# 132(66)/33(11kv) Grid Transformers And Associated Earthing Transformers, And Neutral Earthing Resistors Specification

Date 0000
Classification: Internal

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| Role | Name | Position | Date |
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## Contents



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## 1. Introduction

This specification is to provide guidance on the technical parameters for Grid Transformers subject to adoption by Aurora Utilities Ltd (AUL). The document covers transformers with the rated voltage of the high voltage (HV) winding at 132kV (but is suitable for 66kV transformers as well) and the low voltage (LV) winding operating typically at 33kV or 11kV. Please note that for the purposes of this specification, the term “Low Voltage” refers to the voltage of the winding that is the lowest of the two. In all other cases, referring to other equipment not being part of the transformer (e.g. power cables) they will be referred to as MV (medium voltage) or 11/33kV. The power rating for grid transformers for the use in AUL’s networks would usually be within the range of 10-50MVA, however larger powers may also be adopted for special applications. The also specification covers the directly associated with Grid Transformers Earthing Transformers and Neutral Earthing Resistors. For earthing transformers, the term HV and LV are used in relation to their highest and lowest voltage. This documents has been designed to provide guidance for ICPs proposing a grid transformer for adoption by AUL.

## 2. Transformer Suitability & Acceptance

Section 4 of this document provides an insight into standard parameters of grid transformers AUL consider suitable for the typical range of projects with 132kV(66kV) connection voltage. Further part of the document provides detailed information regarding crucial parameters and aspects of the transformer construction. A transformer may be considered generally accepted if its specification is in line with this document, however its final acceptance may depend on the review of its full technical pack, including GA, datasheet, specification as well as relevant power system studies determining its suitability for the use in a particular location in the grid (e.g. P28 or G99 studies).

## 3. Approved Manufacturers

To aid the transformer procurement, AUL do not provide a closed list of approved manufacturers. However, is it required that the proposed transformer is free of any official reports of incidents or malfunctioning, particularly including:

- Suspension of Operational Practice (SOP) - A notification of a company-specific suspension/change in some operational practice or procedure regarding the proposed transformer,
- Dangerous Incident (DIN) - A dangerous incident is one where the incident resulted in or could have resulted in a fatality or serious injury associated with the proposed transformer.

It is generally accepted to propose a transformer manufacturer approved by any of the UK’s DNOs, the hosting DNO issuing the Connection Offer, provided the above conditions are met. A transformer does not present on any DNO’s approved plant list may also be proposed, but may be subject to more thorough review, therefore swift provision of all technical information would expedite the process. AUL reserve right to, in very rare cases, reject the transformer solely based on its make. In such situation AUL will explain and support this decision with adequate evidence only if the proposed transformer is considered to likely cause issues or danger to AUL’s network.

## 4. Typical Parameters of AUL Grid Transformers

Table 4.1. presents a set of crucial technical parameters of grid transformers together with typical values or range of the parameters they typically fall within. The proposed transformer may be considered generally accepted if the parameters are within the given range. Some of the parameters are at a manufacturer’s discretion and will be determined

by their detailed design. The choice of parameters like type of the tap changer (on/off-load), tapping step, impedance, inrush characteristic shall be driven by application, location in the power system and variable operating conditions suitability. These can be determined by carrying out adequate and project-specific power systems studies (indicated as “subject to supporting studies” in tab. 4.1).

### Tab. 4.1. Required parameters of AUL’s grid transformers

| Parameter | Unit | Required value | Comments |
|---|---|---|---|
| Type | - | Oil-immersed with conservator | - |
| Number of phases | - | 3 | - |
| Rated Power | MVA | 10MVA – 50MVA | Power may be greater for special applications |
| Cooling method | - | ONAN / ONAF | Power shall be given for both natural and forced cooling method if applicable |
| HV side rated voltage | kV | 132kV (or 66kV) | Less commonly 66kV – this specification remains valid for such case |
| LV side rated voltage | kV | 33kV or 11kV | - |
| Insulation grading | - | HV: non-uniform<br>LV: uniform | As per IEC 60076 |
| Insulation levels (HV) Um / LI / AC (132kV) | kV | 145 / 650 / 275 | As per IEC 60076-3 for 132kV rated winding |
| Insulation levels (HV) Um / LI / AC (66kV) | kV | 72.5 / 325 / 140 | As per IEC 60076-3 for 66kV rated winding |
| Insulation levels (LV) Um / LI / AC (33kV) | kV | 36 / 170 / 70 | As per IEC 60076-3 for 33kV rated winding |
| Insulation levels (LV) Um / LI / AC (11kV) | kV | 17.5 / 95 / 38 | As per IEC 60076-3 for 11kV rated winding |
| Min. HV neutral point voltage (66/132kV) | kV | 44kV | - |
| Insulation levels (HV-N) Um / LI / AC (66/132kV) | kV | 52 / 250 / 95 | As per IEC 60076-3 for graded HV insulation |
| Number of LV windings | - | 1 (or 2) | Usually one LV winding, however for special applications there may be 2 LV windings |
| Winding material | - | Copper | For all windings |
| Vector group | - | YNd11 | For delta winding other suitable vector group is acceptable (e.g. d1) |
| Frequency | Hz | 50Hz | Transformer shall be capable of operating continuously without damage within 47-52Hz |
| Tap changer type | - | OLTC / OCTC | OCTC subject to supporting studies |
| Tap changer technology | - | Vacuum | - |

## 5. Construction

The proposed transformer shall be of a 3-phase, oil immersed type with conservator and with a 3-limb core construction. Magnetic flux density shall not exceed 1.9T at any point of the core and any tap position. The dielectric cooling medium shall be in line with IEC 60296. The tank shall be capable of withstanding full vacuum when empty and oil hydraulic pressure test without developing an oil leak or allowing for oil ingress. All winding material shall be copper. The HV winding shall be connected in star with the neutral point access provided at the HV-N bushing. The LV winding will generally be of delta connection. It is not preferable to use same connection group, e.g. star-star. Such solutions will not be accepted unless necessary in specific cases. If a double LV winding transformer is proposed, a designer shall establish if an uneven loading of the LV windings is anticipated as an operation scenario and communicate this to the transformer manufacturer to make suitable design arrangements at an early stage.

## 6. Power

The proposed transformer power rating shall be adequate to the load it is anticipated for the proposed installation. It is a common practise to provide two power ratings: for oil natural and air natural circulation (ONAN) and for oil natural and air forced circulation (ONAF). This is convenient where it is anticipated that the transformer would not operate at close to its maximum rated power most of the time. The two power ratings shall be given in a ONAN/ONAF power (MVA) form. Forced air circulation will be achieved with fans. The designer shall bear in mind sound pressure implications and if there are any environmental restrictions it is advised to communicate this requirement to the transformer manufacturer at an early design stage.

## 7. Insultation Levels

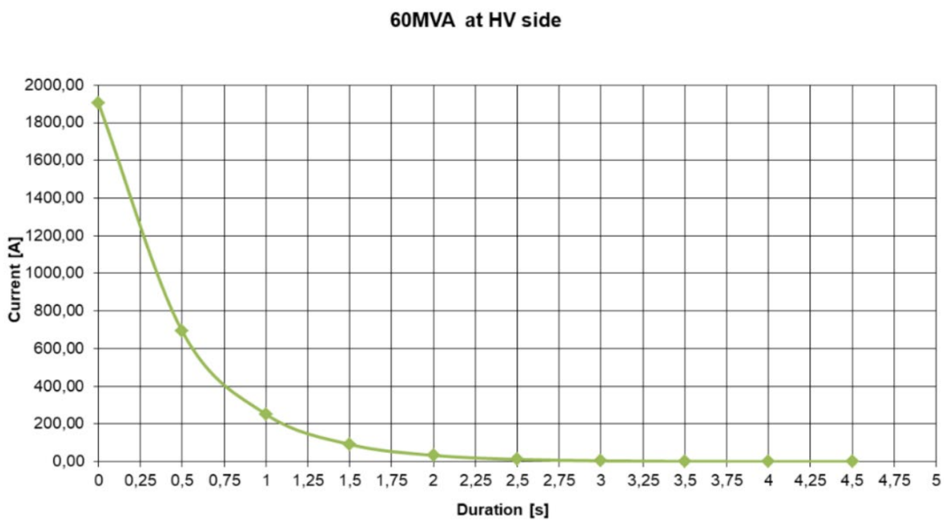
The AUL grid transformer will in most cases operate with the HV winding Starpoint solidly earthed, unless hosting DNO requires otherwise. It is anticipated that the 66kV or 132kV grid the proposed transformer connects to will operate as solidly earthed system, therefore minimum insulation withstand voltage of the HV neutral bushing shall be 44kV. In this case, a graded (non-uniform) HV winding insulation level is preferred, whereas the LV winding insulation shall be uniform. Insulation levels shall be in line with IEC 60076-3 and given in the format shown in the standard: the highest voltage of equipment (Um) / the rated lighting impulse withstand voltage for the terminal of each individual winding (LI) / the highest rated AC withstand voltage level to earth designed for the terminals of each winding (AC). Tab. 4.1. presents the extract from IEC 60076-3 for insulation levels required to cover all range of winding voltages the documents is concerned with.

## 8. Tap Changer and Voltage Control

Most commonly, grid transformers operate with an On-Load Tap Changer (OLTC) and such selection is preferred by AUL since it covers the widest range of prospective projects. However, if a designer believes that an OLTC is not required and it will not noticeably contribute to the proposed installation performance, an Off-Circuit Tap Changer (OCTC) may be considered. If an OCTC is selected, the designer shall support their decision by adequate calculation or power system study simulation proving that in all operational scenarios, all equipment is capable of operating within the range of its admissible parameters. Typical tapping range and tapping steps are presented in tab. 4.1 and the final selection is at the designer’s discretion. OLTC devices operate controlled by Automatic Voltage Controller (AVCs) which are usually mounted in OLTC drive boxes, therefore supplied with the transformer. This is the preferred solution. Alternatively, if an AVC cannot be installed in the transformer, it would usually be installed in the transformer protection panel. The tap changer type, tapping range and step shall be decided at an early stage of the design since late changes may lead to significant cost and lead time implications.

## 9. Inrush Curve

The core of the proposed transformer shall be designed to give as low in value and as quickly decaying energisation inrush current as practicable. A transformer inrush curve shall be requested from the manufacturer at an early stage of the design and checked against the minimum fault level value at the point of connection to ensure the




requirements of the EREC P28 are satisfied. An example of such curve is shown in fig. 9.1. It is highly recommended that the inrush curve is obtained, discussed with transformer manufacturer and approved at an early stage of the design. Any late changes may lead to significant cost and lead time implications.

## 10. Transformer Impedance

The impedance is one of the most important parameters of the proposed transformer and shall be carefully selected. It is usually expressed as an impedance voltage in percentage relation to the rated voltage. Tab. 4.1 presents typical range of grid transformer impedances. This value is usually in the region of 12%. The designer shall ensure that the selected impedance is adequate taking into consideration fault levels, voltage control and reactive power capability. Any selected impedances on the far ends of the given range will need to be supported with adequate power systems studies simulation or calculation. In specific applications, e.g. when an apportionment of the fault level is required at the LV side, there may be two LV windings. In such case two impedance values shall be given for both HV-LV and LV-LV winding pairs with a clear indication of the power level the values are given at. The impedance value shall be decided at an early stage of the design since late changes may lead to significant cost and lead time implications.

## 11. Operation Outside of Nominal Parameters

Changes in voltage in relation to frequency bring about magnetic flux variations in the core of a transformer. The proposed transformer shall be capable of operating continuously without being exposed to damage caused by over fluxing. This applies under the most onerous conditions resulting from the combinations of voltages within +/- 10% system rated voltage and frequencies between 47 and 52Hz.

## 12. Short-Circuit Withstand Capability

In line with IEC 60076-5, the proposed transformer shall be capable of withstanding the short-circuit current, without damage, for 2 seconds. The required withstand values are given in tab. 12.1.

**Tab. 12.1. 12. Short-Circuit Current Withstand Design Values**

| Winding | Rated short-circuit withstand current – RMS | Rated short-circuit withstand current – Peak |
|---|---|---|
| HV | 40kA | 100kA |
| LV | 31.5kA | 82kA |

## 13. Cooling

The proposed transformer may be cooled by radiators attached to the tank or by a freestanding bank of radiators. Maximum winding hot spots and top oil temperature shall be in line with IEC 60076-2 at ONAF and any tap position. For all operating conditions temperature of any part of the core or associated metalwork shall not exceed 95°C. Fans shall be controlled automatically and manually at the transformer as well as remotely from SCADA. All fan motors shall be protected against thermal overload and overcurrent. Fans as well as all other moving parts shall have wire mesh guards so they can be touched using a Standard Test Finger to IEC 60947-1.

## 14. Dehydrating Breather

Dehydrating breathers shall be of a self-regenerative / maintenance free type, that significantly reduces the likelihood of water ingress due to missed maintenance or premature degradation. The design should allow for access to the breather without lifting equipment. The breather for the tank and for the tap changer shall be of the same type.

## 15. Environmental Considerations

The proposed transformer would normally operate between minimum ambient temperature of -25°C and maximum ambient temperature of +40°C, at an altitude of below 1000m. Impact of the transformer on the surroundings as well as environmental conditions affecting the transformer shall be considered. As mentioned in section 6, sound pressure level shall be controlled and considered in the transformer's design. Apart from the ambient temperature, a pollution and a salinity level will have direct impact on the transformer's performance. These two factors affect the required corrosion protection and bushing creepage distances. Generally, AUL require their transformers to have at least C3 degree of corrosion protection and creepage distance of min. 25mm/kV for all bushings. The designer is welcome to support the selection with a suitable environmental report, however if such report is not provided, parameters shall be decided based on geographical location assessment. If the transformer is intended to be installed in highly industrial area or its direct proximity or within 10 miles from the coast, the corrosion protection shall be at C4 level and all bushing creepage shall be 31mm/kV.

## 16. HV Bushings

Bushing for HV windings (66 or 132kV) shall be of the condenser type with core insulation provided by either Epoxy Resin Impregnated Paper (ERIP) or Oil Impregnated Paper (OIP). Bushing creepage shall be coordinated with the environmental characteristics as discussed in section 15, effectively presenting either 25 or 31mm/kV. Care shall be taken when selecting the bushings' cantilever strength. It is generally required that the bushing withstand strength is at least 2kN, however the designer shall be aware of the fault level and the planned lengths of the busbars terminating at the bushings and select greater cantilever strength (e.g. around 3kN) if necessary. It is advised this number is fixed at an early stage of design. Late changes to bushing construction may lead to significant cost and lead time implications.

## 17. HV Surge Arrestors

Surge arrestors are strictly required for the HV side of the transformer. They shall be installed as close as possible to the HV bushings, and they shall be supported off the transformer tank on suitable brackets. The brackets shall be part of the transformer design and shall be manufactured and delivered by the transformer provider. Considerations shall be given to route the high frequency leads from the surge arrestor to earth with a minimum number of bends, bearing in mind relatively challenging location of the surge arrestors usually being installed right above the transformer's radiators. It is also important to consider height and inclination of the HV busbars and ensure that the position of the surge arrestor brackets leaves enough space between the HV busbar and the top of the surge arrestor for down droppers and connectors.

## 18. LV Bushings / Terminals

There are a few solutions for the LV side primary terminals provision. Directly exposed vertical 11kV or 33kV will not be accepted. In this case a suitable fully enclosed cable box with fully enclosed conduit housing busbars is required. The cable box shall be designed and provided by the transformer manufacturer to ensure it is fit for purpose and must not be provided later by others. Please note that an LV cable box may require additional supports at its far end that may fall outside of the transformer manufacturer's scope of supply. These supports, if necessary, shall be of a solid steel column type, subject to bespoke design. It is advised not to leave the procurement of such columns to late design stage and have them ready when landing the transformer. Any provisional support structures e.g. unitrust frame will not be accepted and expose the transformer to a serious damage. For the cable box design an additional structure, either freestanding or supported off the cable box columns, shall be provided for cleating of the LV cables. It is crucial that the number and sizes of the LV cables are decided at an early design stage and suitable provisions are made so the cable box can accept the required cables. Example of this solution is shown in fig. 18.1. As an alternative to the LV cable box design, type C bushings may be provided for connection of 11kV or 33kV cables terminated with tee connectors. Type C bushings shall be installed on the vertical plane of the transformer's LV side of the tank. This shall have a rain canopy installed directly above. Depending on the required number of cables there may be more than one bushing per phase and

/ or cables can be "piggy-backed" allowing to use one bushing for more than one cable. As for the cable box solution, selecting the type C bushing the designer shall ensure that considerations were made that adequate number and size of the LV cables can be terminated. Suitable brackets / support points shall be included on the vertical wall of the tank below the bushings. Example of this solution is shown in fig. 18.2.

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**Fig. 18.1.** LV cable box type transformer GA drawing showing cable box support column and cable support structure. On the HV side, a bracket with surge arrestor is shown.

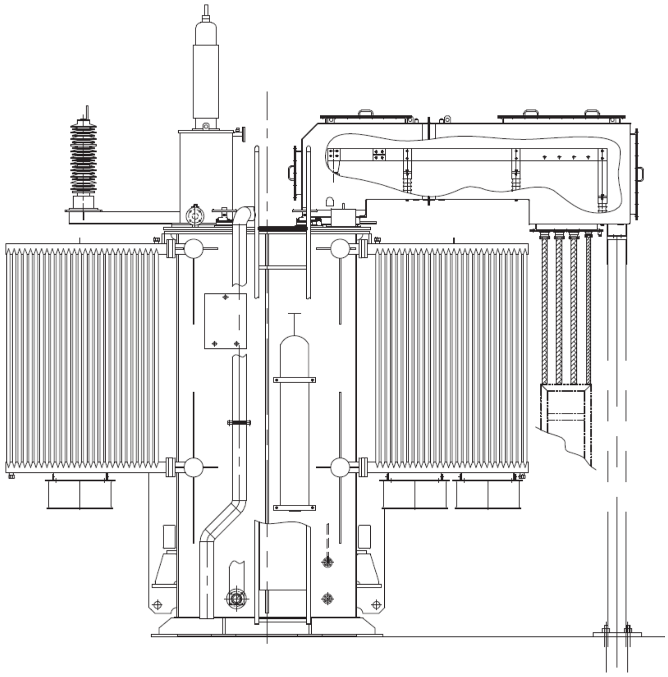
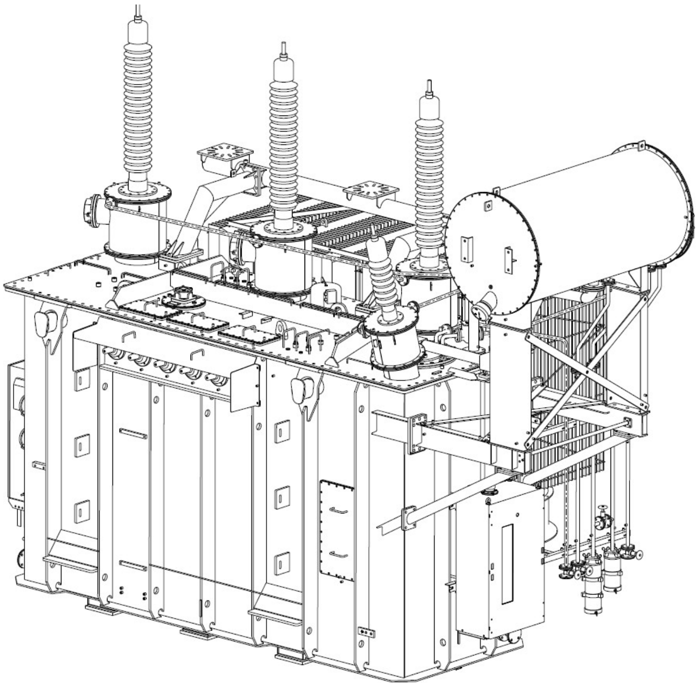


**Fig. 18.2.** LV type C bushing transformer GA drawing showing two bushings per phase with a rain canopy and cable support structure brackets. On the HV side, a bracket is shown for surge arrestors mounting.



## 19. Dissolved Gas Analyser

Dissolved Gas Analyser (DGA) is a device that monitors the contents of gases in the transformer oil. The following gases are usually subject to identification:

- Hydrogen ($H_2$)
- Carbon monoxide (CO)
- Acetylene ($C_2H_2$)
- Ethylene ($C_2H_4$)
- Total dissolved gases
- Moisture ($H_2O$)

Online monitoring of these components provides valuable information regarding any potential issues developing inside the transformer tank before a serious fault occurs. There are two types of measurements: composite and individual. AUL will generally not insist on DGA for transformers up to 50MVA, unless otherwise instructed, which usually cover most of the projects. Composite DGA shall be provided for units above 50MVA and individual DGA shall be provided for units above 75MVA.

## 20. Marshalling Kiosk

The marshalling cubicle shall be suitable for outdoor service and shall have a degree of protection to at least IP54 according to IEC 60529. It shall house and provide access to all terminals and equipment associated with control and protection of the transformer, including cooling control, auxiliary power supply, alarm and trip terminals as well as all CTs terminals. Auxiliary Power Supply, mainly to drive the cooling fans shall be 3ph 400V AC and the control voltage can generally be derived from there. The cubicle shall be adequately ventilated to ensure free air circulation over all equipment. This shall not reduce the stated degree of protection. Doors shall be secured by top and bottom fastenings operated by integral handle(s) capable of being locked. Thermostatically controlled heaters shall be provided to prevent condensation in each compartment. Suitable internal lighting shall be provided, which is suitably protected to avoid accidental contact or damage. Internal lighting shall be controlled by a door operated switch. An AC power socket shall be provided for supply of operator's equipment. The cubicle exterior shall have a non-corrodible finish. Any exposed ferrous parts shall have a zinc coating, and a document holder shall be installed on the inside of the access door. All equipment terminals shall be suitably shrouded and accessible for testing purposes. Sectionalised gland plates shall be provided to accommodate all incoming and outgoing cables.

## 21. OLTC Drive Box

If an On-Load Tap Changer is provided, its drive, controls, monitoring equipment and preferably the automatic voltage controller shall be all housed in a separate OLTC kiosk. The tap changer shall be operated locally by hand or electrically and remotely from SCADA. A manual operating handle shall be provided for local hand operation. The manual operating handle shall inhibit any electrical control when in use. The tap position shall be indicated mechanically and electrically. Key requirements for the OLTC mechanism are as follows:

- A six-figure, non-resettable counter shall be fitted to the tap changer mechanism to indicate the total number of tap-change operations completed by the equipment.
- The mechanism shall be designed to complete a tap-change operation, once movement has been started, in the event of supplies being lost. Restarting devices shall not be required.
- The nominal voltage of the electric motor shall be 3ph 400V AC. The rated frequency shall be 50Hz.

- The supply for the control equipment can generally be derived from the electric motor supply
- All other voltage supply requirements shall be satisfied by internally mounted Power Supply Units
- All electric motors and control circuits shall be protected by suitable overcurrent and thermal overload devices. These devices shall be fitted with a set of auxiliary contacts to provide a remote alarm. The tripping contacts associated with any thermal overload device shall be suitable for making and breaking the motor stalling current.
- A mechanical stop or other approved device shall be provided to prevent over-running of the mechanism under any condition. Over-running shall be prevented by limit switches controlling the motor supply and motor de-clutching mechanism as appropriate
- Facilities for the electrical isolation of the motor and control circuit, for maintenance purposes, shall be provided in the marshalling cubicle.

## 22. Protection

It is crucial that AUL grid transformer is equipped with a suitable protection system allowing for effective clearing of all types of faults affecting the transformer, both originating from inside the transformer as well as external faults affecting the transformer. Protection system dedicated for the transformer shall be focused locally on the transformer as much as practicable therefore the use of zone restricted protections is preferred. Protection system will generally comprise of:

- Transformer Protection Panel – housing protection devices and associated circuits – usually located in a control room at the substation,
- Transformer factory mounted protection devices – alarms and trips from these will be delivered to the transformer protection panel,
- Transformer Mounted CTs – signals from these will be delivered to the transformer protection panel.

### 22.1. Factory Mounted Protection

Grid transformers intended for AUL adoption shall have the following protection installed by the manufacturer with alarms and trip signals available:

- Buchholz relay for main tank: alarm and trip contacts
- Oil Surge Relay (OSR) for OLTC (also called OLTC Buchholz relay): alarm and trip contacts
- Oil level Indicator (OLI) for main tank with max and min alarm contacts
- (If possible) Oil level Indicator (OLI) for OLTC with max and min alarm contacts
- Oil Temperature Indicator (OTI) with alarm and trip contacts
- Winding Temperature Indicator (WTI) for HV winding with alarm and trip contacts
- Winding Temperature Indicator (WTI) for LV winding with alarm and trip contacts
- Pressure Relief Device (PRD) with trip contacts
- (If installed) Dissolved Gas Analyser (DGA) alarm contacts

All signals shall be wired out and available at the Marshalling Kiosk. If a digital AVC is installed, the alarms may be extended to the digital inputs of the AVC and transmitted to SCADA via protocol rather than hardwired signals – this allows for reduction in the number of multicores. All trip signals must be hardwired to the respective trip circuits at the transformer protection panel.

### 22.2. Factory Mounted Protection

It is of paramount importance to ensure enough CTs installed on the transformer. The following number and types of CTs shall be provided (where SET denotes a set of CTs in all phases and CT indicates one phase or neutral):

**HV SIDE:**

- SET 1: HV Restricted Earth Fault (HV REF1) - Adequate PX Class
- SET 2: Back-Up (BUP) / HV Overcurrent (HVOC) – Typically 5P20 Class
- SET 3: Transformer Differential / HV REF2 - Adequate PX Class
- SET 4: HV Connection Unit (Diff) Protection - Adequate PX Class
- CT 5: (usually in one phase installed by default): Thermal imaging (in manufacturer's discretion)

**HV NEUTRAL:**

- CT 1: HV REF1- Adequate PX Class
- CT 2: HV REF2- Adequate PX Class

**LV SIDE:**

- CT 1: (usually in one phase installed by default): Thermal imaging (in manufacturer's discretion)
- CT 2: Line Drop Compensation (LDC): in one phase - if required (space shall be reserved)

The above requirements don't take into consideration any HV installed plant metering/control CTs, since it assumed they are installed elsewhere (usually on HV HAM Units). However, if any more sets of CTs are required, they may be included subject to space restrictions in the transformer. It is recommended to confirm the required number of CTs with the manufacturer at an early design stage. Any late changes to CTs arrangements may lead to significant cost and lead time implications. The designer is responsible for detailed specification of the CTs (including burden, class or detailed PX class parameters) so it corresponds with the requirements of the project- specific protection system.

## 23. Technical Documentation

The design for the proposed transformer intended for AUL's adoption shall be supported by full suite of technical documents obtained from the manufacturer. As a minimum the suite shall contain:

- Datasheet,
- Transformer nameplate drawing,
- GA drawing,
- Schematics,
- Schematics for OLTC cabinet (if applicable),
- Inrush characteristic.

The set of documents shall be sufficiently detailed to carry the following information:

- Overall dimensions of the transformer
- Dimensions of all removable parts of the transformer
- Base/skid dimensions
- Lifting arrangements
- Total weight of the transformer
- Cable entry positions
- Volume of liquid
- Earthing points

- Location of ancillary equipment
- Details of secondary wiring including terminals for all CTs, trips, alarms, control and aux. power supply.

## 24. Testing

All routine tests shall be carried out on every transformer subject to AUL's adoption according to IEC 60076. AUL shall be informed of a planned FAT date and programme reasonably in advance allowing for overseas travel. Alternatively, it should be possible to join the FAT testing virtually. A complete test certificate/report is required upon completion detailing all methodology, equipment and results.

## 25. Transport, Installation, & Commissioning

Transport of the transformer to its destination site shall be carried out by any means recommended and arranged by the manufacturer or their approved appointed contractor. Irrespective of the method the transport shall be fully planned and coordinated taking into consideration dimension and weight of the transformer and associated equipment and any possible obstacles on the way (e.g. narrow roads, bridges etc). All measures shall be taken to prevent any damage to the transformer or its equipment resulting from the transport. The transformer shall be installed by an approved contractor and if necessary witnessed by the manufacturer's representative. Commissioning shall be undertaken by a competent engineer well informed of all technical details, drawings and design documents associated with the transformer.

## 26. Transformer Specification Checklist

Grid transformers intended for AUL adoption shall be complaint with this specification, however there are several crucial design parameters that can only be decided on a project-specific basis and are required relatively early during the design phase to allow for procurement. Grid transformers are one of the most important pieces of equipment and are considered high value long lead-time items and any late changes to the parameters of the transformer may have significant cost and lead-time implications. Running a high-level checklist as proposed below may be helpful to ensure all crucial parameters have been decided considering the range of the most important factors. Please note that the list below is not exhaustive.

**Selection of power, cooling methods, rated voltages and currents**
Considerations: general consideration of intended load, generation and switching equipment, sound pressure restrictions

**Selection of tap changer type, tapping range and impedance**
Considerations: consideration of load/generation/switching equipment range of admissible parameters, voltage control, reactive power capability and stability, load flow, fault levels

**Approval of the proposed inrush characteristic**
Considerations: admissible levels of voltage fluctuations during transformer energisation, EREC P28

**Selection of the HV bushings**
Considerations: location of site, pollution level and proximity of the sea affecting the required bushing creepage, fault level and distance between the bushing and the nearest point of busbar support determining the cantilever force acting on the bushing

**HV Surge arrestor bracket provision**
Considerations: distance between HV busbar and SA terminal to accommodate connectors and down droppers

**Selection of the LV bushings**

Considerations: number and size of 11/33kV cables per phase, provision of LV cable box adequate supports and cable cleating arrangements

**Selection of the transformer mounted CTs:**

Considerations: limitations of space to house the CTs affecting their maximum quantity, consideration of overall protection philosophy, detailed parameters of the CTs

## 27. Earthing Transformers & Neutral Earthing Resistors

It is required that AUL's grid transformers operate with star winding on the HV side and delta winding on the LV side. Due to the nature of the delta winding, there is no availability of the neutral point, which shall be created by means of an Earthing Transformer (ET) and an associated Neutral Earthing Resistor (NER). It is not permitted to operate AUL's 11kV or 33kV grid or any part of MV installation as fully isolated from earth.

Note that both an ET and an NER are required to take part in the earth fault restricting on the MV side (11/33kV) of the installation, which introduces both a reactive as well as a resistive impedance. There are solutions allowing for the earth fault current restriction by an ET only, without using an NER. In such case an ET is often referred to as a high-impedance ET. This solution is generally not preferred by AUL; however it will not be opposed to should the designer wishes to use it. In this case, when the earth fault current is restricted only by a reactive impedance the designer should prove by calculation or simulation, that takes into consideration capacitances of all MV equipment (predominantly cables), that there are no resonances affecting the installation and the designed restricted earth fault current value is achieved with high-impedance earthing transformer.

Similarly to the grid transformer, AUL do not provide a closed list of approved manufacturers for ETs and NERs, and they can be considered generally accepted if in line with this specification and not having any SOP and DIN entries (see section 3).

### 27.1. MV Earth Fault Design Value

Use of an ET+NER with the delta connected side of the grid transformer creates the path for earth current to flow, therefore introduces zero-sequence impedance that will determine its value. Design value of the MV earth fault current shall be a compromise between sufficiently high, that can be effectively picked up by the protection system, and sufficiently low, that does not pose threat to people and animals resulting from an Earth Potential Rise (EPR). It is common to see these values ranging from 1kA to about 3kA. For AUL MV installations it is required that the earth fault current does not exceed 1kA and the adequate impedance of an ET+NER (or Hi-Imp ET) is selected. It is a good practice for the actual earth fault current value to be restricted just below the current rating of the grid transformer so that OC protection is not activated in case of an earth fault, but not significantly lower, if this value is already below 1kA, for protection sensitivity. When an ET+NER is used, it shall be accounted for a scenario in which the NER, due to its fault (e.g. flashover) is excluded from the zero-sequence impedance – in this case the ET on its own shall restrict the earth fault current to at least 2kA.

### 27.2. Earthing Transformer Specification

In most cases an Earthing Transformer (ET) will serve as Earthing Auxiliary Transformer (EAT). This will comprise two windings – an HV (11kV or 33kV) and an LV (0.4kV-0.433kV) winding. The HV winding of an EAT shall be connected in zigzag, also referred to as an interconnected star (ZN connection group), which creates the neutral point and offers a low impedance for the zero sequence currents. The LV winding shall be a star connection with directly earthed neutral point. In most cases this will provide a source of an auxiliary supply for a AUL control room. Procuring very small power EATs may not be economical therefore an EAT shall have power within the range of 50-200kVA, unless larger power is required. During an earth fault, the transformer shall be capable of handling 1kA for 10s. If AUL control room auxiliary supply can be obtained safely elsewhere, and there is no other application for the LV winding, it can be removed, and the transformer may comprise only the HV (zigzag) winding. This is provided that the exclusion of the LV winding offers cost or lead time benefits.

The proposed EAT shall comply with IEC 60289 and shall be of the oil immersed ONAN type as defined in IEC 60076. It shall be of a hermetically sealed construction. Tab. 27.1 presents the range of parameters considered as typical for AUL projects. The proposed transformer may be considered generally accepted if the parameters are within the given range. Further in this section some of the specification aspects are described in more detail.

**Tab. 27.1**. Required parameters of AUL's earthing (auxiliary) transformers

| Parameter | Unit | Required value | Comments |
|---|---|---|---|
| Type | - | Oil-immersed hermetically sealed | - |
| Number of phases | - | 3 | - |
| Rated Power | kVA | 50kVA – 200kVA | Power may be greater for special applications |
| Cooling method | - | ONAN | - |
| HV side rated voltage | kV | 33kV or 11kV | - |
| LV side rated voltage | kV | 0.4kV | Often 415V or 433V are offered, this is acceptable if suitable tapping is available |
| Tap changer type | - | OCTC (off-load) | - |
| Tapping range | % | +/- 2x2.5% | - |
| Winding material | - | Copper or Aluminium | - |
| Vector group | - | ZNyn11 | Exclusion of LV winding can be accepted if justified then ZN (ZN0) group |
| Frequency | Hz | 50Hz | - |
| Positive sequence impedance (HV-LV) | % | >2% | - |
| Zero-sequence impedance | Ω/ph | See comments | Zo shall be coordinated with NER to restrict EF current max. 1kA and to max. 2kA in case NER is excluded due to fault |
| HV earth fault withstand | kA/s | 1kA / 10s | This is a minimum requirement |
| Minimum Continuous neutral current | A | 10A | This is the current that can flow continuously through the neutral terminal without damage |

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|---|---|---|---|
| HV terminals | - | Cable box | - |
| LV terminals | - | MCCB housed in LV cabinet | - |
| Protection | - | DMCR + PRD | - |
| CTs | - | See comments | If with NER: 1 x PX Class CT for LV-N<br>If Hi-Imp: above + 1 x PX + 1 x 5P20 CT for HV-N |
| Losses | - | Subject to detailed design | Losses shall be as low as practicable |
| Paint colour | - | RAL 7033 (grey) | Most common colour however environmental arrangements may call for different (e.g. green) |
| Minimum corrosion protection class | - | C3 (medium) | Typical, C4 is required for location within 10 miles from the sea or for highly polluted areas |
| Weight, dimensions, oil volume | - | Subject to detail TX design | These will be advised by the manufacturer |
| Max temperature rise: oil, winding, hot spots | - | Subject to detail TX design | These will be advised by the manufacturer |

### 27.2.1 Protection

Hermetically sealed transformer shall be equipped with Pressure Relief Device (PRD) with trip contacts and a DMCR. Detection, Measurement and Control Relay (DMCR) shall be equipped with suitable alarm and trip contacts for monitoring of tank's internal parameters such as pressure, temperature, oil level and emitted gas. When it comes to the protection CTs on the HV side, if an EAT operates with an NER, these are not generally required and assumed they will be mounted on the NER. If the NER is not present, HV winding neutral CTs shall be provided (1x5P20 and 1xPX class). Since the EAT is designed to be connected directly to the LV terminals of the grid transformer, care must be taken to prevent any LV (0.4kV) side faults causing tripping of the HV protection and subsequent de-energisation of the grid transformer. The proposed EAT shall have a factory installed LV cabinet housing a suitable MCCB, capable of taking the required size and number of the LV cables, that shall provide OC protection. It is required that AUL adopted EATs have factory installed provisions to facilitate for an LV REF protection. Suitable PX class CTs shall be installed at the neutral point of the star connected LV winding. Bolted link shall be provided after the NCT allowing for connecting the N transformer terminal to the cabinet's earth bar for further connection to earth. The MCCB shall be a 4-pole breaker. Phase CTs shall be located at the incomer of an LVAC board, usually located in the AUL's control room, so that the REF protection zone spans precisely the LV winding of the EAT and the LV cable to the distribution board only. A suitable REF relay shall be installed in the LVAC distribution board and shall pass the trip signal to the MCCB.

## 27.3. Neutral Earthing Resistor Specification

The proposed Neutral Earthing Resistor shall comply with requirements set out in IEEE C57.32a. The required resistance shall be adequate so that the EAT+NER combined zero-sequence impedance restricts the MV side EF current value to a maximum of 1kA. This current shall be withstood for 10s with a continuous current of min. 10A. Space shall be reserved for one 5P20 class CT on the HV side (before) of the resistive element and two PX class CTs on the neutral side (after) of the resistive element. Tab. 27.2 presents

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the range of parameters considered as typical for AUL projects. The proposed NER may be considered generally accepted if the parameters are within the given range.

**Tab. 27.2.** Required parameters of AUL's Neutral Earthing Resistors

| Parameter | Unit | Required value | Comments |
|---|---|---|---|
| Rated System Voltage | kV | 33kV or 11kV | - |
| Line-neutral voltage | kV | 19.05kV or 6.35kV | - |
| Rated Current | kA | 1kA | - |
| Minimum continuous current | A | 10A | - |
| Resistance | Ω | See comments | Adequate so that combined with EAT it restricts the EF current to a max. of 1kA |
| CTs | - | See comments | 1 x 5P20 Class CT for HV and 2x PX class for N side of the resistive element |

## 28. List of Applicable Standards

A transformer / NER manufacturer shall ensure that it is manufactured in line with the latest available version of the applicable standards as listed below (tab. 28.1). Please note that the list is not exhaustive, and manufacturer is not limited to follow these standard alone. For some standards most relevant parts are listed however all parts may be applicable and shall be considered. Large number of standards below are direct equivalents between IEC and BS EN, therefore subject to the corresponding reference numbers and titles, they can be used interchangeably.

**Fig. 28.1.** List of applicable standards

| Reference | Title |
|---|---|
| ESQC | The Electricity Safety, Quality and Continuity Regulations 2002 |
| HASAW | The Health and Safety at Work Act 1974 |
| CDM | Construction Design and Management Regulations 2007 |
| EAW | The Electricity at Work Regulations 1989 |
| COSHH | Control of Substances Hazardous to Health Regulations 2002 |
| BS EN ISO 780 | Packaging. Pictorial Marking of Handling of Goods |
| BS EN ISO 12944-2 | Paints and Varnishes. Corrosion Protection of Steel Structures by Protective Paint Systems. Part 2: Classification of Environments |
| BS EN ISO 14001 | Environmental Management Systems. Requirements with Guidance for use |
| BS EN ISO 1461 | Hot Dip Galvanized Coatings on Fabricated Iron and Steel Articles – Specification and test methods (1999) |

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|---|---|
| BS EN ISO 9000 | Quality management systems. Fundamentals and vocabulary |
| BS EN ISO 9001 | Quality management systems – Requirements |
| IEC 60034-1 | Rotating electrical machines. Rating and performance |
| IEC 60076-1 | Power transformers - Part 1: General |
| IEC 60076-2 | Power transformers - Part 2: Temperature rise |
| IEC 60076-3 | Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air |
| IEC 60076-5 | Power transformers  - Part 5: Ability to withstand short circuit |
| IEC 60076-7 | Power transformers - Part 7: Loading guide for mineral-oil-immersed power transformers |
| IEC 60076-10 | Power transformers - Part 10: Determination of sound levels |
| IEC 60137 | Insulated Bushings for Alternating Voltages Above 1000V |
| IEC 60214-1 | Tap-Changers -Part 1: Performance Requirements and Test Methods |
| IEC 60214-2 | Tap-Changers - Part 2: Application Guide |
| IEC 60269-1 | Low-Voltage Fuses – Part 1: General Requirements |
| IEC 60296 | Fluids for electrotechnical applications. Mineral insulating oils for electrical equipment |
| IEC 60404 | Magnetic Materials |
| IEC 60507 | Artificial Pollution Tests on High-Voltage Insulators to be used on a.c. systems |
| IEC 60529 | Degrees of protection provided by enclosures (IP code) |
| IEC 60898 | Specification for circuit-breakers for overcurrent protection for household and similar installations |
| IEC TS 60815 | Selection and dimensioning of high-voltage insulators intended for use in polluted conditions |
| IEC 60947-1 | Low-Voltage switchgear and controlgear – Part 1: General Rules |
| IEC 60947-2 | Low-voltage switchgear and controlgear - Part 2: Circuit-breakers |
| IEC 60947-3 | Low-voltage switchgear and control gear - Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units |
| IEC TR 60616 | Terminal and Tapping Markings for Power Transformers |
| IEC 61869-1 | Instrument transformers - Part 1: General requirements |
| IEC 61869-1 | Instrument transformers - Part 2: Additional requirements for current transformers |
| BS EN 593 | Industrial valves. Metallic butterfly valves for general purposes |
| BS EN 1171 | Industrial valves. Cast iron gate valves |
| BS EN 10029 | Hot-rolled steel plates 3 mm thick or above. Tolerances on dimensions and shape |
| BS EN 10244 | Steel wire and wire products. Non-ferrous metallic coatings on steel wire |

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|---|---|
| BS EN 12163 | Copper and copper alloys. Rod for general purposes |
| BS EN 12288 | Industrial Valves. Copper Alloy Gate Valves |
| BS EN 13601 | Copper and Copper Alloys – Copper Rod, Bar and Wire for General Electrical Purposes (2002) |
| BS EN 50180 | Bushings above 1kV up to 36 kV and from 250A to 3,15kA for Liquid Filled Transformers |
| BS EN 50216-1 | Power Transformer and Reactor Fittings – General |
| BS EN 50216-2 | Power Transformer and Reactor Fittings – Gas and Oil Actuated Relay for Liquid Immersed Transformers and Reactors with Conservator |
| BS EN 50216-4 | Power Transformer and Reactor Fittings – Basic Accessories (earthing terminal, drain and filling devices, thermometer pocket, wheel assembly) |
| BS EN 50216-5 | Power Transformer and Reactor Fittings - Liquid level, pressure and flow indicators, pressure relief devices and dehydrating breathers |
| BS EN 50216-6 | Power Transformer and Reactor Fittings – Cooling Equipment – Removable Radiators for Oil-Immersed Transformers |
| BS EN 50216-7 | Power Transformer and Reactor Fittings – Cooling Equipment – Electric Pumps for Transformer Oil |
| BS EN 50216-11 | Power Transformer and Reactor Fittings – Oil and winding temperature indicators |
| BS EN 50216-12 | Power Transformer and Reactor Fittings – Fans |
| BS EN 60064 | Tungsten Filament Lamps for Domestic and Similar General Lighting Purposes – Performance Requirements |
| BS EN 60270 | High-voltage test techniques. Charge-based partial discharge measurements |
| BS EN 60470 | High voltage alternating current contactors and contactor-based motor starters |
| BS EN 61184 | Bayonet Lamp holders (1997) |
| BS 148 | Recycled mineral insulating oil for transformers and switchgear. Specification |
| BS 381C | Specification for colours for identification, coding and special purposes |
| BS 2562 | Specification for cable boxes for transformers and reactors |
| BS 3643 | ISO metric screw threads |
| BS 3692 | ISO metric precision hexagon bolts, screws and nuts. Specification |
| BS 3693 | Recommendations for design of scales and indexes on analogue indicating instruments |
| BS 4190 | ISO metric black hexagon bolts, screws and nuts. Specification |
| BS 5154 | Specification for Copper Alloy Globe, Globe Stop and Check, Check and Gate Valves for General Purposes |
| BS 5499 | Graphical Symbols and Signs – Safety Signs, including Fire Safety Signs |
| BS 6724 | Electric cables. Thermosetting insulated, armoured cables of rated voltages of 600/1 000 V and 1 900/3 300 V for fixed installations, having low emission of smoke and corrosive gases when affected by fire. Specification |

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|---|---|
| BS 6231 | Electric cables. Single core PVC insulated flexible cables of rated voltage 600/1000 V for switchgear and control gear wiring |
| ENA TS 09-6 | Auxiliary multicore and multipair cables |
| ENA TS 12-11 | Enclosed unfilled terminations of cables with rated voltages 12, 24 and 36 kV |
| ENA TS 50-18 | Application of ancillary electrical equipment |
| ENA TS 50-19 | Standard numbering for small wiring (for switchgear and transformers together with their associated relay panels) |
| ENA TS 98-1 | Environmental classification and corrosion protection of structures, plant and equipment |
| DEF STAN 61-12:<br><br>PART 5 | Defense Standard – Wires, Cords and Cables, Electrical – Metric Units – Part 5 – Cables, Special Purpose, Electrical and Cables, Power, Electrical (small multi-core cables) |
| CENELEC - HD 629-1-S3 | Test requirements for accessories for use on power cables of rated voltage from 3,6/6(7,2) kV up to 20,8/36(42) kV - Part 1: Accessories for cables with extruded insulation |
| in IEEE C57.32a | IEEE Standard for Requirements, Terminology, and Test Procedure for Neutral Grounding Devices--Amendment 1: Neutral Grounding Resistors Clause (AM) |