure continuous flow of dry air / oxygen during the entire internal inspection period.

ii. To facilitate proper internal inspection, illuminate the inside of the transformer tank with non-emitting heat-type lamps, e.g., LEDs.

iii. Arrange for videography / photography with a high-pixel camera.

iv. Before anyone enters the transformer tank for internal inspection, the engineer / supervisor on site must ensure that the person:
   (a) is wearing bare minimal clothing.
   (b) should not wear any ornamental / religious chain or locket, ring or watch, etc.
   (c) should tie a spanner and wrench of appropriate size with cotton tape around their waist.

b) Internal inspection activity

i. Carefully check the tightness of all core bolts, core-frame-tank leads, and selector-switch leads. Ensure that none of the bolts are left uninspected.

ii. Verify that the job no. is engraved on the core-frame assembly and matches with the job no. written on the R&D plate.

iii. Record by photo or video any abnormality or ambiguity.

4.3 Oil-filling activity

i. Before filling oil, all residual oil in the transformer tank should be drained out, and the tank bottom should be thoroughly cleaned with a cotton cloth.

ii. Fit equalizing pipes between the main tank and on-load tap changer (OLTC) compartments so that equal vacuum is applied in both the tank and the tap changer to prevent damage to the diverter-switch oil chamber / barrier board of the tap changer.

iii. After the activities in item 4.2b are complete, the transformer tank (excluding cooler banks and conservator) shall be evacuated to a vacuum pressure of 1.00 Torr[1] and held for 48 hours up to 220 kV class and for 72 hours for 400 kV transformers and above.

[1] Torr: a unit of pressure equivalent to mmHg

Before filling oil, all residual oil in the transformer tank should be drained out, and the tank bottom should be thoroughly cleaned with a cotton cloth

Note: (a) In the present day, some OEMs design the cooler banks to be vacuum-proof. In that case, cooler banks can be included. (b) Torr to mmHg conversion: 1 torr = 1 mmHg.

iv. Fill the oil / ester fluid* to the core level. Before filling, ensure all oil valves are in the correct position.

***Note:** Depending on the oil (a) mineral oil to conform to IS: 335-2018 (IEC 60296, 5th ed., 2020 and IEEE C57.106, 2015); (b) synthetic ester fluid to conform to IS 16081, June 2013 (IEC 61099:2010 describes specifications for unused synthetic organic esters for electrical purposes); (c) natural ester fluid to conform to IS: 16659 – 2017 (IEC 62770:2013 describes specifications and test methods for unused natural esters in transformers and similar oil-impregnated electrical equipment).

Figure 5. Wheels of the transformer are shown locked on rail pieces grouted on the plinth, and eyes are shown for hooking a wire-rope for dragging

Table 1. Variation of the dew point of dry air/N_2 gas-filled in the transformer/reactor tank w.r.t temperature

For transformer/reactor with a gas pressure of 2.5-3 PSI, the acceptable limits of dew point shall be as under			
Temperature of Insulation in °F	**Permissible dew point in °F**	**Temperature of Insulation in °C**	**Permissible dew point in °F**
0	-78	-17.77	-61.11
5	-74	-15	-58.88
10	-70	-12.22	-56.66
15	-66	-9.44	-54,44
20	-62	-6.66	-52.22
25	-58	-3.33	-49.99
30	-53	-1.11	-47.22
35	-48	1.66	-44.44
40	-44	4.44	-42.22
45	-40	7.44	-39 39
50	-35	9.99	-37.22
55	-31	12.77	-34.99
60	-27	15.55	-32.77
65	-22	18.33	-29.99
70	-18	23.11	-27.77
75	-14	23.88	-25.55
80	-10	26 66	-23.33
85	-6	29.44	-21.11
90	-1	32.22	-18.33
95	3	34.99	-16.11
100	7	37.75	-13.88
110	16	43.33	-8.88
120	25	48.88	-3.88
130	33	54.44	0.55
140	44	59.99	5.55

4.3.1 Before oil filling

v. Before filling oil in 400 kV transformers, the absolute vacuum of 1.00 torr should be held for 72hrs. Then, N2 gas of less than -50 °C dew point should be injected until such time that the vacuum pressure comes to the normal value and then to 0.2 kg/sq. cm pressure and to be kept in this condition for the next 24 hrs. Next, release N2 and measure the dew point of N2 coming out from the transformer. It should not be higher than -40 °C. Otherwise, repeat the N2 purge.

vi. Dew-point acceptable limits against temperature of insulation: For transformer/reactor with a gas pressure of 2.5-3 PSI, the acceptable limits of dew point shall comply with Table 1 [4].

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[2] CBIP Manual on transformers No.: 319-2013

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[10] IS: 16099 / IEC 61203 maintenance for used synthetic organic ester fluid

Authors

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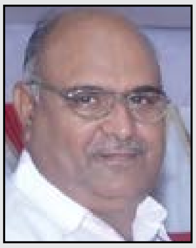

J. J. L. Kapil is a retired assistant engineer, 220 kV S/S, Jabalpur in June 2017, holding a diploma in electrical engineering. Among his commendations, MD MPPTCK has felicitated Mr. Kapil in recognition of his hard and sincere work and for preventing many incidences. He was responsible for the upkeep of 3x40 MVA 220/132/33 kV Mitsubishi transformer bank (1-Ph. units), which are still in service after 53 years.

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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.

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