# CHAPTER 10 – TRANSFORMERS
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# CHAPTER 10 – TRANSFORMERS

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## 10.2. TYPE OF TRANSFORMER AND OPERATING CONDITIONS

### 10.2.1. GENERAL

All transformers shall be oil immersed and suitable for outdoor installation and shall comply with standards mentioned in clause 10.1. Each item or function which is obviously necessary for the proper completion of the work, it's full functionality and safety as well as complete interfacing with other work, whether especially specified in the Bidding documents or not, shall be included in the Bid price.

### 10.2.2. COOLING

The types of cooling shall be as stated in the Employer's Requirements and the letters relating to the method of oil circulating and cooling used in this Specification and Employer's Requirements shall be in accordance with IEC 60076.

Where a combination of two methods of cooling is applied to one transformer as for ONAN/ONAF units, the transformer shall be capable of operating under the ONAN condition as stated in the Employer's Requirements, after which the cooling equipment is to come into operation and the Transformer will operate as an ONAF unit.

Transformers shall be fitted with tank mounted radiators. They shall be capable of remaining at the operation of full load for 20 minutes in the event of failure of blowers associated with both coolers without the calculated winding hot spot temperature exceeding $130^0$C.

Failure of one fan in each group of blowers shall not reduce the continuous maximum rating of the transformer.

### 10.2.3. PARALLEL OPERATION

Transformers supplied against each item shall be designed to operate satisfactorily one with the others when operating on the same tap position.

## 10.3. CONTINUES MAXIMUM RATING

Transformers shall have the continuous maximum rating as stated in the Employer's Requirements and shall comply with the requirements as regards temperature rise and overloads on all tappings irrespective of the direction of power flow and with the voltage of the lower voltage winding at the normal voltage stated in the Employer's Requirements. To allow for high atmospheric temperatures, the allowable temperature rise shall be reduced as stated in this Specification.

The overload capability shall be in accordance with IEC 60076-7.

### 10.3.1. ELECTRICAL CONNECTIONS

Transformer windings shall be connected in accordance with the IEC 60076-1 group symbol specified in the Employer's Requirements. The neutral point shall be brought out of the tank and earthed outside of the tank.

All electrical connections within windings shall be brazed but subject to approval, mechanically crimped joints may be used for round stranded conductors on tapping, bushing or earthing connections and on bundle conductors when design has been proved by the type test and application is subject to rigorous quality control.

## 10.4. ABILITY TO WITHSTAND SHORT CIRCUIT

### 10.4.1. GENERAL

All transformers shall be capable of withstanding on any tapping and without damage the thermal and dynamic effects of external short circuits under the conditions stated in IEC 60076-5 Clause 4.

Manufacturer shall demonstrate the ability to withstand the thermal effect of short circuit by calculation, and the ability to withstand the dynamic effect of short circuit either by test (as per IEC60076-5 Clause 4.2) or calculation, design and manufacture considerations (as per 10.4.2 below). The method of demonstration of the ability to withstand the dynamic effects of short circuit shall be stated in the bid

### 10.4.2. CALCULATIONS, DESIGN AND MANUFACTURE CONSIDERATIONS

Following shall be submitted with the bid.

a) Thermal ability to withstand short circuit

Calculations shall be done according IEC 60076-5:2006 Clause 4.1 to prove the thermal ability to withstand the short circuit, for at least 3 seconds at rated conditions and after all loading conditions as specified in IEC 60076-7 Clause 7.3.3, and shall be submitted with the offer.

b) Ability to withstand dynamic forces

During the bidding stage manufacturer shall prove his ability of designing and manufacturing transformers which can withstand dynamic effects of short circuit as per IEC 60076-5 by means of complete test reports of short circuit tests. These tests shall be conducted in a test laboratory which is a member of Short circuit Testing Liaison ( STL) and the laboratory shall also possess ISO/IEC17025:2015 certification.

## 10.5. LOSSES AND EVALUATION OF LOSSES

The Bidder shall state in the Technical Particulars and Guarantees, guaranteed values for component losses of the total loss which shall be as low as is consistent with transport restrictions, reliability and economic use of materials.

Bids will be assessed on the basis of the least 'Present Worth' of capital cost plus guaranteed losses, being the sum of the installed Bid Price of the transformers plus:

| Sri Lanka Rupees per kW of guaranteed loss | | | |
|---|---|---|---|
| Power Transformer | No load loss | Load loss at CMR | Auxiliary loss at (CMR) |
| Rupees/kW | 2,156,377 | 1,154,493 | 600,599 |

The acceptance of transformers yielding component losses higher than the guaranteed values shall be governed by either of the following: -

(A) Component losses in excess of guaranteed values but within the tolerance permitted under IEC 60076 Part 1. Transformers shall be accepted subject to full compliance with all technical particulars including temperature rises at CMR and subject to the Bidder accepting deduction from the Contract Price of charges for each kW on part thereof of component losses in excess of the guaranteed values, at the above evaluation rates.

(B) Component losses in excess of guaranteed values and exceeding the tolerance permitted under IEC 60076 Part 1.

The acceptance of transformers shall be entirely at the discretion of the Engineer/Employer and subject to the Bidder accepting the deduction from the Contract Price of charges for each kW on part thereof of component losses in excess of the guaranteed values, at the above loss evaluation rates.

In the event of transformers, which are, either equal to or below the guaranteed losses values, the Bidder will not be entitled to any premium in respect of reduction in losses below the guaranteed values.

## 10.6. IMPEDANCE

The value of impedance measured on principal and extreme tappings shall be as stated in the Schedule and minimum and maximum values where stated in the Employer's Requirements shall not be subject to tolerance.

Where transformers are required to operate in parallel with existing units the appropriate data will be stated in the Employer's Requirements.

## 10.7. NOISE

The transformer noise levels shall be measured as a type test and in accordance with IEC 60076-10. The noise level of the transformers shall be as stated in the Employer's Requirements.

When the bottom plate of the transformer tank will be in direct contact with the surface of the foundation anti-vibration pads shall be provided for insertion between the transformer and its foundation.

## 10.8. HARMONIC SUPPRESSION

Transformers shall be designed with particular attention to the suppression of harmonic voltages, especially the third, fifth and seventh harmonics and to minimize the detrimental effects resulting therefrom.

## 10.9. MAGNETIC CIRCUIT AND WINDINGS

### 10.9.1. MAGNETIC CIRCUIT

The design of the magnetic circuit shall be such as to avoid static discharges development of short circuit paths internally or to the earthed clamping structure, and the production of flux components normal to the plane of the laminations. Each lamination shall be insulated with a material stable under the action of pressure and hot oil.

The winding structure and major insulation shall be designed to permit an unobstructed flow of cooling oil through core cooling ducts to ensure efficient core cooling.

The magnetic circuit shall be insulated from all structural parts, and shall be capable of withstanding a test voltage to core bolts and to the frame of 2,500 volts RMS for one minute. In order to allow testing, the magnetic core shall be earthed to the tank cover at one point only through removable links in an appropriate terminal box, placed in an accessible position on the tank cover.

### 10.9.2. FLUX DENSITY

Core shall be constructed from cold rolled grain oriented electrical steel sheets. Design shall be such that there will be no adverse effects due to core or stray flux heating with the quality of steel employed, and that when operating under the most onerous conditions envisaged in IEC 60076 -7, flux density in any part of the magnetic circuit does not exceed 19,000 lines per square centimeter (i.e. 1.9 Tesla).

Core shall be constructed from cold rolled grain oriented (CRGO) electrical steel sheets, and the flux density at magnetizing force of 800 A/m shall not be less than 1.9 T (Data sheet of the CRGO electrical steel shall be provided with the bid including DC magnetizing curve). Design shall be such that there will be no adverse effects due to core or stray flux heating with the quality of steel employed, and that when operating under the most onerous conditions envisaged in IEC 60076 -7.

The maximum flux density in the legs and yokes of the core shall not exceed 1.6 Tesla at nominal ratio at rated voltage and rated frequency. The maximum flux density in any part of the core shall not exceed 1.9 Tesla at highest operating voltage and lowest frequency at any tap position to achieve rated secondary voltage, considering voltage regulation and AVR operation under full load condition at lowest possible power factor.

The no-load current of the transformer at nominal voltage and frequency and at nominal ratio shall not exceed 0.15% of its rated current. Further, no-load current at 1.1 times the nominal voltage shall not exceed 2.5 times the no-load current at nominal voltage.

## 10.9.3. WINDINGS

All windings shall have copper conductors. Transformer 220kV and 132kV star connected windings may have graded insulation as defined in IEC 60076 and 33 kV and 11 kV winding shall have uniform insulation as defined in IEC 60076. All neutral points shall be insulated to withstand an applied voltage test specified in the Employer's Requirements.

The windings shall also be thoroughly seasoned during manufacture by the application of axial pressure at a high temperature for such length of time as will ensure that further shrinkage is unlikely to occur in service.

The windings and leads of all transformers shall be braced to withstand the shocks, which may occur through rough handling and vibration during transport, switching and other transient service conditions including external short circuit.

If the winding is built up of sections or of disc coils splitted by spacers, the clamping arrangements shall ensure that equal pressures are applied to all columns of spacers.

## 10.9.4. INTERNAL EARTHING

(i) General - All metal parts of the transformer with the exception of the individual core laminations, core bolts and associated individual clamping plates shall be maintained at some fixed potential.

(ii) Earthing of Core Clamping Structure - The top main core clamping structure shall be connected to the tank body by a copper strap. The bottom main core clamping structure shall be earthed by one or more of the following methods.

- (a) by connection through vertically tie rods to the top structure;
- (b) by direct metal to metal contact with the tank base maintained by the weight of the core and windings;
- (c) by connection to the top structure of the same side of the core as the main earth connection to the Tank.

(iii) Earthing of Magnetic Circuits - The magnetic circuit shall be earthed to the clamping structure at one point only through a removable link placed in an accessible position just beneath an inspection opening in the tank cover and which, by disconnection, will enable the insulation between the core and clamping plates, etc., to be tested at voltages up to 2.5 kV as specified in IEC 60076-1. The link shall have no detachable components and the connection to the link shall be on the same side of the core and the main earth connection. These requirements are compulsory.

Magnetic circuits having insulated sectional construction shall be provided with a separate link for each individual section. The arrangement of the connections shall be subjected to the plane of the laminations divide the magnetic circuit into two or more electrically separate parts, the ducts and insulating barriers which have a thickness greater than 0.25 mm are to be bridged with tinned copper strips so inserted as to maintain electrical continuity.

(iv) Earthing of Coil Clamping Rings - Where coil clamping rings are of metal at earth potential, each ring shall be connected to the adjacent core clamping structure on the same side of the Transformer as the main earth connection.

(v) Size of Earthing Connections - Main earthing connections shall have a cross-sectional area of not less than 80 sq. mm. but connections inserted between laminations may have cross-sectional areas reduced to 20 Sq. mm. when in close thermal contact with the core.

## 10.10. TANKS AND ANCILLARY EQUIPMENT

### 10.10.1. TRANSFORMER TANKS

Each transformer shall be enclosed in a suitable stiffened welded steel tanks such that the transformer can be lifted and transported without permanent deformation or oil leakage. The construction shall employ weldable mild steel and shall be of sufficient strength and rigidity to withstand moving, shipping and handling without deformation.

Lifting lugs shall be provided, suitable for the weight of the transformer, including core and windings, fittings, and with the tank filled with oil. Each tank shall be provided with jacking lugs suitably positioned for transport.

The design and positioning of lifting points, stiffeners and under-bases on the tank should prevent distortion of the core during lifting and transport.

The transformer tank shall be capable of withstanding full vacuum without deflection as per IEC 60076-1.

Where the design of the tank is such that the bottom plate will be in direct contact with the surface of the foundations, the plates shall have the following minimum thickness: -

| Length of Transformer | Minimum Thickness | |
|---|---|---|
| | Side Plates | Bottom Plates |
| Less than 2500 mm | 6 mm | 19 mm |
| Greater than 2500 mm | 9 mm | 25 mm |
| Greater than 7500 mm | 32 mm | 40 mm |

Where skid type bases are provided, the plates shall have the following minimum thickness: -

| Length of Transformer | Minimum Thickness | |
|---|---|---|
| | Side Plates | Bottom Plates |
| Less than 2500 mm | 6 mm | 9 mm |
| Greater than 2500 mm | 9 mm | 12 mm |

In case of a self-supporting tank bottom of the power transformer without steel crossbeams, the bottom plate shall have a minimum thickness of 40 mm.

The base of each tank shall be so designed that it is possible to move the complete transformer unit in any direction without injury when using rollers, plates, or rails.

Transformers may have flat, skid or wheel bases subject to the approval of Engineer, but, detachable under bases must not be used unless specifically approved by the Engineer.

All joints other than those, which may have to be opened, shall be welded. Caulking of defective welded joints may be re-welded subject to the written approval of the Engineer.

The tank and cover shall be designed in such a manner as to leave no external pockets in which water can lodge no internal pockets in which oil can remain when draining the tank or in which air can be trapped when filling the tank, and to provide easy access to all external surfaces for painting.

When built-on radiators are used, each radiator bank shall be connected to the main tank through flanged valves mounted on the tank at top and bottom and each bank shall be fitted with drain valve and air release plug.

Each tank cover shall be of adequate strength, must not distort when lifted and shall be provided with suitable flanges having sufficient and properly spaced bolts. Inspection openings shall be provided to give access to the internal connections of bushings, winding connections and earthing links. Each opening shall be correctly located and must be of ample size for the purpose of which it is intended. All inspection covers shall be provided with lifting handles.

All the openings on the cover should have a raised flange to prevent water from entering the openings when individual covers are removed.

Tank covers with low level welded flanged joints are preferred, but contractors may offer alternative designs with high level covers.

If transformer cover is welded, a magnetic particle test shall be carried-out after first (root) welding run. Photographs and test results of MPT test shall be submitted to CEB and shall be discussed with CEB if any abnormalities are found. Then only manufacturer should continue next welding runs.

It is also mandatory to preheat all the welding surfaces before starting weldings.

It must be possible to remove any bushing without removing the tank cover.

Pockets shall be provided for a stem type thermometer and for the bulbs of temperature indicators where specified. These pockets shall be located in the position of maximum oil temperature and it must be possible to remove any bulb without lowering the oil level in the tank. Captive screwed caps shall be provided to prevent the ingress of water to the thermometer pockets when they are not in use.

### 10.10.2. CONSERVATOR TANKS, BREATHERS AND AIR DRYERS

Each transformer shall be provided with an overhead conservator tank formed of substantial steel plates and arranged above the highest point of the oil circulating system (see also Clause 10.12.1). Connections into the main tank shall be at the highest point to prevent the trapping of air or gas under the main tank cover. Main tank conservator vessels shall be equipped with elastic diaphragms of the air-bag type.

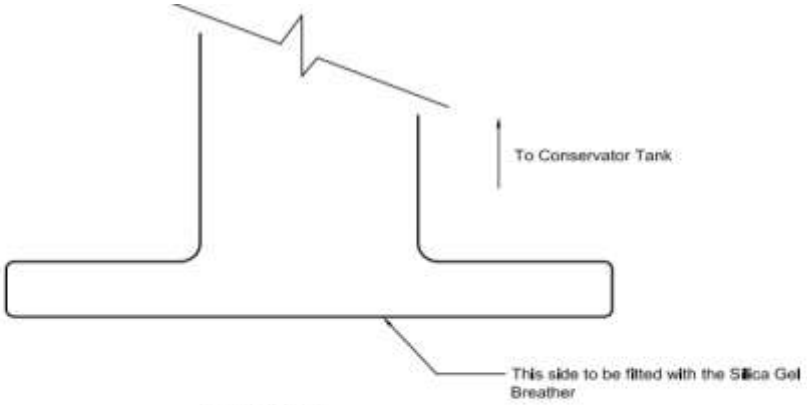
The capacity of each conservator tank shall be adequate for the expansion and contraction of oil in the whole system under the specified operating conditions. Conservator tanks shall also be provided with a cleaning door, filling cap, drain valve with captive cap and a prismatic type oil level indicator with minimum and maximum levels indicated.

The location of the conservator tank shall be so arranged that it does comply with the requirements and a valve shall be provided at the conservator to cut off the oil supply to the tank.

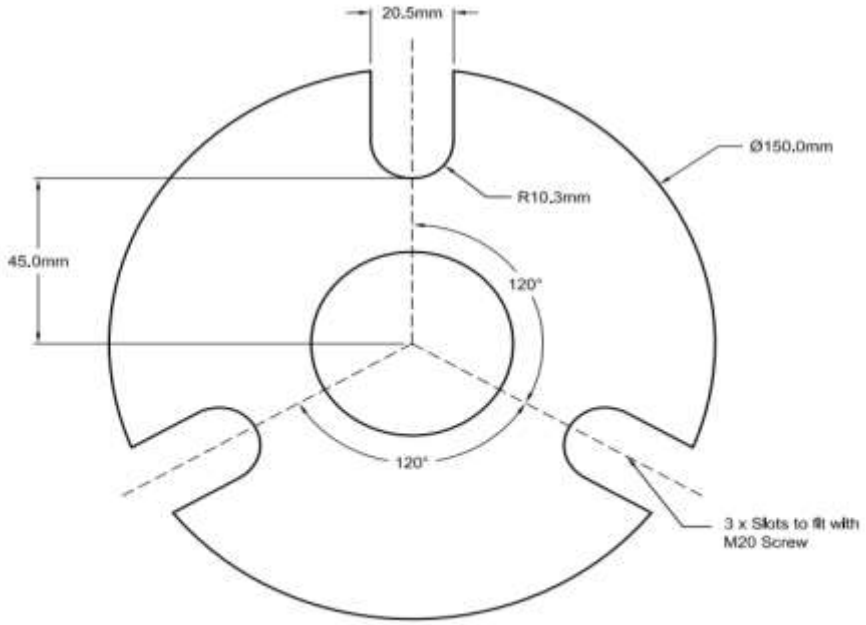
Each conservator shall be fitted with silica gel breather and a magnetic type oil level indicator. The breather shall be a type, which permits the silica gel content to be removed for drying. Due to the climatic conditions at site, this breather shall be larger than would be fitted for use in a temperate climate. All breathers shall be mounted at a height of approximately 1400 mm above ground level. Breathers for the power transformer main tank conservator shall have a minimum filling capacity of 3 kg.

The pipe work between the conservator and the transformer tank shall comply with the requirements of clause 10.12.5 and a valve shall be provided at the conservator to cut off the oil supply to the tank.

Breather mounting flange shall comply following drawing.




SIDE VIEW




BOTTOM VIEW

## 10.10.3. VALVES AND LOCATION

All valves up to and including 75 mm bore shall be made of gunmetal.

Each Transformer shall be fitted with the following valves as a minimum requirement:-

Main Tank

(a) One 50 mm bore filter valve located near to the top of the tank.

(b) One 50 mm bore filter valve located near to the bottom of the tank and diagonally opposite to the filter valve required against (a). Where design permits, this valve may be combined with item (c).

(c) One 50 mm drain valve with such arrangements as may be necessary inside the tank to ensure that the tank can be completely drained of oil as far as practicable. This valve shall also be provided with an approved oil sampling device.

All the valves fitted on main tank specified in item (a), (b) and (c) shall be of the type of 'Gate Valve' or 'Ball Valve' with a flange having PCD of 125mm. Any valve without straight opening shall not be accepted.

Conservator

(d) One valve between the conservator and gas actuated relay for the main tank and, where appropriate, for the tap change diverter switch tank.

(e) One drain valve for oil conservator tank so arranged that the tank could be completely drained of all oil.

Tap Changer Selector Switch

(f) 50 mm filter and 50 mm drain valve where selector switches are contained in a separate tank.

Diverter Switch

(g) One 50 mm drain valve to be fitted to each tank. An approved oil sampling device shall also be provided.

Forced Air Oil Coolers

(h) One ball valve at the top and one ball drain valve at the bottom of each radiator unit.

Blank flanges, plate or captive screw caps shall be fitted to all valves and pipe ends not normally connected in service.

The omission of any, or the provision of alternative arrangements to the above requirements, will not be accepted unless approved in writing by the Engineer before manufacture.

## 10.10.4. JOINTS AND GASKETS

All joint faces shall be arranged to prevent the ingress of water or leakage of oil with a minimum of gasket surface exposed to the action of oil or air.

Oil resisting synthetic rubber is not permissible except where metal inserts are provided to limit compression.

Gaskets shall be as thin as is possible consistent with the provision of a good seal and full details of all gasket sealing arrangements shall be shown on the Plant drawings.

Material of gaskets should be “UV-resistant Nitrile Rubber” (NBR). List of gaskets with dimensions and dimensional drawings should be provided with the transformer manual.

## 10.10.5. PRESSURE RELIEF DEVICE

An approved type pressure relief device of sufficient size for the rapid release of any pressure that may be generated in the tank and designed to operate at a static pressure lower than the hydraulic test pressure called for in Schedule of Works Tests, shall be provided. In the event that the device is a spring operated valve type, it shall be provided with one set of normally open signaling contacts to trip the transformer.

The relief device is to be mounted on the tank cover and is to be provided with a skirt to project at least 25 mm into the tank to prevent gas accumulation.

## 10.10.6. EARTHING TERMINALS

Two bare steel contact surfaces having two 14 mm diameter holes on 45 mm centers shall be located one on either side and near to the bottom of the Transformer to facilitate connection to the local earthing system.

## 10.11. RATING, DIAGRAM AND VALVE PLATES

The following plates, or an approved combined plate, shall be fixed to each transformer tank at an average height of 1500 mm above the ground level:-

(a) A rating plate with the data specified in IEC 60076 Part 1. This plate shall also include a space for the Purchaser's serial number and in addition include the short-circuit current rating and time-factor for each winding.

(b) A diagram plate showing in an approved manner, the internal connections and the voltage relationship of the several windings, in accordance with IEC 60076 Part 1 with the Transformer voltage ratio for each tap and, in addition, a plan view of the Transformer giving the correct physical relationship of the terminals.

(c) A plate showing the location and function of all valves and air release cocks or plugs. This plate shall also if necessary warn operators to refer to the Maintenance instructions before applying vacuum.

Plates are to be of high-quality (Grade 316 or higher) stainless steel with sand blast finish capable for continuous outdoor service and withstanding the climatic conditions of at site.

In addition, the Manufacturer’s Serial Number and transformer model shall be engraved on the main tank, such that it is visible without obstructed by any other part/accessory fixed on the tank. The size of the letters/numbers shall not be less than 25 mm height. The preferable place of engraving the serial number and the transformer model would be, below the panel in which

temperature indication devices are installed. This engraving shall be available for inspection during the Factory Acceptance Testing.

## 10.12. COOLING PLANT

### 10.12.1. COOLING PLANT - GENERAL

Radiators and cooling fans shall be hot dip galvanized accordance with ISO 1461. The design shall also avoid pockets in which water can collect and shall be capable of withstanding the pressure tests specified in Schedule of Works Tests for the transformer main tank.

The clearance between any oil or other pipe work and live parts shall be not less than the minimum clearances as specified in the specification.

### 10.12.2. RADIATORS CONNECTED DIRECTLY TO TANK

Radiators connected directly to the tank shall be detachable and shall be provided with flanged inlet and outlet branches. Plugs shall be fitted at the top of each radiator for air release and at the bottom for draining.

A valve shall be provided on the tank at each point of connection to the tank.

### 10.12.3. COOLER BANKS

Each cooler bank shall be provided with:-

(a) A valve at each point of connection to the tank.

(b) A valve at each point of connection of radiators.

(c) Loose blanking plates to permit the blanking off of the main oil connection to the top.

(d) A 50 mm filter valve at the top of each cooler bank.

(e) A 50 mm drain valve at lowest point of interconnecting oil pipes.

(f) A thermometer pocket, fitted with captive screw cap, in the inlet and in the outlet oil pipes.

(g) Air release and drain plugs on each radiator.

(h) Visual oil flow indicators, on transformers having forced oil circulation fitted with electrical contacts to close when oil did not flowing. Contacts to be connected in the cooler fail alarm circuit.

The omission of any, or the provision of alternative arrangements to the above requirements, will not be accepted unless approved in writing by the Engineer before manufacture.

An approved expansion piece shall be provided in each oil pipe connection between the transformer and each oil cooler bank.

### 10.12.4. FORCED COOLING

The type of forced cooling shall be as stated in the Employer’s Requirements. Forced cooling equipment for transformers of similar rating and design shall be completely interchangeable one with the other without modification on Site.

## 10.12.5. OIL PIPES AND FLANGES

All oil piping shall be of approved material with machined flagged joints.

Copper pipe work is to comply with BS.61.

Dimensions of steel pipes shall be in accordance with BS.10220 and the drilling of all pipe flanges shall comply with BS.4504.

It shall be possible to drain any section of pipe work independently of the rest and drain valves or plugs shall be provided as necessary to meet this requirement.

## 10.12.6. AIR BLOWERS

Air blowers for forced air cooling shall be of approved make and design and be suitable for continuous operation out-of-doors. They shall also be capable of withstanding the stresses imposed when brought up to speed by the direct application of full line voltage to the motor.

To reduce noise to the practical minimum, motors shall be mounted independently from the coolers or, alternatively, an approved form of anti-vibration mounting shall be provided.

It shall be possible to remove the blower complete with motor without disturbing or dismantling the cooler structure framework.

Blades shall be of galvanized steel unless otherwise approved.

Blower casings shall be made of galvanized steel of thickness not less than 2.6 mm (14 S.W.G.) and shall be suitably stiffened by angles or tees.

Galvanized wire mesh guards shall be provided to prevent accidental contact with the blades and to prevent access of birds and their nests. Guards shall also be provided over all moving parts. Guards shall be designed such that blades and other moving parts cannot be touched by test fingers to IEC.60529.

## 10.12.7. COOLER CONTROL

Where multiple fan cooling using small single-phase motors is employed, the motors in each cooling bank shall be grouped so as to form a balance three-phase load.

Each motor or group of motors shall be provided with a three-pole electrically operated contactor and with control gear of approved design for starting and stopping manually. The electrical supply for the control of the cooling units shall be provided by means of two independent feeders.

Where forced cooling is used on transformers provision shall be included under this Contract for automatic starting and stopping from the contacts on the oil / winding temperature indicating device as specified.

Where small motors are operated in group, the group protection shall be arranged so that it will operate satisfactorily in the event of a fault occurring in a single motor. The control arrangements are to be designed to prevent the starting of motors totaling more than 1.5 kW simultaneously either manually or automatically.

All contacts and other parts, which may require periodic renewal, adjustment or inspection, shall be readily accessible.

Outdoor mounted fan control equipment should be housed in a weatherproof cabinet with protection grade IP 55.

All wiring for the control gear accommodated in the marshalling kiosk together with all necessary cable boxes and terminations and all wiring between the marshalling kiosk and the motors shall be included in the Contract.

The first group of fans shall come into operation at lower temperature (i.e. at $75^0$ C hot spot temperature) and the second group at a higher temperature. (i.e. at $85^0$ C hot spot temperature). The winding temperature shall give the starting signal for the fans and the oil temperature shall give the stopping signals.

## 10.13. VOLTAGE CONTROL

### 10.13.1. GENERAL

Transformers shall be provided with voltage control equipment of the on-load tap changing type for varying the effective transformation ratio. Attention is drawn to Clause 10.13.3.

Winding taps as called for in the Employer's Requirements shall be provided on the high voltage winding. But, where stated in the Employer's Requirements, in the case of on-load tap selectors, the Bidder is at liberty to submit transformers with tap selectors on the lower voltage winding if by so doing a more economical and robust design can be offered and provided the transformer complies in all respects with Clause 10.13.2. In this event, details of the tappings shall be given in the Employer's Requirements.

All terminals shall be clearly and permanently marked with numbers corresponding to the cables connected thereto.

### 10.13.2. ON LOAD TAP CHANGERS

#### 10.13.2.1 GENERAL

On-load tap changers shall comply with IEC.60214 and shall be suitable for power flow in both directions. Only designs, which have been type tested in accordance with these standards, will be accepted.

On-load tap changers of Maschinenfabrik Reinhausen manufacture are in wide use on the CEB's transformers for standardization purposes. Tap changers shall be Vacuum Type and shall be mounted from the cover into the transformer tank.

Vacuum interrupter shall be contained in a tank designed in a manner to make it impossible for the oil therein to mix with oil in the main tank of the transformer. The head of oil in this tank may be maintained by a separate compartment of the main conservator or by a separately mounted tank.

An oil surge detector relay and an oil level indicator shall be provided. The same requirements shall apply also in respect of designs in which tap selection and vacuum interrupters are accomplished by the same contacts within a tank separate from the transformer.

### 10.13.2.2 MECHANISMS

The tap change mechanism shall be designed such that when a tap change has been initiated, it will be completed independently of the operation of the control relays and switches. If a failure of the auxiliary supply during tap change or any other contingency would result in that movement not being completed an approved means shall be provided to safeguard the Transformer and its auxiliary equipment.

Limit switches shall be provided to prevent over-running of the tap changing mechanism. These shall be directly connected in the operating motor circuit. In addition, mechanical stops shall be fitted to prevent over-running of the mechanism under any conditions. For on-load tap change equipment these stops shall withstand the full torque of the driving mechanism without damage to the tap change equipment. Thermal devices or other approved means shall be provided to protect the motor and control circuit.

A permanently legible lubrication chart shall be provided and fitted inside the tap change mechanism chamber.

### 10.13.2.3 LOCAL AND REMOTE CONTROL

Equipment for local manual and electrical operation shall be provided in an outdoor cubicle mounted on the transformer. Electrical remote control equipment shall also be supplied where specified in the Employer's Requirements.

The following operating conditions are to apply to the on-load tap selector controls: -

(a) It must not be possible to operate the electric drive when the manual operating gear is in use.

(b) It must not be possible for two electric control points to be in operation at the same time. Operation from the local or remote control switch shall cause one tap movement only unless the control switch is returned to the off position between successive operations.

(c) It must not be possible for any transformer operating in parallel with one or more Transformers in a group to be more than one tap out of step, with the other Transformers. In such case "Transformer out of step" alarm shall be indicated. In the case of Transformers are more than one step out of step all the tap changers shall be blocked.

(d) All electrical control switches and local manual operating gear shall be clearly labeled in an approved manner to indicate the direction of tap changing.

### 10.13.2.4 INDICATIONS

Apparatus of an approved type shall be provided on each Transformer: -

(a) To give indication mechanically at the transformer and electrically at the remote control point of the number of the tapping in use.

(b) To give electrical indication, separate from that specified above, of tap position at the remote supervisory point.

(c) To give indication at the remote control point and at the supervisory control point that a tap change is in progress, this indication to continue until the tap change is completed.

(d) To give indication at the remote control point and at the supervisory control point when the transformers operating in parallel are operating at more than 1 tap apart.

(e) To indicate at the tap change mechanism the number of operations completed by the equipment.

## 10.13.3. AUTOMATIC VOLTAGE CONTROL

Automatic Control shall be suitable for control of all transformers in parallel.

In addition to the methods of control covered by Clause 10.13.2, the following alternative methods shall be provided.

a. Automatic independent Remote - It shall be possible to select non-automatic remote or local electrical control, or automatic remote control for each transformer irrespective of the method of independent control selected for any other of the associated transformers.
b. Automatic parallel control in one group or independent groups. - It shall be possible to select any transformer for either group and also select any transformer in a group for master control.

   It must not be possible to operate any tap changer by remote or local electrical hand control while the equipment is switched for automatic operation.

   In the event of reverse power flow occurring through the transformer, the automatic voltage control function shall be automatically switched out.

## 10.13.4. VOLTAGE REGULATING RELAYS

Automatic voltage control shall be initiated by a microprocessor based voltage regulating relay of an approved type and suitable for flush mounting. The relay shall operate from the nominal reference voltage stated in the Employer's Requirements derived from a circuit mounted LV voltage transformer having Class 3P accuracy to IEC 61869-3 and the relay voltage reference balance point shall be adjustable.

The relay bandwidth shall preferably be adjustable to any value between 1.5 times and 2.5 times the transformer tap step percentage, the nominal setting being twice the transformer tap step percentage.

The relay shall be insensitive to frequency variation between the limits as specified in chapter 1. The relay shall be complete with a time delay element adjustable between 10 and 120 seconds. The relay shall also incorporate an under voltage blocking facility which renders the control inoperative if the reference voltage falls below 80 percent of the nominal value with automatic restoration of control when the reference voltage rises to 85 percent of nominal value.

On each transformer the voltage transformer supply to the voltage regulating relay shall be monitored for partial or complete failure. The specified indicating lamp and alarm will be inoperative when the circuit-breaker automatic control controlling the lower voltage side of the Transformer is open and also that it is disconnected when the tap changer is on control other than automatic control.

## 10.13.5. SUPERVISORY CONTROL

### 10.13.5.1 REQUIREMENTS

Transformer tap change control will be effected from the Sub-station Automation System in the control room. All necessary connections, indicating auxiliary switches, relays and changeover

switches to meet supervisory control requirements shall be provided and connected under this Contract to terminal blocks at the transformer marshalling kiosk or cubicle or at the Transformer control cubicle, as appropriate.

The following supervisory facilities are required:

Control Selection: A multi-pole changeover selector, i.e., switch labelled "remote" and "Automation".

Controls: Tap change raise/lower by direct operation of tap changer. AVR voltage reference adjustment.

Indications and Alarms:

Refer alarm scheme specified in Chapter 5.

## 10.14. BUSHING INSULATORS AND TERMINALS

### 10.14.1. GENERAL

Transformers are to be provided bushing and terminals for phase and neutral terminals as required in the Technical Particulars & Guarantees.

All bushings shall comply with IEC.60137 and the minimum creepage distance for outdoor bushings shall be as specified in the Employer's Requirements and IEC 60815.
Bushings shall be provided with adjustable arcing horns.

Bushings shall be of sealed construction suitable for service under the very humid conditions at Site and, in addition, to the very rapid cooling of equipment exposed to direct sunlight when this is followed by sudden heavy rainstorms.

Typical sections of bushing insulators showing the internal construction, method of securing the top cap and methods of sealing shall be included in the Bid.

The 220/132kV bushing insulators shall be oil impregnated paper type and have no communication with the oil in the transformer. An oil gauge shall preferably be provided in indicate that the correct level is maintained. The 33/11 kV bushing insulators shall be of the oil filled or solid type.

On all condenser bushings a tapping shall be brought out to a separate terminal for testing purposes on Site.

Special precautions shall be taken to exclude moisture from paper insulation during manufacture, assembly, transport and erection. The surfaces of all paper insulators shall be finished with approved non-hygroscopic varnish, which cannot easily be damaged.

### 10.14.2. PORCELAIN

Hollow porcelain shall meet the test requirements of IEC 62155 and IEC 60672. Hollow porcelain shall be sound, free from defects thoroughly vitrified. The glaze must not be depended upon for insulation. The glaze shall be smooth, hard, of a uniform shade of brown and shall cover completely all exposed parts of the insulator. Outdoor insulators and fittings shall be unaffected by atmospheric conditions producing weathering, acids, alkalis, dust and rapid changes in temperature that may be experienced under working conditions.

The porcelain must not engage directly with hard metal and, where necessary, gaskets shall be interposed between the porcelain and the fittings. All porcelain clamping surfaces in contact with gaskets shall be accurately ground and free from glaze.

All fixing material used shall be of suitable quality and properly applied and must not enter into chemical action with the metal parts or cause fracture by expansion in service. Cement thicknesses are to be as small and even as possible and proper care is to be taken to centaur and locate the individual parts correctly during cementing. All porcelain insulators shall be designed to facilitate cleaning.

## 10.14.3. MARKING

Each porcelain insulator shall have marked upon in the manufacturer's name or identification mark and year of manufacture. These marks shall be clearly legible and visible after assembly of fittings and not impressed but shall be imprinted before firing.

When a batch of insulators bearing a certain identification mark has been rejected, no further insulators bearing this mark shall be submitted and the Contractor shall satisfy the Engineer that adequate steps will be taken to mark or segregate the insulators constituting the rejected batch in such a way that there can be no possibility of the insulators being re-submitted for the test or supplied for the use of the Purchaser.

Each bushing shall be marked with the manufacturer's name or identification mark, year of manufacture, serial number, electrical and mechanical characteristics in accordance with IEC 60137.

## 10.14.4. MOUNTING OF BUSHINGS

Bushing insulators shall be mounted on the tank in a manner such that the external connections can be taken away clear of all obstacles. Neutral bushings shall be mounted in a position from which a connection can be taken to a neutral current transformer mounted on a bracket secured to the transformer tank. The current transformer will be supplied by the switchgear manufacturer provision shall be made on the tank for mounting to the Engineer’s requirements.

The clearances from phase to earth and phase to phase must not be less than those stated in the specification.

The line current transformers, where required, will be provided under this contract, the bushing is to be so arranged that it can be removed without disturbing the current transformers, secondary terminals and connections or pipe work.

When bushing with an under-oil end of a re-entrant type is used the associated flexible pull-through lead is to be fitted with a suitably designed gas bubble deflector.

The bushing flanges must not be of re-entrant shape, which may trap air.

Clamps and fittings made of steel or malleable iron shall be galvanized in accordance with the specification and all bolt threads are to be greased before erection.

## 10.14.5. PHASE LOCATIONS OF 220 KV, 132KV AND 33KV BUSHINGS

During the designing stage, the required locations for L1, L2, L3 phases in 220 kV, 132kV and 33kV side shall be obtained from the purchaser.

## 10.15. CABLES AND TERMINATIONS (FOR 31.5MVA, 45 MVA AND 63 MVA TWO WINDING TRANSFORMERS)

### 10.15.1. CABLE BOXES AND SEALING END CHAMBERS

All cable boxes shall have oil-tight joints and are to be tested for leaks with oil as per clause 11.8 of IEC 60076-1 and pressure deflection test as per clause 11.10 of IEC60076-1. During which time no oil leakage shall occur and no permanent deformation shall place in the structure.

### 10.15.2. DISCONNECTING CHAMBERS

Where specified, oil-filled cable disconnecting chamber with removable links shall be provided for testing purposes. Barriers shall be provided on both sides of the disconnecting chamber to prevent ingress of the oil used for filling the chamber into the cable box or the transformer. It must only be necessary to remove part of the oil in the chamber itself when making the necessary testing connections.

The oil level in the disconnecting chamber shall be maintained from the main conservator tank by means of a connection to the highest point of the main conservator tank. Suitable valves shall control this connection. The connection to the conservator shall be made so that any gas leaving the chamber must pass through the gas and oil-actuated relay.

An earthing terminal shall be provided in each disconnecting or sealing-end chamber to which the connections from the transformer winding can be earthed during cable testing.

### 10.15.3. TESTING

The cable boxes and disconnecting or sealing-end chambers shall be capable of withstanding those test voltages for which the transformer is designed as per this specification.

### 10.15.4. CABLES

The HV/MV Cables will be 245 kV or 145kV (if any) and 36kV/12 kV single core XLPE insulation type. Auxiliary power and multicore control cables between the integral parts of the transformer, its marshalling kiosk or tank mounted cubicle and ancillary equipment shall be installed, glanded and have individual cores identified and terminated under this contract.

Cable from each transformer to its associated remote control and protective equipment to auxiliary supply switchboards and interconnections with other transformers will be supplied, glanded and have individual cores identified and terminated.

## 10.16. TEMPERATURE AND ALARM DEVICES

### 10.16.1. TEMPERATURE INDICATING DEVICES AND ALARMS

The transformer shall be provided with two approved devices of direct hot spot temperature measuring and dial type temperature monitoring equipment for indicating the hottest spot HV and LV winding temperatures.

### 10.16.1.1 DIRECT HOT SPOT MEASUREMENT:

The manufacturer shall use the direct hot spot measuring technique using sensors made of photo-luminescent material attached to the end of optical fiber material and in contact with the winding.

The sensor shall be sufficiently small and signal transmission system shall not degrade dielectric strength of transformer and the components used shall withstand thermal, mechanical and chemical shocks and changes of the transformer. Sensors shall be proven zero-drift, GaAs technology based on the wavelength of light. The sensors shall be directly installed in each phase of transformer to measure the winding hotspot and top oil temperatures. There shall be a total of eight (8) sensors inside the transformer, in places specified in table E.1, Annex E of IEC 60076 -2: 2011. The locations of the probes shall be proposed by the transformer manufacturer and locations shall be finalized by agreement of CEB. The sensors shall be able to be completely immersed in hot transformer oil and they shall withstand exposure to hot kerosene vapor during the transformer insulation drying process. Sensors shall be certified by an independent high voltage testing laboratory for the ASTM test, D-2413 and D-149 for lightening impulse withstand, switching impulse withstand, AC voltage withstand and partial discharge measurement.

Temperature range of the system shall be -80$^{o}$C to +250 $^{o}$C with an accuracy of ± 1$^{o}$C.

All the measured temperatures shall be displayed simultaneously in a display mounted in local control cubical. The display should be bright enough and digits shall be large enough to see 1m away from the cubical in day light. The display unit shall withstand higher temperature and durable.

Signal conditioner shall meet IEEE C37.90.1-2002, IEC 60255-5 and IEC 6100-4-2 emissivity and EMI immunity tests on all inputs and outputs and it shall have a fail safe mode. It shall have optically isolated RS-485 serial port for local communication to the transformer monitoring system or remote communication. It shall be possible to install inside the Local Control cabinet of the Transformer. Minimum and maximum temperatures shall be retained by the signal conditioner until they are reset.

The fiber optic cable shall be brought out of the tank up to the instrument through a hole made in the tank with proper oil sealing arrangement. It is preferable that the feed through of the optical fiber cable to have independent connectors inside and outside of the transformer wall plate to prevent oil leakages during the long-term use of the transformer. Literature of the method used shall be furnished with the bid.

The signal conditioner and the sensors shall not require recalibration throughout the life time of the transformer.

The temperature device shall have separate contacts fitted with it for the following purposes:

(1). Control of the cooling plant motors.
(2). Winding temperature high alarm.
(3). Oil temperature high alarm

The continuous measured oil and winding temperature trend curve shall be plotted and to be integrated with DFR to monitor past temperature trend curve of the transformer along with the loading current. All historical trend curves and data should be saved inside and kept for reference at any time without wipe out with time.

Calculation of locations of winding hotspots shall be provided using finite element thermo-fluid analysis. Photographs of fiber optic sensor installed locations for each winding shall be submitted to CEB within one week from the installation for approval.

### 10.16.1.2 DIAL TYPE TEMPERATURE INDICATORS

In addition to clause 10.16.1.1, winding temperature indication, trip and alarm devices and oil temperature indication, trip and alarm device with dial type indicator and a pointer to register the highest temperature reached shall be provided as backup indication, trip and alarm devices. The instrument shall have three sets of contacts, one for alarm and one for trip, and one for stopping the fan motors shall be operated from a sensing bulb installed in the top of the transformer tank. The oil temperature indicator shall be installed in the transformer marshalling kiosk. The tripping contacts are to be adjustable to close between 60°C and 120 °C and re-open when the temperature has fallen by not more than 10°C. The alarm contacts shall be adjustable to close between 50°C and 100°C and to re-open when the temperature has fallen by not more than 10°C.

The alarm contacts and the contacts used to control the cooling plant motors and initiate automatic start-up of the reserve cooler on the above devices shall be adjustable to close between 50°C and 100°C and to re-open when the temperature has fallen by a desired amount between 10°C and 15°C.

All contacts shall be adjustable to a scale and must be accessible on removal of the cover. Alarm and trip circuit contacts shall be suitable for making or breaking 150 VA for 250 volts AC and 245 V DC and for making 500 VA for 250 V AC and 245 V DC. Cooler motor control contacts shall be suitable for operating the cooler contactors direct, or if necessary, through an auxiliary relay.

The temperature indicators in the marshalling kiosk shall be so designed that it is possible to move the pointers by hand for the purpose of checking the operation of the contacts and associated equipment.

The working parts of the instrument shall be made visible by the provision of cut-away dials and glass-fronted covers and all setting and error adjustment devices shall be easily accessible.

Connections shall be brought from the device to terminal boards placed inside the marshalling cubicle.

Terminals, links and a 63 mm moving iron ammeter shall be provided in the marshalling kiosk for each Winding Temperature Indicator for: -

a. Checking the output of the current transformer.
b. Disconnecting the bulb heaters from the current transformer secondary circuit to enable the instrument to be used as an oil temperature indicator.

## 10.16.2. GAS AND OIL ACTUATED RELAYS

Each transformer shall be fitted with gas and oil-actuated relay equipment having alarm contacts, which close on collection of gas or low oil level, and tripping contacts which close following oil surge conditions.

Each gas and oil-actuated relay shall be provided with a test cock to take a flexible pipe connection for checking the operation of the relay.

Each relay shall be fitted with a calibrated glass window for indication of gas volume.

To allow gas to be collected at ground level, a small bore pipe shall be connected to the gas release cock of the gas and oil-actuated relay and brought down to a point approximately 1400 mm above ground level, where it shall be terminated by a cock which shall have provision for locking to prevent unauthorized operation.

The design of the relay mounting arrangements, the associated pipe work and the cooling plant shall be such that mal operation of the relays will not take place under normal service conditions, including starting or stopping of oil circulating pumps whether by manual or automatic control under all operating temperatures.

The pipe work shall be so arranged that all gas arising from the transformer will pass into the gas and oil-actuated relay. The oil circuit through the relay must not form a delivery path in parallel with any circulating oil pipe, or is to be teed into or connected through the pressure relief vent. Sharp bends in the pipe work shall be avoided. When a transformer is provided with two conservators the gas and oil-actuated relays shall be arranged as follows: -

(a) If the two conservators are connected to the transformer by a common oil pipe one relay shall be installed in the common pipe.

(b) If the two conservators are piped separately to the transformer two relays shall be installed, one in each pipe connection.

The clearance between oil pipe work and live metal is to comply with the specifications as specified.

### 10.16.3. FACILITIES FOR FUTURE FITTING OF CONDITION MONITORING SYSTEMS TO TRANSFORMERS

When specified in the scope of works, manufacturer shall provide the necessary facilities for the future fitting of monitoring systems to the offered transformer recommended in table F.1 in Annex F of IEC 60076-1.

## 10.17. ALARMS

One electrically independent N.O./N.C. (C-form) contact shall be furnished for each alarm condition. Each form contact shall be wired to isolated terminal points in the control cabinet for use by the Owner for SCADA system and/or substation annunciator alarms.

Contacts shall be furnished for the following:

Trip Alarms:

Buchholz trip

Winding Temperature trip

Oil Temperature trip

Buchholz Gas

Tap Change Oil Surge trip

Tap change oil level trip

Tap change Buchholz trip

Oil level low trip

Pressure relief valve trip

Tap change pressure relief trip

Non Trip Alarms:

Heater AC supply fail

Winding temperature alarm

Oil temperature alarm

Transformer – pressure alarm

Low oil level

Oil level high

Marshalling kiosk supply fail

Tap changer AVR internal fail

Cooling fan fail ( Group A / Group B)

Air Forced cooling over current

VT fail

Tap Changer in progress. (Only indication)

Air forced cooling equip group running (Only Indication)

Oil Temperature (Only Indication)

Supply Voltage to OLTC failure. (Only Indication)

Tap position Indications to Control

Tap Change Control “On Local” (Only (Indication)

## 10.18. CONDITION REPORT DURING THE MANUFACTURING OF THE TRANSFORMER

The detailed condition report about its manufacturing stage shall be submitted along with invitation letter of FAT and which should include followings in minimum;

a. Design review completion certificate issued by CEB

b. CEB approved protective coating system

c. Photographs of tank top plate before painting
d. Hot spot sensor location photograph
e. Any NCR raised during the manufacturing process
f. Permissible shock values
g. Material test certificate
    - Cu
    - Lamination material
    - Ball and Gate Valves
    - Pipe Lines
    - Flanges
    - Metal Plates
    - Insulation materials
    - T/F Oil

CEB shall be immediately notified of any unusual damage occurring during construction of the transformer and of all tests which do not meet specified or standard values. The CEB shall be permitted, at his option, to personally inspect such damages and/or test failures

## 10.19. SHIPMENT AND DRYING OUT

### 10.19.1. SHIPMENT

Before shipping, transformer shall be completely assembled and filled with oil and Pressure tested to determine that all parts fit properly and no leaks are present. Parts removed for shipment shall be marked so as to permit easy identification for assembly in the field.

Each transformer when prepared for shipment shall be fitted with impact recorder which shall remain in situ until the transformer is delivered to Site.

The impact recorder shall be switched off in the presence of the Engineer if the transformer is kept in a place for a long time and shall switch on when it is carried back to the site.

The impact recorder shall be jointly inspected with the employer at the site and recorded data shall be forwarded to the Employer for approval before the installation, including the analysis software which shall be compatible for Windows 7/8/10, 32/64 bit operating systems with graphic signal analysis & export functions and frequency analysis of shock as per EN13011. The recorder data download shall be possible via USB (or wireless IR/Bluetooth). Procedure for turning off of the impact recorder shall be provided to the employer before dispatching the transformer from the factory.

<u>Impact Recorder</u>

Impact recorder battery life shall be adequate until the transformer is delivered to site and recorder memory shall be non-volatile at least up to 3 months.

Impact recorder shall be 3D - accelerometer impact recorder with measurements in X, Y and Z axis (both plus and minus directions). The impact recorder(s) should have the possibility to measure acceleration events with 3D curve in the range of 1024ms or more. The number of

such stored events must be sufficient for the transport. Acceleration range should be adjustable up to 10g with a frequency range of 1-100Hz. In addition the impact recorder should also be able to register both dynamic inclination curves and time-synchronous inclination events.

In case of transportation without oil one impact recorder should also be fixed to the active part during the transportation and one outside the tank. A master-slave connected system could be of value as events inside and outside the tank will be time synchronized.

Impact recorder mounting

- the impact recorders should be bolted rigidly to the transformer tank (or active part).
- Impact recorders on the transformer tank should be mounted at or near the location where the transformer is supported by the transport vehicle.
- The mounting location inside the tank is dictated by accessibility, i.e. Near a manhole or cover of bushing turret. Fixing to the core and coil clamping system is a good option.
- The mounting orientation is irrelevant as long as the axis of the impact recorder align with the axis of the transformer.
- The mounting location should be rigid, preferably near the corner of three intersecting surfaces, i.e. bottom plate near a stiffener and the tank wall.

Impact records

Manufacturer shall provide maximum allowable readings for the safe transportation filled in following table in advance.

| Axis | Outside tank | Inside tank | Duration (cont. or msec) | Comments |
|---|---|---|---|---|
| | Max g-forces used for the design | | | |
| longitudinal | | | | |
| Vertical | | | | |
| Lateral | | | | |

In the event that the transformer is found to have been subjected to excessive shock/impact or the impact recorder has been damaged in transit, the transformer shall be brought back to the factory for necessary inspection. Such examination as is necessary shall be made in the presence of the Engineer.

The purchaser's inspector shall witness inside abnormalities of the transformer and Factory Acceptance Tests shall be repeated after the necessary repairs. All the expenses including travelling and accommodation incurred for sending the purchaser's inspector to the factory shall be borne by the Manufacturer.

Shipping Documents

Manufacturer shall furnish packing list for each crate or container. Each crate or container shall be numbered or lettered to correspond with the packing list furnished. Packing list shall specify quantity of various items with their serial number, catalog number, purchase order number, or other specific identifying information to facilitate check-off of material when received.

Manufacturer shall furnish receipt, handling, and storage instructions that affect warranties and/or guarantees and that may be used to preserve integrity of equipment placed in outdoor storage. A preliminary set of instructions shall be furnished with the bid.

Transportation without oil

If the transformer is transported without oil, provision should be made to prevent the ingress of moisture and to maintain the internal insulation in first-class condition. In addition the transformer should be filled with breathable dry gas and maintained at a continuous positive pressure. The air pressure and dew-point should be monitored continuously throughout the period immediately after the oil is removed until the transformer is refilled with oil at site. At all times alternative standby means should be provided to restore any loss of air pressure immediately.

The dew point of the dry air should be measured and recorded to ensure it is below -40° C. The dew point should be checked again within 24 hours of the oil having been removed and the transformer dry air filled, the measurements being recorded in the test report and on the shipping tag. If the dew point readings indicate an average moisture level at the surface of the transformer cellulose insulation is higher than 0.5%, the manufacturer must dry the transformer. The estimation of average moisture level shall be done as per IEEE Std. C57.93 and forward for approval before dispatching. The air pressure and dew-point should be monitored immediately before the transformer is refilled with oil at site. **The estimation of average moisture level shall be again done as per IEEE Std. C57.93. If it exceeds 0.5% average moisture level, drying out at site shall be done to the satisfaction of CEB**.

## 10.19.2. DRYING OUT

The transformer shall be dried to less than 0.5% moisture content in cellulose insulation (by dry weight of cellulose). The entire active part of the transformer shall preferably by using by vacuum vapour pressure drying at the manufacturer's works and so arranged that the transformer shall be put into service without further extended drying out at Site. Literature of the vapour pressure drying plant facility available at the manufacturer's work and description of complete drying process of windings and active part shall be furnished with the bid.

Clear instructions shall be included in the Maintenance Instructions regarding any special precautionary measures which must be taken before the specified vacuum is applied to the transformer.

The employer considers seriously the moisture content in cellulose insulation and, hence vapour pressure drying (or approved type) and workmanship thereafter shall be maintained at a

extremely high level of standard. Further, employer adopts estimation of moisture in cellulose insulation by using Ommen's Equilibrium curves and Dielectric Frequency Response Analysis Techniques during commissioning at site, in addition to the estimation of average moisture level as per IEEE Std. C57.93 using dew point. If any serious deviation exists from 0.5% moisture content in cellulose insulation, the transformer may be liable for rejection.

## 10.19.3. OIL STORAGE

The Contractor shall supply the first filling of transformer oil, which in accordance with IEC 60296. It is envisaged that the oil will be supplied to site in 200 L drums and filtered by use of the plant described in the preceding paragraph into the Employer's mobile storage tank prior to transfer again via filter plant into the transformer.

## 10.19.4. OIL TREATMENT PLANT (IF SPECIFIED IN SCOPE OF WORKS)

Plant for the treatment of transformer oil at site shall be mounted on steerable trailer equipped with pneumatic tyres, over-run and parking breakers and weatherproof canopy. The plant shall be capable of treatment of oil to IEC 60296 and IEC 60422, shall be of the replaceable paper filter type and shall have the following facilities: -

a) Oil treatment rate not less than 400lit/hour.
b) Water extraction capability down to 5ppm.
c) Reduction of dissolved gas content to 1% by volume or less.
d) Oil transfer, vacuum pumps and heaters suitable for 415V 3 phase 50Hz, 4 wire supply.
e) Vacuum capability approximately 1 Torr.
f) Facility to apply vacuum to transformer tank during oil filling.
g) Two 15m lengths of wire reinforced housed coloured differently for clean and dirty oil.
h) One 20m length of power supply cable with plug and socket at the filter end only.

## 10.19.5. TRANSFORMER OIL

Transformer and switchgear oil shall be compatible with that available in Sri Lanka. Transformer oil available in Sri Lanka has the following characteristics:

Type of Oil - uninhibited class 1

Required Standard - IEC 60296/ BS 148

Offered transformer oil shall meet general specifications specified in table 2 of IEC 60296.

## 10.19.6. DESIGN REVIEW

### 10.19.6.1. GENERAL

The selected bidder with the **consultation of manufacturer's design engineers and experts** shall conduct an in-depth review of the offered power transformer at site to allow CEB to have a clear understanding of the transformers design, manufacture and test including the likelihood of operating in service as intended. The electrical, thermal and mechanical draft design, documents, the dimensional drawings, the rating plate drawings shall be completed by the manufacturer at the time of design review.

The following the subjects of shall be clearly presented to the CEB representatives during the design review.

- Core
    - A general description of the core design & material
    - Geometry and cross section data
    - Special issues of the core design
- Windings
    - Winding arrangement & material
    - Cross section and number of turns
    - Insulation design
- Thermal design
    - Losses
    - Cooling
    - Temperature
- Short circuit withstand capability as per IEC 60076-5
    - Thermal ability to withstand short circuit
    - Ability to withstand the dynamic effects of short circuit
- Core, Winding Assembly and Drying
- Leads and Cleats
- Insulation Design & material
- Leakage Flux Control
- Drying and Processing
- Sound Level
- Seismic
- Tank, Radiators, Turret & Conservator
    - Design & Drawings
    - Fabrication
    - Testing
    - Surface Preparation and Painting

- Ancillary Equipment
    - HV, LV & Neutral Bushings
    - Bushing/Internal Current Transformers
    - Buchcholz Relay
    - Pressure Relief Device
    - Valves
    - Breather
    - Offline Tap Changer
    - Control Cabinet and External Cabling
    - Cooling fans/oil pumps
    - On-line Monitoring Equipment
- Testing at factory
- Transportation
    - Design for Transport
    - Transportation Route and Preparedness
    - Transportation Shipping Impact Withstand
    - Marking of Center of Gravity
    - Transportation monitoring management of transformer
        - Type/Location of Impact Recorder
    - Transportation of transformer accessories, components removed from the transformer
    - Acceptance criteria for receiving transformer
    - Transformer Unloading at site
- Commissioning Testing at Site

The bidder shall bear all the costs incurred for this design review.

### 10.19.6.2. EVALUATION OF ABILITY TO WITHSTAND THERMAL AND DYNAMIC EFFECTS OF SHORT CIRCUIT

At detailed design stage, manufacturer shall submit evaluation of ability of withstanding thermal and dynamic of short circuit within 4 weeks from contract award.

Following documents, drawings and calculations shall be submitted with this evaluation as per IEC 60076-5 Annex A.

**Documents required under Clause A.3.2**

- Electromagnetic design data sheets as needed for calculation
- Drawings or sketches of the complete winding and insulation arrangement within the core window with indication of the types of material
- Calculation of the short-circuit current values (both peak and symmetrical r.m.s. values) affecting each single winding as a result of the service duty requirements specified and types of fault taken into consideration, with also due regard to the tapping positions in case of winding(s) provided with taps.
- Calculation of the main short-circuit forces (peak values occurring at the highest peak of the respective current), with reference to the fault cases, tapping positions and geometrical and relative positions of windings considered for design purposes. Full information has to be given if any simplified geometrical configurations have been adopted for the windings, core and tank for the purpose of magnetic leakage field and electromagnetic force calculations.
- Calculation of basic mechanical stresses on winding conductors and adjacent mechanically coupled structures originated by the short-circuit forces.
- Drawings, sketches, or computer outputs, concerning the winding support structure and core-and-coil clamping arrangement
- Instructions for quality assurance and quality control concerning both materials and manufacturing practices, with specific reference to manufacturing activities
- Checks concerning main transformer external components, in particular high-voltage bushings, especially in the case where they are slope-mounted on turrets, etc.

**Calculation of EM Forces (Clause :A.3.2 (d))**

- radial inward or outward force on each physical winding
- maximum axial compression force on each physical winding (Fc)
- maximum axial end thrust force (up/down) on each physical winding
- maximum axial force-per-limb on common press ring (or plate), if used, and core clamps
- thrust force acting on the lead exits of each main low-voltage winding (T*f)

**Calculation of Stresses (Clause: A.3.2 (e))**

- mean hoop tensile stress on outer windings (σ*t)
- mean hoop compressive stress on disc-, helical-, single-layer-type inner windings

(σ*c)12

- equivalent mean hoop compressive stress on layer-type inner windings
- stress due to radial bending on conductors in the span between axial sticks and between spacers used to build any axial cooling ducts within the winding radial width
- stress due to axial bending on conductors in the span between radial spacers with disc- and helical-type windings
- compressive stress on radial spacers with disc- and helical-type windings
- compressive stress on conductor paper insulation with layer-type windings
- compressive stresses on end stack insulation structures and end rings
- compressive stress on common press rings (or plates)
- tensile stress on tie rods (flitch plates) of the clamping structure

**Drawings (Clause: A.3.2 (f))**

- arrangement of the radial supports against the core limb
- configuration of the end stack insulation structures
- Arrangement of common press rings
- overall core-and-coil clamping arrangement
- means for securely fastening the winding lead exits and LV connection leads or bars to the bushings and lead runs to tap-changers
- means for the application of any axial pre-load

**Instructions for Quality Assurance and Control (Clause: A.3.2 (g))**

- winding of the conductors on the mandrel and control of the pulling force
- sizing and elastic stabilizing of windings and coils
- assembling within specified tolerances
- drying and impregnation with oil
- application of pre-load
- fastening/securing of winding supports
- leads and clamping devices

**Acknowledgement of the manufacturer's design information for short-circuit strength**

**(Clause A.3.3.3.1 )**

- The list of transformers built by the manufacturer which have been subject to the short-circuit test, including main transformer data, such as rated power, rated voltage, tapping range, and short-circuit impedance
- The results of the tests performed on models, if any, and their impact on the design rules
- The contents of the technical standards for short-circuit strength of power transformers used by the manufacturer in regular design and production activities
- Service records and in-field failure rates as regards short-circuit performance
- The number of units produced and the number of service years of successfully operated transformers

**Checking procedure (Clause A.3.3.3.2)**

- Preliminary examination of the winding and main insulation structures and clamping arrangement of the transformer
- Comparing any force and stress values calculated on the transformer with the corresponding allowable or critical values that the manufacturer has adopted in his design practice

If any of document or documents could not be provided due to proprietary nature of information, manufacturer shall show the those documents to engineer at employers' premises or manufacturers' premises.

## 10.20. 220/33 KV, 132/33 KV AND 132/11 KV TRANSFORMERS

### 10.20.1. GENERAL

The 220/33 kV, 132/33 kV and 132/11 kV transformer shall comply with the general requirements of the specification and the particular requirements of this chapter.

### 10.20.2. CONTINUOUS MAXIMUM RATING

The transformer shall have the continuous maximum rating (CMR) stated in Employer's Requirements when operating as ONAF.

### 10.20.3. IMPEDANCE

The transformer shall have impedance between the 220 kV (or 132 kV) and 33 kV (or 11 kV respectively) windings as stated in Employer's Requirements. The impedance on other tappings shall be stated in Technical Particulars and Guarantees.

It is preferred that the equivalent zero sequence impedance of the transformer, when viewed from the 220 kV (or 132 kV) terminals is not less than the positive sequence impedance between 220 kV (or 132 kV) and 33 kV (or 11 kV respectively) terminals at normal ratio normal rating. The value shall be stated in Technical Particulars and Guarantees on the basis of system short circuit levels stated in Employer's Requirements.

### 10.20.4. WINDING TERMINATIONS

Terminations of delta connected windings and neutral ends of windings shall be as follows: -

(i) Neutral ends of the three phase windings shall be connected at points accessible from hand holes in the cover and brought out via one bushing insulator.

(ii) Delta windings shall be closed within the tank and the termination shall be brought into cable termination boxes.

### 10.20.5. VOLTAGE CONTROL

Winding taps for the transformer shall be provided on the 132 kV neutral end.

### 10.20.6. TEMPERATURE INDICATING DEVICES AND ALARMS

The transformer shall be provided with separate winding temperature indicators associated with the main and delta connected windings.

## 10.21. 220/132/33 KV AUTO CONNECTED TRANSFORMERS

### 10.21.1. GENERAL

Auto connected transformers when required for interconnection between the 220 kV and 132 kV system shall comply with the general requirements of the specification and the particular requirements of this Chapter.

The auto-transformers will be star connected and the system will be solidly earthed at each auto transformer neutral.

A 33 kV delta connected tertiary winding shall be provided to supply the future capacitor banks.

The tank shall be designed without pockets in which gas may collect. Where pockets cannot be avoided, pipes shall be provided to vent the gas into the main expansion pipes.

Drains valves and valves for oil sampling (top and bottom) shall be provided at convenient floor height.

## 10.21.2. CONTINUOUS MAXIMUM RATING

The auto-transformers shall have the continuous maximum rating stated in Scope of Works in Employer's Requirements and be provided with a delta connected winding capable of supplying the load stated in the Employer's Requirements. No compensation shall be made to the rating of the series or common windings of the auto-transformer for any limitation in output consequent on the tertiary load, but Technical Particulars & Guarantees shall be completed showing any restriction in 132kV output, for conditions of input from the 220 kV system, with the tertiary winding fully loaded and with varying 132kV and tertiary power factors of their respective loads down to 0.8 lagging.

The transformers shall be capable of operating continuously at their rated power within the specified temperature rise limit at 10% over or under excited operation. This is applicable for all tap changer settings and all forced cooling in operation.

## 10.21.3. IMPEDANCE

Auto transformers shall have an impedance between 220kV & 132kV windings as stated in Employer's Requirements. The impedance on other tappings and between other windings shall be stated in Technical particulars and Guarantees.

It is preferred that the equivalent zero sequence impedance of the auto-transformer, when viewed from the 220kV terminals and feeding a fault at the 132kV terminals is not less than the positive sequence impedance between 220kV and 132kV terminals at normal ratio and normal rating. The value shall be stated in Technical particulars and Guarantees on the basis of system short circuit levels stated in Scope of Works. Built in short circuit limiting reactors, if any, shall only be installed in the main tank. A separate tank, appended to the main tank is not acceptable.

## 10.21.4. WINDING TERMINALS

Terminations of delta connected windings and neutral ends of windings shall be as follows:

(i) Neutral ends of the phase windings shall be connected at a point outside the transformers.

(ii) Delta windings shall be closed outside the transformers.

Where delta windings are initially loaded, the delta windings shall be terminated as stated above. The system supplied by the delta winding will be separately earthed.

## 10.21.5. TAP CHANGING

Single-phase Tap-changers are required on 132kV winding and 33 kV winding or as per employers requirement. The 132 kV tap changer shall be provided on the line end. Tap-changers shall comply with Clauses 10.13.2. The tap changers of Auto-transformer winding shall be insulated for the higher of the two voltage levels.

## 10.21.6. TEMPERATURE INDICATING DEVICES AND ALARMS

Auto transformers shall be provided with separate winding temperature indicators associated with the series, common and delta connected windings.

## 10.21.7. CURRENT TRANSFORMERS

Where required built-in current transformers for protection shall be provided for 132kV and 33 kV differential REF and over-current protection plus neutral terminal CT's for REF & SBEF protection. The technical data shall be coordinated with the protection requirements and the related switchgear CT's. Where built-in CT's are provided, the related bushing, connection boxes and cable terminal boxes shall be arranged to be removable without interfering with the CT.

## 10.22. EARTHING & AUXILIARY TRANSFORMERS

## 10.22.1. EARTHING TRANSFORMER

### 10.22.1.1 GENERAL

Earthing transformers shall comply with IEC 60076-6 and shall be of the oil immersed ONAN type suitable for outdoor installation and are to have a main zigzag winding which will be directly connected to the 11 kV/33 kV terminals of the associated main transformer.

The neutral point of the zigzag winding shall be brought out of the tank through a bushing insulator. This point will be connected to earth directly in order to provide an earthing point for the neutral of the system.

### 10.22.1.2 ELECTRICAL AND SHORT CIRCUIT CHARACTERISTICS

The maximum fault current for a solid earth fault on the earthing transformer terminals shall not exceed the value given in the Employer's Requirements. To achieve this earthing transformer minimum zero sequence impedance per phase shall not be less than the value given in the Employer's Requirements.

Under the condition of a solid earth fault in the transformer terminals, limited only by the earthing transformer zero sequence impedance, the earthing transformer shall be capable of withstanding this condition, both thermally and dynamically without damage.

Additionally, earthing transformers shall, when operating continuously at any load up to CMR, be capable of withstanding for three seconds the current obtained when a short circuit is applied between any or all of the lower voltage terminals with full line voltage maintained at the higher voltage terminals.

The foregoing conditions shall assume an initial winding temperature which is the sum of the maximum ambient temperature stated in Employer's Requirements and the temperature rise obtained by continuous operation at CMR.

## 10.22.2. AUXILIARY TRANSFORMER

### 10.22.2.1 GENERAL

Auxiliary transformers shall comply with IEC 60076 and shall be of the hermetically sealed oil immersed ONAN type suitable for outdoor installation. Auxiliary transformers shall also be provided with off load tap change from -10% to +5%, arranged to give a 400/230 V, three phase,

four wire supply. The auxiliary transformer winding shall have the continuous rating stated in the Employer's Requirements and shall confirm to IEC.60076.

#### 10.22.2.2 TERMINALS AND CONNECTIONS

The three-phase, four-wire connections from the transformer windings shall be terminated at a three-pole combined switch-fuse unit with bolted neutral link and gland entry for a four-core solid dielectric cable. This shall be accommodated in a lockable, fully weatherproof compartment together with a neutral earthing link. The purpose of the neutral earthing link is to connect the 400V system neutral to earth. It shall be connected between the transformer winding end of the neutral link and a suitably located earthing terminal to which the system earth can be connected. Three L.T. surge arresters shall be provided.

An earthing terminal shall be provided on the transformer core frame with a cross bonding connection to the main earthing terminal which shall be provided at the base of the cubicle.

Three spare fuses shall be supplied with each transformer.

### 10.22.3. TANKS AND FITTINGS

Earthing transformer & Auxiliary transformer shall be provided with the following necessary fittings:-

A) Conservator vessel with removable end cover and prismatic oil gauge.

B) Buchholz Protector.

C) One thermometer pocket with captive screw cap.

D) Silica gel breather of the oil seal type with a minimum capacitive of 2 kg.

E) Pressure relief device.

F) Filter valve and combined filter and drain valves.

G) Oil sampling device.

H) Oil and winding temperature gauges

I) HV cable box

J) LV cable box

## 10.23. QUALITY ASSURANCE

A Quality Inspection and Test Plan (QITP) should be submitted with each tender and agreed with the purchaser before contract.

Any subsequent alteration to and deviation from the agreed QITP should be submitted to the purchaser in advance for approval in writing. No changes to the QITP ought to be permitted without the prior written approval of the purchaser.

## 10.24. UNLOADING EQUIPMENT

Special attention has to be given for unloading the transformers as the harbour in Colombo as today has limited facilities (Maximum lifting capacity under spreader – 65000 Kg, Maximum lifting capacity under hook beam – 75000 Kg) to handle such heavy equipment. Also the transport to site by trailers etc. has to be thoroughly planned by the Contractor, with regard to max.

Permissible loads for roads and bridges or other obstacles and detailed information has to be included in the Bid.

Inside the boundaries of the substations under this project, it is the Contractors responsibility to construct any means required for an easy moving of the transformers onto their foundations, as for example access roads, temporary crossings of culverts or drains, temporary dismantling of existing facilities etc.

For movement and alignment of the main transformers on site, 8(eight) hydraulic jacks of 100t and 50t respectively, each with common hand operated oil pump and housing system and all accessories and spare parts as necessary are to be included in the scope of supply. Individual hand operation shall also be possible. The final capacity shall be matched to the heaviest transformers.

Furthermore, twelve heavy duty tank type steel rollers, and ten numbers 1 cm high, 2m by 1m steel sheets for offloading of the transformers together with $10m^3$ heavy wood oil impregnated, rectangular sectioned timber logs of assorted length between 0.5m and 3m and assorted thickness between 5cm and 20cm shall be supplied.

## 10.25. TEST AT MANUFACTURE'S WORK

### 10.25.1. MAIN TRANSFORMERS

Each of the transformers shall be subject to acceptance tests to be performed at the Contractor's premises (and at site) in order to verify their conformity with the guaranteed and other design data. The methods of testing shall be submitted for approval at least three months before testing. The transformers shall be completely assembled in every respect. All of the tests shall be performed with all original bushings installed. Deviations from this requirement should be by agreement between the purchaser and manufacturer.

The tests shall be performed in accordance with the latest issues of the recommendations of the (International Electro-technical Commission) IEC, in particular IEC 60076 and IEC 60060.

The Contractor is obliged to submit a detailed test program (including detailed test connections for all dielectric tests) for approval in due time, prior to the tests (at least three months before testing). Detailed test schedules separately for each unit showing exactly when each of the tests will be carried out shall be submitted for approval at least six weeks prior to the tests.

Test equipment must have a valid calibration certificate, which should be available for inspection at the test location before starting any tests.

The following test shall be performed in the presence of the Employer/Engineer:

<u>Routine Tests</u>

Routine test shall be according to the IEC 60076, part 1, clause 11.1.2.

a) Measurement of winding resistance (11.2).

b) Measurement of voltage ratio and check of phase displacement (11.3).

c) Measurement of short-circuit impedance and load loss (11.4).

d) Measurement of no-load loss and current (11.5).

e) Dielectric routine tests (IEC60076-3).

f) Tests on on-load tap-changers (11.7).

g) Leak testing with pressure for liquid-immersed transformers (tightness test) (11.8).

h) Check of the ratio and polarity of built-in current transformers.

i) Check of core and frame insulation for liquid immersed transformers with core or frame insulation (11.12).

j) Insulation of Auxiliary wiring (IEC 60076 , part 3)

k) Partial discharge measurement (IEC 60076 , part 3

l) Determination of capacitances windings-to-earth and between windings

m) Measurement of d.c. insulation resistance between each winding to earth and between windings.

n) Measurement of dissipation factor (tan δ) of the insulation system capacitances.

o) Measurement of dissolved gasses in dielectric liquid from each separate oil compartment except diverter switch compartment.

p) Measurement of no-load loss and current at 90 % and 110 % of rated voltage(11.5).

**Note:** Tests e, g, i, k, l, m, n and o shall be performed after temperature rise test.

Type Tests (apply only for one transformer.)

Type test shall be according to the IEC 60076, part 1, clause 11.1.3.

Special test (apply only for one transformer.)

Special test shall be according to the IEC 60076, part 1, clause 11.1.4 -

a) Dielectric special tests (IEC60076-3).

b) Winding hot-spot temperature-rise measurements.

c) Determination of capacitances windings-to-earth, and between windings.

d) Measurement of dissipation factor (tan δ) of the insulation system capacitances.

e) Determination of transient voltage transfer characteristics (Annex B of IEC60076-3:2000).

f) Measurement of zero-sequence impedance(s) on three-phase transformers (11.6).

g) Short-circuit withstand test (IEC60076-5). (Bidder shall understand that, short circuit withstand test as per IEC 60076-5 will have to be performed at the manufacturer's work or the nearest accredited High Voltage Laboratory if the manufacturer fails to provide successful theoretical evaluation of the ability to withstand the dynamic effects of short circuit as per IEC 60076-5, version 2006. Total cost of short circuit test and witnessing of test shall be borne by the manufacturer. Therefore manufacturers are advised to evaluate their own ability of submitting successful short circuit theoretical evaluation before bidding.)

h) Measurement of d.c. insulation resistance each winding to earth and between windings.

i) Vacuum deflection test on liquid immersed transformers (11.9).

j) Pressure deflection test on liquid immersed transformers (11.10).

k) Vacuum tightness test on site on liquid immersed transformers (11.11).

l) Measurement of frequency response (Frequency Response Analysis or FRA). The test procedure shall be agreed between manufacturer and purchaser. Tests shall be performed on following minimum test configurations.

1. End to end open circuit measurements
2. End to end short circuited measurements
3. Capacitive inter winding
4. Inductive inter winding

m) Check of external coating (ISO 2178 and ISO 2409 or as specified).

n) Measurement of dissolved gasses in dielectric liquid.

o) Mechanical test or assessment of tank for suitability for transport (to customer specification).

p) Determination of weight with transformer arranged for transport. For transformers up to 1,6 MVA by measurement. For larger transformers by measurement or calculation as agreed between manufacturer and purchaser.

q) Measurement of the harmonics of the no-load current

r) Level of the TF top plate

s) Markings in bushings and phase locations

t) Dielectric Frequency Response Analysis and estimation of moisture in cellulose insulation.

u) Oil Tests before and after temperature rise tests (Breakdown voltage, Interfacial tension & Moisture in Oil)

**Note:** Tests a, c, d, e, h, i, j, k, l, n and Measurement of sound level test shall be performed after temperature rise test.

## 10.25.2. EARTHING AND AUXILIARY TRANSFORMERS

Routine Tests

a) Measurement of winding resistance (11.2).

b) Measurement of voltage ratio and check of phase displacement (11.3).

c) Measurement of short-circuit impedance and load loss (11.4).

d) Measurement of no-load loss and current (11.5).

e) Dielectric routine tests (IEC60076-3).

f) Leak testing with pressure for liquid-immersed transformers (tightness test) (11.8).

g) Check of the ratio and polarity of built-in current transformers.

h) Check of core and frame insulation for liquid immersed transformers with core or frame insulation (11.12).

i) Insulation of Auxiliary wiring (IEC 60076 , part 3)

j) Measurement of zero-sequence impedance

k) Insulation resistance of each winding

l) Measurement of capacitance and power factor

Type tests

(1) Temperature rise test:

Unless acceptable type test certificates can be submitted in respect of a transformer similar in design to that specified a temperature rise test shall be carried out and the costs shall be included in the contract price.

This test shall take into account temperature rise due to both the specified earth fault current and continuous operation at CMR of the auxiliary winding.

(2) Impulse-voltage withstand (full wave) test

Special Tests

(1) Short-circuit current withstand test included in IEC 60076.

### 10.25.3. ACCEPTANCE CRITERIA FOR FACTORY ACCEPTANCE TESTS

If the results of the inspection are not within the offered values, CEB shall have the right to reject the transformer as defective.

If any defect arises during the testing of the transformer and CEB representative for the inspection considers the defect as a major defect then the transformer will be rejected as defective will not be accepted after the repairs by the manufacturer. In which case the manufacturer shall agreed to replace the transformer with a new design without any additional cost.
However If the CEB representative considers the defect as a minor defect and manufacturer request for repair and re-inspection, this may be considered subjected to the following,

1. Dismantling and inspection of the transformer for repairs shall be done in the presence of an Engineer nominated by Ceylon Electricity Board. The manufacturer shall agree to bear the cost of travelling and accommodation of the representative nominated by CEB for the period of dismantling & inspection of the defective transformer.
2. All the Routine Tests specified in Clause 10.25 must be repeated. Manufacturer shall agree to bear the cost of travelling and accommodation of the representative nominated by CEB for the period of testing of the repaired defective transformer

If CEB decides that the repair to be executed at the manufacturer's work, the cost of transporting the transformer back to the manufacturer's works and rectifying the defects shall be at the manufacturer's expense. In this case the factory acceptance test shall be repeated according to the above conditions 1 and 2. Total cost for transportation back to the site, installation and commission shall be at manufacture's expense.

## 10.26. SITE ACCEPTANCE TESTS

Prior to removal from the transporter at site, following tests shall be carried out to ascertain if any damage has occurred in transportation.

- insulation resistance measurement of core and frame insulation, winding insulation to earth and between windings
- frequency response analysis
- interrogation of shock recorders fitted for transport

After the assembly of the transformer at site, following tests should be performed as a minimum to verify that the unit has not been damaged during transport and that it has been erected correctly.

- Voltage ratio
- Vector group
- Insulation resistance measurement

  - all windings to earth
  - between windings
  - current transformer windings to earth
  - between current transformer windings
  - control cabling
  - auxiliary power cabling
  - between core and tank
  - between core and core clamping
- Check of protective earthing connections
  - bushing turrets
  - on load tap changer and motor drive
  - cubicles
  - control cabling
  - auxiliary power cabling
  - coolers, pipes and bridging of flanges
- Current transformer polarity check
- Control equipment circuit check
- Oil tests
  - oil level check
  - dielectric withstand test
  - oil samples for gas-in-oil analysis
- Operation test of supervisory equipment
- Operation test of cooling equipment
- Operation test of on load tap changer

After erection, following tests and inspections shall be performed before commissioning the transformer.

- visual inspection

- verify and adjust if required:
    - conservator oil level
    - dehydrating breather
    - valves
    - cubicles
    - touch up painting
    - cubicle heaters
    - de-aeration of the gas and oil actuated relay
    - oil leaks
    - tank protective earthing
    - neutral earthing
    - line and bus connections
    - air clearances
- fingerprint tests (Um>72 kV)
    - Determination of capacitances windings-to-earth and between windings (Um >72.5 kV)
    - Measurement of dissipation factor (tan δ) of the insulation system
    - capacitances (Um >72.5 kV)
    - frequency response analysis (FRA)
    - Insulation dielectric response (PDC, RVM or FDS etc.)
    - low voltage no-load magnetisation current measurement
    - low voltage impedance measurement

## 10.27. TRIAL OPERATION

14 days trial operation is required to prove the functional capability of the transformer and to show that it will meet its performance target. The warranty period shall be started after the successful trial operation.

## 10.28. DRAWINGS

All approval drawings shall be sent to the Employer.

### 10.28.1. REQUIRED DRAWINGS PART I

Four (4) paper copies and soft copy of each of the drawings specified below shall be provided.

i. Outline drawings including the following information:
   a. Untanking dimensions.
   b. Center of gravity, shipping and completely assembled, in three dimensions.
   c. Exact bushing terminal locations named with L1,L2,L3 phases, accessory equipment locations, weights and dimensions.
   d. Identification of all components or accessories which will be shipped separately or disassembled due to shipping restrictions.
   e. Base detail required for foundation designing.
ii. Schematics and wiring diagram, which shall include auxiliary power requirements and fuse and breaker sizes.
iii. Instruction nameplate for oil preservation equipment.
iv. Bushing and Surge Arrester detail drawings.
v. OLTC and On Line Transformer Diagnostic Device equipment detail drawings
vi. Excitation and ratio correction curves for all current transformers including hot spot CT.

### 10.28.2. REQUIRED DRAWINGS PART II

Four (4) paper copies and CADD files in AutoCad Ver 2010 of each of the drawings specified below shall be provided.

Certified test data for all testing

Instruction books shall include exact information for all auxiliary equipment, such as thermometers, gauges, relays and alarm set-points, and manual and automatic load tap changing equipment actually supplied on the transformer. It will not be considered sufficient to include only "typical" device instruction books. Instruction books shall include copies of all final drawings.

Four (4) color photographs of the core and coil assemblies shall be taken immediately prior to tanking at such angles as to provide a maximum of design and construction information for record.

One photograph of the completely assembled transformer with cooling equipment in place shall be taken. One print of each of the above photographs shall be incorporated in each copy of the instruction books.