Technical Specification

SECTION- 765 KV SHUNT REACTOR, NEUTRAL GROUNDING REACTOR AND SURGE ARRESTER

REV 08

JUNE 2021

Major changes in the latest Technical Specification Section – 765 kV Shunt Reactor, Neutral Grounding Reactor and Surge Arrester REV 08

Sr. No.	Clause	Brief Description of Major Changes
1.	1.2, 1.3 & 1.4	*New clause added*
2.	3.5, 3.6, 4.3 & 4.4	*Clause revised*
3.	4.6, 4.7 & 4.8	*New clause added*
4.	6.1, 6.2 & 6.4	*Clause revised*
5.	7.1.6, 7.1.7, 7.1.8, 7.1.9, 7.1.10	*New clause added*
6.	7.1.10, 7.2.3, 7.3, 7,4	*Clause revised*
7.	7.5.1	*Conservator Protection relay added*
8.	7.6.3, 7.8, 7.9, 7.10, 7.11, 7.12, 7.14.4, 7.19.2, 7.20.1, 7.20.2, 7.20.3, 7.20.9, 7.20. 7.20.14, 13,9, 9, 9.1, 9.2.6, 11.2, 11.16, 11.17, 13.3, 14.6, 14.7.1, 15	*Clause revised*
9.	16.3	*Material for coastal area added*
10.	17, 18.1, 22, 23.1, 23.2, 23.3.1,23.7.7	*Clause revised*
11.	Annexure-A	*Reactor Technical parameters revised*
12.	Annexure-H	*Surge Arrest rating revised.*
13.	Annexure-I	*Cable specification revised.*
14.	Annexure-L	*On-line insulating oil drying system included with each Reactor*
15.	-	*Optical Temperature Sensors & Measuring Unit deleted*

Disclaimer:
Major changes are listed above. However, for details of all major and minor modifications, please refer the complete technical specification Section - 765 kV Reactor Rev 08.

CONTENTS - SECTION- 765 KV SHUNT REACTOR, NEUTRAL GROUNDING REACTOR AND SURGE ARRESTER

TECHNICAL SPECIFICATION FOR 765 KV SHUNT REACTOR, NEUTRAL GROUNDING REACTOR AND SURGE ARRESTER

1. General

1.1. This specification covers design, engineering, manufacture, testing at manufacturer's works, delivery at site including all materials, accessories, spares, unloading, handling, proper storage at site, erection, testing and commissioning of the equipment specified.

1.2. The Reactor offered by the contractor shall at least conform to the requirements specified under relevant IS standard. In case of discrepancy between IS and other international standard, provisions of IS shall prevail. If the IS standard is not available, then other applicable International standard (IEC/Equivalent), as per the specification, shall be accepted.

1.3. Any material and equipment not specifically stated in this specification but which are necessary for satisfactory operation of the equipment shall be deemed to be included unless specifically excluded and shall be supplied without any extra cost.

1.4. Components having identical rating shall be interchangeable.

2. Type of Reactor

2.1. The shunt reactor shall be of either gapped core type or magnetically shielded air core type (shell type) construction. The impedance ratio (X0/X1) specified shall be achieved by any one of the following methods:

i) Adopting single phase construction in separate tanks.

ii) Adopting 3 limb core construction.

In case of coreless construction following requirements are stipulated.

i) A magnetic shield shall be provided around the coreless coils.

ii) Non-magnetic material sheet shall form the central core to minimize the vibrations.

The neutral grounding reactors are required for grounding of the neutral point of shunt reactors to limit the secondary arc current and the recovery voltage to a minimum value.

3. Transportation

3.1. The Contractor shall be responsible to select and verify the route, mode of transportation and make all necessary arrangement with the appropriate authorities for the transportation of the equipment. The dimension of the equipment shall be such that when packed for transportation, it will comply with the requirements of loading and clearance restrictions for the selected route. It shall be the responsibility of the contractor to coordinate the arrangement for transportation of the Reactor for all the stages from the manufacturer’s work to site.

3.2. The contractor shall carry out the route survey along with the transporter and finalise the detail methodology for transportation of reactor and based on route survey; any modification/ extension/ improvement to existing road, bridges, culverts etc. if required, shall be in the scope of the contractor.

3.3. The inland transportation of the reactor unit shall be on Hydraulic trailer equipped with GPS system for tracking the location of reactor at all times during transportation from manufacturer works to designated site. The contractor shall intimate to Employer about the details of transporter engaged for transportation of the reactor. The requisite details for tracking the reactor during transit shall be provided to Employer.

3.4. All metal blanking plates and covers which are specifically required during transport and storage of the reactor shall be considered part of the reactor and handed over to the Employer after completion of the erection. Bill of quantity of these items shall be included in the relevant drawing/document.

3.5. The Contractor shall despatch the Reactor filled with dry air at positive pressure. The necessary arrangement shall be ensured by the contractor to take care of pressure drop of dry air during transit and storage till completion of oil filling during erection. A dry air pressure testing valve with necessary pressure gauge and adaptor valve shall be provided. The dry air cylinder(s) provided to maintain positive pressure can be taken back by the contractor after oil filling.

In case, turrets are having insulation assembly and is transported separately then the same shall also be filled with dry air.

3.6. The Reactor shall also be fitted with atleast 2 numbers of Electronic impact recorders (on returnable basis) during transportation to measure the magnitude and duration of the impact in all three directions. The acceptance criteria and limits of impact, which can be withstood by the equipment during transportation and handling in all three directions, shall not exceed“3g” for 50mSec (20Hz) or as per contractor standard, whichever is lower.

4. Performance

4.1. Shunt Reactors will be connected to the 800 kV transmission system for reactive load compensation and shall be capable of controlling the dynamic over voltage occurring in the system due to load rejection.

4.2. Shunt Reactors shall be capable of operating continuously at a voltage 5% higher than their nominal rated voltage and thermal and cooling system shall be designed accordingly.

4.3. The reactors shall be designed for switching surge overvoltage of 1.9 p.u. and temporary over voltage of the order of 1.4 p.u. for about 15 cycles followed by power frequency overvoltage upto 830 kVrms for about five minutes. The reactor shall withstand the stress due to above transient dynamic conditions which may cause additional current flow as a result of changed saturation characteristics/slope beyond 1.25 p.u. voltage.

4.4. The reactor shall be designed to withstand the following over-voltages repeatedly without risk of failure (w.r.t. Hotspot temperature 140 Deg C & core saturation):

1.05 U_m for continuous
1.25 U_m for 1 minute
1.50 U_m for 5 seconds

Where maximum continuous operating voltage $U_m = 800/\sqrt{3}$ kV, Nominal rated voltage $U_n = 765/\sqrt{3}$ kV

4.5. The magnetic circuit will be designed such that the reactor is linear upto 125% maximum operating voltage.

4.6. Tank hotspot temperature under over voltage condition specified above shall not exceed 110 deg C considering maximum ambient temperature as 50 deg C

4.7. Also, the most onerous temperature of any part of the core and its supporting structure in contact with insulation or non-metal material shall not exceed the safe operating temperature of that material. Adequate temperature margins shall be provided to maintain long life expectancy of these materials.

4.8. The short circuit level of the 765kV system to which the reactors will be connected is 63kA for 1 sec (sym, rms, 3-phase fault)

4.9. **Radio Interference and Noise Level**

4.9.1. The reactor shall be designed with particular attention to the suppression of harmonic voltage, especially the third and fifth so as to minimise interference with communication circuit.

4.9.2. The noise level of reactor, when energised at maximum continuous operating voltage and frequency shall not exceed the values specified at **Annexure-A** measured under standard conditions.

5. Measurable Defects

The following shall constitute as Measureable Defects for the purpose of Defect Liabilities as per relevant clauses of GCC / SCC of the bidding document:

a) Repair, inside the Reactor either at site or at factory is carried out after commissioning.

b) The concentration of any fault gas is more than values of condition-1 indicated in clause no 6.5 of IEEE-C57.104-2008, which are given below:

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	TDCG
100	**120**	**1**	**50**	**65**	**350**	**2500**	**720**

c) The winding Tan delta goes beyond 0.005 or increase more than 0.001 within a year w.r.t. pre-commissioning values. No temperature correction factor shall be applicable for tan delta

d) The moisture content goes above 12 ppm at any temperature during operation.

6. Design review

6.1. The reactor shall be designed, manufactured and tested in accordance with the best international engineering practices under strict quality control to meet the requirement stipulated in the technical specification. Adequate safety margin w.r.to thermal, mechanical, dielectric and electrical stress etc. shall be maintained during design, selection of raw material, manufacturing process etc. The scope of such design review shall include but not limited to the requirement as mentioned at Annexure – D.

6.2. Design reviews shall be conducted by Employer or an appointed consultant during the procurement process for Reactors; however the entire responsibility of design shall be with the manufacturer. Employer may also visit the manufacturers works to inspect design, manufacturing and test facilities at any time.

The design review will commence after placement of award and shall be and shall be finalised before commencement of manufacturing activity. These design reviews shall be carried out in detail to the specific design with reference of the reactor under the scope. It shall be conducted generally following the "CIGRE TB 529: Guidelines for conducting design reviews for power transformers"

6.3. The manufacturer shall provide all necessary information and calculations to demonstrate that the reactor meets the requirements for mechanical strength and durability due to inrush current. The latest recommendations of IEC and Cigre SC 12 shall be applied for short circuit withstand evaluation.

6.4. **Type test requirement & it's validity**

The offered Reactor or the Reactor, the design of which is similar to the offered Reactor, should have been successfully type tested. Manufacturer may use same or different approved make of Bushings and other accessories used in type tested or short circuit tested unit in their Reactor. Further, type test report of Reactor shall only be acceptable provided the offered Reactor has been manufactured from the same plant. The Reactor Type test validity period shall be as per Technical Specification Section-General Technical Requirement (GTR).

Central Electricity Authority's "Guidelines for the validity period of type tests conducted on major electrical equipment in power transmission system" shall be followed regarding the validity of type tests of Bushings and other accessories.

7. Construction Details

The construction details and features of each Shunt Reactor shall be in accordance with the requirement stated hereunder.

7.1. Tank

7.1.1. Tank shall be fabricated from tested quality low carbon steel of adequate thickness. Unless otherwise approved, metal plate, bar and sections for fabrication shall comply with IS 2062.

7.1.2. All seams and those joints not required to be opened at site, shall be factory welded, and wherever possible they shall be double welded. Welding shall conform to IS 9595. After fabrication of tank and before painting, dye penetration test shall be carried out on welded parts of jacking bosses, lifting lugs and all load bearing members. The requirement of post weld heat treatment of tank/stress relieving shall be based on recommendation of IS 10801.

7.1.3. Tank stiffeners shall be provided for general rigidity and these shall be designed to prevent retention of water.

7.1.4. The tank shall be of proven design either bell type with bolted /welded joint or conventional type with welded / bolted top cover. Bell type tank shall be provided with joint at about 500 mm above the bottom of the tank. The welded joint shall be provided with flanges suitable for repeated welding. The joint shall be provided with a suitable gasket to prevent weld splatter inside the tank. Proper tank shielding shall be done to prevent excessive temperature rise at the joint.

7.1.5. The tank shall be designed in such a way that it can be mounted on the plinth directly.

7.1.6. The base of each tank shall be so designed that it shall be possible to move the complete Reactor unit by skidding in any direction without damage when using plates or rails and the base plate shall have following minimum thickness:

Length of tank (m)	**Minimum plate thickness (mm)**
Flat bases	
over 2.5m but less than 5m	20
over 5m but less than 7.5m	26
exceed 7.5m	32

7.1.7. The hotspot temperature in any location of the tank shall not exceed 110 degree Celsius at 800kV. This shall be measured during temperature rise test at manufacturer's works.

7.1.8. Tank shall be capable of withstanding, without damage, severe strains that may be induced under normal operating conditions or forces encountered during lifting, jacking and pulling during shipping and handling at site or factory. Tank, tank cover and associated structure should be adequately designed to withstand, without damage or permanent deflection / deformation, the forces arising out of normal oil pressure, test pressures, vacuum, seismic conditions and short circuit forces specified.

7.1.9. Tank MS plates of thickness >12 mm should undergo Ultrasonic Test (UT) to check lamination defect, internal impurities in line with ASTM 435 & ASTM 577.

7.1.10. All pipes connected to Reactor shall follow IS 1239.

7.1.11. Tank shall be provided with:

a. Lifting lugs: Four symmetrically placed lifting lugs shall be provided so that it will be possible to lift the complete Reactor when filled with oil without structural damage to any part of the Reactor. The factor of safety at any one point shall not be less than 2.

b. A minimum of four jacking pads in accessible position to enable the Reactor complete with oil to be raised or lowered using hydraulic jacks. Each jacking pad shall be designed to support with an adequate factor of safety at least half of the total mass of the Reactor filled with oil allowing in addition for maximum possible misalignment of the jacking force to the centre of the working surface.

Specific area shall not be provided for jacking pad in the foundation as jacking shall be done by laying temporary metal plates size 400 mm x 400 mm x 32 mm (min) thick. One set of metal plates for jacking of Reactor shall be provided by manufacturer.

c. Suitable haulage holes shall be provided.

d. 04 nos. of Gate valves for UHF sensors for PD Measurements at various locations. Location of valves shall be finalized during design review.

7.2. **Tank Cover**

7.2.1. The tank cover shall be designed to prevent retention of water and shall not distort when lifted. The internal surface of the top cover shall be shaped to ensure efficient collection and direction of free gas to the buchholz relay.

7.2.2. At least two adequately sized inspection openings one at each end of the tank, shall be provided for easy access to bushings and earth connections. The inspection covers shall not weigh more than 25 kg. Handles shall be provided on the inspection cover to facilitate lifting.

7.2.3. The tank cover shall be provided with pockets for OTI, WTI and RTDs including 2 spare pockets. The location of pockets shall be in the position where oil reaches maximum temperature. Further, it shall be possible to remove bulbs of OTI/WTI/RTD without lowering the oil in the tank. The thermometer shall be fitted with a captive screw to prevent the ingress of water.

7.2.4. Bushing turrets, covers of inspection openings, thermometer pockets etc. shall be designed to prevent ingress of water into or leakage of oil from the tank.

7.2.5. All bolted connections shall be fitted with weather proof, hot oil resistant, resilient gasket in between for complete oil tightness. If gasket is compressible, metallic stops/other suitable means shall be provided to prevent over-compression.

7.2.6. **Currents flowing in tank cover and bushing turrets** - To allow for the effect of possible induced and capacitive surge current, the tank cover and bushing turret shall be fixed to the Reactor in such a way that good electrical contact is maintained around the perimeter of the tank and turrets.

7.2.7. The Reactor shall be provided with a 150 mm nominal diameter butterfly valve and bolted blanking plate, gasket and shall be fitted at the highest point of the Reactor for maintaining vacuum in the tank.

7.2.8. **Gas venting** - The reactor cover, and generally the internal spaces of the reactor and all pipe connections shall be designed so as to provide efficient venting of any gas in any part of the reactor to the Buchholz relay. The space created under inspection /manhole covers shall be filled with suitable material to avoid inadvertent gas pockets. The Covers shall be vented at least at both longitudinal ends. The design for gas venting shall take into accounts the slopes of the plinth (if any) on which the Reactor is being mounted.

7.3. **Gasket for tank & cover**

All gasketed joints in contact with oil shall be designed, manufactured and assembled to ensure long-term leak and maintenance free operation. All gasketed joints unless otherwise approved shall be of the O-ring and groove type. All bolted connections shall be fitted with weather proof, hot oil resistant, resilient gasket in between for complete oil tightness. If gasket is compressible, metallic stops/other suitable means shall be provided to prevent over-compression.

All tank gaskets used shall be of NBR (Acrylonitrile butadiene Rubber generally known as NBR) and properties of all the above gaskets / O-Rings shall comply with the requirements of IS-11149 (Grade IV) Material selected shall suit temperature conditions expected to be encountered. Neoprene / cork sheets gaskets are not acceptable. The Gaskets and O-rings shall be replaced every time whenever the joints are opened.

7.4. Foundation, Roller Assembly & Anti Earthquake Clamping Device

The Reactor shall be placed directly on concrete plinth foundation. To facilitate the movement of reactor to its foundation over rail track, bi-directional flanged rollers shall be provided. It shall be suitable for fixing to the under carriage of Reactor. The rail track gauge shall be 1676 mm. Two rails shall be provided as per the drawing mentioned at **Annexure-C.**

Scope shall include supply of complete two sets of rollers assembly for movement of Reactors over rail track for each substation in case scope covers more than one Reactor per sub-station under the package. Otherwise, atleast one set shall be supplied.

Foundation bolts and other locking devices shall be in the scope of contractor.

Regarding cooler pipe supports, Buchholz pipe (if required) and fire-fighting pipe supports shall be fixed on concrete block through Anchor Fastener with chemical grouting and no pockets for bolting shall be provided.

All control cubicles shall be mounted at least one meter above FGL (Finished Ground Level) to take care of water logging (if any) during flooding. Suitable arrangement (ladder and platform) shall be provided for safe access to control cubicles.

All fittings (Foundation bolts, supports, embedded plates if any) including anchor fastener with chemical grouting are in the scope of contractor.

7.5. Conservator

7.5.1. Conservator shall have air cell type constant oil pressure system to prevent oxidation and contamination of oil due to contact with moisture.

Conservator Protection Relay (CPR)/Air cell puncture detection relay shall be installed to give alarm in the event of lowering of oil in the conservator due to puncture of air cell in service.

Conservator shall be fitted with magnetic oil level gauge with potential free high and low oil level alarm contacts and prismatic oil level gauge and Conservator Protection Relay

7.5.2. Conservator tank shall have adequate capacity with highest and lowest visible-levels to meet the requirements of expansion of total cold oil volume in the reactor and cooling equipment from minimum ambient temperature to top oil temperature of 110 deg C. The capacity of the conservator tank shall be such that the reactor shall be able to carry the specified overload without overflowing of oil.

7.5.3. The conservator shall be fitted with lifting lugs in such a position so that it can be removed for cleaning purposes. Suitable provision shall be kept to replace air cell and cleaning of the conservator as applicable.

7.5.4. Conservator shall be positioned so as not to obstruct any electrical connection to Reactor.

7.5.5. The connection of air cell to the top of the conservator is by air proof seal preventing entrance of air into the conservator. The main conservator tank shall be stencilled on its underside with the words **"Caution: Air cell fitted".** Lettering of at least 150 mm size shall be used in such a way to ensure clear legibility from ground level when the Reactor is fully installed. To prevent oil filling into the air cell, the oil filling aperture shall be clearly marked. The Reactor rating and diagram plate shall bear a warning statement that the **"Conservator is fitted with an air cell".**

7.5.6. Contact of the oil with atmosphere is prohibited by using a flexible air cell of nitrile rubber reinforced with nylon cloth. The temperature of oil in the conservator is likely to raise up to 110^{O}C during operation. As such air cell used shall be suitable for operating continuously at this temperature.

7.5.7. The reactor manual shall give full and clear instructions on the operation, maintenance, testing and replacement of the air cell. It shall also indicate shelf life, life expectancy in operation, and the recommended replacement intervals.

7.5.8. The conservator tank and piping shall be designed for complete vacuum / filling of the main tank and conservator tank. Provision must be made for equalising the pressure in the conservator tank and the air cell during vacuum / filling operations to prevent rupturing of the air cell.

7.5.9. The contractor shall furnish the leakage rates of the rubber bag/ air cell for oxygen and moisture. It is preferred that the leakage rate for oxygen from the air cell into the oil will be low enough that the oil will not generally become saturated with oxygen before 10 years. Air cells with well proven long life characteristics shall be preferred.

7.6. Piping works for conservator

7.6.1. Pipe work connections shall be of adequate size for their duty and possibly short and direct. Only radiused elbows shall be used.

7.6.2. The feed pipe to the Reactor tank shall enter the reactor cover plate at its highest point and shall be straight for a distance not less than five times its internal diameter on the reactor side of the Buchholz relay, and straight for not less than three times that diameter on the conservator side of the relay. This pipe shall rise towards the oil conservator, through the Buchholz relay, at an angle of not less than 5 degrees. The feed pipe diameter for the main conservator shall be not less than 80 mm. Gas-venting pipes shall be connected to the final rising pipe between the reactor and Buchholz relay as near as possible in axial direction and preferably not less than five times pipe diameters from the Buchholz relay.

7.6.3. This pipe shall rise towards the oil conservator, through the Buchholz relay, at an angle of not less than 5 degrees. The feed pipe diameter for the main conservator shall be not less than 80mm.

7.6.4. A double flange valve of preferably 50 mm and 25 mm size shall be provided to fully drain the oil from the main tank conservator.

7.6.5. Pipe work shall neither obstruct the removal of the opening of inspection or manhole covers.

7.7. Dehydrating Silicagel Filter Breather

Conservator of Main Tank shall be fitted with a dehydrating silicagel filter breather. Connection shall be made to a point in the oil conservator not less than 50 mm above the maximum working oil level by means of a pipe with a minimum diameter of 25 mm. Breathers having a mass less than 10 kg may be supported by the connecting pipe, whereas units of 10 kg and above shall be supported independent of the connecting pipe. Connecting pipes shall be securely clamped to the reactor, or other structure supplied by the contractor, in such a manner so as to eliminate undesirable vibration and noise. In the case where a breather of less than 10 kg is supported by the pipe, there shall be a cleat directly above the breather flange. The design shall be such that:

a) Passage of air is through silicagel.
b) Silicagel is isolated from atmosphere by an oil seal.
c) Moisture absorption indicated by a change in colour of the crystals.
d) Breather is mounted approximately 1200 mm above rail top level.
e) To minimise the ingress of moisture three breathers (of identical size) shall be connected in series for main tank conservator. Contractor shall provide flexible connection pipes to be used during replacement of any silicagel breather.

7.8. Pressure Relief Device

One PRD of 150 mm Diameter is required for every 30000 Litres of oil. However, at least two numbers PRDs shall be provided. Its mounting should be either in vertical or horizontal orientation, preferably close to bushing turret or cover. PRD operating pressure selected shall be verified during design review. PRD shall be provided with special shroud to direct the hot oil in case of fault condition. It shall be provided with an outlet pipe which shall be taken right up to the soak pit of the reactor. The size (Diameter) of shroud shall be such that it should not restrict rapid release of any pressure that may be generated in the tank, which may result in damage to equipment. Oil shroud should be kept away from control cubicle and clear of any operating position to avoid injury to personnel in the event of PRD operation. The device shall maintain its oil tightness under static oil pressure equal to the static operating head of oil plus 20 kPa. It shall be capable of withstanding full internal vacuum at mean sea level. It shall be mounted directly on the tank. Suitable canopy shall be provided to prevent ingress of rain water. One set of potential free contacts (with plug & socket type arrangement) per device shall be provided for tripping. Following routine tests shall be conducted on PRD:

a) Air pressure test

b) Liquid pressure test
c) Leakage test
d) Contact operation test
e) Dielectric test on contact terminals

7.9. Sudden Pressure Relay

One number of Sudden Pressure relay with alarm/trip contacts **(Terminal connection plug & socket type arrangement**) shall be provided on tank of Reactor. Operating features and size shall be reviewed during design review. Suitable canopy shall be provided to prevent ingress of rain water. Pressurised water ingress test for Terminal Box (routine tests) shall be conducted on Sudden Pressure Relay.

Plug & socket type arrangement with factory fitted cable of adequate length shall be supplied by OEM. Connection of plug and socket with cable at site is not acceptable.

7.10. Buchholz Relay

One number Double float, reed type Buchholz relay complying to IS 3637 shall be provided in the connecting pipe between the oil conservator and the Reactor tank with minimum distance of five times pipe diameters between them. Any gas evolved in the Reactor shall be collected in this relay. The relay shall be provided with a test cock suitable for a flexible pipe connection for checking its operation and taking gas sample. A copper tube shall be connected from the gas collector to a valve located about 1200 mm above ground level to facilitate sampling while the Reactor in service. Suitable canopy shall be provided to prevent ingress of rain water. Each device shall be provided with two potential free contacts **(Plug & socket type arrangement),** one for alarm / trip on gas accumulation and the other for tripping on sudden rise of pressure.

Plug & socket type arrangement with factory fitted cable of adequate length shall be supplied by OEM. Connection of plug and socket with cable is not acceptable at site.

It should be possible to inspect Buchholz relay or Oil surge relay, standing on tank cover and suitable arrangement shall be made to access Buchholz relay safely.

The Buchholz relay shall not operate during starting/stopping of the Reactor oil circulation under any oil temperature conditions. The pipe or relay aperture baffles shall not be used to decrease the sensitivity of the relay. The relay shall not mal-operate for through fault conditions or be influenced by the magnetic fields around the Reactor during the external fault conditions. Pressurised water ingress test for Terminal Box (routine tests) shall be conducted on Buchholz relay.

7.11. Oil Temperature Indicator (OTI)

All Reactors shall be provided with a dial type thermometer of around 150 mm diameter for top oil temperature indication with angular sweep of 270°. It shall have adjustable, potential free alarm and trip contacts besides that required for control of cooling equipment if any. A temperature sensing element suitably located in a pocket on top oil shall be provided. This shall be connected to the OTI instrument by means of flexible capillary tubing with stainless-steel armoured. Temperature indicator dials shall have linear gradations to clearly read at least every 2 deg C. Range of temperature should be 0- 150°C with accuracy of ±1.5% (or better) of full scale deflection. The setting of alarm and tripping contacts shall be adjustable at site. Adjustable range shall be 20-90% of full-scale range. Heavy duty micro switch of 5A at 240V AC shall be used. The instruments case should be weather proof and having epoxy coating at all sides. Instruments should meet ingress protection class of IP55 as per IS 13947/IEC60529. The instruments should be capable of withstanding line to body high voltage of 2.5kV AC rms, 50Hz for 1 minute.

In addition to the above, the following accessories shall be provided for remote indication of oil temperature:

Temperature transducer with Pt100 sensor

RTD shall be provided with PT100 temperature sensor having nominal resistance of 100 ohms at zero degree centigrade. The PT100 temperature sensor shall have three wire ungrounded system. The calibration shall be as per IEC 60751 or equivalent. The PT100 sensor may be placed in the pocket containing temperature sensing element. RTD shall include image coil for OTI system and shall provide dual output 4-20mA for SCADA system. The transducer shall be installed in the Individual Marshalling Box. Any special cable required for shielding purpose, for connection between PT100 temperature sensor and transducer, shall be in the scope of Contractor. 4-20mA signal shall be wired to Digital RTCC panel / BCU for further transfer data to SCADA through IS/IEC 61850 compliant communications.

7.12. Winding Temperature Indicator (WTI)

All Reactor shall be provided with a device for measuring the hot spot temperature of winding with dial type thermometer of 150 mm diameter for winding temperature indication with angular sweep of 270°and shall have adjustable potential free alarm and trip contacts besides that required for control of cooling equipment if any. The setting of alarm and tripping contacts shall be adjustable at site. A temperature sensing bulb located in a thermometer pocket on tank cover should be provided to sense top oil. This shall be connected to the WTI instrument by means of flexible capillary tubing with stainless-steel armoured. WTI shall have image coil and auxiliary CTs, if required to match the image coil, shall be mounted in the Marshalling Box / cooler control cabinet. Temperature indicator dials shall have linear gradations to clearly read at least every 2^0C. Range of temperature should be 0- 150°C with accuracy of ±1.5% (or better) of full scale deflection. Adjustable range shall be 20-90% of full-scale range. Heavy duty micro switch of 5A at 240V AC shall be used. The instruments case should be weather proof and having epoxy coating at all sides. Instruments should meet ingress protection class of IP55 as per IS 13947 /IEC60529. The instruments should be capable of withstanding line to body high voltage of 2.5kV AC rms, 50Hz for 1 minute.

In addition to the above, the following accessories shall be provided for remote indication of winding temperature:

Temperature transducer with Pt100 sensor for each winding

RTD shall be provided with Pt100 temperature sensor having nominal resistance of 100 ohms at zero degree centigrade. The Pt100 temperature sensor shall have three wire ungrounded system. The calibration shall be as per IEC 60751-2 or equivalent. The Pt100 sensor may be placed in the pocket containing temperature sensing element. RTD shall include image coil, Auxiliary CTs, if required to match the image coil, for WTI system and shall provide dual output 4-20mA for remote WTI and SCADA system individually. The transducer, Auxiliary CT shall be installed in the Individual

Marshalling Box. Any special cable required for shielding purpose, for connection between Pt100 temperature sensor and transducer, shall be in the scope of Contractor. 4-20mA signal shall be wired to Digital RTCC / BCU panel for further transfer data to SCADA through IS / IEC 61850 compliant communications.

7.13. The temperature indicators (OTI & WTI) shall be so mounted that the dials are about 1200 mm from ground level. Glazed door of suitable size shall be provided for convenience of reading.

7.14. **Earthing Terminals**

7.14.1. Two (2) earthing pads (each complete with two (2) nos. holes, M16 bolts, plain and spring washers) suitable for connection to 75 x 12 mm galvanised steel grounding flat shall be provided each at position close to earth of the two (2) diagonally opposite bottom corners of the tank.

7.14.2. Two earthing terminals suitable for connection to 75 x 12 mm galvanised steel flat shall also be provided on each individual/common marshalling box and any other equipment mounted separately. For the tank-mounted equipment like online drying/ Online DGA/Optical sensor etc. double earthing shall be provided through the tank for which provision shall be made on the tank and connected through two flexible insulated copper links.

7.14.3. Equi-potential flexible copper link of suitable size at least 4 Nos. for Tank mounted turret with tank and tank with cover and or Bell shall be provided. For other components like - pipes, conservator support etc connected to tank shall also be provided with equipotential flexible copper link.

7.14.4. Each Reactor unit should have provision for earthing and connected to grounding mat when not in service. For this purpose, line Terminal shall also be earthed through neutral by flexible copper connection. Contractor shall provide suitable arrangement for the above. 1.1kV Grade PVC FR type cable of 16 sq.mm (minimum) shall be used for above connection. Neutral shall have provision for connection to ground by a brass/tinned copper grounding bar supported from the tank by using porcelain insulator. The end of the tinned/brass copper bar shall be brought to the bottom of the tank at a convenient point for making bolted connection to 75 X 12 mm GS flat connected to station grounding mat. The other end of the tinned/brass copper bar shall be connected to the neutral bushing through flexible conductor/jumper.

7.15. **Core**

7.15.1. The core shall be constructed from non-ageing, cold rolled grain oriented silicon steel laminations of conventional grade (as per BIS) / regular grade (as per IEC) or better. Indian reactor manufacturers shall use core material as per above specification with BIS certification.

7.15.2. The leg magnetic packets (cheeses) shall be made from state of the art low loss electrical steel CRGO (conventional/regular grade or better). The “Cheeses” shall be designed to minimize losses and equalize the distribution of flux in the legs.

7.15.3. The “cheeses” shall be bonded using high temperature epoxy resins to assure that they will remain bonded in service at the maximum temperatures that will occur in the magnetic circuit and for the full expected life. Vacuum impregnation is preferred. The contractor shall present data on the characteristics of the packets at the time of design review.

7.15.4. Material with high temperature withstand capability such as ceramic/ slate spacers shall be used to separate the packets. High temperature, mechanically stable material shall be used between the end packets and the top and bottom yokes. Special care shall be taken not to impede the cooling in these areas.

7.15.5. Means shall be provided to distribute the flux from the "cheeses" and the windings to the top and bottom yokes to prevent concentrations of flux with resulting high temperatures in the yokes.

7.15.6. The yokes shall be designed such that high temperatures resulting from unequal distribution of the flux in the yokes will not occur.

7.15.7. The spaces between "cheeses" will be designed so that high temperatures will not result due to fringing of flux at the oil gaps between them. The designer shall calculate the temperatures resulting from fringing.

7.15.8. The design of the magnetic circuit shall be such as to avoid static discharges, development of short circuit paths within itself or to the earthed clamping structure and production of flux component at right angles to the plane of laminations which may cause local heating.

7.16. Internal Structure Design

7.16.1. The structural design shall be made so that pressure will be maintained to prevent loosening resulting from thermal expansion and contraction during all loading cycles.

7.16.2. The design shall be made in such a way that excessive vibration does not occur in the windings, structural supports of the windings and magnetic circuit and this will be subjected to design review.

7.16.3. The structure shall be designed to withstand the clamping and magnetic forces. The calculated magnetic forces will be furnished at the time of design review.

7.16.4. Core and winding shall be capable of withstanding the shock during transport, installation and service. Adequate provision shall be made to prevent movement of core and winding relative to tank during these conditions.

7.17. Calculation of hot spots

7.17.1. The winding hot spots shall be calculated using the maximum localized losses, insulation thickness at the maximum loss positions, and the oil flow patterns in the winding. The oil temperature rise in the windings shall be used to determine hot spots rather than the bulk top oil temperature.

7.17.2. The hot spot temperature and surface temperatures in the core shall be calculated for over voltage conditions specified in the document and it shall not exceed 125 deg C and 120 deg C respectively.

7.17.3. The hot spot for all leads shall be calculated and it shall not exceed the calculated hot spot of the windings.

7.17.4. The hot spot in the windings and magnetic circuit shall be calculated for the over voltage conditions specified.

7.17.5. The most onerous temperature of any part of the core and its supporting structure in contact with insulation or non-metal material shall not exceed the safe operating temperature of that material. Adequate temperature margins shall be provided to maintain long life expectancy of these materials.

7.18. **Earthing of core and clamping structure**

7.18.1. If grounding of the core cheeses are required, a separate strap shall be brought to a terminal located in a waterproof enclosure on the tank. Separate ground leads will be routed from the top and bottom yokes to separate terminals in the enclosure.

7.18.2. Single point core earthing should be ensured to avoid circulating current. Core earth should be brought separately on the top of the tank to facilitate testing after installation on all Reactors. The removable links shall have adequate section to carry ground fault current. Separate identification name plate/labels shall be provided for the 'Core' and 'Core clamp'.

Cross section of Core earthing connection shall be of minimum size 80 sq.mm copper with exception of the connections inserted between laminations which may be reduced to a cross-sectional area of 20 sq. mm tinned copper where they are clamped between the laminations.

7.18.3. Where the core laminations are divided into sections by insulating barriers or cooling ducts parallel to the plane of the laminations, tinned copper bridging strips shall be inserted to maintain electrical continuity between sections.

7.18.4. A drawing showing the details of the earthing design and connection shall be furnished during detailed engineering.

7.19. **Windings**

7.19.1. The manufacturer shall ensure that windings of all reactors are made in clean, dust proof (Cleanroom class ISO 9 or better as per ISO 14644-1), humidity controlled environment with positive atmospheric pressure.

7.19.2. The conductors shall be of electrolytic grade copper free from scales and burrs. Oxygen content shall be as per IS 12444.

7.19.3. Epoxy bonded Continuously Transposed Conductor (CTC) shall be used in main winding for rated current of 400 A or more.

7.19.4. The insulation of Reactor windings and connections shall be free from insulating compounds which are liable to soften, ooze out, shrink or collapse and shall be non-catalytic and chemically inactive in Reactor oil during service.

7.19.5. Coil assembly and insulating spacers shall be so arranged as to ensure free circulation of oil and to reduce the hot spot of the winding.

7.19.6. The coils would be made up, shaped and braced to provide for expansion and contraction due to temperature changes.

7.19.7. The conductor shall be transposed at sufficient intervals in order to minimize eddy currents and to equalise the distribution of currents and temperature along the winding.

7.19.8. The windings shall be designed to withstand the dielectric tests specified. The type of winding used shall be of time tested. An analysis shall be made of the transient voltage distribution in the windings, and the clearances used to withstand the various voltages. Margins shall be used in recognition of manufacturing tolerances and the fact that the system will not always be in the new factory condition.

7.19.9. The barrier insulation including spacers shall be made from high density pre-compressed pressboard (1.15 gm/cc minimum for load bearing and 0.95 gm/cc minimum for non-load bearing) to minimize dimensional changes. Kraft insulating paper used on conductor should have density of >0.75 g/cc

7.19.10. All spacers shall have rounded edges. Radially stepped spacers between winding disks will not be accepted.

7.19.11. The conductor insulation shall be made from high-density (at least 0.75 gm/cc) paper having high mechanical strength. The characteristics for the paper will be reviewed at the time of design review.

7.19.12. An electrostatic shield, made from material that will withstand the mechanical forces, will be used to shield the high voltage windings from the magnetic circuit unless otherwise approved.

7.19.13. Either brazing/crimping type of connections are permitted for joints. It shall be time proven and safely withstand the cumulative effect of stress which may occur during handling, transportation, installation and service including line to line and line to ground faults /Short circuits. Manufacturer shall have system which allows only qualified personnel to make brazing or crimping joints.

7.19.14. Winding paper moisture shall be less than 0.5%.

7.19.15. All winding insulation shall be processed to ensure that there will be no detrimental shrinkage after assembly. All windings shall be pre-sized before being clamped. Windings shall be provided with clamping arrangements which will distribute the clamping forces evenly over the ends of the winding.

Full details of the winding clamping arrangements, and their adjustment in or out of the tank together with relevant drawings and values, shall be submitted during design review.

7.20. **Current carrying connections**

The mating faces of bolted connections shall be appropriately finished and prepared for achieving good long lasting, electrically stable and effective contacts. All lugs for crimping shall be of the correct size for the conductors. Connections shall be carefully designed to limit hot spots due to circulating eddy currents.

7.21. **Winding terminations into bushings**

7.21.1. Winding termination interfaces with bushings shall be designed to allow for repeatable and safe connection under site conditions to ensure the integrity of the Reactor in service.

7.21.2. The winding–end termination, insulation system and transport fixings shall be so designed that the integrity of the insulation system generally remains intact during repeated work in this area.

7.21.3. Allowances shall be made on the winding ends for accommodating tolerances on the axial dimensions of the set of bushings and also for the fact that bushings may have to be rotated to get oil level inspection gauges to face in a direction for ease of inspection from ground level.

7.21.4. In particular, rotation or straining of insulated connections shall be avoided during the fastening of conductor pads (or other methods) on the winding ends onto the termination surfaces of the bushing.

7.21.5. Suitable inspection and access facilities into the tank in the bushing oil-end area shall be provided to minimize the possibility of creating faults during the installation of bushings.

8. Painting system and procedures

The typical painting details for reactor main tank, pipes, conservator tank, radiator, control cabinet/ marshalling box / oil storage tank etc. shall be as given in **Annexure – E**. The proposed paint system shall generally be similar or better than this. The quality of paint should be such that its colour does not fade during drying process and shall be able to withstand temperature up to 120 deg C.

9. Unused inhibited Insulating Oil

The insulating oil shall be virgin high grade inhibited, conforming to IS 335 / IEC-60296 & all parameters specified at **Annexure – F**, while tested at oil supplier's premises. The contractor shall furnish test certificates from the supplier against the acceptance norms as mentioned at **Annexure – F**, prior to despatch of oil from refinery to site. The Unused Inhibited Insulating Oil parameters including parameters of oil used at manufacturer's works, processed oil, oil after filtration and settling are attached at **Annexure – F**. The oil test results shall form part of equipment test report.

Sufficient quantity of oil necessary for maintaining required oil level in case of leakage in tank, radiators, conservator etc. till the completion of warranty period shall be supplied.

Oil used for first filling, testing and impregnation of active parts at manufacturer's works shall be of same type of oil which shall be supplied at site and shall meet parameters as per specification.

9.1. Particles in the oil

The particle analysis shall be carried out in an oil sample taken before carrying out FAT at manufacturer's works and after completion of the oil filtration at site. The procedure and interpretation shall be in accordance with the recommendation of

CIGRE report WG-12.17- “Effect of particles on transformer dielectric strength”. Particle limit as shown below shall be ensured by manufacturer, implying low contamination, as per CIGRE Brochure 157, Table 8. After filtration the oil is to be flushed and particle count to be measured.

Limiting value for the particle count are 1000 particle/100 ml with size ≥ 5 µm; 130 particle/100 ml with size ≥ 15 µm.

9.2. **Oil filling**

9.2.1. Procedures for site drying, oil purification, oil filling etc shall be done as per Field Quality Plan (FQP).

9.2.2. The duration of the vacuum treatment shall be demonstrated as adequate by means of water measurement with a cold trap or other suitable method but shall generally not be less than 72 hours. The vacuum shall be measured on the top of the Reactor tank and should be less than 1mbar.

9.2.3. Oil filling under vacuum at site shall be done with reactor oil at a temperature not exceeding 65°C. Vacuum shall not be broken until the Reactor is oil filled up to the Buchholz relay.

9.2.4. The minimum safe level of oil filling (if different from the Buchholz level) to which the Reactor shall be oil filled under vacuum, shall be indicated in the manual.

9.2.5. **Oil treatment plant**

The Ultra High Vacuum type oil treatment plant (on returnable basis) of suitable capacity (**minimum 6000** litres per hour) shall be arranged by the contractor at his own cost for treatment of oil in EHV class Reactor in order to achieve properties of treated oil. The plant shall be capable of treatment of oil at rated capacity on single pass basis as follows:

i) Removal of moisture from 100 ppm to 3 ppm (max.)
ii) Removal of dissolved gas content from 10% by Vol. to 0.1% by vol.
iii) Improvement of dielectric strength break down voltage from 20 to 70 KV
iv) Vacuum level of degassing chamber not more than 0.15 torr/0.2 mbar at rated flow and at final stage. Machine shall have minimum of two degassing chambers and these should have sufficient surface areas to achieve the final parameters.
v) Filter shall be capable of removing particle size more than 0.5 micron in the filtered oil.
vi) Processing temperature shall be automatically controlled and have an adjustable range from 40°C to 80°C.

9.2.6. **Transportation of Oil**

The insulating oil for the Reactor shall be delivered at site generally not before 90 days from the date of commissioning, with prior information to the Employer, in view of risk involved in balk storage, pilferage and fire hazard. In case this oil is not filled in reactor due to delay in commissioning, same oil shall be used only after testing and ensuring that oil parameters are well within the specified limits.

Insulating oil shall be delivered to the site in returnable oil drums / flexi bag / tanker. The oil drums / flexi bag / Stainless steel tanker shall be taken back without any extra cost to Employer within generally 45 days after utilisation of oil but in any case before contract closing. However, the spare oil shall be delivered in non-returnable drums.

10. Spare Reactor Units Storage & Connection Arrangement

Detail procedure for storage of spare reactor unit with and without **isolator switching arrangement** is enclosed at **Annexure-O.**

11. Bushings

11.1. Bushings shall be robust and designed for adequate cantilever strength to meet the requirement of seismic condition, substation layout and movement along with the spare Reactor with bushing erected and provided with proper support from one foundation to another foundation within the substation area. The electrical and mechanical characteristics of bushings shall be in accordance with IEC: 60137/DIN 42530. All details of the bushing shall be submitted for approval and design review.

11.2. Bushing for voltage of 800kV shall be of porcelain or composite polymer housing and hermetically sealed Oil filled condenser type or RIP (Resin Impregnated paper) condenser type with composite polymer insulator (housing) or RIS (Resin Impregnated Synthetic) condenser type with composite polymer insulator (housing).

RIP (Resin Impregnated paper) condenser type with composite polymer insulator (housing) or RIS (Resin Impregnated Synthetic) condenser type with composite polymer insulator (housing). 145kV BPI/support insulator shall be solid porcelain type.

11.3. Oil filled condenser type bushing shall be provided with at least following fittings:

a) Oil level gauge
b) Tap for capacitance and tan delta test. Test taps relying on pressure contacts against the outer earth layer of the bushing is not acceptable
c) Oil filling plug & drain valve (if not hermetically sealed)

11.4. RIP/RIS type bushing shall be provided with tap for capacitance and tan delta test. Test taps relying on pressure contacts against the outer earth layer of the bushing is not acceptable.

11.5. Where current transformers are specified, the bushings shall be removable without disturbing the current transformers.

11.6. Bushings of identical rating of different makes shall be interchangeable to optimise the requirement of spares. Mounting dimensions of bushing shall be as per drawing mentioned at **Annexure – C**.

11.7. Porcelain used in bushing manufacture shall be homogenous, free from lamination, cavities and other flaws or imperfections that might affect the mechanical or dielectric quality and shall be thoroughly vitrified, tough and impervious to moisture.

11.8. Polymer or composite insulator shall be seamless sheath of a silicone rubber compound. The housing & weather sheds should have silicon content of minimum 30% by weight.

It should protect the bushing against environmental influences, external pollution and humidity. It shall be extruded or directly moulded on the core. The interface between the housing and the core must be uniform and without voids. The strength of the bond shall be greater than the tearing strength of the polymer. The manufacturer shall follow non-destructive technique (N.D.T.) to check the quality of jointing of the housing interface with the core. The technique being followed with detailed procedure and sampling shall be decided during finalization of MQP.

The weather sheds of the insulators shall be of alternate shed profile as per IS 16683-3/IEC 60815-3. The weather sheds shall be vulcanized to the sheath (extrusion process) or moulded as part of the sheath (injection moulding process) and free from imperfections. The vulcanization for extrusion process shall be at high temperature and for injection moulding shall be at high temperature & high pressure. Any seams / burrs protruding axially along the insulator, resulting from the injection moulding process shall be removed completely without causing any damage to the housing. The track resistance of housing and shed material shall be class 1A4.5 according to IEC60587**.** The strength of the weather shed to sheath interface shall be greater than the tearing strength of the polymer. The composite insulator shall be capable of high pressure washing.

End fittings shall be free from cracks, seams, shrinks, air holes and rough edges. End fittings should be effectively, sealed to prevent moisture ingress, effectiveness of sealing system must be supported by test documents. All surfaces of the metal parts shall be perfectly smooth with the projecting points or irregularities, which may cause corona. All load bearing surfaces shall be smooth and uniform so as to distribute the loading stresses uniformly.

The hollow silicone composite insulators shall comply with the requirements of the IEC publications IEC 61462 and the relevant parts of IEC 62217. The design of the composite insulators shall be tested and verified according to IEC 61462 (Type & Routine test).

11.9. Clamps and fittings shall be of hot dip galvanised/stainless steel.

11.10. Bushing turrets shall be provided with vent pipes, to route any gas collection through the Buchholz relay.

11.11. No arcing horns shall be provided on the bushings.

11.12. Corona shield shall be provided at 765kV Bushing terminal (Air end) to minimise corona.

11.13. Bushing shall be specially packed to avoid any damage during transit and suitable for long storage, with non-returnable packing wooden boxes with hinged type cover. Without any gap between wooden planks. Packing Box opening cover with nails/screws type packing arrangement shall not be acceptable.

11.14. In case of RIP/RIS bushing with polymer housing, bushing oil end portion shall be fitted with metal housing with positive dry air pressure and a suitable pressure monitoring device shall be fitted on the metal housing during storage to avoid direct contact with moisture with epoxy. Alternatively, oil filled metal housing with suitable arrangement for taking care oil expansion due to temperature variations shall also be acceptable. Manufacturer shall submit drawing/ documents of packing for approval during detail engineering. Detail method for storage of bushing including accessories shall be brought out in the instruction manual.

11.15. The terminal marking and their physical position shall be as per IEC: 60076.

11.16. Tan delta at variable frequency (in the range of 20 Hz to 350 Hz) shall be carried out on each condenser type bushing (OIP & RIP) at reactor manufacturing works / bushing manufacturing works as routine test before despatch and the result shall be compared at site during commissioning to verify the healthiness of the bushing.

11.17. Tan δ value of RIP / RIS condenser bushing shall be 0.005 (max.) in the temperature range of 20°C to 90°C. The measured Tan δ value at site of in-service bushing should not exceed by 0.001 w.r.t. factory results (measured at approx. similar temperature conditions) during warrantee period.

Tan delta value of OIP Bushing shall be 0.004 (Max) measured at ambient temperature. The measured Tan δ value at site of in-service bushing should not exceed by 0.001 w.r.t. factory results during warrantee period.

12. Neutral Formation and Earthing Arrangement (if specified in BPS)

The contractor shall connect the neutrals of three (3) 1-phase reactor by overhead connection using 3" IPS Al tube. The neutral formation shall be such that neutral winding of single-phase spare reactor can be disconnected or connected to of the three phase banks unless approved otherwise. The connection from the neutral bushing to neutral bus shall be through 3" IPS Al tube and wherever flexible jumper needs to be provided, same shall be through twin conductor. All material like Bus post insulator, Aluminium tube, conductor, clamps & connectors, earthing materials, support structure, hardware etc required for neutral formation and connection with neutral CT and earthing of neutral shall be provided by contractor.

13. Cooling Equipment

13.1. The reactor shall be designed for Oil immersed with natural cooling (ONAN)

13.2. The radiator bank of the shunt reactor shall be either tank mounted.

13.3. Design of cooling system shall satisfy the performance requirements. The radiator shall be of sheet steel in accordance with IS 513 and minimum thickness of 1.2 mm. Each radiator bank shall be provided with the following accessories:

(a) Top and bottom shut off valve
(b) Drain Valve and sampling valve
(c) Air release plug
(d) Two grounding terminals for termination of two (2) Nos. 75x12 mm galvanised steel flats.
(e) Thermometer pockets with captive screw caps at cooler inlet and outlet.
(f) Lifting lugs

13.4. Each radiator bank (tank mounted) shall be detachable and shall be provided with flanged inlet and outlet branches. Expansion joint shall be provided on top and bottom cooler pipe connection for separately mounted radiator bank.

13.5. If radiators are directly mounted on tank, sufficient number of thermometer pockets fitted with captive screw cap on the inlet and outlet of tank side pipe of radiators shall be provided to record temperature during temperature rise test.

13.6. The cooler pipes, support structure including radiators and its accessories shall be hot dip galvanised or corrosion resistant paint should be applied to external surface of it.

14. Valves

14.1. All valves upto and including 100 mm shall be of gun metal or of cast steel/cast iron. Larger valves may be of gun metal or may have cast iron bodies with gun metal fittings. They shall be of full way type with internal screw and shall open when turned counter clock wise when facing the hand wheel.

14.2. Suitable means shall be provided for locking the valves in the open and close positions. Provision is not required for locking individual radiator valves.

14.3. Each valve shall be provided with the indicator to show clearly the position of the valve.

14.4. All valves flanges shall have machined faces. Drain valves/plugs shall be provided in order that each section of pipe work can be drained independently.

14.5. All valves in oil line shall be suitable for continuous operation with Reactor oil at 115 deg C.

14.6. Gland packing/gasket material shall be of "O" ring of nitrile rubber for all the valve's flanges. All the flanges shall be machined.

14.7. The oil sampling point for main tank shall have two identical valves to be put in series. Oil sampling valve shall have provision to fix rubber hose of 10 mm size to facilitate oil sampling.

14.7.1. Valves or other suitable means shall be provided to fix various on line monitoring systems to facilitate continuous monitoring.

Type of valves shall be used for Reactor as per following table. The location, size of valves for other application shall be finalised during design review.

Sr. No.	Description of Valve	Type
1	Drain Valve	Gate
2	Filter valve	Gate
3	Sampling Valve	Globe
4	Radiator isolation valve	Butterfly
5	Buchholz relay isolation valve	Gate
6	Sudden pressure relay	Gate
7	Valve for vacuum application on Tank	Gate
8	Conservator Drain valve	Gate
9	Aircell equalizing valve	Gate/Globe/Ball
10	Valve for Conservator vacuum (top)	Gate
11	Valve for UHF Sensors	Gate

14.7.2. All valves shall be painted with a shade (preferably red or yellow) distinct and different from of main tank surface and as per the painting system and procedure specified.

14.8. All hardware used shall be hot dip galvanised / stainless steel.

15. Cabling

15.1. Buchholz Relay, Magnetic Oil Level Gauge, Pressure Relief Device & Sudden pressure relay to be wired through unarmoured cable of 1.5 sq.mm (minimum), inside GI conduit, with no part exposed. Cable shall be protected by flexible stainless steel pipe, at both ends as per requirement. Proper sealing arrangement to be provided at both ends to avoid ingress of water.

The cross section of "control cable" shall be 1.5 sq.mm (minimum) except for CT circuits which should be 2.5 sq.mm (minimum).

All other cables shall be armoured type and shall be routed through covered cable tray or GI conduit and shall be properly dressed.

15.2. Cable terminations shall be through stud type TB and ring type lugs. Typical Technical specification for cables is attached at Annexure-I. All cables should be provided from approved sources with valid type test report. However, charges for type testing is not envisaged. Both ends of all the wires (control & power) shall be provided with proper ferrule numbers for tracing and maintenance. Further, any special cables (if required) shall also be considered included in the scope. All cable accessories such as glands, lugs, cable tags/ numbers etc. as required shall be considered included in the scope of supply.

15.3. Cabling of spare unit with isolator switching arrangement shall be in such a way that spare unit of Reactor can be connected in place of faulty unit without physically shifting and all the control, protection, indication signals of spare unit shall be brought in common marshalling box of all the banks. From CMB all the control, protection and indication signals of R, Y, B and Spare units shall be transferred to Purchaser's Control panels / SCADA. Change-over of spare unit signals with faulty unit shall be done through Purchaser's C & R panels / SCADA level.

16. Individual Marshalling Box and Common Marshalling Box

16.1. Each single phase reactor unit shall be provided with Individual Marshalling Box and Common Marshalling (for a bank of three single phase unit) Box shall be provided.

16.2. Common marshalling box shall be floor mounted and of size, not less than 1600 mm (front) X 650 mm (depth) X 1800 mm (height). Individual Marshalling Box and Cooler Control Box shall be tank mounted.

16.3. The Individual Marshalling Box, Common Marshalling Box, Junction box and all other outdoor cubicles shall be made of stainless-steel sheet of minimum grade of SS304 (SS 316 for coastal area) and of minimum thickness of 1.6 mm.

16.4. The degree of protection shall be IP: 55 for outdoor and IP: 43 for indoor in accordance with IS 13947/IEC: 60947.

16.5. All doors, removable covers and plates shall be gasketed all around with suitably profiled. All gasketed surfaces shall be smooth straight and reinforced if necessary to minimize distortion to make a tight seal. For Control cubicle / Marshalling Boxes etc. which are outdoor type, all the sealing gaskets shall be of EPDM rubber or any better approved quality, whereas for all indoor control cabinets, the sealing gaskets shall be of neoprene rubber or any better approved quality. The gaskets shall be tested in accordance with approved quality plan, IS: 1149 and IS: 3400.

16.6. Ventilating Louvers, if provided, shall have screen and filters. The screen shall be fine wire mesh of brass. All the separately mounted cabinets and panels shall be free standing floor mounted type and have domed or sloping roof. All the control cabinets shall be provided with suitable lifting arrangement. Individual Marshalling Box shall be tank mounted only.

16.7. All the contacts of various protective devices mounted on the reactor and all the secondary terminals of the bushing CTs shall also be wired upto the terminal board in the Individual Marshalling box. All the CT secondary terminals in the Individual Marshalling box shall have provision for shorting to avoid CT open circuit while it is not in use. All the necessary terminations for remote connection to Employer's panel shall be wired upto the Common Marshalling box.

16.8. A space heater and cubicle lighting with ON-OFF switch shall be provided in each panel.

16.9. Control and power supplies are to be given after suitable selection at Common Marshalling Box. Necessary isolating switches and protective devices shall be provided at suitable points as per Employer's approved scheme.

16.10. All the control circuit connections from individual marshalling box and of three single phase units of a bank including spare reactor unit to Employers Control panels shall be routed through common marshalling box. Common marshalling box shall be floor mounted and of size not less than 1600mm (front) X 650mm (depth) X 1800mm (height).

16.11. Details of stationed auxiliary power supply are mentioned in GTR specification. Common marshalling box shall have following arrangement:

16.12. Two auxiliary power supplies, 415 volt, three phase four (4) wire shall be provided by the Employer at common marshalling box. Power supply to Spare unit shall be extended from nearest CMB only through MCCB by contractor.

16.13. Suitably rated power contactors, MCBs/MCCBs as required for entire auxiliary power supply system including distribution to individual marshalling boxes, Online Moisture & DGA monitoring system, Online drying system and Fibre optic sensor Box etc., shall be provided by contractor. For each circuit separate MCBs / MCCBs shall be provided in the Common Marshalling Box.

16.14. In case auxiliary power supply requirement is different than station auxiliary AC supply, then all necessary converters shall be provided by the Contractor. Auxiliary power supply distribution scheme shall be submitted for approval.

16.15. Supply and laying of Power, Control and special cables from common marshalling box to individual units (including spare unit) is in the scope of the contractor.

16.16. All loads shall be fed by one of the two feeders through an electrically interlocked automatic transfer switch housed in the common marshalling box.

16.17. Design features of the transfer switch shall include the following:

a) Provision for the selection of one of the feeder as normal source and other as standby.
b) Upon failure of the normal source, the loads shall be automatically transferred after an adjustable time delay to standby sources.
c) Indication to be provided at cooler control cabinet for failure of normal source and for transfer to standby source and also for failure to transfer.
d) Automatic re-transfer to normal source without any intentional time delay following re-energization of the normal source.
e) Both the transfer and the re-transfers shall be dead transfers and AC feeders shall not be paralleled at any time.

17. SCADA Integration and Interconnection

17.1.1. All required power & control cables including optical cable, patch chord (if any) upto Common MB shall be in the scope of contractor. Further, any special cable between CMB to switchyard panel room/control room shall be under the present scope.

17.1.2. Fiber optic cable, power cable, control cables, as applicable, between CMB to switchyard panel room/control room and power supply (AC & DC) to MB and integration of above said IEC-61850 compliant equipment with Substation Automation System shall be under the scope of EPC contractor.

17.1.3. SCADA Integration of online monitoring equipment (**if applicable**):

All the online monitoring equipment i.e. Online Dissolved Gas (Multi-gas) and Moisture Analyser, On-line insulating oil drying system (Cartridge type) etc. provided for individual Reactor unit including Spare (if any), are IEC 61850 compliant (either directly or through a Gateway). The monitoring equipment are required to be integrated with SAS through managed Ethernet switch conforming to IEC 61850. This Ethernet switch shall be provided in IMB or CMB. The switch shall be powered by redundant DC supply (110V or as per available Station DC supply). Ethernet switch shall be suitable for operation at ambient temperature of 50 Deg C.

18. Current Transformer (Bushing & Outdoor Neutral Current Transformer)

18.1. Current transformers shall comply with IS 16227 (Part 1 & 2)/IEC 61869 (part 1 & 2).

18.2. It shall be possible to remove the turret mounted current transformers from the Reactor tank without removing the tank cover. Necessary precautions shall be taken to minimize eddy currents and local heat generated in the turret.

18.3. Current transformer secondary leads shall be brought out to a weather-proof terminal box near each bushing. These terminals shall be wired out to common marshalling box using separate cables for each core.

18.4. Bushing Current transformer parameters indicated in this specification are tentative and liable to change within reasonable limits. The Contractor shall obtain Employer's approval before proceeding with the design of bushing current transformers.

18.5. Technical Parameters of Bushing CTs and Neutral CTs (outdoor type) are enclosed at **Annexure – G.** The CT's used for REF protection must have the identical parameters in order to limit the circulating current under normal condition for stability of protection. Bushing Current transformer parameters indicated in this specification are tentative and liable to change within reasonable limits. The Contractor shall obtain Employer's approval before proceeding with the design of bushing current transformers.

18.6. One number single phase current transformer (outdoor) for earth fault protection shall be provided for each bank of reactor and shall be located in the neutral conductor connecting common neutral point with earth.

18.7. Secondary resistance and magnetising current characteristics of PX / PS class (protection) (as per IS or IEC) CT of same rating shall match. This is applicable for Neutral CT (outdoor) also and shall be reviewed during detail engineering.

19. Surge Arrester

19.1. General

The surge arresters shall conform in general to IEC-60099-4 except to the extent explicitly modified in the specification. The bidder shall offer surge arresters of gapless type without any series or shunt gap. Arresters shall be hermetically sealed units, of self-supporting construction, suitable for mounting on structures.

19.2. Duty Requirements

The surge arresters shall be of heavy duty station class type. It shall be physically located between the neutral of 765kV shunt reactor (brought out at bushing) and neutral grounding reactor and shall be electrically in parallel with the latter.

The surge arresters shall be capable of discharging over voltage occurring during switching of unloaded Reactors.

The surge arresters shall be able to withstand wind load.

19.3. Constructional Features

The features and constructional details of surge arresters shall be in accordance with requirement stipulated hereunder:

19.3.1. The non-linear blocks shall be of sintered metal oxide material. These shall be provided in such a way as to obtain robust construction, with excellent electrical and mechanical properties even after repeated operations.

19.3.2. The reference current of the arrester shall be high enough to eliminate the influence of grading and stray capacitance on the measured reference voltage.

19.3.3. The surge arresters shall be fitted with pressure relief devices and arc diverting parts suitable for preventing rupture of polymer housing and providing path for flow of rated fault currents in the event of arrester failure.

19.3.4. The arresters shall incorporate anti-contamination feature to prevent arrester failure consequent to uneven voltage gradient across the stack in the event of contamination of the arrester housing.

19.3.5. Seals shall be provided in such a way that these are always effectively maintained even when discharging rated lightning current.

19.3.6. Outer insulator shall be polymer / composite insulator housing. Details specification of polymer/composite insulators are given in clause 11.8

19.3.7. The end fittings shall be made of non-magnetic and corrosion proof material.

19.3.8. The name plate shall conform to the requirement of IEC incorporating the year of manufacture.

19.3.9. The arrester shall be supplied with suitable support structure either of tubular GI pipe or lattice steel galvanised.

19.3.10. The heat treatment cycle details along with necessary quality checks used for individual blocks along with insulation layer formed across each block to be furnished. Metallised coating thickness for reduced resistance between adjacent discs to be furnished along-with procedure for checking the same.

19.3.11. Technical specification of Surge Arrester is enclosed at **Annexure-H**

19.4. **Fittings and Accessories**

19.4.1. Each arrester shall be complete with insulating base, support structure and terminal connector. The height of the support structure shall not be less than 2500 mm. The structure would be made of galvanized steel generally conforming to IS: 802. The surge arrester can also be mounted on the neutral grounding reactor in lieu of separate support structure.

19.4.2. Self-contained discharge counter, suitably enclosed for outdoor use and requiring no auxiliary or battery supply for operation along with necessary connection, shall be provided for each unit. The counter shall be visible through an inspection window from ground level. The counter terminals shall be robust and of adequate size and shall be so located that incoming and outgoing connections are made with minimum possible bends. One no. potential free change over type contacts (rated for 220V DC) shall be provided for monitoring of surge counter operation in substation automation system.

19.4.3. Suitable milliammeter on each arrester with appropriate connections shall be supplied to measure the resistor grading leakage current. The push buttons shall be mounted such that it can be operated from ground level.

19.4.4. Discharge counter and milliammeter shall be suitable for mounting on support structure of the arrester with minimum protection class IP 55.

19.4.5. Grading/Corona rings shall be provided on each complete arrester unit as required for proper stress distribution.

19.5. **Tests**

19.5.1. The surge arresters shall conform to type tests and shall be subjected to routine tests as per IEC-60099-4.

19.5.2. Surge arrester shall be subjected to additional acceptance tests.

(i) Polymer insulator test as per IEC 61462
(ii) Construction check (visual check)
(iii) Measurement of insulation resistance by 1kV megger.

20. Hand Tools (if specified in BPS)

One set of hand tools of reputed make packed in a carry bag/box broadly comprising of double ended spanners (open jaws, cranked ring, tubular with Tommy bar each of sizes 9mm to 24mm, one set each), adjustable wrenches (8 &12 inch one set), gasket punches (of different sizes used - one set), pliers (flat nose, round nose & side cutting one of each type), hammer with handle (one), files with handle (two), knife with handle (one), adjustable hacksaw (one), and cold chisel (one), bushing handling and lifting tools with nylon rope/belt, chain block (2 Nos.) and D-Shackle shall be supplied.

21. Test Kit (if specified in BPS)

BDV Kit as per Annexure-J of specification
Portable DGA Kit as per Annexure-J of specification

22. Fittings

The following fittings & accessories (as applicable) shall be provided with each Reactor & NGR covered in this specification. The fittings listed below are not exhaustive and other fittings, which are required for satisfactory operation of the Reactor, are deemed to be included.

22.1. **Shunt Reactor**

i) Conservator for main tank of reactor with aircell, isolating valves, drain valve, magnetic oil level gauge (with canopy) with potential free high and low oil level alarm contacts and prismatic oil level gauge and Dehydrating Silicagel Filter Breather with flexible connection pipes to be used during replacement of any silicagel breather

ii) Pressure relief devices with special shroud to direct the oil

iii) Sudden pressure relief relay with alarm contact

iv) Buchholz relay with isolating valves on both sides, bleeding pipe with pet cock at the end to collect gases and alarm / trip contacts.

v) Air release plug

vi) Conservator air cell rupture detection relay

vii) Inspection openings and covers

viii) Bushing of each type with metal parts and gaskets to suit the termination arrangement

ix) Winding & Oil temperature indicators

x) Cover lifting eyes, reactor lifting lugs, jacking pads, towing holes and core and winding lifting lugs

xi) Rating and diagram plates on reactors and auxiliary apparatus

xii) Roller Assembly (as per clause 7.4)

xiii) Marshalling Box, Common Marshalling Box, Fibre optic sensor box as applicable

xiv) Cooling equipment

xv) Drain valves/plugs shall be provided in order that each section of pipe work can be drained independently

xvi) Bushing Current Transformers, Neutral CT (if applicable)

xvii) Terminal marking plates

xviii) Valves schedule plate

xix) Bottom oil sampling valve, Drain valves, Filter valves at top and bottom with threaded male adaptors, Shut off valves on the pipe connection between radiator bank and reactor tank, Shut off valves on both sides of Buchholz relay, Sampling gas collectors for Buchholz relay at accessible height, Valves for Radiators, Valve for vacuum application, Valve for on line DGA, valves for Drying out system, Valve for UHF sensors etc.

xx) Suitable terminal connectors on bushings and surge arrester

xxi) Ladder to climb up to the Reactor tank cover with suitable locking arrangement to prevent climbing during charged condition.

xxii) Haulage lugs

xxiii) Fibre optic sensor based temperature measuring system

xxiv) Two earthing terminals each on shunt reactor tank, radiators & marshalling boxes, SA structures etc.

xxv) Neutral bus connection arrangement (3-Phase Reactor)

xxvi) Online Dissolved Gas (Multi-gas) and Moisture Analyser (if specified in BPS) as per **Annexure-K**

xxvii) On-line insulating oil drying system (Cartridge type) as per **Annexure-L**

xxviii) Oil Sampling Bottle & Oil Syringe (if specified in BPS) as per **Annexure-M**

xxix) All Cables (Power, control and shielded / twisted pair for 4-20mA cable from Reactor MB, etc. (as applicable) to CMB and CMB to employer's C&R panell shall be under the present scope. Any special cable if required to be included upto employer's C&R panel.

xxx) Managed Ethernet switch, LIU patch cords etc. (if applicable) shall be provided in CMB/MB (as per clause 17). All IEC 61850 compliant signals from various monitoring equipment/accessories shall be wired upto the Ethernet switch.

22.2. **NGR**

i) Rating and diagram plates

ii) Terminal marking plates

iii) Suitable terminal connection arrangement

iv) Lifting lugs

v) Support structure etc.

22.3. All hardware used shall be hot dip galvanised / stainless steel.

23. Inspection and Testing

The Contractor shall carry out a comprehensive inspection and testing programme during manufacture of the equipment. The inspection envisaged by the Employer is given below. This is however not intended to form a comprehensive programme as it is Contractor's responsibility to draw up and carry out such a programme in the form of detailed quality plan duly approved by Employer for necessary implementation. All accessories and components of reactor shall be purchased from approved soured of Employer. All process tests, critical raw material tests and witness / inspection of these testing shall be carried out as per approved manufacturing quality plan (MQP) by Employer.

23.1. Factory Tests

The manufacturer shall be fully equipped to perform all the required tests as specified. Bidder shall confirm the capabilities of the proposed manufacturing plant in this regard when submitting the bid. Any limitations shall be clearly stated in.

The contractor shall bear all additional costs related to tests, which are not possible to carry out at his own works.

The contractor shall carry out type & routine tests as per "**Annexure-B & Standard Test Procedure".** Complete test report shall be submitted to purchaser after proper scrutiny and signing on each page by the test engineer of the contractor.

23.2. Type Tests on fittings:

Type test reports of following Bushing & accessories, shall be furnished by the contractor along with drawings.

a) Bushing Type Test as per IS/ IEC:60137 for all voltage class (Seismic test on 800kV Bushings)
b) Marshalling & Common Marshalling Box and other outdoor cubicle (IP-55)

23.3. Pre-Shipment Checks at Manufacturer's Works

23.3.1. Check for inter-changeability of components of similar reactor for mounting dimensions.

23.3.2. Check for proper packing and preservation of accessories like radiators, bushings, breather, rollers, buchholz relay, Marshalling boxes, connecting pipes, conservator etc.

23.3.1. Before dispatch of Reactor from factory, following impact recorder settings are to be implemented for graphical analysis:

>1g: Start recording

>2g: Warning

>3g: Alarm

Further, drop-out setting shall be 1g and threshold setting shall be in the range of 3g to 10g.

23.3.2. Check for proper provision for bracing to arrest the movement of core and winding assembly inside the tank.

23.3.3. Gas tightness test to confirm tightness and record of dew point of gas inside the tank. Derivation of leakage rate and ensure the adequate reserve gas capacity.

23.4. **Inspection and Testing at Site**

The Contractor shall prepare a detailed inspection and testing programme for field activities covering areas right from the receipt of material stage up to commissioning stage. An indicative inspection programme as envisaged by the Employer is given below. Testing of oil sample at site shall be carried out as per specification. Contractor shall follow Employer Field Quality Plan (FQP).

23.5. **Receipt and Storage Checks**

23.5.1. Check and record condition of each package, visible parts of the reactor etc. for any damage.

23.5.2. Check and record the gas pressure in the reactor tank as well as in the gas cylinder.

23.5.3. Check and record reading of impact recorder at receipt and verify the allowable limits as per manufacturer's recommendations.

23.6. **Installation Checks**

23.6.1. Visual check for wedging of core and coils before filling up with oil and also check conditions of core and winding in general.

23.6.2. Check whole assembly for tightness, general appearance etc.

23.6.3. Oil leakage test

23.6.4. Capacitance and tan delta measurement of bushing before fixing/connecting to the winding, contractor shall furnish these values for site reference.

23.6.5. Leakage check on bushing before erection.

23.6.6. Measure and record the dew point of gas in the main tank before assembly.

23.7. **Commissioning Checks**

23.7.1. Check the colour of silicagel breather.

23.7.2. Check the oil level in the breather housing, conservator tanks, cooling system, condenser bushing etc.

23.7.3. Check the bushing for conformity of connection to the lines etc,

23.7.4. Check for correct operation of all protection devices and alarms/trip :

i. Buchholz relay
ii. Excessive winding temperature
iii. Excessive oil temperature
iv. Low oil level indication

23.7.5. Check for the adequate protection on the electric circuit supplying the accessories.

23.7.6. Check resistance of all windings. Insulation resistance measurement for the following:

i) Control wiring
ii) Main windings
iii) Bushing Current Transformer

23.7.7. 2 kV AC for 1 minute test between bushing CT terminal and earth.

23.7.8. Check for cleanliness of the reactor and the surroundings

23.7.9. Measure vibration and noise level

23.7.10. Capacitance and Tan delta measurement of winding and bushing

23.7.11. Frequency response analysis (FRA). FRA equipment shall be arranged by Employer.

23.7.12. DGA of oil just before commissioning and after 24 hours energisation at site.

23.7.13. Contractor shall prepare a comprehensive commissioning report including all commissioning test results as per Pre-Commissioning Procedures and handover to Employer for future record.

Annexure – A

Technical Particulars / Parameters of Reactor of
80 MVAR & 110 MVAR, 765/√3kV, 1-phase Shunt Reactor

Clause No.	Description	Unit	Parameters	
1.	Rated capacity at 765/√3 kV	MVAR	**80**	**110**
	a) Rated Voltage (U_n)	kV	**765/√3**	
	b) Maximum continuous operating voltage (U_m)	kV	**800/√3**	
1.1.	Connection (3 Phase Bank)		**Star with neutral brought out**	
1.2.	Cooling System		ONAN	
1.3.	Frequency	Hz	50	
1.4.	No of Phases		1 (SINGLE)	
1.5.	Service		Outdoor	
1.6.	Duty		Continuous at **800/√3kV**	
1.7.	Permissible current unbalance among different phases		±1%	
1.8.	Crest value of third harmonic component in phase current when reactor is energised at rated voltage with sinusoidal wave form		≤ 3% of the crest value of fundamental	
1.9.	Range of constant impedance (Linearity)		Up to 1.25 Um voltage (the bidder shall furnish complete saturation characteristics of the Reactors up to 1.5 Um Voltage)	
1.10.	Tolerance on current		(i) 0 to +5% for a single phase unit (ii) ±1% for between units	
1.11.	Ratio of zero sequence reactance to positive reactance (X0/X1)		Between 0.9 & 1.0.	
1.12.	Temperature rise over 50 deg C Ambient Temp. and at 800/√3 kV			
i)	Top oil measured by thermometer	^{O}C	40	
ii)	Average winding measured by resistance method	^{O}C	45	
iii)	Winding hot spot temperature rise over yearly weighted average temperature of 32 °C	^{O}C	61	
1.13.	Max. tank surface temperature	^{O}C	110	
1.14.	Max. design Ambient temp	^{O}C	50	
1.15.	Windings			
i)	Lightning Impulse withstand Voltage			

	HV	kV_p	1950
	Neutral	kV_p	550
	Chopped Wave Lightning Impulse Withstand Voltage		
	Line end	kV_p	2145
ii)	Switching Impulse withstand Voltage		
	HV	kV_p	1550
	Neutral		-
iii)	One Minute Power Frequency withstand Voltage		
	HV	kV_{rms}	830kV rms (Ph-Earth) for 5 min (to be tested)
	Neutral	kV_{rms}	230
iv)	Neutral		Solidly Earthed
v)	Whether neutral is to be brought out		Yes (through 145kV class bushing)
vi)	Tan delta of windings at ambient Temperature		< 0.005
1.16.	Bushing		
i)	Rated voltage		
	HV	kV	800
	Neutral	kV	145
ii)	Rated current (Min.)		
	HV	A	2500
	Neutral	A	1250
iii)	Lightning Impulse withstand Voltage		
	HV	kV_p	2100
	Neutral	kV_p	650
iv)	Switching Impulse withstand Voltage		
	HV	kV_p	1550
	Neutral		-
v)	One Minute Power Frequency withstand Voltage		
	HV	kVrms	970
	Neutral	kVrms	305
vi)	Minimum total creepage distances		(Specific Creepage Distance: of 31mm/kV corresponding to highest line to line voltage)
	HV	mm	24800

	Neutral	mm	4495	
vii)	Partial discharge level at U_m			
	HV	pC	<10	
	Neutral	pC	<10	
1.17.	Max Partial discharge level	pC	100 at 1.58 U_r / √3	
1.18.	Vibration and stress level at 800/√3 kV	micron	The maximum vibration amplitude in any panel shall not exceed 200 microns peak to peak at rated voltage and frequency. Average vibrations shall not exceed 60 microns peak to peak. Tank stresses shall not exceed 2.0kg/sq.mm at any point on tank. The measurement are to be made at U_m	
1.19.	Maximum Noise level at 800/√3 kV	dB	80	
1.20.	Maximum Permissible Losses of Reactor	kW	80MVAR	110MVAR
1.21.	Maximum Total Load Loss at rated Voltage, Frequency and at 75^{O} C (kW)	kW	98	120
1.22.	Max. I2R Loss at rated current and frequency and at 75°C	kW	52	60

Technical Particulars / Parameters of Neutral Grounding Reactor

Clause No.	Description	Unit	Parameters
2.	Technical Parameters		
	Rated voltage from insulation	kV	**145**
2.1.	Connection		Between neutral of reactor and ground
2.2.	Cooling System		ONAN
2.3.	Frequency	Hz	50
2.4.	No of Phases		1 (SINGLE)
2.5.	Service		Outdoor
2.6.	Type		Dry type air core for outdoor application
2.7.	Insulation		Graded /uniform
2.8.	Max. continuous current (rms)		20 A
2.9.	Rated short time current (rms) (60secs.)		240A (however the NGR shall be designed for a current rating of 600 Amp rms short time current to ensure mechanical robustness which will be verified during design review.
2.10.	Rated impedance at rated short time and continuous current		As specified in section project
2.11.	Insulation level for winding		
i)	Lightning Impulse withstand Voltage		
	Line side	kV_p	550
	Ground side	kV_p	550
ii)	One Minute Power Frequency withstand Voltage		
	Line side	kV_{rms}	275
	Ground side	kV_{rms}	275
2.12.	Method of grounding		Solidly connected between neutral of shunt reactor and earth.
2.13.	Mounting of NGR		Pedestal insulator
i)	Type		Porcelain/ Silicon rubber
ii)	Minimum creepage	mm	4495
iii)	1 Min. power frequency withstand voltage	kV rms	305
iv)	Lightning Impulse withstand Voltage	kVp	650
2.14.	Mounting structure		Non magnetic material

Note:

The NGR shall be mounted high above ground level (support structure height 2.55 meter excluding support insulator) to allow free and safe access at ground level for personnel.

Annexure -B

Test Plan

No.	Reactor	Test Category
1.	Measurement of winding resistance	Routine
2.	Reactance and loss measurement (Measured in Cold and Hot state for the unit on which temperature rise test is performed & in Cold state for all other units)	Routine
3.	Measurement of insulation resistance & Polarization Index	Routine
4.	Measurement of insulation power factor and capacitance between winding and earth	Routine
5.	Measurement of insulation power factor and capacitance of bushings	Routine
6.	Core assembly dielectric and earthing continuity test	Routine
7.	High voltage with stand test on auxiliary equipment and wiring after assembly	Routine
8.	Chopped wave lightning impulse test for the line terminals (LIC)	Routine
9.	Lightning impulse test on Neutral (LIN)	Routine
10.	Switching impulse test	Routine
11.	Separate source / Applied voltage withstand test	Routine
12.	Short time over voltage Test (830kVrms)	Routine
13.	Induced over voltage test with Partial Discharge measurement (IVPD)	Routine
14.	Gas-in-oil analysis	Routine
15.	2-Hour excitation test except type tested unit	Routine
16.	Vibration & stress measurement at Um/√3 level Cold and Hot state for the unit on which temperature rise test is performed & in Cold state for all other units. (Measurement shall also be carried out at 1.05Um/√3 level for reference purpose)	Routine
17.	Temperature rise test	Type
18.	Measurement of harmonic content of current (Measured in Cold state)	Type
19.	Measurement of acoustic noise level (Measured in Cold and Hot state of temperature rise test)	Type
20	Knee point voltage measurement of reactor (Measured in Cold and Hot state of temperature rise test)	Type
21.	Frequency Response analysis (Soft copy of test report to be submitted to site along with test reports)	Routine
22.	Oil leakage test on Reactor tank	Routine
23.	Appearance, construction and dimension check	Routine
24.	Tank vacuum test	Routine
25.	Tank pressure test	Routine
	Tests on NGR (Air core type)	
(a)	Measurement of winding resistance	Routine
(b)	Measurement of impedance at rated continuous current	Routine
(c)	Measurement of loss	Routine
(d)	Lightning impulse test	Routine
(e)	Appearance, construction and dimension check	Routine

Annexure - C

Reference Drawings

The list of drawings indicated below form a part of this specification.

Sr. No	Drawing Description	Drawing No.
i)	Standard Foundation Drawing	STD/RT/765/FDN/POWERGRID/80/110 R01
ii)	Standard details for OIP & RIP Condenser bushings for 765 kV Transformer & Reactors (Lower portion)	Annexure-Q
iii)	Conceptual Drawing for Optical Fibre Sensor	C/ENGG/STD/OPTICAL FIBRE SENSOR/AT-SR/REV 00
iv)	Conceptual drawing for showing power and control cable connection for operation with spare unit	C/ENGG/RT/SPARE/CABLE/STD; REV 01
v)	Standard Test Procedure of Transformer & Reactor	POWERGRID/STD/TEST PROCEDURE/TR-RT/REV02

Annexure – D

Design Review Document

Sr. No.	Description
1.	Core and Magnetic Design
2.	Over-fluxing and Linear characteristics
3.	Inrush-current characteristics while charging
4.	Winding and winding clamping arrangements
5.	Short-circuit withstand capability considering inrush current.
6.	Thermal design including review of localised potentially hot area
7.	Cooling design
8.	Overload capability
9.	Eddy current losses
10.	Seismic design, as applicable
11.	Insulation co-ordination
12.	Tank and accessories
13.	Bushings
14.	Protective devices
15.	Radiators
16.	Sensors and protective devices– its location, fitment, securing and level of redundancy
17.	Oil and oil preservation system
18.	Corrosion protection
19.	Electrical and physical Interfaces with substation
20.	Earthing (Internal & External)
21.	Processing and assembly
22.	Testing capabilities
23.	Inspection and test plan
24.	Transport and storage
25.	Sensitivity of design to specified parameters
26.	Acoustic Noise
27.	Spares, inter-changeability and standardization
28.	Maintainability
29.	PRD and SPR (number & locations) and selection
30.	Conservator capacity calculation
31.	Winding Clamping arrangement details with provisions for taking it “in or out of tank”
32.	Conductor insulation paper details
33.	Location of Optical temperature sensors
34.	The design of all current connections
35.	Location & size of the Valves

Note: Design review document for NGR shall be decided during detailed engineering.

Annexure – E

Painting Procedure:

PAINTING	Surface preparation	Primer coat	Intermediate undercoat	Finish coat	Total dry film thick-ness (DFT)	Colour shade
Main tank, pipes, conservator tank, oil storage tank & DM Box etc. (external surfaces)	Shot Blast cleaning Sa 2 ½*	Epoxy base Zinc primer (30-40μm)	Epoxy high build Micaceous iron oxide (HB MIO) (75μm)	Aliphatic polyurethane (PU) (Minimum 50μm)	Minimum 155μm	RAL 7035
Main tank, pipes (above 80 NB), conservator tank, oil storage tank & DM Box etc. (Internal surfaces)	Shot Blast cleaning Sa 2 ½*	Hot oil proof, low viscosity varnish or Hot oil resistant, non-corrosive Paint	--	--	Minimum 30μm	Glossy white for paint
Radiator (external surfaces)	Chemical / Shot Blast cleaning Sa 2 ½*	Epoxy base Zinc primer (30-40μm)	Epoxy base Zinc primer (30-40μm)	PU paint (Minimum 50μm)	Minimum 100μm	Matching shade of tank/ different shade aesthetically matching to tank
	contractor may also offer Radiators with hot dip galvanised in place of painting with minimum thickness of 40μm (min)					
Radiator and pipes up to 80 NB (Internal surfaces)	Chemical cleaning, if required	Hot oil proof, low viscosity varnish or Hot oil resistant, non-corrosive Paint	--	--	--	--
Digital RTCC Panel	Seven tank process as per IS:3618 & IS:6005	Zinc chromate primer (two coats)	--	EPOXY paint with PU top coat or POWDER coated	Minimum 80μm / for powder coated minimum 100μm	RAL 7035 shade for exterior and Glossy white for interior
Control cabinet / Marshalling Box/Common Marshalling Box - No painting is required.						

Note: (*) indicates Sa 2 ½ as per Swedish Standard SIS 055900 of ISO 8501 Part-1.

UNUSED INHIBITED HIGH GRADE INSULATING OIL PARAMETERS

Sl. No.	Property	Test Method	Limits
A	**Function**		
1a.	Viscosity at 40degC	IS 1448 Part 25 or ISO 3104 or ASTM D7042	(Max.)12 mm^2/s
1b.	Viscosity at -30degC		(Max.)1800 mm^2/s
2.	Appearance	A representative sample of the oil shall be examined in a 100 mm thick layer, at ambient temperature	The oil shall be clear and bright, transparent and free from suspended matter or sediment
3.	Pour point	IS 1448 Part 10/Sec 2 or ISO 3016	(Max.) - 40degC
4.	Water content a) for bulk supply b) for delivery in drums	IEC 60814	(Max.) 30 mg/kg 40 mg/kg
5.	Electric strength (breakdown voltage)	IS 6792 or IEC 60156	(Min.) 50kV (new unfiltered oil) / 70 kV (after treatment)
6.	Density at 20 deg C	IS 1448 Part 16 or ISO 12185 or ISO 3675 or ASTM D7042	Max 0.895 g/ml
7.	Dielectric dissipation factor (tan delta) at 90 deg C	IS 16086 or IEC 60247 or IEC 61620	(Max) 0.0025
8.	Negative impulse testing KVp @ 25 deg C	ASTM D-3300	145 (Min.)
9.	Carbon type composition (% of Aromatic, Paraffins and Naphthenic compounds)	IEC 60590 and IS 13155 or ASTM D 2140	Max. Aromatic: 4 to12 % Paraffins: <50% & balance Naphthenic compounds.
B	**Refining/Stability**		
1.	Colour	ISO 2049	L0.5 (less than 0.5)
2.	Acidity	IEC 62021-2 or 62021-1	(Max) 0.01 mg KOH/g
3.	Interfacial tension at 27degC	IEC 62961 or ASTM D971	0.043 N/m (min)
4.	Total sulphur content	ISO 14596 or ISO 8754	0.05 % (Max.) (before oxidation test)
5.	Corrosive sulphur	DIN 51353	Not-Corrosive
6.	Potentially corrosive sulphur	IEC 62535	Not-Corrosive
7.	DBDS	IEC 62697-1	Not detectable (< 5 mg/kg)
8.	Presence of oxidation inhibitor	IS 13631 or IEC 60666	0.08% (Min.) to 0.4% (Max.) Oil should contain no other additives. Supplier should declare presence of additives, if any.
9.	Metal passivator additives	IEC 60666	Not detectable (<5 mg/kg)

10.	2-Furfural content and related compound content	IS 15668 or IEC 61198	Not detectable (<0.05 mg/kg) for each individual compound
11.	Stray gassing under thermooxidative stress	Procedure in Clause A.4 of IEC 60296-2020 (oil saturated with air) in the presence of copper	Non stray gassing: < 50 µl/l of hydrogen (H2) and < 50 µl/l methane (CH4) and < 50 µl/l ethane (C2H6)
C	**Performance**		
1.	Oxidation stability	IEC 61125 (method c) Test duration 500 hour	
2.	Total acidity*	4.8.4 of IEC 61125:2018	0.3 mg KOH/g (Max.)
3.	Sludge*	4.8.1 of IEC 61125:2018	0.05 % (Max.)
4.	Dielectric dissipation factor (tan delta) at 90degC	4.8.5 of IEC 61125:2018	0.05 (Max.)
	*values at the end of oxidation stability test		
D	**Health, safety and environment (HSE)**		
1.	Flash point	IS 1448 Part 21 or ISO 2719	(Min.)135deg C
2.	PCA content	IP 346	< 3%
3.	PCB content	IS 16082 or IEC 61619	Not detectable (< 2 mg/kg)
E	**Oil used (inhibited) for first filling, testing and impregnation of active parts at manufacturer's works shall meet parameters as mentioned below:**		
1	Break Down voltage (BDV)		70kV (min.)
2	Moisture content		5 ppm (max.)
3	Tan-delta at 90°C		0.005 (max)
4	Interfacial tension		0.04 N/m (min)
F	**Each lot of the oil shall be tested prior to filling in main tank at site for the following:**		
1	Break Down voltage (BDV)		70 kV (min.)
2	Moisture content		5 ppm (max.)
3	Tan-delta at 90°C		0.0025 (Max)
4	Interfacial tension		0.04 N/m (min)
G	**After filtration & settling and prior to energisation at site oil shall be tested for following:**		
1	Break Down voltage (BDV)		70 kV (min.)
2	Moisture content at hot condition		5 ppm (max.)
3	Tan-delta at 90°C		0.005 (Max)
4	Interfacial tension		More than 0.04 N/m
5	*Oxidation Stability		
	a) Acidity		0.3 (mg KOH /g) (max.)
	b) Sludge		0.05 % (max.)
	c) Tan delta at 90 °C		0.05 (max.)
6	*Total PCB content		Not detectable (less than 2 mg/kg total)
* Separate oil sample shall be taken and test results shall be submitted within 45 days after commissioning for approval of EMPLOYER.			

Note: Supplier shall declare the chemical family and function of all additives and the concentrations in the cases of inhibitors, antioxidants and passivators.

Annexure – G

Technical Parameters of Current Transformers
(for 1-ph, 80 & 110 MVAR, $(765/\sqrt{3})$kV Shunt Reactors)

Description	**Current Transformer Parameters (Shunt Reactor)**	
	Line Side	Neutral Side
(a) Ratio		
CORE 1	300/1A	to be decided by contractor for WTI
CORE 2	300/1A	3000-2000-500/1A
CORE 3	300/1A	3000-2000-500/1A
CORE 4	300/1A	300/1A
(b) Minimum knee point voltage or burden and accuracy class		
CORE 1	300V, PX / PS Class	Suitable for WTI
CORE 2	300V, PX / PS Class	3000V, PX / PS Class
CORE 3	300V, PX / PS Class	3000V, PX / PS Class
CORE 4	10VA, Class 1.0	300V, PX / PS Class
(c) Maximum CT Secondary Resistance		
CORE 1	1 Ohm	-
CORE 2	1 Ohm	12-8-2 Ohm
CORE 3	1 Ohm	12-8-2 Ohm
CORE 4	-	1 Ohm
(d) Application		
CORE 1	Reactor Differential	Winding Temperature Indicator
CORE 2	Restricted earth fault	Line Protection (Main-I)/T zone differential Protection/spare
CORE 3	Reactor Backup	Line Protection (Main-I)/T zone differential Protection/spare
CORE 4	Metering	Reactor Differential

Technical Parameters of Neutral Current Transformer (Outdoor type):
Common Neutral Side (for each three phase bank)

(a)	Ratio	: 300/1 A
(b)	Minimum knee point voltage	: 300 V
(c)	Accuracy class	: PX / PS
(d)	Maximum CT Resistance	: 1 Ohms
(e)	Application	: Earth fault protection
(f)	Maximum magnetization Current at $V_k/4$ (V_k= knee-point voltage)	: 40 mA

Note:

i) The secondary excitation current of class PX / PS shall not be more than 4 % of rated secondary current at 25% of knee point voltage.

ii) For PX / PS class CT's, Dimensioning parameter "K", Secondary VA shall be considered 1.5 and 20 respectively.

iii) Rated continuous thermal current rating shall be 200% of rated primary current.

iv) Parameters of WTI CT for each winding shall be provided by the contractor.

v) For estimation of spares, one set of CTs shall mean one CT of each type used in Reactor & NGR.

vi) The CT used for REF protection must have the identical parameters in order to limit the circulating current under normal condition for stability of protection.

vii) In case of single phase reactor, Common Neutral Side shall be out door type.

Gapless Surge Arrester – Technical parameters

a.	Rated arrester voltage	132 kV
b.	Rated system voltage	145 kV
c.	Rated system frequency	50Hz
d.	System neutral earthing	Earthed through NGR
e.	Installation	Outdoor
f.	Nominal discharge current	10kA of 8/20 microsec wave.
g.	Class of arrester	20kA heavy duty type
h.	Minimum discharge capacity	12 kJ/kV (referred to rated voltage)
i.	Continuous operating voltage at 50°C	106 kV
j.	Maximum switching surge residual voltage (1kA)	280 kVp
k.	Maximum residual voltage at	
(i)	10kA	314kVp
(ii)	20kA nominal discharge current	334kVp
l.	Long duration discharge class	4
m.	High current short duration test value (4/10micro-sec.wave)	100kAp
n.	Current for pressure relief test	40kArms
o.	Low current long duration test value (2000microsec.)	1000Apeak
p.	Min. total creepage distance	4495 mm.
q.	One minute dry power frequency withstand voltage of arrester housing	275kVrms
r.	Impulse withstand voltage of arrester housing with 1.2/50 micro-sec. wave	+ 550KVp
s.	Pressure relief class	A
t.	RIV at 92 kVrms.	Less than 500microvolts
u.	Partial discharge at 1.05 continuous over voltage	Not more than 50pC
v.	Seismic acceleration	As specified in section project
w.	Reference ambient temperature	50 deg C

1.1 KV GRADE POWER & CONTROL CABLES

1.1 All Power & Control cables shall be supplied from Employer's approved vendors.

1.2 Separate cables shall be used for AC & DC.

1.2 Separate cables shall be used for DC1 & DC2.

1.3 At least one (1) core shall be kept as spare in each copper control cable of 4C, 5C or 7C size whereas minimum no. of spare cores shall be two (2) for control cables of 10 core or higher size.

1.4 The Aluminium/Copper wires used for manufacturing the cables shall be true circular in shape before stranding and shall be uniformly good quality, free from defects. All aluminium used in the cables shall be of H2 grade and shall conform to IS 8130.

1.5 The fillers and inner sheath shall be of non-hygroscopic, fire retardant material, shall be softer than insulation and outer sheath shall be suitable for the operating temperature of the cable.

1.6 Progressive sequential marking of the length of cable in metres at every one metre shall be provided on the outer sheath of all cables.

1.7 Strip wire armouring method (a) mentioned in Table 5, Page-6 of IS: 1554 (Part 1) – 1988 shall not be accepted for any of the cables. For control cables only round wire armouring shall be used.

1.8 The cables shall have outer sheath of a material with an oxygen index of not less than 29 and a temperature index of not less than 250°C.

1.9 All the cables shall conform to fire resistance test as per IS: 1554 (Part - I).

1.10 The normal current rating of all PVC insulated cables shall be as per IS: 3961.

1.11 Repaired cables shall not be accepted.

1.12 Allowable tolerance on the overall diameter of the cables shall be ±2 mm.

1.13 PVC Power Cables

1.13.1 The PVC insulated 1100V grade power cables shall be of Fire Retardant Low Smoke Halogen (FRLSH) type, C2 category, conforming to IS: 1554 (Part-I) and its amendments read along with this specification and shall be suitable for a steady conductor temperature of 85°C. The conductor shall be stranded aluminium H2 grade conforming to IS 8130. The Insulation shall be extruded PVC to type-C of IS: 5831. A distinct inner sheath shall be provided in all multi core cables. For multi core armoured cables, the inner sheath shall be of extruded PVC. The outer sheath shall be extruded PVC of Type ST-2 of IS: 5831 for all cables. The copper cable of required size can also be used.

1.14 PVC Control Cables

1.14.1 The 1100V grade control cables shall be of FRLSH type, C2 category conforming to IS: 1554 (Part-1) and its amendments, read along with this specification. The conductor shall be stranded copper. The insulation shall be extruded PVC of type A of IS: 5831. A distinct inner sheath shall be provided in all cables whether armoured or not. The outer sheath shall be extruded PVC of type ST-1 of IS: 5831 and shall be grey in colour except where specifically advised by the purchaser to be black.

1.14.2 Cores shall be identified as per IS: 1554 (Part-1) for the cables up to five (5) cores and for cables with more than five (5) cores the identification of cores shall be done by printing legible Hindu Arabic Numerals on all cores as per clause 10.3 of IS: 1554 (Part - 1).

STANDARD TECHNICAL DATA SHEET (1.1kV GRADE XLPE POWER CABLES)

Sr. No	Description	Parameters	
1a	Name of manufacturer	As per approved list	
b	Cable Sizes	1 C x 630	3½ C x 300
c	Manufacturer's type designation	A2XWaY	A2XWY
2	Applicable standard	IS: 7098/PT-I/1988 & its referred specifications	
3	Rated Voltage(volts)	1100 V Grade	
4	Type & Category	FR & C1	FR & C1
5	Suitable for earthed or unearthed system	for both	
6	Continuous current rating when laid in air in a ambient temp. of 50°C and for maximum conductor temp. of 70 °C of PVC Cables[For information only]	732	410
7	Rating factors applicable to the current ratings for various conditions of installation	As per IS-3961-Pt-II-67	
8	Short circuit Capacity		
a	Guaranteed Short Circuit Amp. (rms) KA for 0.12 sec duration at rated conductor temperature of 90 degree C, with an initial peak of 105 KA	45kA	45kA
b	Maximum Conductor temp. allowed for the short circuit duty (deg C.) as stated above	250°C	
9	Conductor		
a	Material	Stranded Aluminium as per Class 2 of IS : 8130	
b	Grade	H 2 (Electrolytic grade)	
c	Cross Section area (Sq.mm.)	630	300/150
d	Number of wires(No.) minimum	53	30/15
e	Form of Conductor	Stranded and compacted circular	Stranded compacted circular/sector shaped
f	Direction of lay of stranded layers	Outermost layer shall be R.H lay & opposite in successive layers	
10	Conductor resistance (DC) at 20 °C per km-maximum	0.0469	0.1/0.206
11	Insulation		
a	Composition of insulation	Extruded XLPE as per IS-7098 Part(1)	
b	Nominal thickness of insulation(mm)	2.8	1.8/1.4
c	Minimum thickness of insulation	2.42	1.52/1.16
12	Inner Sheath		
a	Material	Extruded PVC type ST-2 as per IS-5831-84	
b	Calculated diameter over the laid up cores,(mm)	NA	52
c	Thickness of Sheath (minimum)mm	NA	0.6
d	Method of extrusion	NA	Pressure/Vacuum extrusion
13	Armour		
a	Type and material of armour	Al wire [H4 grade]	Gal. Steel wire
b	Direction of armouring	Left hand	
c	Calculated diameter of cable over inner sheath (under armour), mm	33.9	53.2
d	Nominal diameter of round armour wire (minimum)	2	2.5
e	Guaranteed Short circuit capacity of the armour for 0.12 sec at room temperature.	45kA	45kA
f	DC resistance at 20 °C (Ω/Km)	$	0.577
14	Outer Sheath	ST-2 & FR	ST-2 & FR

A	Material (PVC Type)	38.3	59.50
B	Calculated diameter under the sheath	1.72	2.36
C	Min. thickness of sheath(mm)	Min 29.0	Min 29.0
D	Guaranteed value of minimum oxygen index of outer sheath at 27 °C	Min 250	Min 250
E	Guaranteed value of minimum temperature index at 21 oxygen index	Black	Black
f	colour of sheath	$	$
15a	Nominal Overall diameter of cable	+2/-2 mm	
b	Tolerance on overall diameter (mm)	shall conform to IS 10418 and technical specification	
16	Cable Drums	1000/500	1000/500
a	Max./ Standard length per drum for each size of cable (single length) with ±5% Tolerance (mtrs)		
b	Non-standard drum lengths	Maximum one(1) non-standard lengths of each cable size may be supplied in drums only over & above the standard lengths as specified above.(if required for completion of project)	
17	Whether progressive sequential marking on outer sheath provided at1 meter interval 18	Yes	
18	Identification of cores		
a	colour of cores	As per IS 7098 Part(1)	
b	Numbering	NA	
19	Whether Cables offered are ISI marked	Yes	
20	Whether Cables offered are suitable for laying as per IS 1255	Yes	

$'- As per manufacturer design data

STANDARD TECHNICAL DATA SHEET - 1.1kV kV GRADE PVC POWER CABLES

Name of manufacturer: As per approved list

SN	Description	Parameters					
1a	Cable Sizes	1 c x 150	3.5 cx 70	3.5 cx 35	4 c x 16	4c x 6	2 c x 6
1b	Manufacturer's type designation	AYWaY	AYFY	AYFY	AYFY	AYWY	AYWY
2	Applicable standard	IS: 1554/PT-I/1988 & its referred standards					
3	Rated Voltage(volts)	1100 V grade					
4	Type & Category	FR & C1	FR & C1	FR & C1	FR & C1	FR & C1	FR & C1
5	Suitable for earthed or unearthed system	for both					
6	Continuous current rating when laid in air in a ambient temp. of 50oC and for maximum conductor temp. of 70 oC of PVC Cables[For information only]	202	105	70	41	24	28
7	Rating factors applicable to the current ratings for various conditions of installation:	As per IS-3961-Pt-II-67					
8	Short circuit Capacity						
a)	Short Circuit Amp. (rms)KA for 1 sec duration	11.2	5.22	2.61	1.19	0.448	0.448
b)	Conductor temp. allowed for the short circuit duty (deg C.)	160^0C					
9	Conductor						
a)	Material	STRANDED ALUMINIUM					
b)	Grade	H 2 (Electrolytic grade)					
c)	Cross Section area (Sq.mm.)	150	M-70 N-35	M-35 N-16	16	6	6
d)	Number of wires(No.)	as per Table 2 of IS 8130					
e)	Form of Conductor	Non-compacted Stranded circular	shaped conductor	shaped conductor	shaped conductor	Non-compacted Stranded circular	Non-compacted Stranded circular
f)	Direction of lay of stranded layers	Outermost layer shall be R.H lay & opposite in successive layer					
10	Conductor resistance (DC) at 20 oC per km-maximum	0.206	0.443/0.868	0.868/1.91	1.91	4.61	4.61
11	Insulation						
a)	Composition of insulation	Extruded PVC type A as per IS-5831-84					
b)	Nominal thickness of insulation(mm)	2.1	1.4/1.2	1.2/1.0	1.0	1.0	1.0
c)	Minimum thickness of insulation	1.79	1.16/0.98	0.98/0.8	0.8	0.8	0.8
12	Inner Sheath						
a)	Material	Extruded PVC type ST-I as per IS-5831-84					
b)	Calculated diameter over the laid up cores,(mm)	N.A	27.6	20.4	15.7	11.6	9.6
c)	Thickness of Sheath (minimum) mm	N.A	0.4	0.3	0.3	0.3	0.3
13	Armour	as per IS 3975/88					
a)	a) Type and material of armour	Al. Wire[H4 grade]	Gal.steel strip	Gal.steel strip	Gal.steel strip	Gal.steel wire	Gal.steel wire

b)	b) Direction of armouring	left hand					
c)	c) Calculated diameter of cable over inner sheath (under armour), mm	18	28.4	21	16.3	12.2	10.2
d)	d) Nominal diameter of round armour wire/strip	1.6 4	0.8 4	0.8 4	0.8	1.4	1.4
e)	e) Number of armour wires/strips	Armouring shall be as close as practicable					
f)	f) Short circuit capacity of the armour along for 1 sec-for info only	K x A√t (K Amp)(where A = total area of armour in mm^2& t = time in seconds), K=0.091 for Al & 0.05 for steel					
g)	g) DC resistance at 20 oC (Ω/Km)	0.44	2.57	3.38 4	3.99	3.76	4.4
14	Outer Sheath						
a)	a) Material (PVC Type)	ST-1& FR	ST-1& FR	ST-1& FR	ST-1& FR	ST-1& FR	ST-1& FR
b)	b) Calculated diameter under the sheath	21.2	30.1	22.6	17.9	15	13
c)	c) Min.thickness of sheath(mm)	1.4	1.56	1.4	1.4	1.4	1.24
d)	d) Guaranteed value of minimum oxygen index of outer sheath at 27oC	Min 29.0	Min 29.0	Min 29.0	Min 29.0	Min 29.0	Min 29.0
e)	e) Guranteed value of minimum temperature index at 21 oxygen index	Min 250	Min 250	Min 250	Min 250	Min 250	Min 250
f)	f) colour of sheath	Black	Black	Black	Black	Black	Black
15a)	a) Overall diameter of cable	$					
b)	b) Tolerance on overall diameter (mm)	+2/-2 mm					
16	Cable Drums	shall conform to IS 10418 and technical specification					
a)	a) Max./ Standard length per drum for each size of cable (single length) with ±5% Tolerance (mtrs)	1000/500	1000/500	1000/500	1000/500	1000/500	1000/500
b)	b) Non standard drum lengths	Maximum one(1) non standard lengths of each cable size may be supplied in drums only over & above the standard lengths as specified above.(if required for completion of project)					
17	Whether progressive sequential marking on outer sheath provided	Yes					
18	Identification of cores						
a)	a) colour of cores	Red	R,Y,Bl & Bk	R,Y,Bl& Bk	R,Y,Bl & Bk	R,Y,Bl & Bk	Red & Bk
b)	b) Numbering	N.A	N.A	N.A	N.A	N.A	N.A
19	Whether Cables offered are ISI marked	YES					
20	Whether Cables offered are suitable for laying as per IS 1255	YES					

$'- As per manufacturer design data

STANDARD TECHNICAL DATA SHEET - 1.1kV kV GRADE PVC CONTROL CABLES

Name of manufacturer: As per approved list

SN	Description	Parameters							
1a	Cable Sizes	2 c x 2.5	3c cx 2.5	5c x 2.5	7 c x 2.5	10 c x 2.5	14 c x 2.5	19 c x 2.5	27 c x 2.5
1b	Manufacturer's type designation	YWY	YWY	YWY	YWY	YWY	YWY	YWY	YWY
2	Applicable standard	IS: 1554/PT-I/1988 & its referred standards							
3	Rated Voltage(volts)	1100 V grade							
4	Type & Category	FR & C1							
5	Suitable for earthed or unearthed system	for both							
6	Continuous current rating when laid in air in a ambient temp. of 50oC and for maximum conductor temp. of 70 oC of PVC Cables[For information only]	22	19	19	14	12	10.5	9.7	8
7	Rating factors applicable to the current ratings for various conditions of installation:	As per IS-3961-Pt-II-67							
8	Short circuit Capacity								
a)	Short Circuit Amp. (rms)KA for 1 sec duration	0.285	0.285	0.285	0.285	0.285	0.285	0.285	0.285
b)	Conductor temp. allowed for the short circuit duty (deg C.)	160^0C							
9	Conductor								
a)	Material	Plain annealed High Conductivity stranded Copper (as per IS 8130/84)							
b)	Grade	Electrolytic							
c)	Cross Section area (Sq.mm.)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
d)	Number of wires(No.)	as per Table 2 of IS 8130							
e)	Form of Conductor	Non-compacted Stranded circular shaped conductor							
f)	Direction of lay of stranded layers	Outermost layer shall be R.H lay							
10	Conductor resistance (DC) at 20 oC per km-maximum	7.41	7.41	7.41	7.41	7.41	7.41	7.41	7.41
11	Insulation								
a)	Composition of insulation	Extruded PVC type A as per IS-5831-84							
b)	Nominal thickness of	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

	insulation(mm)								
c)	Minimum thickness of insulation	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
12	Inner Sheath								
a)	Material	Extruded PVC type ST-I as per IS-5831-84							
b)	Calculated diameter over the laid up cores,(mm)	7.2	7.8	9.7	10.8	14.4	15.9	18	22.1
c)	Thickness of Sheath (minimum)mm	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
13	Armour	as per IS 3975/99							
a)	Type and material of armour	Gal. Steel Wire							
b)	Direction of armouring	left hand							
c)	Calculated diameter of cable over inner sheath (under armour), mm	7.8	8.4	10.3	11.4	15	6.5	18.6	22.7
d)	Nominal diameter of round armour wire/strip	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6
e)	Number of armour wires/strips	Armouring shall be as close as practicable							
f)	Short circuit capacity of the armour along for 1 sec-for info only	0.05 x A√t (K Amp)(where A = total area of armour in mm2 & t = time in seconds)							
g)	DC resistance at 20 oC (Ω/Km) & Resistivity	As per IS 1554 Part (1), wherever applicable and IS 3975-1999							
14	Outer Sheath								
a)	Material (PVC Type)	ST-1& FR							
b)	Calculated diameter under the sheath	10.6	11.2	13.1	14.2	18.2	19.7	21.8	25.9
c)	Min.thickness of sheath(mm)	1.24	1.24	1.24	1.24	1.4	1.4	1.4	1.56
d)	Guaranteed value of minimum oxygen index of outer sheath at 27oC	Min 29.0	Min 29.0	Min 29.0	Min 29.0	Min 29.0	Min 29.0	Min 29.0	Min 29.0
e)	Guranteed value of minimum temperature index at 21 oxygen index	Min 250	Min 250	Min 250	Min 250	Min 250	Min 250	Min 250	Min 250
f)	colour of sheath	Grey	Grey	Grey	Grey	Grey	Grey	Grey	Grey
15a)	Overall diameter of cable	$							
b)	Tolerance on overall diameter (mm)	+2/-2 mm							
16	Cable Drums	shall conform to IS 10418 and technical specification							
a)	Max./ Standard length per drum for each size of cable (single length) with ±5% Tolerance (mtrs)	1000/500							

b)	Non standard drum lengths	Maximum one(1) non standard lengths of each cable size may be supplied in drums only over & above the standard lengths as specified above.(if required for completion of project)							
17	Whether progressive sequential marking on outer sheath provided								
18	Identification of cores	Yes							
a)	colour of cores	R & Bk	R, Y & Bl	Red R,Y,Bl	Grey	Grey	Grey	Grey	Grey
b)	Numbering	N.A	N.A	N.A	Numerals in black ink				
19	Whether Cables offered are ISI marked	YES							
20	Whether Cables offered are suitable for laying as per IS 1255	YES							

$'- As per manufacturer design data

Technical Specification of Oil BDV Test Set (Applicable as per BPS)

Item	Specification
Functional Requirement	1. The instrument should be suitable for Automatic Measurement of Electrical Breakdown Strength of Reactor oil as per relevant standards. 2. The test results should have repeatability, consistency in laboratory condition.
Test Output	0-100 kV (Rate of rise: 0.5 to 5KV/Sec)
Accuracy	± 1 kV
Resolution	0.1 KV
Switch off Time	≤ 1ms
Display/Control	LCD/Keypads.
Printer	Inbuilt/External
Measurement Programmes	Fully Automatic Pre-programmed/User programmed Test Sequences including as per latest IEC & other national/international standards.
Test Lead/ Accessories	One complete set of electrodes, gauge etc. compatible with the instruments should be provided for successfully carrying out the test in EMPLYER S/S. Additionally all the required accessories, tools, drawing, documents should be provided for the smooth functioning of kit. Further hard carrying case (which should be robust/ rugged enough) for ensuring proper safety of the kit during transportation shall have to be provided.
Design/Engg.	The complete equipment along with complete accessories must be designed / engineered by Original Equipment Manufacturer.
Power Supply	It shall work on input supply variations, V: 230 ±10 %, f: 50 Hz ±5 % on standard sockets.
Operating Temperature	0 to +50 deg C
Relative humidity	Max. 90% non-condensing.
Protection/ Control	Against short circuit, over load, transient surges etc. Also the instrument should have facility of stopping automatically on power failure. Also the kit should have facility of HV chamber interlocking as well as zero start interlocking.
Environment	The test kit shall be compatible for EMI/EMC/Safety environment requirement as per IEC.
Guarantee	Warranty/Guarantee Period: Min 05 year from the date of successful & complete commissioning at Emplyer sub-station. All the materials, including accessories, cables, laptops etc. are to be covered under warranty/guaranty period. If the kit needs to be shifted to supplier’s works for repairs within warranty/guaranty period, suppliers will have to bear the cost of spares, software, transportation of kit for repair at test lab / works.
Calibration Certificate	Unit shall be duly calibrated before supply and the date of calibration shall not be older than two month from the date of supply of Kit.
Training	Supplier shall have to ensure that the instrument is made user friendly. Apart from the detailed demonstration at site, the supplier shall also have to arrange necessary training to EMPLYER engineers.
Commissioning, handing over the Instrument	Successful bidder will have to commission the instrument to the satisfaction of EMPLOYER. The instrument failed during the demonstration shall be rejected and no repairs are allowed.
After sales service	Bidder will have to submit the documentary evidence of having established mechanism in India for prompt services.

Technical Specification of Portable Dissolved Gas Analysis of Oil (Applicable as per BPS)

S.No.	Particulars	Specification
01	Functional Requirement	The Portable DGA equipment to extract, detect, analyze and display the dissolved gases in insulating oil as specified in IEEE C 57-104-2008 and IEC 60599-2007.
02	Detection of Gases	All the fault gases i.e. H2, CH4, C2H2, C2H4, C2H6, CO & CO2 concentrations shall be individually measured and displayed. The minimum detection limits of the instrument for the above gases shall strictly be met the requirement of IEC-60567-2011-Page No. 47-clause 9.2, table-5.
03	Power Supply	It shall be operated with AC single phase,50 Hz +/-5%, 230 V +/- 10% supply. All power cable and necessary adaptors shall be provided by supplier.
05	Instrument control and Data handling, Internal Memory	a) Instrument shall be having in-built control for all the functions (data acquisitions and data storage), it shall have a facility for communication with computer for downloading the data from instrument via USB port. b) Laptop shall be provided for communication with the instrument. it shall be of latest specification along with licensed preloaded OS and software as well as software for interpreting DGA results accordance with IEEE C 57-104-1991 and IEC 60559-1999. Laptop carrying case shall also be provided. c) Internal Memory can capable of store atleast 15000 records
06	General Conditions	a) Performance Parameters like - Minimum Detection Limits, Working Range, Accuracy, repeatability etc. shall be finalized during detailed engineering. b) The portable DGA equipment supplier shall demonstrate during commissioning of the kit that the results shown by the kit are within the specified accuracy and repeatability range and EMPLOYER will provide only the insulating oil/ GAS-IN-OIL standard for testing. c) All required items/instruments /spares /consumable /connecting cables/communication cables/instruments/manuals/Certificates/training materials/original software/original licensed data/station operating software/education CD/DVDs that are essential to understand and operate the instrument shall be supplied at no extra cost.
07	Operating Temperature, Relative humidity	01. Temperature 0-50 Deg. C

	& Dimensions	02. 85% non-condensing 03. Portable
08	Warranty	The entire test set up shall be covered on warranty for a period of 5 year from the last date of complete commissioning and taking over the test set up. If the kit needs to be shifted to suppliers works for repairs, supplier will have to bear the cost of, spares, software, transportation etc of kit for repair at test lab/works.
09	Service Support	The supplier shall furnish the requisite documents ensuring that the equipment manufacturer is having adequate service team and facility in India to take care of any issues during operation of the instrument.
10	Training	The supplier shall provide adequate training for a period of two working days pertaining to the operation and troubleshooting to site personnel.

ANNEXURE - K

Online Dissolved Gas (Multi-gas) and Moisture Analyser (Applicable as per BPS)

1.1. Online Dissolved Gas (Multi-gas) and Moisture Analyser along with all required accessories including inbuilt display shall be provided with each reactor for measurement & analysis of dissolved gases and moisture in the oil. Interpretations shall be as per IEC 60599-1999.

1.2. The equipment shall detect, measure and analyse the following gases:

Gases & Moisture Parameters	Typical Detection Range
H_2	5 – 5,000 ppm
CH_4	5 – 5,000 ppm
C_2H_6	5 – 5,000 ppm
C_2H_4	3 – 5,000 ppm
C_2H_2	1 – 3,000 ppm
CO	10 – 10,000 ppm
CO_2	20 – 30,000 ppm
H_2O	2 – 100 % RS should have facility for measurement of moisture in oil in ppm

1.3. The analyser should measure (not calculate) all above gases and should have 100% sensitivity. The equipment shall be capable of transferring data to sub-station automation system confirming to IEC 61850. Necessary interface arrangement shall be provided by the contractor for integration with automation system. The necessary type test report for such confirmation shall be submitted during detailed engineering.

1.4. Equipment shall havefacility to give SMS alert to at least three users whenever any fault gas violates the predefined limit.

1.5. Equipment should work on station auxiliary supply. In case other supply is required for the equipment then suitable converter shall be included. All the necessary power and control cables, communication cables, cable accessories as required shall be provided by the supplier.

1.6. Online DGA shall be installed out door on reactor in harsh ambient and noisy condition (Electromagnetic induction, Corona, and capacitive coupling). Equipment shall be mounted separately on ground. Suitable arrangement shall be provided to support and protect the inlet and outlet piping arrangement. The connecting oil lines must be of Stainless Steel rigid pipes or flexible hoses.The equipment shall be suitable for proper operation in EHV substation (800kV) environment where switching takes place in the EHV/HV System. The suitable indications for power On, Alarm, Caution, normal operation etc. shall be provided on the front panel of the equipment. The equipment shall have IP55 Stainless Steelenclosure, suitable for 55 ^{0}C ambient temperature and EMI and EMC compatibility.The Equipment must carry a minimum of five (5) years manufacturer's Warranty.

1.7. The equipment shall display all the individual gas and moisture concentration on its display unit and shall have facility to download all the stored the data from the unit for further analysis. The sampling rate shall be selectable as 2 or 4 or 6 or 12 hours etc.

The equipment shall have inbuilt memory to store these results for complete one year even if sampling is done at the lowest interval. The carrier and calibration gas (if applicable) shall have minimum capacity to work for at least three years without replacement. All the consumable (if any) upto warrantee period shall be included in the scope of supply

1.8. The Equipment must have an automatic Calibration facility at fixed intervals. For calibration if anything required including cylinder must be mounted with the Equipment.

1.9. The technical feature of the equipment shall be as under:

Accuracy	± 10%
Repeatability	±3% to 10% depending upon gases
Oil temperature range	- 20^0 C to + 120^0 C
External Temp. Range	- 20^0 C to + 55^0 C (External temp range of 55^0 C is important and should not be compromise due to Indian ambient & operating conditions.)
Humidity range	10 to 95 %
Operating Voltage	230 Vac; 50 Hz (±20% variation)
Communications	USB&IEC 61850 compliant

1.10. Software for fault indication and fault diagnostics shall include following:
Fault indication:

i) IEEE, IEC or user configurable levels of dissolved gases
ii) Rate of change trending

Fault Diagnosis:

i) Key gases
ii) Ratios (Rogers, IEC. etc.)
iii) Duval's Triangle

1.11. The equipment shall be supplied with all necessary accessories required for carrying out DGA of oil sample complete in all respect as per the technical specification. The following shall be also form a part of supply.

i) Software
ii) Operation Manual (2 set for every unit),
iii) Software Manual and
iv) Compact disc giving operation procedures of Maintenance Manual & Trouble shooting instructions.

1.12. The installation and commissioning at site shall be done under the supervision of OEM representative or OEM certified representative.

On-line insulating oil drying system (Cartridge type)

In addition to provision of air cell in conservators for sealing of the oil system against the atmosphere, each reactor shall be provided with an on line insulating oil drying system of adequate rating with proven field performance. This system shall be separately ground mounted and shall be housed in metallic (stainless steel) enclosure. The bidder shall submit the mounting arrangement. This on line insulating oil drying system shall be

i. Designed for very slow removal of moisture that may enter the oil system or generated during cellulose decomposition. Oil flow to the equipment shall be controlled through pump of suitable capacity (at least 5 LPM).

ii. The equipment shall display the moisture content in oil (PPM) of the inlet and outlet oil from the drying system.

iii. In case, drying system is transported without oil, the same shall be suitable for withstanding vacuum to ensure that no air / contamination is trapped during commissioning.

   In case, drying system is transported with oil, the oil shall conform to EMPLOYER specification for unused oil. Before installation at site, oil sample shall be tested to avoid contamination of main tank oil.

iv. Minimum capacity of moisture extraction shall be 10 Litres before replacement of cartridge. Calculation to prove the adequacy of sizing of the on line insulating oil-drying system along with make and model shall be submitted for approval of Employer during detail engineering.

v. The installation and commissioning at site shall be done under the supervision of OEM representative or OEM certified representative.

vi. The equipment shall be capable of transferring data to substation automation system confirming to IEC 61850 through FO port. Necessary interface arrangement shall be provided by the contractor for integration with automation system.

The equipment shall be supplied with Operation Manual (2 set for every unit), Software (if any), and Compact disc giving operation procedures of Maintenance Manual & Trouble shooting instructions.

ANNEXURE - M

Oil sampling bottles (Applicable as per BPS)

Oil sampling bottles (if specified in BPS) shall be suitable for collecting oil samples from Reactors and shunt Reactors, for Dissolved Gas Analysis. Bottles shall be robust enough, so that no damage occurs during frequent transportation of samples from site to laboratory.

Oil sampling bottles shall be made of stainless steel having a capacity of 1litre. Oil Sampling bottles shall be capable of being sealed gas-tight and shall be fitted with cocks on both ends.

The design of bottle & seal shall be such that loss of hydrogen shall not exceed 5% per week.
An impermeable oil-proof, transparent plastic or rubber tube of about 5 mm diameter, and of sufficient length shall also be provided with each bottle along with suitable connectors to fit the tube on to the oil sampling valve of the equipment and the oil collecting bottles respectively.

The scope of oil sampling bottles shall be included in the bid price as per the quantity indicated in the bid price schedule.

Oil Syringe (Applicable as per BPS)

If specified in BPS, the glass syringe of capacity 50ml (approx) and three way stop cock valve shall be supplied. The syringe shall be made from Heat resistant borosilicate Glass. The material and construction should be resistant to breakage from shock and sudden temperature changes, reinforced at luer lock tip Centre and barrel base.

The cylinder-Plunger fitting shall be leak proof and shall meet the requirement of IEC-60567. Plunger shall be grounded and fitted to barrel for smooth movement with no back flow. Barrel rim should be flat on both sides to prevent rolling and should be wide enough for convenient finger tip grip. The syringe shall be custom fit and uniquely numbered for matching. The syringe shall be clearly marked with graduations of 2.0 ml and 10.0 ml and shall be permanently fused for life time legibility.

Oil Storage Tank (Applicable as per BPS)

1. Oil storage tank shall be of minimum capacity (as per BPS) along with complete accessories. The oil storage tank shall be designed and fabricated as per relevant Indian Standards e.g. IS 10987 (1992). Transformer oil storage tanks shall be towable on pneumatic tyres and rested on manual screw jacks of adequate quantity & size. The tank shall be cylindrical in shape and mounted horizontally and made of mild steel plate of thickness as per standard. Diameter of the tank shall be 2.0 meter approximately. The tank shall be designed for storage of oil at a temperature of 100°C.

2. The maximum height of any part of the complete assembly of the storage tank shall not exceed 4.0 metres above road top.

3. The tank shall have adequate number of jacking pad so that it can be kept on jack while completely filled with oil. The tank shall be provided with suitable saddles so that tank can be rested on ground after removing the pneumatic tyres.

4. The tank shall also be fitted with manhole, outside & inside access ladder, silica gel breather assembly, inlet & outlet valve, oil sampling valve with suitable adopter, oil drainage valve, air vent etc. Pulling hook on both ends of the tank shall be provided so that the tank can be pulled from either end while completely filled with oil. The engine capacity in horsepower to pull one tank completely fitted with oil shall be indicated. Oil level indicator shall be provided with calibration in terms of litre so that at any time operator can have an idea of oil in the tank. Solenoid valve (Electro-mechanically operated) with Centrifugal pump shall be provided at bottom inlet so that pump shall be utilised both ways during oil fill up and draining. Suitable arrangement shall also be provided to prevent overflow and drain form the tank.

5. Each tank shall be thoroughly cleaned internally of all loose matter and then tested to a pressure of 0.7 bar, measured at the top of the tank as per standard. Tank shall also be tested at internal vacuum of 10mbar.

6. The following accessories shall also form part of supply along with each Oil storage tank.

7.1 Four numbers of 50NB suitable rubber hoses for Transformer oil application up to temperature of 100°C, full vacuum and pressure up to 2.5 Kg/ cm2 with couplers and unions each not less than 10 metre long shall be provided.

7.2 Two numbers of 100NB suitable for full vacuum without collapsing and kinking vacuum hoses with couplers and unions each not less than 10 metre long shall also be provided.

7.3 One number of digital vacuum gauge with sensor capable of reading up to 0.001 torr, operating on 240V 50Hz AC supply shall be supplied. Couplers and unions for sensor should block oil flow in the sensor. Sensor shall be provided with at-least 8-meter cable so as to suitably place the Vacuum gauge at ground level.

7.4 The painting of oil storage tank and its control panel shall be as per technical specification.

The tank shall contain a self-mounted centrifugal oil pump with inlet and outlet valves, with couplers -suitable for flexible rubber hoses and necessary switchgear for its control. There shall be no rigid connection to the pump. The pump shall be electric motor driven, and shall have a discharge of not less than 6.0 kl/hr. with a discharge head of 8.0m. The pump motor and the control cabinet shall be enclosed in a cubicle with IP-55 enclosure.

Annexure–O

Spare Reactor Unit Storage & Connection Arrangement

1.1. **Reactor with Isolator switching arrangement:** Employer intends to replace any of the Reactor unit by the spare Reactor unit using isolator switching arrangement so as to avoid physical shifting the Reactor.

Connection of spare unit of Reactor with other units shall be made by isolator switching arrangement. Neutral formation for spare unit of Reactor shall be done by manual connection. The spare Reactor unit shall be completely erected and commissioned similar to the other Reactor units. The contractor shall carry out all pre-commissioning tests on the spare Reactor similar to the unit kept in service.

For this purpose if specified in BPS, HV and Neutral Connections of spare unit shall be extended upto the other unit(s) by forming auxiliary buses connection through flexible/rigid conductor. All associated materials like Bus post insulators, Aluminium tube, conductors, clamps & connectors, insulator strings, hardware, cables, support structures, required for the above-mentioned arrangement shall be provided by the contractor. However, the detail configuration and hardware shall be finalised during detailed engineering and shall be subject to Employer's approval.

Any special maintenance procedure required shall be clearly brought out in the instruction manual.

1.2. **Reactor without isolator switching arrangement:** Employer intends to keep the spare Reactor unit without isolator switching arrangement due to space limitation. In case of failure of any of the running unit, this spare reactor shall be physically shifted to replace faulty reactor.

The spare Reactor shall be placed on the elevated foundation block to facilitate quick movement. The Reactor unit may be required to be stored for long duration. The spare Reactor unit shall be completely erected and commissioned similar to the other Reactor units. However, erection of separate cooler bank is not envisaged. In case conservator is cooler bank mounted, suitable arrangement for mounting of conservator on tank top cover shall be provided. The contractor shall carry out all pre-commissioning tests on the spare Reactor similar to the unit kept in service.

All other items shall be suitably packed in reusable boxes. Arrangement shall be made to minimize moisture ingress inside the boxes. All pipes and radiators shall be provided with blanking plates during long duration storage to prevent entry of foreign material/ water.

In case spare Reactors needs to be commissioned in switchyard bay (as advised by Engineer in-charge), the contractor shall erect, test and commission the spare reactor unit similar to other units in service. However packaging material as above for long-term storage shall be included in the scope of bidder.

Condition Controlled Maintenance Free Type Breather (If specified in BPS)

1. The main Reactor tank conservator shall be fitted with a Maintenance-Free type silica gel Breather which shall be equipped with a microprocessor control unit and LED status indication.

2. **Dehydrating breather's operating principle:**

   When the oil conservator breaths-in (e.g. at reduced load), the air flows through a filter made of high-grade steel wire mesh. The equipment fitted with filter & the dust cap, filters the dust, sand and other dirt particles from the air. The filtered air flows through the desiccant chamber filled with colorless, moisture adsorbing pellets and are dehydrated. The dehydrated air rises further via the pipe in the oil conservator. The desiccant is dehydrated by the built-in heating unit which is controlled by sensors, thus obviating the need for periodic desiccant replacement. The dehydrating breather is mounted on the pipe to the oil conservator at a height of 1200 mm approximately from Reactor rail top level.

3. Technical **Features:**

3.1 Material & External Construction of the Breather shall be such that all external parts are suitable for outdoor use & resistive to transformer oil, ultraviolet rays, pollution & salt water and shall work without any trouble for ambient temperature between 0o C to +80o C.

3.2 Following LEDs for local display on control unit, and suitable contacts & analog signal shall be provided for wiring to remote location:

a) LED for Power of control unit - ON
b) LED for Filter heater- ON
c) LED for Anti-condensation heater (of control unit) - ON
d) LED & relay contact for "Device Error"
e) LED & relay contact for Regeneration active (De-humidification in process)
f) Analogue output signal (4-20mA) for the Temperature of air (in filter unit / pipe).

3.3 The Breather shall be equipped with test button which should allow to carry out a self-test and to check the functions like relay circuits, heating or the signal transmission in the control room, etc. at any time.

3.4 Control unit shall be equipped with a communication port for downloading the operational data logged by the unit. All necessary software required for downloading and analysing the logger data shall also be provided by the supplier. Supply of Laptop/PC for above software is not envisaged.

3.5 The moisture and temperature measurement system (sensor) installed should be modular making it easy to replace the same if at all the same is necessary during the service of breather.

3.6 The equipment shall operate at input supply of 230V AC, 50 Hz. Any converter if required shall be supplied with the equipment.

3.7 Degree of Protection shall be at least IP55 for which type Test report shall be submitted. Necessary protective devices shall be provided in order to protect the equipment against over voltages & high-frequency interference.

3.8 The control unit shall be equipped with suitable heater to prevent moisture condensation.

3.9 The size of Condition controlled maintenance free dehydrating breather shall be decided based on the volume of Reactor oil during detailed engineering.

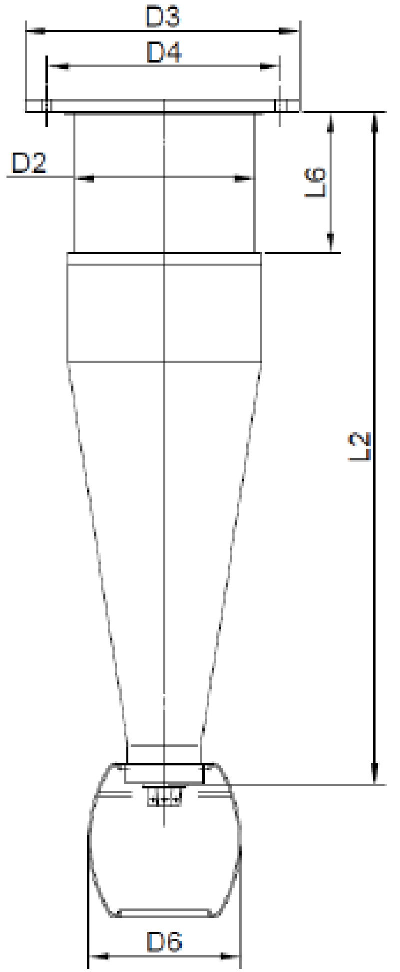
4. The equipment shall be covered on warranty for a period of 5 years from the last date of complete commissioning and taking over. During this period, if the equipment needs to be shifted to suppliers works for repairs, supplier will have to bear the cost of, spares, software, transportation etc. of this equipment for repair at test lab/works. Further supplier shall make alternate arrangement for smooth operation of the Reactor.

5. Condition Controlled Maintenance Free Type Breather of alternate proven technology shall also be acceptable.

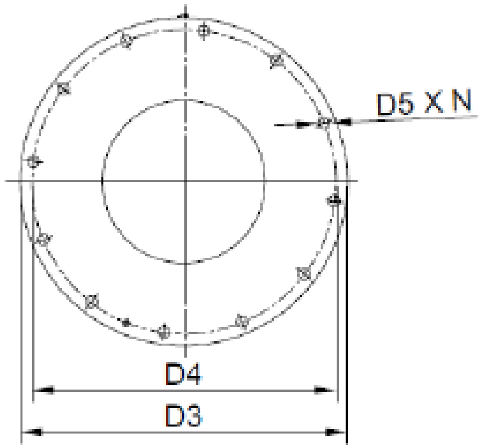
------------- X -------------

STANDARD DIMENSIONS FOR LOWER PORTION OF CONDENSER BUSHINGS

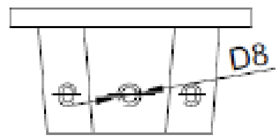
(For 2500 A, 800 kV and 420 kV voltage class Bushings)



Bushing Mounting Flange Details



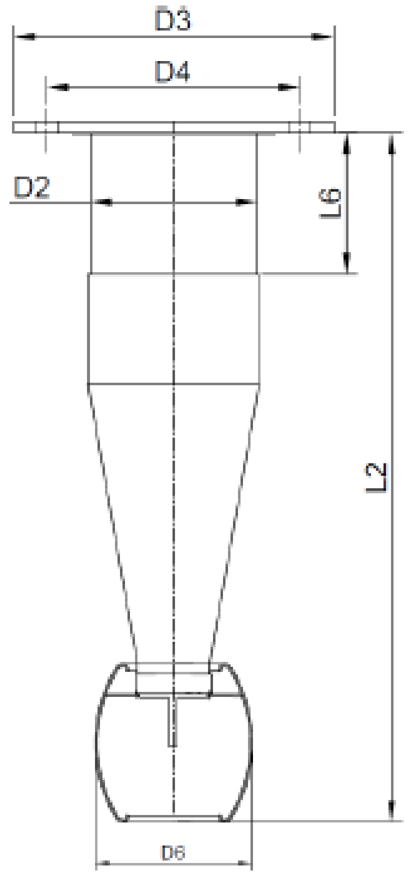
Bottom Connection Details



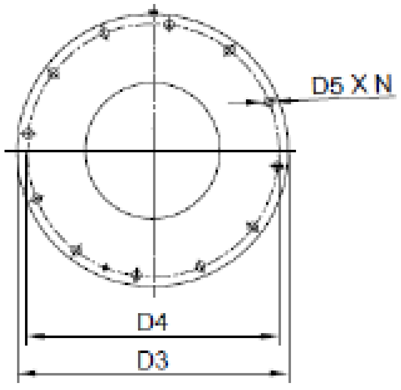
Symbol	Description
L2	Length between bottom seat of flange and bottom of the oil end shield/ stress relieving electrode/ oil end terminal whichever is the longest
L6	Length for accommodating Bushing Current Transformer (BCT)
D2	Maximum diameter of oil immersed end
D3	Outside diameter of fixing flange
D4	Pitch Circle Diameter of fixing holes of flange
D5	Diameter of fixing hole
N	Number of fixing holes
D6	Maximum diameter of oil end shield/stress relieving electrode
D8	Diameter of hole for oil end terminal

STANDARD DIMENSION FOR LOWER PORTION OF CONDENSER BUSHINGS

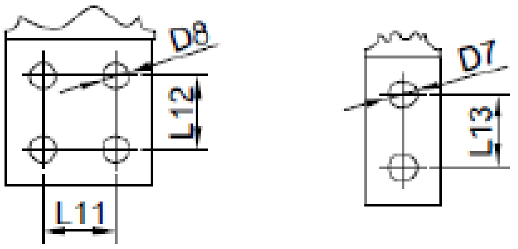
(For 420 kV and below voltage class Bushings)



Bushing Mounting Flange Details



Bottom Connection Details



Symbol	Description
L2	Length between bottom seat of flange and bottom of the oil end shield/ stress relieving electrode/ oil end terminal whichever is the longest
L6	Length for accommodating Bushing Current Transformer (BCT)
D2	Maximum diameter of oil immersed end
D3	Outside diameter of fixing flange
D4	Pitch Circle Diameter of fixing holes of flange
D5	Diameter of fixing hole
N	Number of fixing holes
D6	Maximum diameter of oil end shield/stress relieving electrode
L11	Horizontal Distance between holes for bushing bottom connection for 4 hole connection
L12	Vertical Distance between holes for bushing bottom connection for 4 hole connection
L13	Vertical Distance between holes for bushing bottom connection for 2 hole connection
D7	Diameter of hole for bushing bottom connection for 2 hole connection
D8	Diameter of hole for bushing bottom connection for 4 hole connection

Voltage Rating (kV)	**800**	**420**
BIL kVp	2100	1425 1550 (for GT)
Creepage Distance (mm) (min.)	24800	13020
Current Rating (A)	**2500**	**2500**
Type of lead	Solid Stem (SS)	SS
L2 ±5	1955 (excluding bottom terminal end shield)	1335
L6 (min.)	600	600
D2 (max.)	528	350
D3±2	780	480
D4±1 (PCD)	711	430
D5xN	32x12	20x8
D6 (max.)	420	350
D8	Φ12	Φ12
No. of holes and depth of bolt for oil end terminal	6; 20	6; 20
Length & Diameter of Air End Terminal	125 & Φ 60	125 & Φ 60

Voltage Rating (kV)	420	245		145		72.5		52
BIL kVp	1425 1550(for GT)	1050		650		325		250
Creepage Distance (mm)	13020	7595		4495		2248		1612
Current Rating (A)	**1250**	**1250**	**2000**	**1250**	**2000**	**800**	**2000**	**1250**
Type of lead	Solid Stem (SS)	SS	SS	SS	SS	SS		SS
L2 ±5	1640	1130	1230	800/ 1250[a]	1030	695		450
L6 (min.)	400	300		300/500[a]	300	300		100
D2 (max.)	350	270		165	180	115	165	115
D3±2	720	450		335	335	225	335	225
D4±1 (PCD)	660	400		290	290	185	290	185
D5xN	24x12	20x12		15x12	15 x12	15x6	15x12	15x6
D6 (max.)	350	270		180		115		115
L11	-	-	45	-	45	-	55	-
L12	-	-	40	-	40	-	40	-
L13	40	40	-	40	-	40	-	40
D7	Φ14	Φ14		Φ14	Φ14	Φ14	Φ14	Φ14
D8	-	-	Φ 14	-	-	-	-	-
Length & Diameter of Air End Terminal	125 & Φ60	125 & Φ60	125 & Φ60	125 & Φ60	125 & Φ60	125 & Φ60	125 & Φ60	125 & Φ60

[a] for 765 kV class shunt reactor

Notes:

1. All dimensions are in mm.
2. No positive tolerance where maximum dimension specified and no negative tolerance where minimum dimension is specified.
3. For other details of oil end terminal for 2000 A (145 kV/245 kV) solid stem type bushing, refer Fig 4 of IS 12676.
4. For other details of oil end terminal for 2000 A, 72.5 kV solid stem type bushing, refer Fig 3B of IS 12676.
5. For other details of oil end terminal for 800 A and 1250 A (52kV/72.5 kV/145 kV/245 kV/420 kV) solid stem type bushing, refer Fig 3A of IS 12676.

ANNEXURE-R

Standard Test Procedure of Transformer & Reactor

STANDARD TEST PROCEDURE FOR

TRANSFORMER & REACTOR

DOC. No.: POWERGRID/STD/TEST PROCEDURE/TR-RT

Revision-02

June 2021

INDEX

Test procedure for transformer & Reactor are similar. Hence, same method as mentioned for transformer shall be applicable for reactor also. However, few tests which only to be performed in Reactor are given below:

1. General

Tests shall be carried out as per following procedure. However, IEC 60076 shall be followed in general for other tests. Manufacturer shall offer the transformer/reactor unit for type testing with all major fittings including radiator bank, Marshalling Box, Common Marshalling Box RTCC (as applicable) (excluding ODS, DGA, Fire protection system) assembled.

RTCC and Common Marshalling Box testing may be carried during routine testing of any one unit (Transformer/Reactor). In case of only one unit is being manufactured, RTCC and Common Marshalling Box testing may be carried out along with that unit.

All measuring systems used for the tests shall have certified traceable accuracy and be subjected to periodic calibration, according to the rules given in ISO 9001. Specific requirements on the accuracy and verification of the measuring systems are described in IEC 60060 series and IEC 60076-8.

Latest IEC standards (as applicable) shall be followed for all the tests.

1.1. Before start of FAT following tests shall be carried out on insulating oil:

Break Down voltage (BDV), Moisture content, Tan-delta, Interfacial tension and Particle count

Acceptance Criteria: POWERGRID Specification of Insulating Oil

2. Low Voltage Tests

2.1. Voltage ratio measurement & Polarity check (Vector Group)

Refer IEC 60076-1for procedure and acceptance criteria. Manufacturer’s standard practice may be followed.

2.2. Measurement of insulation power factor and capacitance between winding and earth and Bushings

Standards: IEC 60076-1 & POWERGRID Technical Specification for Transformers & Reactors.

Capacitance & tan delta of HV bushings, IV bushings, LV bushings and neutral shall be measured at 5kV & 10kV. It is applicable only for condenser type bushing (having test tap)

Tan delta measurement at variable frequency (in the range of 20 Hz to 350 Hz, at multiple of 17 Hz and applied voltage shall be 2 – 5kV) shall be carried out on each condenser type bushing (OIP & RIP) at Transformer manufacturing works as routine test before dispatch for reference and the result shall be compared at site during commissioning to verify the healthiness of the bushing. No temperature correction factor shall be applicable for tan delta.

Further winding capacitances & tan delta shall also be measured in the following modes as per the table given below:-

Transformer

Connection	Configuration Auto/Two Winding Transformer	Mode	Voltage (in kV)	Capacitance in pF	Tan delta
1	(HV-IV)/LV (C_{HL})	(UST)	5		
			10		
2	(HV-IV)-E (LV GUARD) (C_H)	(GSTg)	5		
			10		
3	(HV-IV)/(LV+E) (GST) (C_{HL} + C_H)	(GST)	5		
			10		
4	LV/(HV-IV) (C_{HL})	(UST)	5		
			10		
5	LV-E (HV+IV GUARD) (C_L)	(GSTg)	5		
			10		
6	LV/(HV + IV+GROUND) (C_{HL} + C_L)	(GST)	5		
			10		

Test Criteria

The test is successful if tan delta measured is less than 0.5% or as mentioned in specification. The capacitances measured for above combinations (C_H, C_L, C_{HL} + C_H, C_{HL} +$C_{L,}$ C_{HL}) may be compared.

Reactor

Connection	Configuration Auto/Two Winding Transformer	Mode	Voltage (in kV)	Capacitance in pF	Tan delta
1	(HV+N) - E (C_H)	(GST)	5		
			10		

For bushings and neutral the following table shall be filled:-

Configuration		Voltage (in kV)	Capacitance in pF	% tan delta
HV Bushing	U-Phase Sl. No.--	5		
		10		
	V-Phase Sl. No.--	5		
		10		
	W-Phase Sl. No.--	5		
		10		
IV Bushing	U-Phase Sl. No.--	5		
		10		
	V-Phase Sl. No.--	5		
		10		
	W-Phase Sl. No.--	5		
		10		
LV Bushing	U-Phase Sl. No.--	5		
		10		
	V-Phase Sl. No.--	5		
		10		
	W-Phase Sl. No.--	5		
		10		
Neutral		5		
		10		

2.3. Measurement of insulation resistance & Polarization Index

Measurement of insulation resistance between winding & earth by 5 kV megger.

Insulation resistance tests are made to determine the insulation resistance from individual winding to ground or between individual windings. The insulation resistance in such tests is commonly measured in mega-ohms, or may be calculated from measurements of applied voltage and leakage current. The dc voltage applied for measuring insulation resistance to ground shall not exceed a value equal to the half of the rated voltage of the winding or 5 kV whichever is lower.

Note

1. The insulation resistance of electrical apparatus is subjected to wide variation in design, temperature, dryness, and cleanliness of the parts. When the insulation resistance falls below prescribed values, it can, in most cases of good design and where no defect exists, be brought up to that required standard by cleaning and drying the apparatus. The insulation resistance, therefore, may offer a useful indication as to whether the apparatus is in suitable condition for application of dielectric tests.

2. Under no conditions, test should be made while the transformer is under vacuum.

Polarisation Index (PI)

The purpose of polarisation index test is to determine if equipment is suitable for operation or even for an overvoltage test. The polarisation index is a ratio of insulation resistance value at the end of 10 min test to that at the end of 1 min test at a constant voltage. The total current that is developed when applying a steady state dc voltage is composed of three components:

(1) Charging current due to the capacitance of the insulation being measured. This current falls off from maximum to zero very rapidly.

(2) Absorption current due to molecular charge shifting in the insulation. The transient current decays to zero more slowly.

(3) Leakage current which is the true conduction current of the insulation. It has a component due to the surface leakage because of the surface contamination.

The advantage of PI is that all of the variables that can affect a single IR reading, such as temperature and humidity, are essentially the same for both the 1 min and 10 min readings. Since leakage current increases at a faster rate with moisture present than does absorption current, the IR readings will not increase as fast with insulation in poor condition as with insulation in good condition. After 10 min the leakage current becomes constant and effects of charging current and absorption current die down.

Acceptable PI value for power transformer shall be better than 1.3.

2.4. Core assembly dielectric and earthing continuity test

After assembly each core shall be tested for 1 minute at 2000 AC Volts between all yoke clamps, side plates and structural steel work (core to frame, frame to tank & core to tank).

The insulation of core to tank, core to yoke clamp (frame) and yoke clamp (frame) to tank shall be able to withstand a voltage of 2.5 kV (DC) for 1 minute. Insulation resistance shall be minimum 0.5 GΩ for all cases mentioned above.

2.5. Measurement of winding resistance

After the transformer has been under liquid without excitation for at least 3 h, the average liquid temperature shall be determined and the temperature of the winding shall be deemed to be the same as the average liquid temperature. The average liquid temperature is taken as the mean of the top and bottom liquid temperatures. Measurement of all the windings including compensating (in case terminal is available at outside) at normal and extreme taps shall be done.

In measuring the cold resistance for the purpose of temperature-rise determination, special efforts shall be made to determine the average winding temperature accurately. Thus, the difference in temperature between the top and bottom liquid shall not exceed 5 K. To obtain this result more rapidly, the liquid may be circulated by a pump.

If fibre optic sensors are installed, temperature of winding and oil by FO sensors are also to be recorded in the test report. Further ensure that the FO reading should approx. match with RTD temperature reading.

Type tested unit:

Test engineer (manufacturers) add terminal cables/tube for taking immediate reading of hot resistance of winding. In that case the reference value of cold resistance of the same circuit to be measured and witnessed. Average oil temperature is also to be measured. The above is required for calculation of temperature at shut down condition.

2.6. Measurement of no load current & short circuit Impedance with 415 V, 50 Hz AC.

Measurement of no load current

415V, 50HZ 3-Ph supply (controlled) shall be supplied LV side (Tertiary side for Auto) and magnetising current shall be measured.

Voltage			Current		
U-Φ	V-Φ	W-Φ	U-Φ	V-Φ	W-Φ

Short circuit Impedance with 415 V, 50 Hz AC

Impedances shall be measured for all combinations and at Maximum, Minimum & Normal Voltage Tap – HV/IV, HV/LV & IV/LV

HV/IV – Connection

Applied Voltage at HV, IV Short circuited, Tertiary Open

Tap No.	Voltage			Current			%Z @ Base MVA
	U-Φ	V-Φ	W-Φ	U-Φ	V-Φ	W-Φ	
Max. Tap							
Normal Tap							
Min Tap							

HV/LV – Connection

Applied Voltage at HV, LV Short circuited, IV Open

Tap No.	Voltage			Current			%Z @ Base MVA
	U-Φ	V-Φ	W-Φ	U-Φ	V-Φ	W-Φ	
Max. Tap							
Normal Tap							
Min Tap							

IV/LV – Connection

Applied Voltage at IV, LV Short circuited, HV Open

Tap No.	Voltage			Current			%Z @ Base MVA
	U-Φ	V-Φ	W-Φ	U-Φ	V-Φ	W-Φ	
Normal							

Measured impedance shall be approximately matched with the impedances measured at rated current. The current at all the phases shall be approximately same.

3. No-load loss and current & harmonic measurement

As per IEC 60076-1:2011 clause 11.5. The transformer shall be approximately at factory ambient temperature. Measurement should be carried out at rated specified voltage of the transformer. Harmonics in no load current shall be measured during No Load Loss measurement.

Check points:

- The value of CT measurement range should be kept sufficiently high (3 to 5 times of measuring value) for better measurement and take care of distortions.
- Inputs like - constants, scaling factors, ratio errors, phase angle errors etc. to the loss measuring instrument shall be as per the latest calibration certificate.
- All wirings used for secondary measurements should be original as supplied by equipment manufacturer without any modification.

Note: After No load loss measurement Load loss measurement shall be commenced immediately and shall be carried out as per procedure mentioned at Sr. No. 6 below.

4. Magnetic Balance Test on 3-phase Transformers

This test is conducted only in three phase transformers to check the imbalance in the magnetic circuit. In this test, no winding terminal should be grounded; otherwise results would be erratic and confusing. Applied Test voltage shall be 415V.

Evaluation criteria

The voltage induced in the centre phase shall be 40% to 90% (approx.) of the applied voltage on the outer phases. However, when the centre phase is excited then the voltage induced in the outer phases shall be 30 to 70% (approx.) of the applied voltage. Zero voltage or very negligible voltage induced in the other two windings should be investigated. The purpose of this test basically is to ensure that there is no inter turn fault in the winding which is generally reflected in high excitation current in faulty winding.

5. Tests on On-load Tap-Changers

Operation Test

With the tap-changer fully assembled on the transformer the following sequence of operations shall be performed without failure:

a) With the transformer un-energised, eight complete cycles of operations (a cycle of operation goes from one end of the tapping range to the other, and back again).

b) With the transformer un-energised, and with the auxiliary voltage reduced to 85% of its rated value, one complete cycle of operation.

c) With the transformer energized at rated voltage and frequency at no load, one complete cycle of operation

d) With one winding short circuited and, as far as practicable, two rated current according to IEC 60076-1 in the winding, 10 tap-change operations across the range of two steps on each side from where a coarse or reversing changeover selector operates, or otherwise from the middle tapping(the tap changer will pass 20 times through the changeover position). Total tap change operations shall be 80.

6. Measurement of short-circuit impedance and load loss

The short-circuit impedance and load loss for a pair of windings shall be measured at rated current & frequency with voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited. The difference in temperature between the top and bottom liquid shall not exceed 5 K. To obtain this result more rapidly, the liquid may be circulated by a pump. Loss measurement for all combinations (HV-IV, HV-LV, IV-LV and at Normal and extreme taps).

If fibre optic sensors are installed, hotspot temperature of winding and oil may be recorded for reference.

Following parameters shall be recorded:
Current, voltage (RMS & Average), power factor, apparent power, active power, reactive power etc.

Current measured at all the phases shall be approximately same. If more variation is observed between current values of all phases measured, test circuit shall be reviewed and test shall be repeated.

Check points:

- Inputs like - constants, scaling factors, ratio errors, phase angle errors etc. to the loss measuring instrument shall be as per the latest calibration certificate.
- All wirings used for secondary measurements should be original as supplied by equipment manufacturer without any modification.
- Current can also be verified from one of the measuring type bushing CTs.

7. Dielectric Tests

Dielectric tests shall be carried in the following sequence as per IEC 60076-3:2013 clause 7.2.3:

a) Lightning impulse tests (LIC, LIN)
b) Switching impulse (SI)
c) Applied voltage test (AV)
d) Line terminal AC withstand test (LTAC)
e) Measurement of transferred surge on LV or Tertiary as applicable due to HV lightning impulse and IV lighting impulse (as applicable). This test may be carried out followed by LI & SI test.
f) Short time over voltage Test (830kVrms) for 765kV Reactor
g) Induced voltage test with partial discharge measurement (IVPD)

Oil Sample shall be taken before starting and after completion of dielectric tests for DGA. In case any abnormality during testing, oil samples may also be taken for DGA.

7.1 **Full wave lightning impulse test (LI) & chopped wave lightning impulse test (LIC)**

Reference Standard:

IEC 60076-3:2013, IEC 60060-1(General definitions of terms related to impulse tests and requirements for test circuits), IEC 60060-2 (measuring devices) & IEC 60076-4 & IEEE Std C57.98-1993

General

For liquid-immersed transformers, the test voltage is normally of negative polarity, because this reduces the risk of erratic external flashovers in the test circuit.

Tap positions

If the tapping range is ± 5 % or less and the rated power of the transformer is ≤ 2 500 kVA then, the lightning impulse tests shall be made with the transformer connected on the **principal tapping**.

If the tapping range is larger than ± 5 % or the rated power of the transformer is > 2 500 kVA then, the two extreme tappings and the principal tapping shall be used, one tapping for each of the three individual phases of a three-phase transformer or the three single-phase transformers designed to form a three-phase bank.

Records of tests

1. Applied Voltage; the records obtained shall clearly show the applied voltage impulse shape (front time, time-to-half value and amplitude).

   The recorded curve and the extreme value of the recorded curve (as defined in IEC 60060-1) shall be presented in the test record.

   The value of the test voltage (after the application of any filtering or correction for overshoot, U_t see IEC 60060-1) shall be reported in the test record.

2. At least one more measurement channel shall be used. In most cases an oscillogram of the current flowing to earth from the tested winding (neutral current). Further recommendations about failure detection, suitable time-base durations, etc. are given in IEC 60076-4.

Test connections

Test connections for lightning impulse on the Line Terminals

The impulse test sequence is applied to each of the line terminals of the tested winding in succession. The other line terminals of the transformer shall be earthed directly or, if needed to achieve the required wave shape, through an impedance. The impedance shall not exceed the surge impedance of the connected line (if a value is supplied by the purchaser) or 400 Ω whichever is lower. In all circumstances, the voltage appearing during the impulse test at the other line terminals shall not be more than 75 % of their rated lightning impulse withstand voltage for star-connected windings, or 50 % for delta-connected windings. The lowest value of impedance at each terminal needed to achieve the required wave shape shall be used.

If the winding has a neutral terminal, the neutral shall be earthed directly or through low impedance such as a current measuring shunt. The tank shall be earthed. If the required wave shape cannot be obtained without the use of a resistor between neutral and earth, then an additional complete impulse test sequence shall be applied. In this case the first impulse test sequence tests the winding at the full voltage without the resistor but the required wave shape may not be achieved and the second sequence with the resistor achieves the wave shape. Chopped waves, if required, would not be repeated in the second sequence.

When a transformer is fitted with internal non-linear elements such as surge arresters which will limit the voltage on internal parts during the impulse test then the provisions of Clause 13.2.3 of IEC 60076-3 apply. Any such internal non-linear elements which are present in the service condition shall be present during the tests. External non-linear elements and other external voltage control elements such as capacitors shall be disconnected for test.

The impulse circuit and measuring connections shall remain unchanged during reference and full voltage tests

Test connections for lightning impulse on Line terminals

Lightning impulses are applied directly to the neutral with all other terminals earthed.

Full wave lightning impulse test (LI)

Wave shape, determination of test voltage value and tolerances

The test impulse shall be a full standard lightning impulse: 1.2 ± 30 % / 50 μs ± 20 %.

The test voltage value shall be the test voltage value as defined specification If the maximum relative overshoot magnitude is 5 % or less, the test voltage value may be taken as the extreme value as defined in specification.

The tolerance on the test voltage value is ± 3 %.

If the standard impulse shape cannot reasonably be obtained because of low winding inductance or high capacitance to earth and the resulting impulse shape is oscillatory so that the relative overshoot magnitude exceeds 5 % then for windings that will receive a chopped wave lightning impulse test, the front time may be increased to reduce the overshoot. In all cases with Um ≤ 800 kV the front time shall not exceed 2.5 μs. If the relative overshoot magnitude exceeds 5 % at the full wave voltage level, then a test voltage function shall be applied in accordance with IEC 60060-1 to determine the test voltage value. It is permissible to apply the requirements of IEC 60060-1 Annex B to the evaluation of the parameters of the lightning impulse irrespective of the overshoot value.

NOTE
Case of overshoot of more than 5 % the peak voltage of the impulse (maximum value of the recorded curve) shall be increased and the frequency of oscillation is higher than about 100 kHz by the application of the test voltage function in accordance with IEC 60060-1.

Tests on transformers without non-linear elements

Test sequence

The test sequence shall consist of:

a) one reference impulse of a voltage between 50 % and 70 % of the full test voltage
b) Three subsequent impulses at full voltage.

If, during any of these applications, an external flashover in the circuit or across a bushing spark gap occurs, or if the recording fails on any of the specified measuring channels, that application shall be disregarded and a further application made.

NOTE

Additional impulses at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report.

Test acceptance criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the reference impulse and those recorded at the full test voltage.

NOTE

The detailed interpretation of the test records and the discrimination between marginal differences and differences indicating failure shall be clearly stated in the report. Further information is given in IEC 60076-4.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

Tests on transformers with non-linear elements

Test sequence

If non-linear elements or surge arresters are built into the transformer for the limitation of transferred overvoltage transients, they may operate during the test procedure and this may cause differences between impulse records made at different voltages. There will be a threshold voltage at which the differences caused by the non-linear elements start to appear and the test sequence shall include at least one record below this threshold. The test sequence shall consist of:

a) one reference impulse at between 50 % and 60 % of the full test voltage;
b) one reference impulse at between 60 % and 75 % of the full test voltage;
c) one reference impulse at between 75 % and 90 % of the full test voltage;
d) three consecutive 100 % full wave impulses;
e) a comparison impulse at as nearly as possible the same voltage as c) above;

f) a comparison impulse at as nearly as possible the same voltage as b) above;
g) A comparison impulse at as nearly as possible the same voltage as a) above.

The reference impulse voltages shall be at least 10 % (of the 100 % level) different from each other. If none of the 100 % full wave records differ from the lowest voltage record of the reference impulse records, then impulses e), f) and g) above may be omitted.

The time interval between the application of the last chopped wave and the first full wave after the chop waves shall be as short as practicable.

NOTE

Additional impulses at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report. If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

The same types of measuring channels and oscillographic records are specified as for the full wave impulse test.

As far as possible the same time to chop shall be used for all chopped impulses in the sequence.

Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the lowest voltage reference impulse and those recorded at the full test voltage. If this is not the case then the records of current and voltage from the following impulses shall be compared:

– a) and g)
– b) and f)
– c) and e)
– all the 100 % level impulse records.

The test is successful if there is no significant difference between the compared records (beyond that which can reasonably be explained by small differences in the test voltage) and any changes between successive records are progressive and smooth, consistent with the proper operation of the non-linear element.

NOTE
Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

Chopped wave lightning impulse test (LIC)

Wave shape

The chopped wave lightning impulse shall have a time to chopping between 3 μs and 6 μs. The time to first voltage zero after the instant of chopping shall be as short as possible. The test shall be made without the deliberate addition of impedance in the chopping circuit, but if the overswing observed during a reduced voltage application is more than 30 % then the minimum impedance required to bring the over swing below 30 % may be added to the chopping circuit.

NOTE

Transformers are normally designed to withstand an over swing to the opposite polarity of 30 % of the amplitude of the chopped wave lightning impulse. Usually, the same settings of the impulse generator and measuring equipment are used, and only the chopping gap equipment is added.

Different time bases may be used to record the chopped wave lightning impulses. It is recommended to use a triggered-type chopping gap with adjustable timing, although a plain rod-rod gap is allowed. The peak value of the chopped wave lightning impulse shall be 110 & of rated impulse voltage.

Tests on transformers without non-linear elements

Test sequence

The test is combined with the full impulse test in a single sequence. The order of the different impulse applications shall be:

a) one full wave reference impulse at between 50 % and 70 % of the full wave lightning
b) impulse test voltage;
c) one full wave impulse at the full wave lightning impulse test voltage;
d) two chopped impulses at the chopped wave lightning impulse test voltage;
e) Two full wave impulses at the full wave lightning impulse test voltage.

The same types of measuring channels and oscillographic records are specified as for the full wave impulse test.

NOTE

Additional impulses (full or chopped) at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made. As far as possible the same time to chop shall be used for all chopped wave lightning impulses in the sequence.

Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the reference reduced level full impulse and those recorded at the full test voltage including the chopped impulses up to the time of chop. In the case of the chopped impulses differences after the chopping time may be due to minor variations in the performance and timing of the chopping gap.

NOTE

The detailed interpretation of the test records and the discrimination between marginal differences and differences indicating failure requires a great deal of skill and experience. Further information is given in IEC 60076-4.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

Tests on transformers with non-linear elements

Test sequence

The test is combined with the full impulse test in a single sequence.
If non-linear elements or surge diverters are built into the transformer for the limitation of transferred overvoltage transients, they may operate during the test procedure and this may cause differences between impulse records made at different voltages. There will be a threshold voltage at which the differences caused by the non-linear elements start to appear and the test sequence shall include at least one record below this threshold.

The test sequence shall consist of:

a) one full wave reference impulse at between 50 % and 60 % of the full wave lightning impulse test voltage;
b) one full wave reference impulse at between 60 % and 75 % of the full wave lightning impulse test voltage;
c) one full wave reference impulse at between 75 % and 90 % of the full wave lightning impulse test voltage;
d) one full wave impulse at the full wave lightning impulse test voltage;
e) two chopped impulses at the chopped wave lightning impulse test voltage;
f) two full wave impulses at the full wave lightning impulse test voltage;
g) a comparison impulse at as nearly as possible the same voltage as c) above;
h) a comparison impulse at as nearly as possible the same voltage as b) above;
i) a comparison impulse at as nearly as possible the same voltage as a) above.

The reference impulse voltages shall be at least 10 % (of the 100 % level) different from each other. If none of the 100 % full wave records differ from the lowest voltage of the reference impulse record then impulses g), h) and i) above may be omitted.

The time interval between the application of the last chopped wave and the first full wave after the chop waves shall be as short as practicable.

NOTE

Additional impulses (full or chopped) at amplitudes not higher than 75 % of the full level can be used, these do not need to be shown in the test report. If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made. The same types of measuring channels and oscillographic records are specified as for the full wave impulse test. As far as possible the same time to chop shall be used for all chopped impulses in the sequence.

Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the lowest voltage reference impulse and those recorded at the full test voltage including the chopped wave impulses up to the time of chop. In the case of the chopped impulses differences after the chopping time may be due to minor variations in the performance and timing of the chopping gap. If this is not the case then the records of current and voltage from the following impulses shall be compared:
– a) and i);
– b) and h);
– c) and g);
– all the 100 % level impulse records;
– both the chopped wave records up to the time of chop.

The test is successful if there is no significant difference between the compared records (beyond that which can reasonably be explained by small differences in the test voltage) and any changes between successive records should be progressive and smooth, consistent with the proper operation of the non-linear element.

NOTE

Further information is given in IEC 60076-4.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

NOTE

The information given in IEC 60076-4 with reference to waveshape evaluation is based on the visual observation of oscillographic records. Under certain circumstances it might be appropriate to evaluate the waveshape parameters of non-standard waveshapes and perform the interpretation of deviations manually rather than relying completely on software tools.

Lightning impulse test on a neutral terminal (LIN)

General
Full wave lightning impulses at the impulse voltage level specified for the neutral are applied directly to the neutral with all other terminals earthed.

Waveshape
The wave shape of the full wave impulses shall be as given in 13.2.1 of IEC-60076-3 except that the duration of the front may be up to a maximum of 13 μs.

Test sequence
The test sequence shall be as given in clause 13.2.2.1 of IEC-60076-3 for transformers without a non-linear element and clause 13.2.3.1 of IEC-60076-3for transformers with a non-linear element.

Test criteria

The test criteria shall be as given in clause 13.2.2.2 of IEC-60076-3 for transformers without a non-linear element and clause 13.2.3.2 of IEC-60076-3 for transformers with a non-linear element.

7.2 **Switching impulse test**

Standards:

IEC 60076-3, 60076-4, IEC 60060-1 (for Reactor IEC 60076-6) & IEEE Std C57.98-1993
General

During switching impulse tests, the voltages developed across different windings are approximately proportional to the ratio of numbers of turns. The switching impulse test voltage shall be as specified for the winding with the highest *U*m value. If the ratio between the windings is variable by tappings, the tappings shall be used to bring the test voltage for the winding with lower *U*m as close as possible to the corresponding test value given in Table 2 of IEC-60076-3.

The windings with lower *U*m values may not receive their full test voltage; this shall be accepted. In a three-phase transformer, the voltage developed between line terminals during the test shall be approximately 1.5 times the voltage between line and neutral terminals.

Test Connection

The impulses are applied either directly from the impulse voltage source to a line terminal of the highest voltage winding, or to a lower voltage winding so that the test voltage is inductively transferred to the highest voltage winding. The specified test voltage shall appear between the line terminal of the highest voltage winding and earth. The voltage shall be measured at the line terminal of the highest voltage winding. A three-phase transformer shall be tested phase by phase.

Star connected windings with the neutral brought out shall be earthed at the neutral terminal either directly or through a low impedance such as a current measuring shunt. A voltage of opposite polarity and about half amplitude appears on the two remaining line terminals which may be connected together but not connected to earth. To limit the voltage of opposite polarity to approximately 50 % of the applied level, it is permissible to connect high resistance damping resistors (5 kΩ to 20 kΩ) to earth at the non-tested phase terminals.

For delta connected windings the terminal corresponding to the end of the phase under test shall be earthed either directly or through a small measuring impedance, the other terminals shall be open circuit. Tests on a three-phase transformer shall be arranged so that a different terminal of the delta is earthed for each phase test. Delta connected windings with more than three terminals brought out shall have the delta closed for the test.

For a single phase transformer with one or more windings which will have both ends connected to a line in service and with a switching impulse test specified, then the switching impulse test shall be applied to both ends of the winding.

Bushing spark gaps may be removed or their spacing increased to prevent spark over during the test.

Reactor shall also be tested by the method mentioned above. However, additionally for reactor, clause 8.3 of IEC 60076-4 may also be referred. Since there is only one winding per phase, the application point for the test voltage is the line terminal of the phase winding which is to be tested. The other terminal of this phase winding should be earthed.

For three-phase reactors, the normal impulse test procedures as used for lightning impulse tests are required.

Wave shape

The test voltage is normally of negative polarity to reduce the risk of erratic external flashover in the test circuit.
The voltage impulse shall have a time to peak (*T*p as defined in IEC 60060-1) of at least 100 μs, a time above 90 % (*T*d as defined in IEC 60060-1) of the specified amplitude of at least 200 μs, and a time to zero (*T*z as defined in IEC 60060-1) of a minimum of 1000 μs.

Normally the transformer characteristic of Td ≥ 200 μs is not a problem for small reactors (<100 Mvar for three-phase reactors with relatively high impedances). For large reactors, Td and Tz as specified for transformers would require excessive impulse generator extension. For such cases, a minimum value for Td and Tz should be 120 μs and 500 μs respectively to assure adequate volt-time stress.

Test Sequence

The test sequence shall consist of one reference impulse of a voltage between 50 % and 70 % of the full test voltage and three impulses at full voltage. Sufficient reverse polarity applications shall be made before each full impulse to ensure the magnetization of the core is similar before each full wave impulse in order to make the time to first zero as uniform as possible.

Oscillographic records shall be made of the impulse wave-shape on the line terminal under test and the current between the tested winding and earth. If during any of these applications an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

Acceptance Criteria

The test is successful if there is no sudden collapse of voltage or discontinuity in the voltage or current indicated on the oscillographic records.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the oscillographic records, but they do not constitute evidence in themselves.

7.3 Applied voltage test (AV)

The test shall be carried out on each separate winding of the transformer in turn.

The full test voltage shall be applied for 60 s between all accessible terminals of the winding under test connected together and all accessible terminals of the remaining windings, core, frame and tank or casing of the transformer, connected to earth.

The test shall be made with an approximately sinusoidal single-phase alternating voltage at rated frequency. The peak value of voltage shall be measured. The peak value divided by √2 shall be equal to the test value.

NOTE
Approximately sinusoidal can be taken to mean that the peak value divided by √2 does not differ from the r.m.s value of the waveform by more than about 5 % (see IEC 60060-1), but wider deviations may be accepted.

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

For windings with non-uniform insulation, the test is carried out with the test voltage specified for the neutral terminal. In transformers where windings having different U_m values are connected together within the transformer (usually auto-transformers), the test voltages shall be determined by the insulation of the common neutral and it's assigned U_m.

7.4 Line terminal AC withstand test (LTAC)

The test shall be arranged so that the test voltage appears between the tested terminal and earth. Each phase terminal of the tested winding shall be tested in turn. The test time, frequency and voltage application shall be same as Induced voltage withstand test (IVW).

Test time in Seconds = $120 \times \frac{\text{rated frequency}}{\text{test frequency}}$, but not less than 15 s

For transformers with taps and a non-uniformly insulated lower voltage winding, the tap position for test shall be selected so that when the required test voltage appears on the highest voltage winding terminals, the voltage appearing on the lower voltage winding terminals shall be as close as possible to the required test value. For transformers with a uniformly insulated lower voltage winding subject to an applied voltage test, the tap position may be chosen by the manufacturer.

The test is successful if no collapse of the test voltage occurs.

NOTE
This test is intended only as a withstand test for each line terminal of a non-uniformly insulated transformer to earth, it is not intended to test the phase to phase or turn to turn insulation so the test arrangement can be made in any convenient way, for example with voltage at the neutral to reduce the turn to turn voltage and the test will normally be carried out as three single phase tests. Partial discharge measurements can be made during this test.

7.5 Induced voltage withstand test (IVW)

The test time at full test voltage shall be 60 s for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

$$120 \times \frac{\text{rated frequency}}{\text{test frequency}}, \text{ but not less than 15 s}$$

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

7.6 Measurement of transferred surge on LV or Tertiary due to HV & IV Lightning impulse

The voltage shall be applied on the phase for which transferred surge shall be measured in the same phase of tertiary (i.e. if voltage is applied on 1W, the transferred surge shall be measured at 3W terminal). The above process shall be repeated for the remaining HV & IV terminals.

Similar tests to be conducted for switching surge transformer at Max, Nor. and Min. Voltage Tap (if applicable). However, applied voltage shall be selected such a way that induced voltage at other winding should not go more than the SI limit of that winding.

Following tests shall be carried out with applying 50% to 80% of rated Impulse & Switching impulse (upto 60% for IV to limit the max. limit of HV SI level) voltage. Finally, measured value shall be extrapolated for 100% rated voltage.

For each tap position, atleast 2 nos. shots (for LI - one at approx. 50% and other at approx. 80% and for SI – one at approx. 40% & at approx. 60%*) shall be applied and measured values shall be extrapolated to 100%. Measured and extrapolated values shall be recorded.

Transformer with non-linear element in the winding

If Lightning Arrestor (or **non-linear element)** is connected with tertiary or LV to limit the surges, transfer surge shall be carried out with LA (as to be connected in service) during Test at factory for HV and IV lightning & switching impulse Test. In that case applied voltage shall be raised gradually to the level where the LA shall operate/actuate. It shall be below the impulse / SI level of LV or tertiary winding.

Table for Transfer surge (Impulse) at Max, Nor. and Min. Voltage Tap

1-Phase Transformer

Sr. No.	Impulse Type	Voltage applied	Earthed Points	Open / not earthed point	Measurement Point
1	FW	1.1	2.1, N & 3.2	-	3.1
2	FW	1.1	2.1, N & 3.1	-	3.2
3	FW	2.1	1.1, N & 3.2	-	3.1
4	FW	2.1	1.1, N & 3.1	-	3.2

Where,

1.1 : HV Terminal
2.1 : IV Terminal
3.1 & 3.2 : LV or Tertiary Terminal

(*): Should not reach beyond the SI limit of HV winding

3-Phase Transformer

Sr. No.	Impulse Type	Voltage applied	Earthed Points	Open / not earthed point	Measurement Point
5	FW	1U	1V, 1W, 2U, 2V, 2W, N, 3V & 3W	-	3U
6	FW	1V	1U, 1W, 2U, 2V, 2W, N, 3U & 3W	-	3V
7	FW	1W	1U, 1V, 2U, 2V, 2W, N, 3V & 3U	-	3W
8	FW	2U	1U, 1V, 1W, 2V, 2W, N, 3V & 3W	-	3U
8	FW	2V	1U, 1V, 1W, 2U, 2W, N, 3U & 3W	-	3V
9	FW	2W	1U, 1V, 1W, 2U, 2V, N, 3V & 3U	-	3W

Acceptance criteria

Transfer surge at Tertiary should not exceed the rated impulse level of that winding. The extrapolated values measured at 50% and 80% (for LI) or 40% and 60% (for SI) as stated above shall be approximately matched.

When non-linear element is connected in the winding, the non-linear element should limit the transferred voltage below the rated impulse level of that winding. LA / nonlinear element shall operate/actuate below the impulse level of Tertiary or LV winding.

7.7 Induced voltage test with partial discharge measurement (IVPD)

Standards

IEC 60076-3, IEC 60270 & POWERGRID Technical Specification for Transformers & Reactors.

General

This test is intended to verify that the transformer will be free of harmful partial discharges under normal operating conditions. The test voltage is applied in the same way as the voltage that the transformer will experience in service. During the test, symmetrical voltages appear at all the line terminals and between turns, **with no voltage at the neutral**. The test is performed with a three phase voltage on three phase transformers

Each PD measurement channel including the associated bushing or coupling capacitor shall be calibrated in terms of apparent charge (pC) according to the method given in IEC 60270.

Voltage calibration to be done to check the test voltages to be applied as per test sequence given below before start of PD Test as there is no option of keeping the voltage divider connected to the transformer for voltage measurement continuously during PD test.

The PD measurement shall be given in pC and shall refer to the highest steady-state repetitive impulses indicated by the measuring instrument**. Occasional bursts of high partial discharge level may be disregarded.**

If high partial discharge is coming repeatedly, and may be due to external reason, manufacturer should improve the system and bring the value to ambient level before starting the PD cycle.

For each required PD measurement step in the test sequence, PD measurements shall be made and recorded on all the line terminals equipped with bushings with a Um ≥ 72.5 kV, during the test, however if there are more than six such terminals then only six measurements need to be made (one on each of the highest voltage terminals) unless otherwise specified.

Test sequence

The test sequence shall be as follows:

a) The voltage shall be switched on at a voltage not higher than $(0.4 \times Ur)/\sqrt{3}$.
b) The voltage shall be raised to $(0.4 \times Ur)/\sqrt{3}$ and a background PD measurement shall be made and recorded.
c) The voltage shall be raised to $(1.2 \times Ur)/\sqrt{3}$ and held there for a minimum duration of 1 min and only long enough to make a stable PD measurement.
d) The PD level shall be measured and recorded.
e) The voltage shall be raised to the one hour PD measurement voltage and held there for a minimum duration of 5 min and only long enough to make a stable PD measurement.
f) The PD level shall be measured and recorded.
g) The voltage shall be raised to the enhancement voltage and held there for the test time mentioned below.

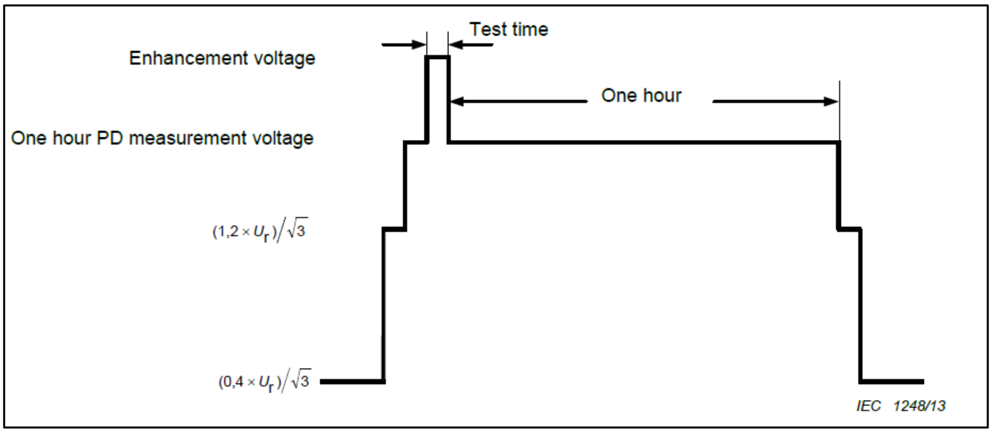
h) Immediately after the test time, the voltage shall be reduced without interruption to the one hour PD measurement voltage.
i) The PD level shall be measured and recorded.
j) The voltage shall be held at the one-hour PD measurement voltage for a duration of at least one hour following the PD measurement.
k) The PD level shall be measured and recorded every 5 min during the one hour period.
l) After the last PD measurement in the one hour period the voltage shall be reduced to (1.2 × Ur) /√3 and held there for a minimum duration of 1 min and only long enough to make a stable PD measurement.
m)The PD level shall be measured and recorded.
n) The voltage shall be reduced to (0.4 × Ur) /√3 and the background PD level shall be measured and recorded.
o) The voltage shall be reduced to a value below (0.4 × Ur) /√3.
p) The voltage shall be switched off.

An enhancement (phase to earth) voltage level of (1.8 × Ur) /√3 and a one hour PD measurement voltage of (1.58 × Ur) /√3. Alternative higher voltage levels may be used if specified by the purchaser. In particular an enhancement voltage of Um and a one hour PD measurement voltage of (1.5 × Um) /√3 may be used if higher.

The partial discharge level shall be continuously observed on at least one measuring channel for the entire duration of the test.

During the test sequence the inception and extinction voltages of any significant PD activity should be noted to aid the evaluation of the test result if the test criteria are not met.

Test sequences are illustrated in below figure.



Test Duration & Frequency

The test time at the enhancement voltage shall be 60 s in case Um ≤ 800 kV and 300 s in case U_m > 800 kV for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

120 × rated frequency / test frequency, but not less than 15 s for Um ≤ 800 kV

The duration of the test, except for the enhancement level, shall be independent of the test Frequency.

Test acceptance criteria

The test can only be considered valid if the measured background PD level does not exceed 50 pC at both the beginning and the end of the test. For tests on shunt reactors a background PD level higher than 50pC may be accepted.

The test is successful if all the following criteria are fulfilled:

a) No collapse of the test voltage occurs;
b) None of the PD levels recorded during the one hour period exceed 100 pC;
c) The PD levels measured during the one hour period do not exhibit any rising trend and no sudden sustained increase in the levels occur during the last 20 min of the test;
d) The measured PD levels during the one hour period do not increase by more than 50 pC;
e) The PD level measured at a voltage level of $(1.2 \times U\text{r})/\sqrt{3}$ after the one hour period does not exceed 100 pC.
f) If the criteria c) or d) are not met, the one hour period may be extended and these criteria will be considered to have been met if they are fulfilled for a continuous period of one hour.

Check points:

1. For 3-Ph Transformer/Reactor, IVPD test shall be carried out by 3-Phase supply

2. Before start of the test, all parameters / data used for PD testing and mentioned in the computer software to be checked with calibrated result of the instrument.

3. In case of doubt, change of PD measuring channel, creating PD temporarily, and check the healthiness of the measuring channel.

4. Before and after the PD test, calibration of the channel and measuring circuit to be repeated.

5. Continuous PD recording (if facility available) to be carried out for reference.

8. Temperature Rise Test on Transformer

Reference Standard:

IEC 60076-1 Edition 3.0 2011-04 Clause 11.4 Measurement of short-circuit impedance and load loss & IEC 60076-2 Edition 3.0 2011

For each cooling combination with cooler bank, tests shall be done for a minimum of 12 hours for ONAN/ONAF and 24 hours for ODAF or OFAF or ONAF2 with saturated temperature for at least 4 hours while the appropriate power and current for core and load losses are supplied.

The total testing time, including ONAN heating up period, steady period and winding resistance measurements is expected to be about 48 hours.

Gas chromatographic analysis on oil shall also be conducted before, during and after this test and the values shall be recorded in the test report. The sampling shall be in accordance with IEC 60567.

Oil sample shall be drawn before and after heat run test and shall be tested for dissolved gas analysis. Oil sampling to be done 2 hours prior to commencement of temperature rise test. Keep the pumps running for 2 hours before and after the heat run test. Take oil samples during this period. For ONAN/ONAF cooled transformers, sample shall not be taken earlier than 2 hours after shut down. The acceptance norms with reference to various gas generation rates shall be as per IEC 61181. The DGA results shall generally conform to IEC/IEEE/CIGRE guidelines.

Temperature of the cooling media

Ambient temperature

For the temperature rise test, the cooling air temperature should be in the range between 10 °C and the maximum ambient temperature 50 °C for which the transformer is designed.

At least four sensors shall be provided and the average of their readings shall be used to determine the ambient temperature for the evaluation of the test results.

Around an ONAN transformer, the ambient sensors shall be placed at a level about half-way up the cooling surfaces. The sensors shall be distributed around the tank, about 2 m away from the perimeter of tank and cooling surfaces, and protected from direct heat radiation.

For a forced-air-cooled (ONAF, OFAF, ODAF) transformer the sensors shall be placed in the air at about 0.5 m from the intake of the coolers.

Readings should be taken at regular intervals (30 minutes). Automatic continuous recording may be used.

In the case of separate cooling equipment placed at a distance of at least 3 m from the transformer tank, the ambient temperature shall be measured around the cooling equipment applying the same rules given above. For separate cooler bank arrangement (distance of at least 3 m from the transformer tank) 4 numbers sensors shall be used to measure the ambient temperature.

Attention shall be paid to possible recirculation of hot air. The transformer should be placed so as to minimize obstructions to the air flow and to provide stable ambient conditions.

Total loss injection

The Contractor before carrying out this test shall submit detailed calculations showing losses on various taps and for the three types of ratings of the transformer and shall recommend the combination that result in highest temperature rise for the test. The Temperature rise type test results shall serve as a “finger print” for the units to be tested only with short term heat run test.

2-Winding Transformer

Load Loss measurement for HV-LV connection and at Normal & extreme taps) shall be carried out. For 2-winding transformer, total losses to be fed during temperature rise test shall be **2-Winding Loss at tap corresponding to maximum measured loss and No load loss.**

2-Winding Loss = [HV-LV] (Max MVA)

The total losses to be injected during the first part of the test shall be equal to the highest value of total loss appearing at any tapping (corresponding to the particular tapping). This tapping is also often, but not always, the maximum current tapping. This part of the test determines the maximum top-liquid temperature rise. For the determination of winding temperature rise at the maximum current tapping, the value of liquid temperature rise to be used in the evaluation shall correspond to the total losses of that tapping.

3-Winding Transformer

Load Loss measurement for all combinations (HV-IV, HV-LV, IV-LV and at Normal and extreme taps) shall be carried out. The temperature rise test shall be conducted at a tap for the worst combination of loading (3-Winding Loss) for the Top oil of the transformer. Total losses to be fed during temperature rise test shall be **3-Winding Loss and No load loss.**

3-Winding Loss = HV (Max MVA) + IV (Max MVA) + LV (Max MVA)

The injection of total loss for the determination of liquid temperature rise may be made in an approximate manner by not short-circuiting or closing certain windings. The total losses shall be fed to HV or IV while LV winding is left open and raise the current until the correct total loss is obtained.

The top-liquid temperature and cooling medium temperature are monitored, and the test is continued until steady-state liquid temperature rises are established. The first part of the test may be terminated when the rate of change of top-liquid temperature rise has fallen below 1 K/h and has remained there for a period of 4 h. If discrete readings have been taken at regular intervals, the mean value of the readings during the last hour is taken as the result of the test. If continuous automatic recording is applied, the average value during the last hour is taken.

After the top-liquid temperature rise has been established, the test shall be continued without a break with the test current reduced to rated current for the winding combination connected. This condition is maintained for 1 h, during which time continuous temperature records of top-liquid, winding hot-spot (if measured) and external cooling medium should be taken at least every 15 min.

At the end of the hour, the resistances of the windings are measured, either after a rapid disconnection of the supply and short circuits (IEC 60076-2 clause 7.8 and Annex C) or, without switching off the supply, by means of the superposition method which consists of injecting into the windings and measuring direct current of low value superimposed on the load current. In the similar way winding hotspot, average winding rise etc. shall be measured for tertiary winding for various cooling.

Determination of liquid temperatures

Top-liquid temperature

The top-liquid temperature (θo) is conventionally determined by one or more sensors immersed in the insulating liquid at the top of the tank or, in pockets in the cover. The recommended number of pockets is the following:

− rated power ≥ 100 MVA:	3 pockets;
− rated power from 20 MVA to <100 MVA:	2 pockets;
− rated power < 20 MVA:	1 pocket.

The position of the sensors should be chosen to present the top-liquid temperature possibly in correspondence to the wound columns.

If more than one pocket is used, the readings of the sensors shall be averaged in order to obtain a representative temperature value.

Bottom and average liquid temperatures

The bottom liquid temperature (θb) shall be determined by sensors placed at the return headers from coolers or radiators. If several banks of cooling equipment are fitted, more than one sensor should be used and the reading average assumed as bottom liquid temperature.

Average liquid temperature (θom) is used for the calculation of the average winding gradient and correction of certain temperature rise test results. The average liquid temperature is:

$$\theta om = (\theta o + \theta b)/2$$

Determination of top, average and bottom liquid temperature rises

The top-liquid temperature rise (Δθo) shall be determined by difference between the top-liquid temperature measured at the end of the test period with total losses (θo) and the external cooling medium temperature at the end of the test period with total losses (θa), that is:

$$\Delta\theta o = \theta o - \theta a$$

The average liquid temperature rise ($\Delta\theta om$) shall be determined by difference between the average liquid temperature (θ om) calculated according to 4.2 and the external cooling medium temperature (θa), that is:

$\Delta\theta om = \theta om - \theta a$

The bottom liquid temperature rise ($\Delta\theta b$) shall be determined by difference between the bottom liquid temperature (θb) defined according to clause 7.4.2 of IEC 60076-2 and the external cooling medium temperature (θa), that is:

$\Delta\theta b = \theta b - \theta a$

Determination of average winding temperature

The average winding temperature is determined by measurement of winding resistance. On three-phase transformers, the measurement should be normally performed including the middle phase of the windings.

For star connected, low voltage and high current windings, the measurement should be made between line terminals in order to exclude the neutral connection from the test circuit. A reference measurement (R1,θ1) of all winding resistances is made with the transformer at ambient temperature, in a steady-state condition (see IEC 60076-1).

When the resistance (R2) is measured after disconnection of the power supply, extrapolated to the instant of shutdown, this yields the temperature value:

$$\theta_2 = \frac{R_2}{R_1}(235 + \theta_1) - 235 \qquad \text{for copper}$$

Where θ2 is the average temperature of the winding at the instant of shutdown. In the formula, the temperatures are expressed in Celsius degrees.

Determination of winding resistance at the instant of shutdown

The winding resistance (R2) before shutdown shall be determined using the rules indicated below.

Immediately after disconnection of the test power supply and removal of the short-circuiting connection, a direct current measuring circuit shall be connected across the winding terminals corresponding to the resistance to be measured.

As the resistance of the winding varies with time as the winding cools down, it shall be measured for a sufficient time to permit extrapolation back to the instant of shutdown.

As the windings have a large electrical time constant (L/R), accurate readings are therefore obtained only after a certain delay.

The delay can be reduced by minimizing as much as possible the time between the shutdown and the switching on the resistance circuit, as well as reducing the electrical time constant by an adequate choice of the parameters of the circuit.

The cooling conditions should preferably not be disturbed during the time the resistance measurements are made. If pumps are operating during the temperature rise test, they should be maintained during the measurements.

The detailed execution of the measurement are given in IEC 60076-2 Annex C. Resistance shall be measured for atleast 30 minutes.

Determination of average winding temperature rise at the instant of shutdown

The average winding temperature rise shall be determined using the value of resistance at the instant of shutdown. The corrected winding average temperature rise of the winding ($\Delta\theta w$) is:

$$\Delta\theta_w = \theta_2 + \Delta\theta_{ofm} - \theta_a$$

where $\theta 2$ is the average winding temperature at the instant of shutdown, θa is the external cooling medium temperature at the end of the test period with total losses, $\Delta\theta ofm$ the fall of the temperature of the average liquid during the 1 h test at rated current.

The detailed execution of the measurement are given in IEC 60076-2 Annex C. The calculation details, Graph with Annexure C (duly filled) shall be submitted with temperature rise test result.

After hot resistance measurement of HV and IV winding, Tertiary winding shall be loaded at rated MVA (of LV) for 1 hour. After it, hot resistance measurement shall be carried for LV winding. The above sequence shall be followed for all cooling combinations (ONAN/ONAF/OFAF as applicable).

Determination of the average winding to liquid temperature gradient

The average winding to average liquid temperature gradient (g) shall be determined as the difference between the uncorrected average winding temperature ($\theta 2$) and the average liquid temperature θom at shutdown:

$$g = \theta_2 - \theta_{om}.$$

Determination of the hot-spot winding temperature rise

Direct measurement during the temperature rise test

A number of thermal sensors (e.g., optical fibre sensors) shall be mounted inside the windings in positions where it is supposed the hot-spots are located.

When more than one sensor is used on the same winding, the maximum reading shall be taken as the hot-spot winding temperature.

The hot-spot winding temperature rise ($\Delta\theta h$) is then obtained by:

$$\Delta\theta_h = \theta_h + \Delta\theta_{of} - \theta_a$$

where θh is the temperature reading at shutdown, $\Delta\theta$ of the fall of the top-liquid temperature during the 1 h test at rated current, and θa the ambient temperature at the end of the total loss test period.

Determination by calculation

The hot-spot winding temperature rise can be determined using the following equation:

$\Delta\theta h = \Delta\theta o + Hg$

The average thermal gradient between each winding and liquid along the limb (g) is taken as the difference between the average winding temperature rise ($\Delta\theta w$) and average liquid temperature rise ($\Delta\theta om$).

$(g)= (\Delta\theta w) - (\Delta\theta om)$.

H = Hotspot factor = 1.3 (As per existing practice) and also furnish the design calculate of this factor in line with IEC. Derive winding hotspot rise based on above factors and values should not exceed the guaranteed parameters for both the cases.

Hotspot temperature rise shall be measured by direct FO sensors and shall be recorded for reference only.

Calculation of Hotspot factor as per IEC 60076-2 shall also be furnished during design review.

The format of measuring parameters is attached at Annexure-I.

ANNEXURE-I

TRANSFORMER SR. NO.			
TRANSFORMER RATING : COOLING :			WNDING
The top-liquid temperature (θo)	(θo)	^{o}C	
The bottom liquid temperature (θb)	(θb)	^{o}C	
External cooling medium temperature at the end of the test period with total losses (θa)	(θa)	^{o}C	
The average liquid temperature θom	= (θo +θb)/ 2	^{o}C	
The top-liquid temperature rise (Δθo)	Δθo =θo −θa	^{o}C	
The average liquid temperature rise (Δθom)	=θom −θa	^{o}C	
Winding			
Average winding temperature at the instant of shutdown, θ2	θ2	^{o}C	
Fall of the temperature of the average liquid during the 1 h test at rated current , Δθofm	Δθ ofm	^{o}C	
The corrected winding average temperature rise of the winding Δθw	=θ2 + Δθofm −θa	^{o}C	
The average winding to average liquid temperature gradient (g) (Uncorrected)	g =θ2 −θom	^{o}C	
Temperature reading at shutdown by fiber optic sensor (direct reading), θh	θh	^{o}C	
The top-liquid temperature during the 1 h test at rated current, Δθof	Δθof	^{o}C	
The average winding to average liquid temperature gradient (g) (corrected)	g =g (uncorrected)+Δθofm	^{o}C	
The hot-spot winding temperature rise (Δθh)	=θh + Δθof −θa	^{o}C	
The average thermal gradient of Winding, (g)	= (Δθw) - (Δθom)	^{o}C	
Calculated Hotspot rise (Δθh) [where Hotspot factor, H = 1.3]	=Δθo +H g	^{o}C	
Hotspot rise (Δθh) [where design Hotspot factor, H = to be furnished by manufacturer]	=Δθo +H g	^{o}C	
Top liquid temperature rise		^{o}C	
HV Winding average temperature rise		^{o}C	
The hot-spot winding temperature rise (Δθh) by fiber optic sensor (reference purpose)		^{o}C	
The hot-spot winding temperature rise (Δθh) by conventional method		^{o}C	
The hot-spot winding temperature rise (Δθh) considering design hotspot factor and measured top oil rise.		^{o}C	

9. Overload testing in short-circuit method

The test shall be carried out on the tapping position that will cause the highest current under normal conditions. Hot spot temperature measurement shall be done by using temperature probes or sensors in approved locations.

The transformer shall be fully erected as for service with all cooling equipment.

I. Testing option 1:

Pre-load the unit with 100% of full load current for a period long enough to stabilise the top oil temperature with cooling as for service conditions.

- Increase the loading to 120% overload rating. Forced cooling shall be activated as per service conditions.
- Scan and record infra-red images of all four sides and the top of the transformer at the interval of every one hour.
- Hold the overload current for a period of 4 hours.
- Measure and record the hotspot temperatures (by resistance method & fiber optic sensors).

II. Testing option 2:

Pre-load the unit with 100% of full load current for a period long enough to stabilise the top oil temperature with 100% cooling as per service conditions.

- Increase the loading to 130% overload rating.
- Scan and record infra-red images of all four sides and the top of the transformer every 30 minutes.
- Hold the current at 130% for a period of 2 hours.
- Measure and record the hotspot temperature (by resistance method & fiber optic sensors).

III. Acceptance criteria:

Winding hotspot temperatures shall not exceed 130°C for option 1 and 135 °C for option 2.
The temperature rise recorded by infra-red shall be not more than 10°K above top oil temperature or 15°K above the local oil temperature.
The rate of gas development as determined from oil samples shall be determined. Samples shall be taken before and after the test and acceptance criteria shall be in accordance with IEC/IEEE guidelines.

IV. Test records:

Full details of the test arrangements, procedures and conditions shall be supplied with the test certificates and shall include the following:

- Purchaser’s reference number and site designation
- Manufacturer’s name and transformer serial number
- MVA rating and voltage ratio
- Vector group

- Altitude of test bay
- Designation of terminals supplied and terminals strapped
- Colour photographs of the four sides and top of the transformer.

V. Overload test:

A log of the following quantities taken at a minimum of 30-minute intervals:

- time
- voltage between phases
- current in each phase
- power in each phase and total power
- ambient temperature
- top oil temperature
- FO sensors readings

10. Short duration heat run test (Not Applicable for unit on which temperature rise test is performed)

In addition to the type test for temperature rise conducted on one unit, each cooling combination shall routinely be subjected to a short term heat run test to confirm the performance of the cooling system and the absence of manufacturing defect such as major oil flow leaks that may bypass the windings or core.

DGA samples shall be taken at intervals to confirm the gas evolution.

For ODAF or OFAF cooling, the short term heat run test shall be done with the minimum number of pumps for full load operation in order to shorten the temperature build up. Each short term heat run test is nevertheless expected to take about 3 hours.

For ODAF or OFAF cooled transformers an appropriate cross check shall be performed to prove the effective oil flow through the windings. For this purpose the effect on the temperature decay by switching the pumps off/ on at the end of the heat run should demonstrate the effectiveness of the additional oil flow. Refer to SC 12, 1984 cigre 1984 SC12-13 paper by Dam, Felber, Preiniger et al.

Short term heat run test may be carried out with the following sequence:

- Heat run test with pumps running but oil not through coolers.
- Raise temperature to 5 deg less than the value measured during temperature rise test.
- Stop power input and pumps for 6 minutes and observe cooling down trend
- Restart pumps and observe increased cooling trend due to forced oil flow

The cooling down trend shall be observed by recording top and bottom oil temperature and winding resistance.

This test is applicable for the Transformer without Pump also (ONAN or ONAF rating). For such type of transformer test may be carried out with the following sequence:

Arrangement shall be required with pump of suitable capacity (considering the oil velocity) without cooler bank. Raise the oil temperature 20-25 deg C above ambient. Stop power input and pumps for 6 minutes and observe cooling down trend. Restart pumps and observe increased cooling trend due to forced oil flow. FO sensors data shall be recorded during the test.

11. Over excitation test

A routine over excitation test at 1.05 p.u voltage for 12 hours shall be done on the tap position giving the highest flux. This test shall be carried out immediately after the routine short-term heat run test on the transformer. The rate of gas development during the test shall be evaluated using IEEE /IEC/CIGRE guidelines. FO sensors data shall be recorded during the test.

12. Measurement of zero-sequence impedance(s) on three-phase transformers/reactors

Standards: IEC 60076-1:2011, IEC 60076-8

General

In the case of transformers having more than one star-connected winding with neutral terminal, the zero-sequence impedance is dependent upon the connection.

The zero-sequence impedance may have several values because it depends on how the terminals of the other winding or windings are connected and loaded.

The zero-sequence impedance may be dependent on the value of the current and the temperature, particularly in transformers without any delta-connected winding.

The zero-sequence impedance may also be expressed as a relative value in the same way as the (positive sequence) short-circuit impedance

Test Procedure

The zero-sequence impedance is measured at rated frequency between the line terminals of a star-connected or zigzag-connected winding connected together, and its neutral terminal. It is expressed in ohms per phase and is given by ($3U/I$), where U is the test voltage and I is the test current. The test current per phase ($I/3$) shall be stated in the test report.

It shall be ensured that the current in the neutral connection is compatible with its current carrying capability.

In the case of a transformer with an additional delta-connected winding, the value of the test current shall be such that the current in the delta-connected winding is not excessive, taking into account the duration of application.

If winding balancing ampere-turns are missing in the zero-sequence system, for example, in a star-star-connected transformer without delta winding, the applied voltage shall not exceed the phase-to-neutral voltage at normal operation. The current in the neutral and the duration of application should be limited to avoid excessive temperatures of metallic constructional parts.

For autotransformers and YY transformers, there are several combinations of tests to perform:
– HV with LV open circuit;
– HV with LV short circuit;
– LV with HV open circuit;
– LV with HV short circuit.
– For YD transformers, the zero sequence impedance is measured from the Y side only.
– Auto-transformers with a neutral terminal intended to be permanently connected to earth shall be treated as normal transformers with two star-connected windings.

Thereby, the series winding and the common winding together form one measuring circuit, and the common winding alone forms the other. The measurements are carried out with a current not exceeding the difference between the rated currents on the low-voltage side and the high voltage side.

For Reactor, this measurement shall be carried out at a voltage corresponding to a neutral current equal to the rated phase current.

NOTE 1 In conditions where winding balancing ampere-turns are missing, the relation between voltage and current is generally not linear. In that case, several measurements at different values of current may give useful information.

NOTE 2 The zero-sequence impedance is dependent upon the physical disposition of the windings and the magnetic parts, measurements on different windings may therefore not agree. In particular, for a transformer with a zigzag winding the zero sequence impedance measured between line terminals connected together and the neutral may result in a different value to that obtained when a three phase symmetrical voltage is applied and one line terminal is connected to the neutral.

NOTE 3 An additional zero-sequence impedance test may be required for transformers with delta windings with two connections to one corner brought out so that it can be either open or closed.

NOTE 4 Further guidance is given in IEC 60076-8.

315MVA, 500MVA 400/220/33kV Transformer Connections

Tap No.	**Current Applied**	**Open Terminals**	**3xU/I**	**%ZO**
1	Between HV (1U, 1V & 1W Shorted) and Neutral	2U, 2V, 2W and Tertiary		
9	-Do-	-Do-		
17	-Do-	-Do-		
1	Between IV (2U, 2V & 2W Shorted) and Neutral	1U, 1V, 1W and Tertiary		
9	-Do-	-Do-		
17	-Do-	-Do-		

The above measurements shall be repeated with Tertiary terminals shorted. Voltage and current shall be measured and recorded.

13. Measurement of acoustic noise level (Measured in Cold and Hot state of temperature rise test)

Test shall be performed as per IEC 60076-10 and clause 7.8.12 of IEC 60076-6 (for reactor). The measured value shall not be exceeded the limit as specified at Annexure-A of this specification. Sound pressure levels shall be established in line with specification. Sound power level shall be calculated from sound pressure level using the method described in IEC 60076-10. Location of microphones shall be in line with IEC 60076-10.

Important check points

The available frequency response of the measuring instrument shall range from below the rated power frequency to above the upper limit of the human ear capability of 20 kHz.

The upper limit for the actual measurement shall be chosen in accordance with the highest emitted significant frequency, usually below 10 kHz. The selected frequency range for background noise measurements and the test measurement shall be the same.

Sound pressure measurements shall be made using a type 1 sound level meter complying with IEC 61672-1 and IEC 61672-2 and calibrated in accordance with 5.2 of ISO 3746:2010.

The sound pressure method of measurements described in this standard is based on ISO 3746. Measurements made in conformity with this standard tend to result in standard deviations of reproducibility between determinations made in different laboratories which are less than or equal to 3 dB.

The measuring equipment shall be calibrated in accordance with manufacturer's instructions immediately before and after the measurement sequence. If the calibration changes by more than 0.3 dB, the measurements shall be declared invalid and the test repeated.

All measurements shall be made using the energetic average over the measurement duration of the sound quantity (pressure). Statistically derived sound quantities such as percentiles shall not be applied.

The fast response indication of the meter shall be used to identify and avoid measurement errors due to transient background noise.

The sound level measurement is usually of manual operation but the errors introduced by varying distances will tend to average out. Their impact on the final measurement is of less significance than other acoustical factors. Nevertheless, all effort shall be made to keep the measurement distance as constant as possible.

Test Report shall be in line with Annexure-B of IEC 60076-10.

14. Measurement of power taken by fans and oil pumps (100 % cooler bank)

Losses of each fan and pumps including spare shall be measured at rated voltage (415V) and frequency. Fans and Pumps shall be mounted with cooler bank as per approved drawing during measurement. Serial No, Applied voltage, measured current, frequency and make shall be furnished in the test report.

15. High voltage with stand test on auxiliary equipment and wiring after assembly

The wiring for auxiliary power, and control circuitry shall be subjected to a 1 min AC separate source test of 2 kV to earth. The test is passed if no voltage collapse or other sign of breakdown occurs.

The wiring for current transformer secondary windings shall be tested at 2.5 kV AC to earth for 1 min. The test shall be carried out at the manufacturer's works. If the current transformer knee-point voltage exceeds 2 kV AC the test shall be performed at 4 kV AC. The test is passed if no voltage collapse or other sign of breakdown occurs.

16. Frequency Response analysis (SFRA)

Frequency Response Analysis (FRA) is conducted to assess the mechanical integrity of the transformer. FRA signatures will be taken at works in oil filled condition after completion of all tests.

It is recommended to follow the standard procedure for the SFRA measurement as per the below Table. It should be done on maximum, normal and minimum tap of the transformer.

Combination of test for Autotransformer

Test Type	Test	3- Phase	1-Phase
Series Winding (Open circuit) All other terminals floating	Test 1	H1-X1	H1-X1
	Test 2	H2-X2	
	Test 3	H3-X3	
Common Winding (Open circuit) All other terminals floating	Test 4	X1-H0X0	X1-H0X0
	Test 5	X2-H0X0	
	Test 6	X3-H0X0	
Tertiary Winding (Open circuit) All other terminals floating	Test 7	Y1-Y3	Y1-Y2 (Y1-Y0)
	Test 8	Y2-Y1	
	Test 9	Y3-Y2	
Short circuit (SC) High (H) to Low (L) Short (X1-X2-X3)	Test 10	H1-H0X0	H1-H0X0 Short (X1- H0X0)
	Test 11	H2-H0X0	
	Test 12	H3-H0X0	
Short circuit (SC) High (H) to Tertiary (Y) Short (Y1-Y2-Y3)	Test 13	H1-H0X0	H1-H0X0 Short (Y1-Y0)
	Test 14	H2-H0X0	
	Test 15	H3-H0X0	
Short circuit (SC) Low (L) to Tertiary (Y) Short (Y1-Y2-Y3)	Test 16	X1-H0X0	X1-H0X0 Short (Y1-Y2)
	Test 17	X2-H0X0	
	Test 18	X3-H0X0	

H1: HV Terminal; X1: IV Terminal; H0X0: Neutral

In case of Shunt Reactor, FRA to be done in following combinations:

- H1-H0
- H2-H0
- H3-H0

17. Tank Tests

i. Oil Leakage Test

All tanks and oil filled compartments shall be completely filled with oil of a viscosity not greater than that of insulating oil conforming to IEC 60296 at the ambient temperature and subjected to a pressure equal to normal head of oil plus 35 kN/sq.m (5 psi) measured at the base of the tank. This pressure shall be maintained for a period of not less than 12 hours for oil during which no leakage shall occur. Pressure may slightly vary with ambient temperature change during 12 hours.

ii. Vacuum Test

All transformer tanks shall be subjected to the specified vacuum. The tank designed for full vacuum shall be tested at an internal pressure of 3.33 KN/Sq.m absolute (25 torr) for one hour. The permanent deflection of flat plate after the vacuum has been released shall not exceed the values specified below:

Horizontal Length of flat plate (in mm)			Permanent deflection (in mm)
Up to and including 750			5.0
751	to	1250	6.5
1251	to	1750	8.0
1751	to	2000	9.5
2001	to	2250	11.0
2251	to	2500	12.5
2501	to	3000	16.0
Above		3000	19.0

iii. Pressure Test

All transformer tanks, its radiator, conservator and other fittings together or separately shall be subjected to a pressure corresponding to twice the normal head of oil or normal oil head pressure plus 35 KN/sq.m whichever is lower, measured at the base of the tank and maintained for one hour. The permanent deflection of flat plates after the excess pressure has been released shall not exceed the figure specified above for vacuum test.

18. Appearance, construction and dimension check

At Complete assembled transformer, Dimensions, fittings/accessories, clearances shall be verified in line with approved General Arrangement drawing, Bill of material, drawings of other accessories (OLTC, Bushing, Online DGA, Drying system, Buchhoolz relay, PRD, SPR, OTI, WTI, etc. as applicable).

19. Dynamic Short circuit withstand Test

19.1 Reference Standard: IEC 60076-5 (Latest Standard)

19.2 The tests shall be carried out on a new transformer ready for service. Protection accessories, such as gas-and-oil-actuated relay and pressure-relief device, shall be mounted on the transformer during the test. However, Detachable type cooler bank may not be required to install during short circuit test.

19.3 Prior to the short-circuit tests, the transformer shall be subjected to the routine tests and type tests as per POWERGRID specification (including routine tests which are specified in IEC 60076-1). If the windings are provided with tappings, the reactance and, if required, also the resistance shall be measured for the tapping positions at which short-circuit tests will be carried out. All the reactance measurements shall be to a repeatability of better than ±0.2 %. A report containing the result of the routine tests shall be available at the beginning of short-circuits tests.

Manufacturers shall compare the reactance measured at short circuit test lab with the value measured at their manufacturing works before proceeding to short circuit test.

19.4 At the beginning of short-circuit tests, the average temperature of the oil/winding shall preferably be between 10 °C and 40 °C (see 4.2.2.3 of IEC 60076-5).

19.5 During the tests, winding temperature may increase owing to the circulation of the short-circuit current. This aspect shall be taken into consideration when arranging the test circuit for transformers of category I.

19.6 Test current peak value $\hat{\imath}$ for two-winding transformers

The test shall be performed with current holding maximum asymmetry as regards the phase under test. The amplitude $\hat{\imath}$ of the first peak of the asymmetrical test current is calculated as follows:

$\hat{\imath} = I \cdot k \cdot \sqrt{2}$, where I the is symmetrical short-circuit current (see 4.1.2 of IEC 60076-5).

The factor k accounts for the initial offset of the test current and $\sqrt{2}$ accounts for the peak to-r.m.s. value of a sinusoidal wave. The factor $k\sqrt{2}$, or peak factor, depends on the ratio X/R

Where, X is the sum of the reactances of the transformer and the system (Xt + Xs), in ohms (Ω); R is the sum of resistances of the transformer and the system (Rt + Rs), in ohms (Ω), where Rt is at reference temperature (see 10.1 of IEC 60076-1).

In the case X/R >14 the factor $k \cdot \sqrt{2}$ is assumed to be equal to

$1.8\sqrt{2} = 2.55$ for transformers of category II;

$1.9\sqrt{2} = 2.69$ for transformers of category III.

19.7 **Tolerance on the asymmetrical peak and symmetrical r.m.s. value of the short-circuit test current**

If the duration of the short-circuit test is sufficiently long, the asymmetrical current having first peak amplitude î will change into the symmetrical current having r.m.s. value I (see 4.1.2 of IEC 60076-5). The peak value of the current obtained in testing shall not deviate by more than 5 % and the symmetrical current by more than 10 % from the respective specified value. However any positive tolerance may be acceptable subject to meeting the other requirements as per IEC.

The short-circuiting of the winding may either follow (post-set short circuit) or precede (pre-set short circuit) the application of the voltage to the other winding of the transformer.

If the post-set short circuit is used, the voltage shall not exceed 1.15 times the rated voltage of the winding

19.8 In order to avoid injurious overheating, an appropriate time interval (minimum 15 minutes between two consecutive shots) shall occur between successive overcurrent applications.

19.9 In order to check the values î and I of the test currents, oscillographic records shall always be taken.

19.10 The frequency of the test supply shall be, in principle, the rated frequency of the transformer.

19.11 Test connection shall be followed as per Clause 4.2.5.4 of IEC 60076-5.

19.12 The number of tests on three-phase and single-phase transformers is determined as follows, not including preliminary adjustment tests carried out at less than 70 % of the specified current to check the proper functioning of the test set-up with regard to the moment of switching on, the current setting, the damping and the duration.

19.13 For categories I, II & III single-phase transformers, the number of tests shall be three. The three tests on a single-phase transformer with tappings are made in a different position of the tap-changer, i.e. one test in the position corresponding to the highest voltage ratio, one test on the principal tapping and one test in the position corresponding to the lowest voltage ratio.\

19.14 For categories I, II & III three-phase transformers, the total number of tests shall be nine, i.e. three tests on each phase. Unless otherwise specified, the nine tests on a three-phase transformer with tappings are made in different positions of the tap changer, i.e. three tests in the position corresponding to the highest voltage ratio on one of the outer phases, three tests on the principal tapping on the middle phase and three tests in the position corresponding to the lowest voltage ratio on the other outer phase (manufacturer may change sequence).

19.15 For particular winding combination (HV-IV, HV-LV or HV-LV) number of shots shall be as per the following:

– for single-phase transformers: three;

– for three-phase transformers: nine.

19.16 For Tertiary winding dynamic short circuit shall be carried out either on HV-LV or IV-LV combination, whichever draws higher short circuit current as per calculation.

19.17 The duration of each test shall be 0.5 s for transformers of category I & 0.25 s for transformers of categories II and III, with a tolerance of ±10 %.

19.18 Detection of faults and evaluation of test results including acceptance criteria shall be followed as Clause 4.2.7 of IEC 60076-5. However, variations of short-circuit reactance (Acceptable limit) values shall be as per the following :

19.18.1 Transformers of categories I and II

2% for transformers with circular concentric coils and sandwich non-circular coils. However, for transformers having metal foil as a conductor in the low-voltage winding and with rated power up to 10 000 kVA, higher values, not exceeding 4 %,are acceptable for transformers with a short-circuit impedance of 3 % or more.

7,5 % for transformers with non-circular concentric coils having a short-circuit impedance of 3 % or more.

19.18.2 Transformers of categories III

The short-circuit reactance values, in ohms, evaluated for each phase at the end of the tests do not differ from the original values by more than 1 %.

Detail information pertaining to sort circuit test shall be furnished as per the format attached in Annexure-A.

ANNEXURE-A

Sr. No.	Parameters	Data
1	MVA Rating	
2	Phase	
3	Voltage Rating	
4	Tapping Range & Variation	
5	Fault MVA	
6	Fault Current	
7	Short circuit current feed to HV/LV	*Ex. From HV side for HV-IV Combination* *From LV side for HV-LV combination*

Tap Position	Maximum Voltage Tap	Normal Voltage Tap	Minimum Voltage Tap
Combination		HV-IV	
Short circuit method (Pre/Post short circuit connection)			
Precaution for saturation of the magnetic core / inrush of magnetizing current considered or not			
Transformer Impedance at Base MVA			
System Impedance			
Symmetrical short circuit current (Feeding current)			
$k.\sqrt{2}$ Value			
Asymmetrical short circuit current			
No of Shots			
Combination		IV-LV	
Short circuit method (Pre/Post short circuit connection)			
Precaution for saturation of the magnetic core / inrush of magnetizing current considered or not			
Transformer Impedance at Base MVA			
System Impedance			
Symmetrical short circuit current (Feeding current)			
$k.\sqrt{2}$ Value			
Asymmetrical short circuit current			
No of Shots			

20. Short time over voltage Test (830kVrms)

The test duration is 5 minutes at rated frequency. When the test frequency exceeds the rated frequency, the test time in seconds of the test shall be:

300 × rated frequency / test frequency

21. Shunt reactor loss measurement & temperature rise test

Reference Standard:

IEC 60076-6:2007 Clause 7.8.6 & Annex D (Temperature correction of losses for liquid-immersed gapped-core and magnetically-shielded air-core reactors)

Losses are based on reactor operation with rated current at rated frequency and at reference temperature. Measured losses shall be corrected to rated current and reference temperature.

For three-phase reactors, the measurement of loss shall be performed under three-phase excitation and loss shall be measured phase wise.

Method

Reactor shall be assembled with all accessories, cooling system as per approved GA drawing (Unit being offered for Type test). No deviation shall be accepted. The tests shall be done for a minimum of 24 hours with saturated temperature for at least 4 hours. DGA tests shall be performed before and after heat run test and DGA results shall generally conform to IEC61181. Please also refer temperature rise test procedure of transformer.

Full details of the test arrangements, procedures and conditions shall be provided with the test certificates and the following shall at least be included.

All the parameters as per specification shall be measured and recorded.

After completion of temperature rise test (24 hours) hot resistance shall be measured. During this period of hot winding resistance measurement, preparation for loss measurement at hot state shall be made. After completion of resistance measurement (atleast for 20 minutes) connection shall be made for loss measurement at hot state. During this complete process oil temperature shall be recorded.

Calculation methodology:

Average oil temperature at cold state: θ_c

Top oil temperature after 24 hours: θ_1

Average winding temperature at shut-down (measured by resistance): θ_2

Difference between Average winding & Top oil temperature: $\theta_2 - \theta_1$

Rated voltage shall be supplied during hot loss measurement. The supply shall continue for at least 30 minutes and subsequently loss shall be measured.

Top oil temperature during loss measurement: $\theta_{3\,(U, V, W)}$

Average winding temperature during loss measurement: $\theta_4 = \theta_3 + (\theta_2 - \theta_1)$

Calculation of Temperature co-efficient phase wise
Following parameters shall be measured during Loss measurement;

Rated Voltage KV	Current $I_{measured}$ A		Loss (Measured or calculated)		Top Oil Temperature $\theta_{3\,(U, V, W)}$		Tan Delta	
	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
90%								
100%								
110%								

Loss measured at cold state: W_c

Cold Loss at rated current: $W_{cr} = W_c \times (I_{rated}/I_{measured})^2$

Loss measured at hot state: W_h

Hot Loss at rated current: $W_{hr} = W_h \times (I_{rated}/I_{measured})^2$

Establishing the temperature coefficient of loss for individual phase:
$\Delta P\text{tot} / \Delta\theta = (W_{hr} - W_{cr})\text{ kW} / (\theta_4 - \theta_c)\text{ °C} = \alpha\text{ kW / °C}$

Recalculation to reference temperature 75 °C with temperature coefficient:
$P\text{tot}\ (75\text{ °C}) = P\text{tot}\ (\theta_4) + \alpha\ (75 - \theta_4)\text{ °C}$

The same process shall be followed for other 2 phases for calculation of temperature coefficient of individual phase.

Measurement of loss on a second identical unit at ambient temperature (routine test):

Measured mean oil temperature at cold state: θt
Loss measured at cold state: W_c
Cold Loss at rated current Ptot (θt °C): $W_c \times (I_{rated}/I_{measured})^2$

Total losses, Ptot (Measured)	I^2R loss (at rated current)	Additional losses
Ptot (θt °C) = $W_1 + W_2$	W_1 (Calculated)	W_2 (Calculated)

Re-calculation to reference temperature 75 °C with temperature coefficient derived after temperature rise test:

Ptot (75 °C) = Ptot (θt °C) + α × (75 – θt) °C

The loss shall be calculated for each phase at reference temperature (75 Deg C) and shall be added for total losses of all three phases. This value is the measured loss value against the guaranteed loss value for the second identical unit.

Check Points:

Inputs like – Value of Standard Capacitor, constants, scaling factors, ratio errors, phase angle errors etc. to the loss measuring instrument shall be as per the latest calibration certificate.

22. Two hours excitation test

a) Each reactor to be excited at Um for 2 hours except type tested unit.
b) Measure Vibration at Um and 1.05Um
c) DGA rate interpretation shall be as per IEC/ CIGRE/ IEEE guidelines
d) Test shall be performed before partial discharge test
e) Reactance & Loss measurement shall be carried out after completion of the above test to check the healthiness of the reactor

23. Stress measurement

After all dielectric test reactor shall be energized and Stress will be measured at one point (please refer specification for no. of points) of each wall where vibration reordered is maximum. Measurement shall be carried out at Um and 1.05Um voltage.

24. Measurement of harmonic content of current (Measured in Cold state) - Reactor

The harmonics of the current in all three phases are measured at rated voltage, by means of a harmonic analyser. The magnitude of the relevant harmonics is expressed as a percentage of the fundamental component. For more information on the magnetic characteristic, see Annex B of IEC 60076-6. The harmonics of the applied voltage shall be adequately measured at the same time.

25. Knee point voltage measurement of reactor (Measured in Cold state)

The test shall be carried out as per IEC 60076-6 clause B.7.1 “DC current charging – discharging method (theory)” or applying AC voltage from 0.7p.u, 0.8p.u, 0.9p.u and so on upto the level as per specification and measure the current at various voltages and calculate the tolerance of reactance as per annexure-A of this specification.

26. Standards:

IEC Standards	Latest IEC
Power transformers - Part 1: General	Edition 3.0 2011 -04
Power transformers - Part 2: Temperature rise for liquid-immersed transformers	Edition 3.0 2011-02
Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air	Edition 3.1 2018-03
Power transformers - Part 4: Guide to the lightning impulse and switching impulse testing - Power transformers and reactors	First edition 2002-06
Power transformers - Part 5: Ability to withstand short circuit	Third edition 2006-02
Power transformers - Part 6: Reactors	Edition 1.0 2007-12
Power transformers - Part 7: Loading guide for mineral-oil-immersed power transformers	Edition 2.0 2018-01
Power transformers - Part 8: Application guide	First edition 1997-10
Power transformers - Part 10: Determination of sound levels	Edition 2. 0 201 6 -03
Power transformers - Part 14: Liquid-immersed power transformers using high-temperature insulation materials	Edition 1.0 2013-09
Power transformers - Part 18: Measurement of frequency response	Edition 1.0 2012 -07
Power transformers - Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors	Edition 1.0 2013-03

Check Lists for Transformer & Reactor Tests

Sr. No.	Test	Acceptance Criteria*	Check list (✓ if conducted)
1.	Measurement of insulation power factor and capacitance between winding and earth and Bushings	Insulation power factor for windings < 0.5% Insulation power factor for Bushing as per GTP/TS	
2.	Measurement of insulation resistance & Polarization Index	PI > 1.3	
3.	Core assembly dielectric and earthing continuity test	IR >1 GΩ	
4.	Measurement of winding resistance	As per GTP	
5.	Full wave & Chopped lightning impulse test for the line terminals (LI & LIC) and Neutral (LI)	Refer procedure	
6.	Switching impulse test for the line terminal (SI)		
7.	Applied voltage test (AV)	No collapse of voltage or other sign of breakdown	
8.	Induced voltage withstand test (IVW)		
9.	Induced voltage test with PD measurement (IVPD)	Refer procedure	
10.	Temperature rise test	As per GTP/ TS	
11.	Measurement of acoustic noise level	As per GTP/ TS	
12.	High voltage with stand test on auxiliary equipment and wiring after assembly	No voltage collapse or other sign of breakdown	
13.	Frequency Response analysis (Soft copy of test report to be submitted to site along with test reports)	For record	
14.	Oil leakage test on transformer/ Reactor tank	No oil leakage	
15.	Tank vacuum test	Refer procedure	
16.	Tank pressure test	Refer procedure	
17.	Appearance, construction and dimension check	Dimensions measured shall match with approved GA drawing	

(*) Acceptance criteria to be read in conjunction with applicable Technical Specification

Check lists for additional tests applicable only for Transformer

Sr. No.	Test	Acceptance Criteria*	Check list (√ if conducted)
1.	Voltage ratio measurement & Polarity check (Vector Group)	≤0.5% as per IEC 60076-1 for Voltage ratio. Vector group as per specification.	
2.	Measurement of no load current & Short circuit Impedance with 415 V, 50 Hz AC	For record	
3.	No-load loss and current measurement	As per GTP / TS	
4.	Measurement of harmonic level in no load current	For record	
5.	Magnetic balance test (for three phase Transformer only)	Refer procedure	
6.	On-load tap changer test	Refer procedure	
7.	Measurement of short-circuit impedance and load loss	As per GTP/ TS	
8.	Line terminal AC withstand voltage test (LTAC)	No collapse of voltage or other sign of breakdown	
9.	Measurement of transferred surge on LV or Tertiary as applicable due to HV lightning impulse and IV lighting impulse (as applicable)	Refer procedure	
10.	Overload testing in short-circuit method	Refer procedure	
11.	Short duration heat run test (Not Applicable for unit on which temperature rise test is performed)	Refer procedure	
12.	Over excitation test	Refer procedure	
13.	Measurement of Zero seq. reactance (for three phase Transformer only)	As per GTP/ TS	
14.	Measurement of power taken by fans and oil pumps (Not applicable for ONAN)	As per GTP/ TS	
15.	Dynamic Short circuit withstand test (If specified in BPS)	Refer procedure	

Check lists for additional tests applicable only for Reactor

Sr. No.	Test	Acceptance Criteria*	Check list (√ if conducted)
1.	Short time over voltage Test (830kVrms) (765kV Reactor)	No voltage collapse or other sign of breakdown	
2.	Reactance and loss measurement (Measured in Cold and Hot state for the unit on which temperature rise test is performed & in Cold state for all other units)	As per GTP/ TS	
3.	2-Hour excitation test except type tested unit	Refer procedure	
4.	Vibration & stress measurement in Cold and Hot state for the unit on which temperature rise test is performed & in Cold state for all other units (Measurement shall also be carried out at 1.05Ur for reference only on one unit of each type)	As per GTP/ TS	
5.	Measurement of harmonic content of current (Measured in Cold state)	As per TS	
6.	Knee point voltage measurement of reactor (Measured in Cold state)	As per GTP/ TS	

(*) Acceptance criteria to be read in conjunction with applicable Technical Specification