

POWER TRANSFORMERS AND REACTORS

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PURPOSE AND SCOPE

This is a Functional Specification for transformers and liquid filled reactors connected to the National Grid Electricity Transmission System in the UK. This specification is intended to be functional to obtain best value, encourage innovation in suppliers and support the development of new and emerging transformer technology. This specification may be used in general for quadrature boosters and phase shifting transformers but additional requirements relating to the overall performance of the units will apply. It includes coolers, cooler controls, cooler monitoring, tap-changers, ancillary equipment and auxiliary cable marshalling accommodation, and local controls and indications but not protection, automatic voltage controls or remote controls. An overview of the National Grid System is given in National Grid Technical Specification (NGTS/TS) TS 1.

Site specific requirements such as voltage ratio, impedance, rating, etc provided in a format similar to that set out in Appendix A will be included in the enquiry document. Normally these requirements will be in accordance with the standard ratings given in PS(T) 031.

Dry type reactors are covered by TS 3.3.2.

PART 1 – PROCEDURAL

1 GENERAL REQUIREMENTS

1.1 Overall Requirements

- 1.1.1 Transformers and reactors shall comply with the latest editions of IEC 60076, this Specification and other applicable IEC, European and BS Standards. For the avoidance of doubt where there exists a difference between the Standards and this Specification the more onerous requirement will apply.

- 1.1.2 Component parts that can be replaced on site shall be to a standard design and corresponding parts shall be interchangeable.

For example: Parts such as fans, pumps, valves and radiators shall be to standard dimensions where standards exist e.g. EN 50216 series and all parts fulfilling the same function on the transformer shall be interchangeable.

- 1.1.3 Transformers and reactors shall be designed for a minimum operating life of 40 years under the conditions of operation specified herein and in TS 1. Items that are expected to require renewal within the 40 year period shall be stated on the TGN(E) 185 non conformance schedule included with the tender document.

Informative: The anticipated lifetime of transformers on the system is well in excess of 40 years because the ordinary loading and operating temperatures are generally lower than the stated criteria. It is expected that this will be taken into account in the transformer design and the selection of components, materials and manufacturing techniques.

- 1.1.4 Where possible the transformer and its components shall be designed or selected to minimise or eliminate maintenance requirements. Where this requirement incurs significant additional cost the lower cost alternative may be given as an option in the tender.

- 1.1.5 The transformer or reactor will be connected to an electricity transmission system that is subject to voltage transients due to lightning strikes, switching operations and other causes. The voltage of these transients is only limited by the action of the co-ordinating gaps and surge arresters fitted to the system, these items are specified to the relevant National Grid Technical Specification. Any plant connected to the transmission system must be designed to withstand the effects of any transient voltage that might occur below the protective level of the insulation co-ordination. Such transients may contain very high frequency components and may be repetitive in nature. The frequency of occurrence of transients and their frequency content will be site dependent and cannot be accurately predicted. Either surge arresters or co-ordinating gaps (where justified by PS (T) 021) will be used.

*Informative: Co-ordinating gaps and mounting structures for surge arresters **are** in the scope of supply of the transformer manufacturer but the line terminal surge arresters **are not**.*

- 1.1.6 Rated power for each winding shall be as given in the enquiry. Standard ratings are given in PS (T) 031.
- 1.1.7 Rated voltage for each winding shall be as given in the enquiry. Standard ratings are given in PS (T) 031.
- 1.1.8 Transformers and reactors shall be designed, manufactured and installed to ensure zero leakage of liquid over the specified lifetime. The manufacturer shall be required to provide procedures and guidance to eliminate the risks of leakage due to maintenance or other activities.

All materials used shall be suitable for the purpose intended. Materials in contact with insulating liquid shall be compatible with the liquid and not cause the production of dissolved gas in liquid, in particular, zinc coated fasteners, in National Grid's experience, can generate gas in liquid.

- 1.1.9 Where oil is referred to in this specification it can be construed to mean any insulating liquid e.g. mineral oil or synthetic ester. See also clause 1.35.

1.2 Temperature Rise

- 1.2.1 The temperature rise of transformers, quadrature boosters and series reactors at rated power under the test conditions given in IEC 60076-2 shall not exceed:

- a) Top oil temperature rise 60K.
- b) Winding average temperature rise 65K.
- c) Hotspot temperature rise 78K.

- 1.2.2 The temperature rise of shunt reactors operating under ONAF cooling at system maximum voltage and 49.5Hz shall not exceed:

- a) Top oil temperature rise 50K
- b) Winding average temperature rise 55K
- c) Hotspot temperature rise 68K

- 1.2.3 Transformers, series reactors and quadrature boosters are required to have an ONAN rating of at least 50% of the rated power. Shunt reactors are required to operate with ONAN cooling at system maximum voltage at 49.5Hz. Under these ONAN ratings the temperature rise of all transformers reactors and quadrature boosters shall also not exceed the figures given in clause 1.2.1.

1.3 Transport

- 1.3.1 Transformers and reactors shall be suitable for transport on UK roads by girder frame trailer. Passage under normal height motorway and trunk road bridges requires that the maximum height of the equipment when arranged for transport is 4.87 m and the maximum height when arranged on the trailer is 4.95 m. The width of the tank below the transport lugs shall be less than 4.4 m. The lug height shall be not less than 1300mm where the lugs are more than 6 m apart. If the lugs cannot be arranged to be 6 m or more apart the lug height may need to be increased, this shall be stated in the tender.

- 1.3.2 Unless special arrangements can be agreed the weight of the largest indivisible load arranged for transport shall not be greater than 220 tonnes.

- 1.3.3 For transformers and reactors with an **equivalent double wound rated power** of less than 130MVA the transport weight of the largest indivisible load including a suitable trailer shall not exceed 150 tonnes. However this limit may be exceeded if the overall evaluated cost of the transformer including the cost of losses, the cost of transport and the cost of installation can be reduced with a heavier unit.

1.4 Environmental Conditions

- 1.4.1 All transformers, reactors and associated equipment shall be suitable for outdoor operation. Transformers and reactors shall be designed for the environmental conditions at any National Grid site including coastal locations. All liquid containing parts and any equipment mounted in their immediate vicinity shall operate normally during, and not be damaged by,

the activation of active automatic fire protection (water deluge) systems. Adequate drainage facilities shall be provided to ensure that accumulation of water cannot occur on or in any of the transformer external parts or supporting structures. Horizontal flat surfaces shall be made slightly sloped to prevent water accumulation.

- 1.4.2 The transformer shall be suitable for use in either Class d (Heavy) or Class e (Very Heavy) pollution environments as defined in IEC 60815. Unless otherwise specified in the enquiry the transformer including the bushings shall be suitable for application in a Class e (Very Heavy Pollution) environment. See also TS 3.2.7.
- 1.4.3 The transformer shall be designed to accept bushings for either pollution class without internal modification.

1.5 Tertiary Windings

- 1.5.1 Where specified in the site specific requirements (Appendix A), a delta connected tertiary winding with a rated voltage of 13 kV and a rated power of 60 MVA shall be provided on the transformer. The rated power of the tertiary shall apply to both OFAF and ONAN cooling. Unless otherwise specified, no increase in the rated power of the series or common windings of auto transformers is required to allow for external load on the tertiary winding.

Informative: Some additional cooling capacity may be required to allow for simultaneous loading of the three windings if the tertiary loss is greater than the reduction in loss from an equivalent reduction in loading on either of the other windings.

- 1.5.2 When specified in Appendix A, the tertiary no-load terminal voltage shall be maintained constant irrespective of tap position.
- 1.5.3 Unless otherwise stated in the site specific requirements (Appendix A) the vector grouping of auto transformers with a delta tertiary winding shall be YNa0d11.
- 1.5.4 The tertiary winding shall be suitable for connection to a Relocatable Static Var Compensator (RSVC) capable of a capacitive load of 60 MVar at 0.9 pu voltage. The RSVC is specified to operate at 1.2 pu voltage (continuous 50 Hz plus harmonics) and 1.5 pu current under certain conditions until reduced by tertiary winding temperature and/or voltage controls. The tertiary and its connections shall be designed to accommodate this mode of operation although no special provision for higher ratings or voltage of the winding itself are required. The maximum acceptable voltages available at the tertiary terminals (usually limited by the acceptable flux density in the core) for continuous and short time operation shall be identified by the supplier in Schedule A1 “the technical data to be supplied by manufacturer”, which is a separate document associated with this specification.

The tertiary shall be designed for operation with one terminal earthed and the other corners open circuit. In this condition no more than 150 kVp shall be induced on the open circuit terminals of the tertiary when the relevant impulse voltage specified in Table 3 is applied to any of the other terminals. Although not preferred, surge arresters may be used for this purpose, if this is the case a set of three arresters must be provided complete with tank mountings and connections for permanent installation. See clause 1.6.1.

- 1.5.5 See also section **Error! Reference source not found..**

1.6 Electrical and Safety Clearances

- 1.6.1 Electrical and safety clearances shall be in accordance with TS 2.1. The minimum clearance does not apply to directly earthed neutral bushings. For the purposes of this part of the Specification 13 kV terminals shall be treated as 22 kV. Where 11 kV and 22 kV connections do not comply with the Basic Electrical Clearance (phase to earth) in TS 2.1 bare metal shall be insulated.

1.7 Test Windings and Voltage Limiting Devices

- 1.7.1 Transformers and reactors shall be designed so that the use of non-linear voltage limiting devices to control internal voltages during testing shall be avoided wherever practicable. Where it is considered their use is unavoidable or offers significant advantages to National Grid this shall be stated clearly in the tender. The use of such devices shall always be by agreement with National Grid. Any non-linear voltage limiting device must be accommodated in the tap-changer selector compartment if this is a separate liquid compartment. In all cases the non-linear device must be accessible for replacement at site without removing the active part of the transformer from the tank.
- 1.7.2 Transformers and reactors shall be designed so that the use of test windings shall be avoided wherever practicable. Where it is considered that their use is unavoidable this shall be stated clearly in the tender. The inclusion of test windings shall always be by agreement with National Grid.
- 1.7.3 If exceptionally a test winding is incorporated in the transformer design, terminations shall be provided to enable earthing of the test winding to be achieved externally. A delta connected test winding shall have the two ends of one corner brought out to bushings and the delta closed and connected to one of the main HV winding neutral connections by means of external links. A star connected test winding shall have the star point brought out via a bushing and connected externally to one of the main HV winding neutral connections. In each case a separate HV winding neutral bushing for this purpose is desirable.

1.8 Flux Density

- 1.8.1 If a maximum continuous peak flux density exceeding 1.9T will be induced in the core or any other magnetic component under any combination of the voltage and frequency conditions given in clause 1.25 at any tap position (see also clause 1.8.2), then this shall be clearly stated in the tender. In this case evidence shall be provided with the tender to show that the proposed flux density will not have any adverse operational impact.
- 1.8.2 For 400 kV transformers and reactors, for the purposes of determining the maximum continuous peak flux density in the core and other magnetic components of it may be assumed that 420 kV at 47 Hz represents the worst combination of voltage and frequency for continuous operation. For other voltages the worst case of highest voltage and lowest frequency must be assumed.
- 1.8.3 Additionally 400 kV transformers and reactors shall be suitable for operation at 440 kV and 49.5 Hz for up to 15 minutes with frequency excursions to 47 Hz for at least 20 seconds.

1.9 Cooling, Liquid Pipework and Valves

- 1.9.1 The cooling medium unless otherwise stated is air.
- 1.9.2 Transformers, series reactors and quadrature boosters are required to have an ONAN rating of at least 50% of the rated power see clause 1.2.3.
- 1.9.3 Shunt reactors shall have a 100% ONAN rating and shall be provided with ONAF cooling to reduce operating temperatures from the ONAN condition. See clause 1.2.3. Fans are not required if the ONAF temperature rise requirements can be met with ONAN cooling.
- 1.9.4 The cooler arrangements shall allow for the maintenance or failure of any one pump, fan or radiator bank without the loss of more than 50% of the total cooling capacity. A suitable arrangement would be two separate free standing cooler banks each with an oil pump, each bank capable of supplying 50% of the total cooling requirement. Greater redundancy in the cooling plant may be desirable and may be offered.

- 1.9.5 To allow for the fitting of an acoustic enclosure around the transformer or for installation indoors in a transformer 'pen' the coolers shall be separate free-standing units. Alternative layouts of separate cooler banks may be required to accommodate the site arrangement at particular sites (for example side-by-side or in-line).
- 1.9.6 The transformer or reactor shall be arranged so that separate free standing coolers can be connected to either end of the transformer. Drawings must be supplied for both cooler configurations and the change from one configuration to the other shall be capable of being made with the minimum of additional or replacement parts.

Informative: The orientation of the coolers may need to be revised at any point during the contract or even after delivery to site.

- 1.9.7 The cooler fans and pumps if fitted are to be controlled separately by a winding temperature indicator with at least three stages of cooling e.g. OFAF/OFAN/ONAN or ONAF2/ONAF1/ONAN. The normal temperature settings are pumps (stage 1) switching on at 65°C and off at 40°C and fans (stage 2) switching on at 75°C and off at 50°C. Other values and cooler control stages may be suggested by the manufacturer where reduced losses and/or maintenance can be achieved without reducing the lifetime of the transformer, 75°C is the maximum hotspot temperature at which all cooling shall be switched on.
- 1.9.8 The fans shall be divided electrically into at least two groups so that the fans corresponding to each radiator bank are separate.
- 1.9.9 Lockable electrical isolation facilities shall be provided to allow for the maintenance of fans and pumps. It shall be possible to electrically isolate any pump or fan for maintenance or replacement with the other pump(s) or fan group(s) operating under manual or automatic control.
- 1.9.10 The cooler controls shall be fitted with a sequence start relay(s) to prevent the simultaneous starting of the fan and pump motors on any two cooler banks however the pump and fan motors on a given cooler bank may start together. Not more than approximately 50% of the total cooling load shall be switched on simultaneously. The sequence start relays must reset on loss of auxiliary power so that this condition is fulfilled when the auxiliary supply is restored.

Informative: For clarity: pump A and fans on cooler bank A can start together, but a timer shall be fitted to ensure that pump B and fans on cooler bank B start 30 seconds later, and so on for any further cooler banks. This is to reduce the starting current requirements of the 400 V auxiliary supply.

- 1.9.11 Appropriate electrical protection devices are required for fan and pump motors. Separate protection devices are required for each motor arranged so that the tripping of one motor will not affect the operation of the remaining motors.
- 1.9.12 A manual control shall be provided in the marshalling kiosk for testing and manual selection of full cooler operation. Each pump and fan group shall be capable of being switched on individually for routine testing. Additionally the manual control shall allow all fans and duty pumps to be run together to give continuous cooler operation.
- 1.9.13 It shall not be possible under any circumstances to cause an operation of any of the oil surge relays by the manual or automatic operation of any of the cooler controls including isolators. Additionally, supply disturbances such as momentary loss of auxiliary supply under any cooler operating state shall not cause an operation of any of the oil surge relays. These requirements shall be met after the failure of any single component in the cooler control system which produces a cooler fail alarm, and any combination of cooler control system failures that could be present without initiating an alarm.

Informative: The requirements of this section can be met by demonstrating that starting and stopping both (or all) pumps simultaneously does not operate any of the oil surge relays. A test to demonstrate that the requirements of this clause have been met is required (see section 2.3.12).

- 1.9.14 A cooler monitoring system which may be incorporated in the WTI shall be supplied to provide the functionality specified in TS 3.3.9.
- 1.9.15 The control/monitoring system shall be enabled to exercise the cooler at least once per week if the liquid temperature is not below a given limit.
- 1.9.16 A relay is required to detect a failure of the electrical supply to the cooler. In this case a "supply monitoring relay" alarm shall be generated irrespective of whether the cooler is called for or not.
- 1.9.17 Valves are required to allow the isolation of the transformer, each cooler bank and each pump from the rest of the cooling system. These valves shall be capable of satisfactory and safe operation (without sticking or slamming) under all conditions of pressure, vacuum and liquid flow.
- 1.9.18 Radiators shall be galvanised (to BS EN ISO 1461 or similar) before being provided with a protective paint finish in accordance with clause 1.31.

Informative: It is not normally possible to adequately maintain the paint finish between radiator plates and galvanising cannot normally be expected to last 40 years without the protection of paint. Alternative corrosion protection systems that can offer 40 year lifetimes would be considered.

- 1.9.19 Thermometer pockets shall be provided in each top and bottom liquid pipe adjacent to the transformer, or in the top and bottom cooler headers.
- 1.9.20 Pipework shall be provided with suitable expansion devices as required. Mechanical protection for these devices shall be provided if necessary to avoid damage during maintenance etc.
- 1.9.21 Air release and drain plugs or valves are required for all pipework, expansion devices, pumps, valves, radiators etc.
- 1.9.22 Separate drain and filter valves are required at the top and bottom of the main tank, the cooler headers, and separate liquid compartments e.g. for tap-changer selectors.
- 1.9.23 Valves for liquid filtering require 50 mm flexible hose adapters.
- 1.9.24 All valves shall be provided with open/shut indication and locking facilities.
- 1.9.25 Visual indication at ground level of liquid flow or pump impeller rotation is required.
- 1.9.26 It shall be possible to carry out safely all operations associated with the replacement of a pump with the transformer in service at reduced load, with the exception of final liquid filling and commissioning.

1.10 Winding Temperature Indicators

- 1.10.1 One winding temperature indicator calibrated to indicate winding hottest spot temperature is required for each winding (i.e. one for each of: common, series, HV, LV and tertiary winding as appropriate). Where a tertiary winding is not brought out for loading only the WTI CT (and direct temperature sensing transducer on type tested transformers) is required. As an alternative a single electronic WTI may be provided monitoring all windings, together with a

separate oil temperature indicator with two contacts. WTIs shall be supplied to comply with TS 3.3.9.

Note: WTIs shall be mercury free.

- 1.10.2 Information shall be supplied with the transformer test certificate giving the operating characteristics of the WTI. The WTI gradient settings and WTI secondary current at transformer rated current shall be permanently displayed next to the WTI in the marshalling kiosk.

- 1.10.3 Ammeters are required to indicate the currents in the WTI CT secondary circuits, and a switch for each WTI is required to enable the WTI calibration to be safely checked by current injection with the transformer on load.

Informative: If the CT secondary current is indicated by the WTI itself then a separate ammeter is not required.

- 1.10.4 Cooler control and WTI fail contacts shall close in the event of a failure of the WTI.

- 1.10.5 If the WTI requires external power this shall be from the 110V DC supply.

1.11 Tap-changer

- 1.11.1 Unless otherwise specified in the enquiry tap-changers shall be of the on-load type in accordance with IEC 60214.

- 1.11.2 Tapping ranges and tapping steps shall be as given in the enquiry. Standard values are given in PS (T) 031.

- 1.11.3 Tap-changers shall be capable of at least 300 000 operations between maintenance inspections.

- 1.11.4 A liquid flow operated relay shall be fitted in the pipework connection from the diverter switch to the diverter oil conservator. This device shall be arranged to trip the transformer in the event of a diverter malfunction resulting in an increase in pressure and a consequent oil surge condition.

- 1.11.5 Where required, a lifting device for maintaining the tap-changer diverter shall be supplied if National Grid does not already have a suitable lifting device. Appropriate facilities for fitting the lifting device shall be provided.

- 1.11.6 A rating plate shall be supplied for the tap-changer stating rated through current, rated step voltage and transition resistor value in addition to the requirements of IEC 60214.

- 1.11.7 A rating plate shall be supplied for the motor drive stating the number of service tap positions in addition to the requirements of IEC 60214.

1.12 Tap-changer Barrier Board

- 1.12.1 A barrier board between the tap-changer and the main tank is required if any of the following is true:

- (a) The diverter is of a type that under normal operation, causes the production of any liquid breakdown products or dissolved gas in the liquid and there is a rotating seal between the diverter liquid and the selector/main tank liquid or
- (b) The selector is of a type where current normally flows in any contact whilst it is moving, either making or breaking including any capacitive current to floating windings (for

example any transformer design with a reversing winding and some coarse-fine designs where a tie-in resistor is required) or

- (c) Any design where sparking at the contacts is a part of normal operation.

Otherwise the selector may be mounted in the main tank.

- 1.12.2 If a barrier board is included, creating one or more selector compartments then the following applies:

- (a) The liquid in the selector compartment may share the conservator with the main tank liquid, but any gas from the selector compartment must not pass through the main tank.
- (b) Buchholz relays shall be provided for each selector compartment. This relay will be arranged to trip the transformer in the event of a tap selector malfunction resulting in either the generation of free gas or an increase in pressure and consequent oil surge condition. Where three single phase tap-changers are supplied in three separate compartments then a gas and oil operated relay is required for each of the three compartments.

Note: Relays shall be mercury free.

- (c) Spring operated pressure relief devices are required for each selector compartment.

- 1.12.3 Tap-changer barrier boards shall be treated as an integral part of the tap-changer and shall be subjected to the same dielectric and hydraulic test levels as the tap-changer.

1.13 Tap-changer Control

- 1.13.1 The tap-changer shall be driven by a motor drive mechanism. The motor shall be powered by a 400V AC three phase supply. All motor drive circuits shall be provided with thermal overload protection.
- 1.13.2 Facilities shall be provided to allow for the tap-changer to be physically locked in either “local” or “remote” position to enable maintenance.

1.14 Tap-changer Monitoring

- 1.14.1 A tap-changer monitoring system capable of detecting slow operation, increased mechanical resistance (increased motor torque), high temperature in the diverter switch and drive shaft failure shall be provided. The operation (position and timing) of the diverter shall be monitored by auxiliary switches in the diverter or other means.
- 1.14.2 The tap-changer monitoring shall be capable of tripping the tap-changer motor drive under circumstances when conditions are detected that might cause failure if the tap-changer operates again.
- 1.14.3 The tap-changer monitor shall provide alarm indications if the tap-changer requires attention or if the monitoring system fails.

1.15 Ancillary Equipment, Tap-changer, Motor Drive and Auxiliary Cable Marshalling Accommodation

- 1.15.1 A marshalling kiosk or other suitable accommodation is required for housing cooler control equipment, tap-changer control equipment (if appropriate), winding temperature indicators (if appropriate), and terminations for protection current transformers.
- 1.15.2 Each compartment shall have a suitable thermostatically or hygrostatically controlled heater (to prevent condensation) and a light.

- 1.15.3 The degree of protection required for the accommodation against the ingress of solid foreign objects and water shall be at least to IP 54 according to IEC 529 (see also section 1.4.1). With any doors open the degree of protection for persons against access to hazardous parts shall be at least to IP 1X according to IEC 529.
- 1.15.4 The accommodation may be in the form of a free standing marshalling kiosk or separate accommodation for tap-changer and cooler equipment. Accommodation may be attached to the transformer or cooler structure provided it is readily and safely accessible with the transformer in service. Specific site requirements regarding the marshalling accommodation may be included in the enquiry.
- 1.15.5 In addition the marshalling kiosk or one of the marshalling cubicles shall have an externally mounted 230 V AC single phase switched socket fitted with a residual current protection device.
- 1.15.6 All ancillary equipment and wiring shall comply with TS 2.19. Installations shall be based on the use of armoured cables terminated with suitable glands (non stuffing type), alternatively, a solution utilising a rugged conduit based system may be considered. All cables must be securely fixed to the transformer structure and arranged to minimise damage.
- 1.15.7 All moving parts shall be adequately guarded to prevent danger to personnel.

1.16 Controls, Indications, Trips, Alarms and Analogues

Informative: All the controls, indications, trips, alarms and analogues for the transformer main tank, tertiary, tap-changer and cooling system are specified in this document. For alarm handling (local, remote) and grouping information refer to the generic equipment model (GEM) documents, which are available via the National Grid intranet and extranet.

- 1.16.1 Separate “raise” and “lower” control inputs shall be provided to allow remote control of the tap-changer.
- 1.16.2 Pushbutton control facilities and a remote/off/local switch shall be provided local to the tap-changer i.e. in the marshalling kiosk or the tap-changer control cubicle.
- 1.16.3 A “step-by-step” control mechanism shall be provided to ensure that only one complete tap-step change will occur even if the control input is contiguously energised.
- 1.16.4 An electrical and/or mechanical device shall be provided which, after an interruption of the supply voltage, will complete a tap-change operation once it has initiated.
- 1.16.5 A normally open clean contact, which is closed during a tap-change operation, shall be provided to indicate at a remote point that a tap-change is in progress.
- 1.16.6 A mechanical indication is required in the motor drive cubicle to show that a tap-change is in progress and to confirm that a tap-change has been completed.
- 1.16.7 Means for remote indication of tap position shall be provided. This shall comprise one electrically independent switch (with one contact for each tap-position), one 4-20mA transducer and one resistive potentiometer type indicator.
- 1.16.8 Facilities shall be provided to trip the motor Mini Circuit Breaker (MCB) from a remote location. An alarm shall be provided to indicate at the remote location when the MCB is tripped.
- 1.16.9 Controls, indications, trips, alarms and analogues shall be provided according to Appendix B of this document. Each digital output shall be a clear contact, which has two separate terminals. Analogue outputs shall be in the form of a 4 to 20 mA current powered by the

instrument or transducer. Some sites may require analogue outputs of 0-10 mA as an alternative.

- 1.16.10 All the control and indication contacts shall be capable of being powered by 48 V or 110 V DC supply. All the trips shall be capable of being powered by 110 V DC supply.

1.17 Main Terminals

- 1.17.1 Where liquid/air terminations are specified, bushings shall comply with TS 3.2.7 Bushings.
- 1.17.2 Where liquid/SF6 terminations are specified, the terminations shall comply with TS 3.2.7 and to ensure interchangeability with existing spare transformers the relevant transformer and bushing dimensions shall be as shown on the relevant drawing in Appendix D.
- 1.17.3 No connections or installation work at site should require the use of solid insulation materials that have not been tested with the transformer e.g. connections to be made at site should not require paper taping.
- 1.17.4 In addition to the requirements of TS 3.2.7, bushings supplied shall be of a type that if they fail externally shall not release liquid from the transformer.

Informative: The intent of this clause is to reduce the chance of the transformer catching fire following a bushing failure. This clause would be satisfied by the use of solid composite bushings but not by the use of conventional oil filled paper insulated bushings.

- 1.17.5 To ensure satisfactory mating of the flanges of the busbar trunking with the flanges of the HV and LV bushings, the maximum permitted tolerances on relevant dimensions of the transformer, taking the centre of the turrets as the datum point, shall be as stated below. These tolerances shall be applicable to the transformer in its on-site position after any necessary processing and when filled with liquid. The variation allowed between phases is to be contained within, and is not additional to the tolerances on the principal dimensions.

Relevant Dimensions		Tolerance $\pm$ (mm)
(a) Phase-to-phase distance between centre lines of bushings		6
(b) Between the centre line of each bushing and the longitudinal centre line of tank		5
(c) Variation between phases for dimensions as for (b) above		4
(d) From top of turrets to corresponding point on	(i) the edge of the tank base	8
	(ii) the plinth or floor	13
(e) Variation between phases for dimensions as for (d)		4
(f) Level of top of turrets		$\pm 0.5^{\circ}$
(g) Angular alignment of flange bolt holes		$\pm 0.1^{\circ}$

- 1.17.6 The bushing flange shall be insulated from the transformer tank (see clause 2.3.22 SF6 Bushing Flange Isolation - Applied Voltage (RT)). In service the bushing flange will be connected to the same substation earth mat as the transformer tank.

Informative: The bushing flange shall be earthed during all testing except testing of the flange insulation itself.

- 1.17.7 Where termination interchangeability is specified in the site specific requirements (Appendix A), the internal and external arrangements of the transformer shall permit the fitting of either

liquid/air or liquid/SF6 bushings (the requirements in clauses 1.17.3 and 1.17.6 shall apply to the SF6 arrangement) on-site without factory modifications. The additional parts, if any, required to allow the change of bushings shall be fully designed but they are not normally required to be supplied with the transformer.

- 1.17.8 HV winding terminals shall be marked A, B, and C (from left to right when looking at the HV side of the transformer) with the subscript assigned to the winding end (the neutral end of the winding being 1). LV winding terminals shall be marked a, b, and c with the appropriate subscript unless connected to a tap-changer. HV and auto winding neutral terminals shall be marked NA, NB and NC. If applicable the LV neutral terminal shall be marked yn and a single star point HV neutral shall be marked YN. Any means of marking the terminals shall be readable from ground level and shall be sufficiently robust to meet the requirements of section 1.1.3.

- 1.17.9 Phase colour plates (red, yellow and blue disks) shall be provided for all terminals. The red and blue disks are to be interchangeable.

1.18 Tertiary Terminals

- 1.18.1 Where a tertiary winding is required, the initial configuration of the tertiary terminations will be specified in the site specific requirements (Appendix A) as either

- (a) Bring out the tertiary terminals for loading or
- (b) Bring out one corner of the tertiary winding for closing and earthing externally.

Whichever configuration is specified initially the design shall be such that it is possible to revert to the other configuration without modification to the transformer internals, although dropping the transformer liquid to a level above the top of the windings may be required for example to remove the tertiary loading box and re-configure bolted links.

- 1.18.2 Tertiary terminations for loading shall be arranged to permit connection via busbars, irrespective of which end the coolers are connected. This may be achieved by ensuring that the tertiary terminations can be brought out at either end of the tank or by other suitable means.

- 1.18.3 Where it is specified in the site specific requirements (Appendix A) that the tertiary terminals will be brought out for loading, the arrangement shall meet the requirements specified in the following clauses

- (a) Where liquid/air bushings are specified, a liquid filled tertiary loading box shall be supplied in the form of a turret supporting bushings suitable for loading the tertiary to its full capability (see also clause 1.29.1 provision for a noise enclosure). The bushings shall be suitable to withstand the mechanical and thermal effects of the maximum tertiary fault level of 50 kA and the appropriate tertiary dielectric test levels. Typically bushings rated 22 kV, 4000 A are suitable, although alternative ratings may be offered.
- (b) An earthing transformer may or may not be connected at the time of commissioning. A facility shall be provided to enable the transformer to be put into service with the tertiary not connected to an earthing transformer. This shall be arranged in such a way that a tertiary earth fault will operate the transformer electrical protection. A suitable arrangement is to provide an additional neutral bushing adjacent to the tertiary terminals so one of the tertiary terminals may be connected to the neutral of one of the HV windings. The additional neutral bushing shall be clearly labelled to indicate that it is an HV neutral and not a tertiary neutral connection, see clause 1.18.6.
- (c) It shall be possible to disconnect the earthing transformer from the tertiary terminals and connect one tertiary terminal to one HV winding neutral without the need to remove liquid from the main tank. All relevant parts (e.g. bushings and links) and instructions required to complete the changeover shall be supplied with the transformer.

- (d) Provision shall be made to prevent the possibility of faults occurring between external tertiary terminals in the tertiary unloaded condition. This may be achieved by insulating all live parts on exposed tertiary terminals (with appropriately rated shrink-wrap material or similar) or by inter-phase barriers or other means.
 - (e) The connection symbol shall be as given in PS (T) 031. The rating and diagram plate for the transformer shall clearly indicate the removable link and shall be annotated to identify the two possible operating conditions, preferably using a reversible plate.
 - (f) Current transformers and CT test loops shall be included in the tertiary turret box.
 - (g) Where a tertiary cable box is specified this shall be designed to ensure phase segregation either by the use of three separate cable boxes or metallic barriers. A disconnection chamber shall be provided so that the transformer and the cable can be tested separately on-site without the need to remove liquid from the main tank
- 1.18.4 Where specified in the site specific requirements (Appendix A) that a tertiary winding is to be provided but not brought out for external loading, the winding shall have the two ends of one corner brought out to bushings and the delta closed and connected to one of the main winding neutral connections by means of external links. A separate neutral bushing for this purpose is desirable.
- 1.18.5 As an alternative to the tertiary terminal configuration specified above - a suitable standard modular type plug-in type cable connection may be used in accordance with EN 50299 (when the revision incorporating this type of connection is published). The tertiary delta shall be closed internally and the three line connections shall be available for loading using at least three cables per phase. Arrangements must be made using a cable or otherwise to connect one corner of the tertiary to one of the transformer neutrals when the tertiary is not connected to a load in such a way that the connection can be made or broken without liquid handling. The positioning of the plug-in connection on the transformer tank is not specified, but must be such that a cable can be led to the connection irrespective of the position (hanging) of the cooler. Suitable fittings to attach the cables or a cable tray to the tank are required.
- 1.18.6 Tertiary winding terminals shall be marked 3A, 3B and 3C if brought out for loading or TA, TB, or TC as appropriate if brought out for closing and earthing only. The neutral connection used for earthing the tertiary shall be labelled NA, NB or NC as appropriate. Any means of marking the terminals shall be readable from ground level and shall be sufficiently robust to meet the requirements of section 1.1.3.
- 1.18.7 Phase colour plates (red, yellow and blue disks) shall be provided for all terminals. The red and blue disks are to be interchangeable.
- 1.18.8 13kV reactors shall be designed to accept a direct, phase-segregated cable connection preferably of a standard plug-in modular type using at least three cables per phase.
- 1.19 Number of Phases**
- 1.19.1 Unless otherwise specified in the enquiry transformers shall be three phase in a single main tank.
- 1.20 Number of phases in system**
- 1.20.1 All transformers shall be designed to be connected to a three phase transmission system.
- 1.21 Frequency**
- 1.21.1 The nominal system frequency is 50Hz and the transformer shall be able to operate safely and without any degradation in performance with system and auxiliary supply frequencies in

the range 47.5Hz – 52Hz continuously and between 47Hz - 47.5Hz for at least 20 seconds. See also section 1.8.

1.22 Highest voltage for equipment (U_m)

1.22.1 The U_m for each winding shall be based on rated voltage as given in the table below.

Nominal System Voltage	400kV	275kV	132kV	66kV	13kV tertiary
U_m	420kV	300kV	145kV	72.5kV	24kV

1.22.2 Transformers for use on the 400kV system shall also operate safely and without any degradation in performance when operated in the range 420kV-440kV for up to 15 minutes. See also Section 1.25.

1.23 Winding Insulation, Neutral Connections and Earthing

1.23.1 For star and auto connected 400kV, 275kV and 132kV windings the neutral will be directly earthed in service and the insulation may be graded.

1.23.2 66kV, 33kV and lower voltage windings shall be fully insulated with the neutral of star connected windings brought out to a single bushing for earthing either directly or via an impedance.

1.23.3 Arrangements for effectively earthing the transformer tank and winding neutrals are required in accordance with TS 2.1.

1.24 Current Transformers and Current Transformer Accommodation

1.24.1 Current transformers of the types and quantities stated in Appendix E of this document relevant to the particular voltage and rating of the transformer shall be provided for HV, LV, tertiary and neutral terminals.

1.24.2 Current Transformer Accommodation

To allow interchangeability of transformers between sites with current transformers different to those specified in Appendix E the following accommodation must be provided. This accommodation shall be used for the current transformers supplied with the transformer.

- (a) HV and LV terminals: A space according to the relevant dimensions given in Table 1 and suitable mounting arrangements for protection and measurement current transformers shall be provided close to each HV and LV line terminal.

Informative: Usually this accommodation is provided over the earth band of the bushing in the bushing turret. The current transformers which are to be supplied with the transformer would normally be installed in this accommodation. The internal diameter of the CT can be chosen to suit the bushing used, and can be less than the maximum internal diameter stated in Table 1.

Rated Voltage	Max Internal diameter	Min External diameter	Min Axial length
400 kV	680 mm	1000 mm	740 mm
275 kV	440 mm	820 mm	640 mm
132 kV	320 mm	520 mm	620 mm

Table 1 - Accommodation required for Current Transformers

- (b) Tertiary Loading Box: Where bushings are specified for connecting the tertiary winding to an external load in the site specific requirements (Appendix A), provision shall be made within a separate trunking in each under-liquid line connection of the tertiary winding for protective current transformers. The space required shall allow the fitting of a current transformer with overall dimensions of approximately 330 mm outside diameter and 305 mm axial length. A removable through connection designed for at least a 22 kV insulation level with the current transformer installed, having an overall length of approximately 760 mm shall be provided. Alternatively the current transformers may have an integral fully insulated conductor.
- (c) Neutral CT: Provision for the mounting of external neutral CTs for the HV or auto winding shall be made on the transformer tank. In the case of autotransformers safety clearance requirements apply to conductors between the winding and the external star point. For star connected LV windings of double wound transformers suitable CT accommodation shall be provided in the neutral bushing turret.
- (d) Delta LV windings: Transformers with delta 33kV and 66kV windings are required to have provision for protection CTs mounted in the delta.

1.25 Operating Conditions

1.25.1 Transformers and reactors are required to operate satisfactorily i.e. without any degree of failure, distress or overheating at the rated power given in the site specific requirements (Appendix A) under any combination of the following factors:

- a) Tap position.
- b) Tertiary load 0 to 60 MVar capacitive or inductive.
- c) The transformer shall be capable of supplying power to a load connected to the LV up to the limits given in clauses 1.25.2 and 1.25.5 with rated voltage applied to the HV windings at any tap-position including that for highest LV voltage but supplying only rated LV voltage due to voltage drop in the transformer (constant current taps).
- d) The transformer shall be capable of supplying power to a load connected to the HV winding at nameplate rating at rated HV and LV voltage at all tap-positions including the tap for minimum LV voltage (power flow from LV to HV).
- e) Load power factor.
- f) HV voltage variation of + or -10% (voltages between 420 kV and 440 kV will not be sustained for more than 15 minutes).
- g) LV voltage variation of + or -10% (of tapping voltage).
- h) Frequency variation between 47 Hz and 52 Hz (this applies to the system and auxiliary supplies) but see also clause 1.8.3.
- i) Auxiliary supply voltage variation +10 -15%.

Informative: It may be assumed that a capacitive load on the tertiary winding will be reduced or tripped at a voltage corresponding to that given as a maximum by the transformer manufacturer in the Schedule A.

1.25.2 Transformers, quadrature boosters, phase shifting transformers and series reactors shall be capable of operation at 1.2 pu load current at an ambient temperature of 20°C as an emergency post-fault condition for an indefinite period in excess of 6 hours without exceeding a hotspot temperature of 125°C (the Winding Temperature Indicator (WTI) trip

temperature). It is recognised that under these circumstances loss of insulation life will occur.

- 1.25.3 The anticipated hottest spot temperature for this loading condition shall be stated in the tender.
- 1.25.4 The calculation of the hotspot temperature and loss of insulation life under emergency loading conditions shall be according to the method given in IEC 60076-7 based on the temperature rise test results. Where the manufacturer believes that such a calculation would be seriously in error for the supplied transformer this shall be stated in the tender and details of the calculation supplied.
- 1.25.5 Transformers, quadrature boosters, phase shifting transformers and series reactors shall have a 10 minute rating (following a 0.75PU pre-load) of 1.5PU current at an ambient temperature of 20°C without exceeding a hotspot temperature of 125°C. The complete plant including bushings, tap-changers, WTIs and all other components shall be capable of operating at 1.5PU for 30 minutes without generating gas and without damage apart from some loss of insulation life.
- 1.25.6 The plant shall also be capable of other short time loadings according to the relevant guidelines given in IEC 60076-7.

1.26 Short Circuit Capacity

- 1.26.1 The transformer or reactor shall withstand the through fault currents derived from the maximum three phase and single phase symmetrical short circuit currents given in TS 1. The peak current used in short circuit capability calculations shall be based on the X/R ratio of the transformer.
- 1.26.2 The maximum short circuit current available at the terminals of a delta connected 13 kV tertiary winding assuming infeed from both HV and LV terminals shall not exceed 50 kA.
- 1.26.3 Transformers with a lower voltage of 132kV or less (not including the tertiary winding) shall be able to withstand the thermal effects of a short circuit on the LV winding for 3 seconds without exceeding the temperature rise figures given in IEC 60076-5.

1.27 Losses and Impedance

- 1.27.1 The guaranteed no-load and load losses shall be stated in Schedule A associated with this specification. Unless otherwise specified, they shall be subject to the tolerances specified in IEC 60076 for the purposes of acceptance or rejection.
- 1.27.2 For transformers without taps the impedance between higher voltage and lower voltage terminals at rated current shall be as stated in the Schedule A subject to the tolerances in IEC 60076 unless otherwise stated.
- 1.27.3 For transformers with taps, envelope impedances are quoted in the Schedule A, the impedance between higher voltage and lower voltage terminals on any tap at the corresponding rated current shall not fall outside the stated envelope, linearly interpolated between maximum and minimum tapping.
- 1.27.4 The impedance between higher voltage and tertiary terminals shall not exceed 15% on a 60 MVA base.
- 1.27.5 The impedance between the higher voltage and tertiary terminals and between lower voltage and tertiary terminals shall be arranged to ensure that the fault levels stated in clause 1.26 are not exceeded, assuming simultaneous infeed from both higher voltage and lower voltage systems.

1.28 Noise

- 1.28.1 The Maximum Sound Power Level for the main unit shall be determined according to IEC 60076-10 under the operating conditions given in the following table.
- 1.28.2 The maximum sound power level for OFAF type coolers determined according to IEC 60076-10 with all fans and pumps operating in the normal service condition for rated power shall, unless otherwise agreed, be as given in the following table. Where a duty/standby pump, fan or cooler system is used then the operating combination that gives the highest sound power level shall be used to determine the measured level.
- 1.28.3 For shunt reactors the load and no load sound power limits may be combined.

Equivalent Double Wound Rated Power (MVA)	Maximum No Load Sound Power Level (100% excitation voltage) of Main Unit dB(A)	Maximum Sound Power Level of Main Unit at 50% Load and 102.5% excitation voltage (Log sum of measured 50% Load noise and measured 102.5% excitation voltage No Load noise) dB(A)	Maximum Sound Power Level of Cooler dB(A)
100 to 199	90	92	84
200 to 350	91	95	87
>350	91 (each main tank)	According to site specific requirements	87 (at reduced capacity stage) and 93 (maximum)

Table 2 - Maximum Sound Power Levels

Informative: It is expected that best available technology will be used to minimise noise levels and if lower guaranteed sound power levels can be provided then this should be stated in the tender.

- 1.28.4 Site specific requirements, if different from above, will be included with the enquiry.

1.29 Provision for a Noise Enclosure

- 1.29.1 Where specified in the site-specific requirements (Appendix A) the transformer shall be designed to allow the installation of a noise enclosure and the following requirements apply.
- 1.29.2 Coolers shall be mounted outside the noise enclosure.
- 1.29.3 When the cooling capability of the transformer is designed the presence of a noise enclosure shall be taken into account when calculating the heat loss (if any) from the transformer tank.
- 1.29.4 HV and LV bushing turrets are required with a minimum vertical clearance of 500 mm between the highest point of the tank and the underside of the turret flange. Additionally the turrets must be clear of fittings, handholes etc. at the level of the noise enclosure roof except for a 25 mm wide shelf or fittings to attach a shelf at approximately the mid depth of the roof of the enclosure for the support of weatherproofing materials. A cowl shall be provided at the level of the top of the roof on each turret, pipe or support penetrating the roof for weather protection.
- 1.29.5 Turret mounted CT terminal boxes shall be positioned inside the noise enclosure.
- 1.29.6 CT test loop terminals shall be either all inside or all outside the noise enclosure, and shall be easily accessible with the noise enclosure fitted.

- 1.29.7 Air release pipes between the turrets and the gas and oil actuated relay pipe shall be external to the noise enclosure.
- 1.29.8 The tertiary winding loading box where specified in the site specific requirements (Appendix A) shall be designed so that the tertiary bushings are external to the enclosure.
- 1.29.9 Neutral terminals of autotransformers and 400kV and 275kV windings shall be positioned inside the enclosure. The neutral connection provided specifically for earthing the tertiary winding when brought out for loading but not connected and the neutral connection of 66kV star connected windings shall be outside the enclosure.
- 1.29.10 Sufficient clearance shall be allowed between the noise enclosure and the transformer to allow easy and safe access for inspection, maintenance, testing and any other foreseeable activity associated with the operation of the transformer over its lifetime. Consideration shall be given to clearances required from the tank due to raised temperatures during operation or any other reason. Sufficient space shall be available to perform all maintenance and other operations safely including the use of scaffolding and platforms where appropriate. Where necessary hatches can be included in noise enclosures, for example, for the extraction of diverter switches.
- 1.29.11 The ducting from pressure relief devices may terminate inside the noise enclosure.

1.30 Core and Support Structure Earthing

- 1.30.1 The magnetic circuit and support structure earth connections in the main tank (including for example those from tertiary booster transformers) are required to be brought out separately to terminals and securely earthed externally in such a way that the integrity of the core and frame insulation can be checked without liquid handling. The HV and LV frames shall be earthed separately so that the insulation between the frames can be checked externally.
- 1.30.2 The terminals shall be covered by a suitable secure liquid-tight terminal box carrying an appropriate label.
- 1.30.3 The terminals shall be arranged so that the fitting of a core to earth resistance is not precluded in the event of a core earth fault developing.
- 1.30.4 The terminals shall be easily accessible during transport from ground level.

1.31 Paint or Other Finish

- 1.31.1 The protective paint or other finish shall be to a recognised quality standard and be suitable for long term protection in an outdoor environment. For all **oil** filled equipment the colour of the paint finish shall be to BS 381C (Dark Admiralty Grey) or similar shade. For all **synthetic ester liquid** filled equipment the paint finish shall be to BS 381C (110 - Roundel Blue) or similar shade. The internal surfaces of the marshalling kiosk and the tap-changer motor drive cubicle shall, by preference, be painted white.

1.32 Fittings

The following fittings shall be provided on each transformer:

- 1.32.1 A gas and oil actuated relay fitted in the pipe between the main tank and the conservator arranged to collect all gas emanating from the main tank and any bushing turrets. The gas and oil relay shall be provided with gas release/sampling petcocks accessible from ground level with the transformer in service. A window or other means of determining the gas content of the relay is required. Baffles in the pipework leading to the relay or between the relay and the conservator are not permitted. Alternative means of detecting gas production and sudden increases in liquid pressure may be acceptable but any proposal for alternative arrangements shall be agreed explicitly at the tender stage. The alarm and trip contacts

must be capable of being tested either by means of a test button which causes the floats to move or by introducing gas to operate the contacts. The gas method of test is not acceptable if a rubber bag is fitted in the conservator.

- 1.32.2 Conservator, provided with liquid level gauges easily readable unaided from ground level at each end **or** a liquid level gauge readable from the platform plus a remote liquid level indication at ground level, drain valve, liquid filling facility, lifting lugs, removable end covers, and sump. The conservator volume shall be sufficient to ensure that the liquid level remains visible and on-scale of the indicators when the transformer is off load at the minimum temperature of -25°C and when the transformer is operating with a hotspot of 125°C with an ambient temperature of 40°C.
- 1.32.3 A liquid level indication transducer with a 4-20mA output for 0-100% and two low liquid level alarm contacts shall be provided for the main conservator. The liquid level alarms shall be set to operate at the liquid levels corresponding approximately to the expected liquid level at liquid temperatures of -10°C and -20°C.
- 1.32.4 A maintenance free dehydrating breather for main conservator complete with isolating valves and a control unit. If a rubber bag type breather is fitted it must be supplied with a bag rupture alarm contact and a maintenance free type dehydrating breather with breather fail alarm.
- 1.32.5 A maintenance free dehydrating breather shall be supplied for the tap-changer diverter conservator.
- 1.32.6 A liquid level gauge and two low liquid level alarm contacts shall be provided for the diverter conservator (where fitted). The liquid level alarms shall be set to operate at the liquid levels corresponding approximately to the expected liquid level at liquid temperatures of -10°C and -20°C.
- 1.32.7 Liquid sampling devices easily accessible from ground level are required to sample liquid from the bottom and top of the main tank, each separate tap-changer selector compartment, each separate diverter compartment (for vacuum type diverters) and other liquid volumes as appropriate. The volume of liquid contained in the pipework between the sampled liquid volume and the sample valve shall be limited to one litre.
- 1.32.8 Anti-vibration pads.
- 1.32.9 Blanking plates and any other parts required for transport not used on the transformer in-service (for example removable lifting lugs) must be supplied with spare transformers together with suitable storage arrangements.
- 1.32.10 Earthing lugs at each corner of the main tank and on each cooler structure.
- 1.32.11 Main tank jacking lugs.
- 1.32.12 Main tank transport lugs fitted at a minimum height of 1.3 m. (See clause 1.3.1).
- 1.32.13 Main haulage points.
- 1.32.14 Main tank haulage rope fairings.
- 1.32.15 Transport holding down lugs for both sea and road transport.
- 1.32.16 Lifting lugs for tap-changer, cooler structure(s) main tank cover and other components as necessary.