Specification

Traction Rectifier Transformer

Version 1.0
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Standard governance

Owner: Lead Electrical Engineer, Asset Standards Authority
Authoriser: Chief Engineer, Asset Standards Authority
Approver: Executive Director, Asset Standards Authority on behalf of the ASA Configuration Control Board

Document history

<table>
<thead>
<tr>
<th>Version</th>
<th>Summary of changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>First issue</td>
</tr>
</tbody>
</table>
Preface

The Asset Standards Authority (ASA) is a key strategic branch of Transport for NSW (TfNSW). As the network design and standards authority for NSW Transport Assets, as specified in the ASA Charter, the ASA identifies, selects, develops, publishes, maintains and controls a suite of requirements documents on behalf of TfNSW, the asset owner.

The ASA deploys TfNSW requirements for asset and safety assurance by creating and managing TfNSW’s governance models, documents and processes. To achieve this, the ASA focuses on four primary tasks:

- publishing and managing TfNSW's process and requirements documents including TfNSW plans, standards, manuals and guides
- deploying TfNSW's Authorised Engineering Organisation (AEO) framework
- continuously improving TfNSW’s Asset Management Framework
- collaborating with the Transport cluster and industry through open engagement

The AEO framework authorises engineering organisations to supply and provide asset related products and services to TfNSW. It works to assure the safety, quality and fitness for purpose of those products and services over the asset's whole-of-life. AEOs are expected to demonstrate how they have applied the requirements of ASA documents, including TfNSW plans, standards and guides, when delivering assets and related services for TfNSW.

Compliance with ASA requirements by itself is not sufficient to ensure satisfactory outcomes for NSW Transport Assets. The ASA expects that professional judgement be used by competent personnel when using ASA requirements to produce those outcomes.

About this document

This document provides requirements for the procurement of rectifier transformers for use in the RailCorp 1500 V dc traction system. This document also incorporates requirements to ensure compatibility with the existing systems that interface with the rectifier transformer.

This document has been developed from RailCorp document EP 03 01 40 00 SP Rectifier Transformer, version 3.1.

EP 03 01 40 00 SP is withdrawn with the publication of this document.

This document is a first issue.

The changes from the previous content include the following:

- addition of requirements for dry type rectifier transformers
- details on the use of synthetic esters
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1. **Introduction**

The existing direct current (dc) traction system is a nominal 1500 V dc system.

The 1500 V dc traction power supply is provided to the overhead wiring (OHW) from traction substations and is obtained by transforming and rectifying the incoming high voltage (HV) (66 kV or 33 kV) obtained from the RailCorp HV distribution network.

The rectifier transformers covered by this document are used to transform the incoming HV ac supply to a suitable low voltage (LV) for input to the 1500 V dc rectifier.

2. **Purpose**

This document stipulates the whole-of-life performance and technical requirements for a traction rectifier transformer to enable suitable equipment to be procured for use in the RailCorp electrical network.

2.1. **Scope**

This document provides specifications for traction rectifier transformers that are type and routine tested and fitted with all auxiliary equipment for use in the RailCorp electrical network.

2.2. **Application**

This document applies to procurement of new dry or liquid immersed traction rectifier transformers for use with uncontrolled 12 pulse full wave series bridge rectifiers.

The traction rectifier transformer specified in this document is not suitable for use with the full wave parallel bridge or 6 pulse or 12 pulse half-wave rectifiers that have also been used in the RailCorp network.

The requirements of this document do not apply to the operation or maintenance of existing traction rectifier transformers in the RailCorp electrical network.

If, when using the standard, the intent of stated requirements is not clear, a clarification should be sought from the Lead Electrical Engineer, Asset Standards Authority (ASA).

3. **Reference documents**

The following documents are cited in the text. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document applies.

**International standards**

EN 50180 Bushings above 1 kV up to 52 kV and from 250 A to 3.15 kA for liquid filled transformers
IEC 60296 Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear

IEC 60840 Power Cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) – Test methods and requirements

IEC 61378-1 Converter transformers – Part 1: Transformers for industrial applications

IEC 62535 Insulating liquids – Test method for detection of potentially corrosive sulphur in used and unused insulating oil

Australian standards

AS 1627.4 Metal Finishing – Preparation and pretreatment of surfaces Part 4: Abrasive blast cleaning of steel

AS 1657 Fixed platforms, walkways, stairways and ladders – Design, construction and installation

AS 2067 Substations and high voltage installations exceeding 1 kV a.c.

AS 2700 Colour Standards for general purposes

AS/NZS 3000 Electrical installations “Wiring Rules”

AS 60146.1.3 Semiconductor converters Part 1.3: General requirements and line commutated converters – Transformers and reactors

AS/NZS 1891.4 Industrial fall-arrest systems and devices - Selection, use and maintenance

AS/NZS 4680 Hot-dip galvanised (zinc) coatings on fabricated ferrous articles

AS/NZS 60076.1 Power transformers Part 1: General (IEC 60076-1, Ed. 3.0 (2011) MOD)

AS/NZS 60076.2 Power transformers Part 2: Temperature rise for liquid-immersed transformers (IEC 60076-2, Ed. 3.0 (2011) MOD)

AS/NZS 60076.3 Power transformers Part 3 Insulation levels, dielectric tests and external clearances in air (IEC 60076-3:2013 (ED. 3.0) MOD)

AS/NZS 60076.7 Power transformers Part 7: Loading guide for oil-immersed transformers (IEC 60076-7, Ed. 1.0 (2005) MOD)

AS/NZS 60076.10 Power transformers Part 10: Determination of sound levels (IEC 60076-10, Ed. 1 (2001) MOD)

AS/NZS 60137 Insulated bushings for alternating voltages above 1000 V (IEC 60137, Ed. 5.0 (2003) MOD)

Transport for NSW standards

EP 00 00 00 13 SP Electrical Power Equipment - Design Ranges of Ambient Conditions

EP 00 00 00 15 SP Common Requirements for Electrical Power Equipment
4. Terms and definitions

The following terms and definitions apply in this document:

**ac** alternating current

**ACCB** alternating current circuit breaker

**AEO** Authorised Engineering Organisation

**ASA** Asset Standards Authority

**dc** direct current

**DCCB** direct current circuit breaker

**HV** high voltage
5. **ASA type approval**

All rectifier transformers procured in accordance with this specification requires type approval by the ASA prior to being connected to the RailCorp electrical network.

The type approval process is contained in T MU MD 00005 GU *Type Approval of Products*.

6. **Functional requirements**

Rectifier transformers shall provide for the following:

- transformation of HV (66 kV or 33 kV ac) to 2 x 600 V ac (star and delta windings)
- provision of offline remotely operated and monitored tap-changer
- measurement of the rectifier transformer temperature
- provision of transformer protective devices
- connection of HV cables to the associated HV switchgear or outdoor busbar
- connection of 600 V ac cables to the 1500 V dc rectifier power cubicle
- connection of supervisory control and data acquisition (SCADA), protection and auxiliary cabling
- provision for operation in an environment with conditions as prescribed in this document

7. **Performance requirements**

Where not specifically detailed in this document, the performance requirements of the transformer shall be in accordance with the following standards:

- AS/NZS 60076 *Power Transformers* (all parts)
- AS 60146 *Semiconductor converters Part 1.3: General requirements and line commutated converters – Transformers and reactors*

Rectifier transformers shall be specifically designed for traction rectifier duty.
AS 60146 provides applicable requirements for heavy traction duty (class V1) rectifier transformers for use with a 12 pulse, series bridge uncontrolled rectifier.

Table 1 provides general requirements for dry type rectifier transformer.

### Table 1 – Dry type transformer general requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Outdoor or indoor</td>
</tr>
<tr>
<td>Construction type</td>
<td>Encapsulated vacuum cast resin</td>
</tr>
<tr>
<td>Cooling method</td>
<td>AN</td>
</tr>
<tr>
<td>IP rating (indoor)</td>
<td>IP22</td>
</tr>
<tr>
<td>IP rating (outdoor)</td>
<td>IP43</td>
</tr>
</tbody>
</table>

Table 2 provides general requirements for liquid immersed rectifier transformer.

### Table 2 – Liquid immersed type transformer general requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Outdoor</td>
</tr>
<tr>
<td>Cooling method</td>
<td>ONAN (oil natural air natural)</td>
</tr>
<tr>
<td>Type of liquid</td>
<td>Liquid immersed (mineral oil or synthetic ester)</td>
</tr>
</tbody>
</table>

Table 3 provides details on the technical ratings for both dry type and liquid immersed 33 kV rectifier transformers.

### Table 3 – 33 kV Transformer technical ratings

<table>
<thead>
<tr>
<th>Technical parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage:</td>
<td></td>
</tr>
<tr>
<td>• HV</td>
<td>• 33 kV (rms)</td>
</tr>
<tr>
<td>• LV</td>
<td>• 600 V (rms) × 2</td>
</tr>
<tr>
<td>System highest voltage:</td>
<td></td>
</tr>
<tr>
<td>• HV</td>
<td>• 36 kV (rms)</td>
</tr>
<tr>
<td>• LV</td>
<td>• 3.6 kV (rms)</td>
</tr>
<tr>
<td>Rated insulation level:</td>
<td></td>
</tr>
<tr>
<td>• HV – lightning impulse</td>
<td>• 200 kV (peak)</td>
</tr>
<tr>
<td>• HV – power frequency</td>
<td>• 70 kV (rms)</td>
</tr>
<tr>
<td>• LV – lightning impulse</td>
<td>• 20 kV (peak)</td>
</tr>
<tr>
<td>• LV – power frequency</td>
<td>• 10 kV (rms)</td>
</tr>
</tbody>
</table>

Table 4 provides the technical ratings for both dry type and liquid immersed 66 kV rectifier transformers.
### Table 4 – 66 kV Transformer technical ratings

<table>
<thead>
<tr>
<th>Technical parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage:</td>
<td></td>
</tr>
<tr>
<td>• HV</td>
<td>66 kV (rms)</td>
</tr>
<tr>
<td>• LV</td>
<td>600 V (rms) x 2</td>
</tr>
<tr>
<td>System highest voltage:</td>
<td></td>
</tr>
<tr>
<td>• HV</td>
<td>72.5 kV (rms)</td>
</tr>
<tr>
<td>• LV</td>
<td>3.6 kV (rms)</td>
</tr>
<tr>
<td>Rated insulation level:</td>
<td></td>
</tr>
<tr>
<td>• HV – lightning impulse</td>
<td>325 kV (peak)</td>
</tr>
<tr>
<td>• HV – power frequency</td>
<td>140 kV (rms)</td>
</tr>
<tr>
<td>• LV – lightning impulse</td>
<td>20 kV (peak)</td>
</tr>
<tr>
<td>• LV – power frequency</td>
<td>10 kV (rms)</td>
</tr>
</tbody>
</table>

Table 5 provides the technical ratings that are common to both dry type and liquid immersed 33 kV and 66 kV transformers.

### Table 5 - Technical ratings common to both 33 kV and 66 kV transformers

<table>
<thead>
<tr>
<th>Technical parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection symbol</td>
<td>Yy0d1 or YNy0d</td>
</tr>
<tr>
<td>Rated frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Rated power (continuous MVA) exclusive of harmonics</td>
<td>4.28 MVA (HV), 2 x 2.205 MVA (LV) - not to be used for new locations</td>
</tr>
<tr>
<td></td>
<td>5.35 MVA (HV), 2 x 2.714 MVA (LV)</td>
</tr>
<tr>
<td>Note: <em>The rating of the two LV windings are equal and are slightly higher than ( \frac{1}{2} ) of the HV rating.</em></td>
<td></td>
</tr>
<tr>
<td>LV ratio</td>
<td>Voltage ratio between star and delta LV shall match within 0.5%</td>
</tr>
<tr>
<td>Overload ratings</td>
<td>Refer to T HR EL 90003 ST Heavy Rail Traction System Current Ratings of 1500 V dc Equipment</td>
</tr>
<tr>
<td>Maximum winding temperature rise (oil immersed at 40°C ambient)</td>
<td>50°C in accordance with AS 60146.1.3 for duty class VI</td>
</tr>
<tr>
<td>See note 1</td>
<td></td>
</tr>
<tr>
<td>Maximum winding temperature (dry type at 40°C ambient)</td>
<td>70°C insulation class F</td>
</tr>
<tr>
<td></td>
<td>85°C insulation class H in accordance with AS 60146.1.3 for duty class V1</td>
</tr>
<tr>
<td>See note 1</td>
<td></td>
</tr>
<tr>
<td>Fault level:</td>
<td></td>
</tr>
<tr>
<td>• HV</td>
<td>1500 MVA for 3 phase symmetrical fault</td>
</tr>
<tr>
<td>• LV</td>
<td>limited by transformer impedance</td>
</tr>
</tbody>
</table>
### Technical parameter | Rating
---|---
Sound power level | Refer to AS 60076.10 Power transformers Part 10: Determination of sound levels
Ambient temperature range | In accordance with EP 00 00 00 13 SP Electrical Power Equipment – Design Ranges of Ambient Conditions

**Note 1:** The maximum winding temperature is required to be reduced to correspond to the maximum ambient temperature as specified in EP 00 00 00 13 SP.

Table 6 provides the reactance requirements for both dry type transformers and liquid immersed transformers.

#### Table 6 - Transformer reactance

<table>
<thead>
<tr>
<th>Reactance (at rated primary MVA base - on principal tap)</th>
<th>4.28 MVA</th>
<th>5.35 MVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both LV windings shorted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>minimum</td>
<td>12.0%</td>
<td>14.0%</td>
</tr>
<tr>
<td>maximum</td>
<td>13.0%</td>
<td>15.0%</td>
</tr>
<tr>
<td>Either LV winding shorted, the other LV winding open circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>minimum</td>
<td>12.5%</td>
<td>14.5%</td>
</tr>
<tr>
<td>maximum</td>
<td>13.5%</td>
<td>15.5%</td>
</tr>
<tr>
<td>Reactance between LV windings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>maximum</td>
<td>2.6%</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

Table 7 Provides details on the general requirements of the off load tapchanger.

#### Table 7 – Off load tap-changer requirements

<table>
<thead>
<tr>
<th>Technical parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High voltage winding tapping range</td>
<td>-4.5% to +4.5% of nominal voltage in increments of 1.5%</td>
</tr>
<tr>
<td>Type of tap-changer</td>
<td>Off load</td>
</tr>
<tr>
<td>Tap-changer motor drive voltage (see note 2)</td>
<td>Option 1 – 415 V ac (3 phase) Option 2 – 220 V ac (3 phase)</td>
</tr>
<tr>
<td>Tap-changer control voltage</td>
<td>125 V dc</td>
</tr>
</tbody>
</table>

**Note 2:** The substation auxiliary ac voltage will be nominated at time of order of the transformer. The 220 V supply is an unearthed supply.

### 8. Technical requirements

All equipment supplied shall withstand normal handling during transportation and installation, continuous operation under the conditions specified in this document, and is suitable for the required duty.
All bolts, nuts and washers used outside the tank shall be hot dip galvanised or stainless steel.

All nuts within the tank shall be fitted with locking devices.

All valves, flanges and other equipment shall be easily accessible with the transformer installed on a flat concrete slab. The transformers shall be transported complete and be simple to install to minimise construction time.

### 8.1. Transformer overload conditions

The rectifier transformer shall be capable of conducting 100 percent rated load continuously followed by any one of the overload conditions detailed in T HR EL 90003 ST *Heavy Rail Traction System Current Ratings of 1500 V dc Equipment*. The equipment shall meet each one of these individual overload conditions after temperature stabilisation at 100 percent load. The intent is not to apply the overload conditions consecutively.

The rectifier transformer can be expected to sustain overload conditions twice a day, once in the morning peak period and once in the afternoon peak period.

An allowance for harmonics in winding currents due to 12 pulse rectifications shall be added to the overload requirements in accordance with the conditions specified in T HR EL 90003 ST.

### 8.2. Transformer winding configuration requirements

The transformer shall be provided with a single primary winding (star connected) and two secondary windings; one connected in star and one connected in delta. The delta winding can be a split delta to obtain a close coupled design. The secondary windings shall be of adequate power and voltage and they shall be arranged such that leakage reactance between them shall be small compared with the leakage reactance between secondary and primary winding.

Table 6 details the minimum and maximum reactance.

Rectifier transformers are subject to frequent short circuits that are consistent with railway traction duty. The design is required to incorporate features to ensure all applied stresses do not result in unacceptable strains.

### 8.3. Transformer core and winding construction requirements

The transformer core and winding construction requirements are provided in Section 8.3.1 through to Section 8.3.3.

#### 8.3.1. Core material

Laminations shall be formed from the highest grade of cold rolled grain oriented silicon steel.
8.3.2. **Winding material**

HV windings shall be manufactured using the following:

- copper for liquid immersed transformers
- aluminium for dry type transformers

8.3.3. **Core construction**

The core shall be designed and constructed to withstand the stresses imposed by service conditions, lifting, transport, handling and earthquakes and without deterioration.

The core earth connection shall be inserted in the core lamination to a depth that the core clamp brings sufficient pressure to bear upon it such that the connection is maintained for all operating conditions.

Only one connection shall be present between the core and the earth bushing, the core connection of which shall be readily accessible during assembly. TfNSW intends to verify that the core to tank insulation is sound during the erection programme and accordingly the earth shall be designed to allow easy disconnection without the risk of dropping loose components into the winding.

Split ring washers, star washers and other types of locking washer shall not be used inside the transformer tank.

8.4. **Harmonics**

Guaranteed load loss values provided in the schedules shall be based on sinusoidal currents with the same rms values in the line leads as would exist in normal operation at rated direct current if the rectifier overlap is disregarded and at the rated frequency. These values shall be verified by transformer manufacturers’ factory testing.

Harmonics in the current waveform cause a multiplier effect on all eddy current losses within the transformer, and require suitable design allowances including cooling design, where it increases both the number of cooling ducts in the windings and the radiator area.

The minimum acceptable approach to determine the effect of harmonics is provided in IEC 61378-1 *Converter transformers – Part 1: Transformers for industrial applications*, which defines an ‘eddy loss enhancement factor (\(F_{we}\)) for windings’ as follows:

\[
F_{we} = \sum_{n} (f_n \cdot h)^2
\]

Where \(f_n\) is the per unit amount of harmonics at harmonic order \(n\) and
For LV windings use the 6 pulse figures from Table 1 of EP 03 00 00 01 TI Rectifier Transformer & Rectifier Characteristics, version 3.1. This shall be applied to the LV windings.

For HV windings, assume some harmonic cancellation and use the 12 pulse figures from Table 1 of EP 03 00 00 01 TI version 3.1.

8.5. Fault level and protection

The transformer shall be suitable for a supply from a HV system with fault levels as specified in Table 5.

An HV alternating current circuit breaker (ACCB) and ac instantaneous over-current and earth leakage relays provide the primary and backup protection. The ac clearing time (including ACCB clearing time) may be as high as 0.15 s for a 1500 V dc fault condition. Rectifier cubicle frame leakage, reverse current and transformer Buchholz relay will trip both the HV ACCB and 1500 V DCCBs and ‘lockout’ the rectifier.

8.6. Transformer thermal model

The transformer manufacturer shall provide a thermal model that uses the transformer HV current, transformer thermal time constants (for example, tank and winding time constants) and ambient air temperatures to calculate the following:

- winding hot spot, top oil temperature and insulation aging for liquid immersed transformers
- winding hot spot and insulation aging for dry type transformers

The electrical thermal equation shall be provided in differential form that is suitable to be solved by entering time varying values of HV current and ambient temperature as inputs. The input data sampling time interval shall be selectable. The model shall be developed and provided by the transformer manufacturer in Microsoft (MS) Excel.

The thermal model shall be validated against results from the temperature rise testing specified in Section 9 and results from fibre optic sensors.

The output of the electrical thermal model shall facilitate the prediction of the expected winding hot spot and top oil temperatures for varying load conditions and compared to specified thermal limits. The output shall be both numerically and graphically represented time-varying profiles of winding hot spot and top oil temperatures and insulation ageing.

The location and value of the maximum winding hot spot temperature shall be determined by design and verified for the 100%, 150% and 200% loadings detailed in T HR EL 90003 ST. This location of the hot spot temperature shall also be used for locating the fibre optic sensors.
All other information required to calculate the 'thermal ageing of transformer insulation' in accordance with AS/NZS 60076.7 *Power transformers: Part 7: Loading guide for oil-immersed transformers* shall also be supplied by the manufacturer.

### 8.7. Transformer enclosure requirements

Sections 8.7.1 through to Section 8.7.10 detail requirements for the transformer enclosure.

#### 8.7.1. Interchangeability (oil immersed)

The majority of rectifier transformers installed in the RailCorp electrical network are liquid immersed (mineral oil). The oil-immersed rectified transformers shall comply with the following drawings to ensure physical interchangeability with other rectifier transformers of the same rating:

- EL 0269498 *General, Substations - 33 kV rectifier transformer basic configuration requirements Arrangement*
- EL 0269499 *General, Substations - 66 kV rectifier transformer basic configuration requirements Arrangement*

The rectifier transformer motorised tapchanger controls shall comply with EL 0269500.

#### 8.7.2. Accumulation of gas - liquid immersed

The internal surfaces of the main tank shall be designed such that accumulation of gas is prevented. All gas generated within the tank shall find an easy route to the Buchholz relay. All unavoidable pockets in the lid, such as bushing turrets, shall have pipes fitted to their highest point to direct any gas collected into the main oil feed pipe from the conservator. All such gases shall collect in the Buchholz relay.

#### 8.7.3. Access to bushing and core connections

Hand-holes complete with covers shall be provided to allow all bushings to be replaced and the tap changer inspected without removing the main transformer cover.

The inspection covers and the tank lid shall be fitted with eyebolts for lifting.

Inspection covers shall be permanently labelled with details of the equipment that is accessible under the cover.
8.7.4. **Earth Terminal**

Two earthing tabs (stainless steel) with 2 x 14 mm diameter hole suitable for connection of 2 x M12 bolts shall be located externally, near the bottom of the transformer enclosure for connection to the substation earth grid. Earthing tabs shall provide a flat surface to install lugged earthing connections with a minimum surface area of 50 mm x 100 mm.

8.7.5. **Drain valves - liquid immersed**

A drain valve of 50 mm nominal bore pipe internal thread with flanged plug suitable for quick release fittings shall be fitted at the bottom of the transformer tank and the radiators to allow the oil and any moisture to be withdrawn.

An oil-sampling valve shall be provided at the bottom of the tank.

8.7.6. **Provision for temperature measurement devices - liquid immersed**

Suitable oil tight pockets shall be provided in the lid for top oil and winding temperature devices. The location of the pockets shall be carefully chosen to enable the measurements of the hottest top oil temperature.

The design of the cover of the tank shall be such that the cover prevents the build-up of pockets of still hot oil. The thermometer pockets shall be provided with a sealing cap to prevent moisture ingress and shall be of the external hexagonal head type with a gasket seal.

8.7.7. **Cable cleats - HV cable entry type only**

A channel support system shall be provided below the HV cable connection locations for attachment of cable cleats and the earth bar for the HV cable screen as detailed in EL 0494459 *General, Substations – 33 kV Transformers & SWBDS, HV Cable Screen Earthing Requirements*.

Cable support structures shall be designed such that transformer vibrations are managed, and not transferred to others substation structures or buildings (that is, suitable vibration damping is provided between the transformer, cable support structures, and other structures).

8.7.8. **Surge arrester mounting plate - HV bushing type only**

Where the transformer configuration is for connection of HV busbar, appropriate mounting brackets shall be affixed to the tank for the mounting of suitable surge arresters adjacent to the HV bushings.
8.7.9. Lifting attachments

Lifting lugs shall be fitted to the transformer that allows the transformer to be lifted into or out of place (full of oil for liquid immersed). Lifting lugs shall be located so that the transformer can be lifted without removal or fouling of any part. All lifting lugs shall be appropriately rated and identified with a suitable lifting symbol. The tank lifting lugs or eyes shall be suitable for lifting the complete transformer (full of oil for liquid immersed).

Lifting attachments of appropriate capacity shall be provided on all devices that have to be removed for inspection purposes. This includes the tank top cover of liquid immersed transformers if this is capable of being removed from the tank.

Jacking plates shall be provided approximately 500 mm from the transformer foundation. The jacking plates shall be suitable for jacking the transformer when full of oil, and shall be accessible when the transformer is installed at site.

8.7.10. Wheels and mounting plates

The transformer shall be provided with bi-directional wheels for rolling the transformer (full of oil for liquid immersed) into position. Wheels shall be of solid construction; flanged wheels are not acceptable.

The wheels shall be able to be removed and the transformer shall have mounting plates welded externally to the tank base at the designed load bearing areas to facilitate adequate support of the transformer. Anti-vibration pads shall be supplied by the manufacturer.

8.8. Pressure relief device - liquid immersed

A pressure relief device complete with directional discharge shield and highly visible semaphore shall be provided to minimise the build-up of pressure within the main tank in the event of an internal fault.

Vented oil shall have provisions made to direct its flow to ground level in the bunded area within a control gully or pipe. Vented oil shall not be directed over manual control points of the transformer.

Alarm and Indication contacts shall be provided, integral with the pressure relief valve and shall be wired back to terminals in the transformer marshalling box.

8.9. Marshalling box

A marshalling box with an ingress protection (IP) rating of IP65 shall be provided for connection of alarms and indications. All wiring shall be terminated on standard DIN rail terminals and labelled with non-ferrous labels. The terminals shall also be clearly labelled in accordance with EP 00 00 00 15 SP Common Requirements for Electrical Power Equipment.
The marshalling box shall contain the following:

- vertically hinged lockable doors, with a flexible earth bond to the main cabinet
- thermostatically controlled anti-condensation heater (appropriate warning label to be installed in the marshalling box)
- door operated light
- double general purpose outlet (GPO) that can be locked and protected by a residual current device (RCD) in accordance with AS 3000 Electrical Installations

Wiring from the marshalling box to other substation equipment shall be installed by others (including supply of cable glands). A removable blank gland plate shall be supplied by the transformer manufacturer for the entry of cables and shall be located to permit cable entry from below.

8.10. **Alarm and indication contacts**

One normally closed and one normally open contact shall be provided for each alarm or indication.

The contacts shall be suitable for making and breaking up to 100 mA in a 125 V dc circuit and the contacts shall be suitable for switching relay coils and similarly inductive loads.

8.11. **Conservator - liquid immersed**

An appropriately sized conservator shall be fitted to the main tank. The conservator shall meet the following requirements:

- Maintain positive oil pressure in the main tank.
- Conservator shall be designed for the rating of the transformer and operation over full duty cycle as specified in T HR EL 90003 ST. The design shall be for the ambient temperature range for conservators as specified in EP 00 00 00 13 SP.
- A 50 mm nominal bore pipe internal thread with flanged plug suitable for quick release fittings shall be fitted above the maximum oil level of the transformer tank for filling purposes.
- Internal surfaces shall be treated with an approved oil resistant coating sufficient to ensure that the conservator meets the specified design life.
- The main oil feed pipe to the tank shall project through the bottom of the conservator by an amount sufficient to provide a sump with a volume of approximately 5% of the conservator volume. Flanged pipes of 50 mm diameter shall be fitted at each end of the conservator so that oil may be completely drained and all sludge and foreign matter may be extracted by filtering. The pipes shall be fitted with 50 mm valves.
• A magnetic oil level gauge with alarm contacts shall be fitted (due to air bag conservator compatibility). The contacts shall be wired back to the marshalling box. Visibility of the oil level from ground level with the transformer in its installed position in the substation is required.

• A membrane (that is, air bag) between the oil and air to prevent moisture in the air from contaminating the oil in the conservator. Air bag shall be Fujikura type FNH8-045 or an equivalent to be approved by Lead Electrical Engineer, ASA.

• A bag rupture relay shall be provided with a set of contacts for an alarm to SCADA.

• The conservator base brackets shall be bolted to the main tank.

• Access shall be provided to all compartments of the conservator to facilitate cleaning.

• A stop valve on both sides of the Buchholz type relays.

• The conservator shall be arranged so that all air can be excluded from below the membrane at the time of filling.

• Lifting eyes shall be fitted to the conservator of sufficient capacity to allow removal of a full conservator.

8.12. Breather - liquid immersed

A breather shall be provided for the air space above the membrane in the conservator. If the space has not been designed to be unaffected by moisture, then a de-hydrating breather shall be provided that is sized to allow for humid air conditions.

The breather shall be provided with an effective oil seal and an inspection window so that the colour of the crystals can be observed. Crystals shall be able to be replaced in a simple and straightforward manner that does not require de-energisation of the transformer.

The breathers shall be arranged so that insects cannot enter the conservator air space. The breather shall be mounted in such a position that it can be serviced from ground level.

8.13. Radiators - liquid immersed

The radiators shall be designed to adequately dispose of all heat generated inside and outside the transformer to maintain the top oil, winding and core temperature rises within the specified limits.

Galvanized radiators suitable for full vacuum shall be attached to the side of the tank through readily accessible isolating valves.

The main connection to the radiators shall be fitted with valves immediately adjacent to the tank to allow removal without lowering of the transformer oil level. Operation of the valves shall be possible when the transformer is in its installed position.
A drain plug shall be fitted to the lowest point to allow removal of oil from individual radiators independent of the transformer tank oil and other radiator sections.

The external surfaces of the radiators shall be hot dip galvanised in accordance with AS/NZS 4680 *Hot-dip galvanised (zinc) coatings on fabricated ferrous articles*.

The internal surfaces of the radiator shall be flushed to remove any contamination, then dried and treated with an approved oil-resistant coating.

Radiators shall be fitted with lifting eyes capable of supporting the combined weight of the radiator and oil.

Radiators shall be fitted with mounting points to allow future installation of cooling fans that will provide forced airflow through the fins.

### 8.14. Terminal arrangements

Connection to the primary terminals will be made by cables or bare conductor as indicated in the request for tender (RFT).

Connection to the LV terminals is usually through cables; refer to T HR EL 20002 ST 1500 V DC Cables and Cable Ratings, for guidance on the preferred LV cable number and sizes.

The design of the terminal arrangements shall be such that the mechanical loading of the connecting cables, including allowance for thermal expansion of the cables is minimised.

#### 8.14.1. HV bushing terminals

Where HV bushings are specified in the RFT as the HV connection method, the HV and LV terminal bushings shall be arranged on opposite sides of the transformer and in rows parallel with the major axis of the transformer in accordance with EL 0269499.

A transformer configuration with HV bushings shall comply with the minimum safety clearances in accordance with AS 2067 *Substations and high voltage installations exceeding 1 kV a.c.* The minimum safety clearance is applicable for the transformer with wheels or when the wheels have been removed.

The terminal bushings shall be fitted with flat connecting palms that comply with AS/NZS 60137 *Insulated bushings for alternating voltages above 1000 V* for a medium polluted atmosphere and be a solidly insulated bushing. Oil filled bushings are not acceptable.

Access to the neutral connection of the HV star connected winding shall be possible without the removal of any oil and also allow the testing of individual HV phase windings.
8.14.2. **33 kV cable connection interface**

Where the transformer HV connection is 33 kV cable, a bolted, dead break separable, tee shape connector suitable for interfacing with a 33 kV, single core, 120 mm² XLPE copper cable shall be provided for each phase by the transformer manufacturer.

Separable connectors shall comply with EN 50180 *Bushings above 1 kV up to 52 KV and from 250 A to 3.15 kA for liquid filled transformers*.

Suitable mechanical and weather protection to the HV plug-in connector shall be incorporated in the design of the transformer.

8.14.3. **66 kV cable connection interface**

Where the transformer HV connection is 66 kV cable, a separable, screened, touch safe connector such as a Pfisterer Connex connector that is suitable for interfacing with a 66 kV, single core, XLPE Cu cable shall be provided for each phase. The connector shall comply with IEC 60840 *Power Cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) – Test methods and requirements*.

8.14.4. **LV (600 V) bushing terminals**

All rectifier transformers shall be equipped with appropriately rated LV bushings. The bushings shall comply with AS/NZS 60137 for a medium polluted atmosphere and be a solidly insulated bushing. Oil filled bushings are not acceptable. The palm shall be in accordance with EL 0269498.

LV bushings shall be equipped with Raychem bushing connection animal covers or equivalent.

Safety clearances to the LV bushing shall be in accordance with AS 2067 for voltages up to 3.3 kV. The safety clearance shall be applied when the transformer wheels are removed.

The physical arrangement of the connections between the rectifier transformer and the rectifier power cubicle is important. The connections shall be aligned to avoid crossing of the 600 V ac cables. The relationship of the connections is highlighted in Figure 1.
8.14.5. Neutral bushing - HV winding

Where required, a neutral bushing shall be provided that is located on the upper surface of the transformer tank and shall be grouped with the HV bushings.

Alternatively for a transformer with separable connectors, the neutral connection shall be brought out using HV cable connected, bolted dead break separable methods as specified in Section 8.14.2.

Although intended to allow the neutral point to be earthed when required, the neutral terminal will not normally be earthed.

Calculations justifying the level of insulation provided when the neutral point is not earthed shall be supplied with the tender response.

8.15. Tap-changer requirements

HV winding tappings at increments, as detailed in Table 7, shall be provided for liquid immersed and dry type transformers.

Liquid immersed transformers shall have an off load tap-changer as detailed in Sections 8.15.1 through to Section 8.15.2.

The required configuration of the tap-changer for dry type transformers will be specified in the RFT and shall be an offline tap-changer or the tap shall be selected by moveable links that shall be accessible from ground level.
Where the tap is selected by moveable links, the links shall be enclosed behind a bolted panel.

The options for the tap-changer arrangement shall be discussed during the design phase and approved by the Lead Electrical Engineer, ASA.

### 8.15.1. Off load tap-changer tappings

A remotely controlled, motor operated, tap-changer with visible position indicator shall be provided to change tappings in the HV winding.

The tapchanger shall be rated for the full overload requirements including harmonics as specified in Section 7 and shall be capable of changing taps with the primary circuit de-energised.

All leads and connections to fixed and moving contact assemblies shall be supported and adequately braced to withstand short circuit currents for which the transformer is designed. The tapping switch shall be capable of withstanding the overload characteristic specified in T HR EL 90003 ST.

The following requirements apply to the tapchanger:

- All contacts shall be of the self-wiping type.
- The design shall be such that the ingress of moisture into or the leakage of oil from, the tank is prevented.
- Tapping switches shall be provided with mechanical end stops that prevent movement beyond an end position.
- The tap position shall be clearly determined safely from the ground without isolating the transformer.

Taps shall be numbered from one (1) to Seven (7) from the highest input voltage to the lowest. Typical numbering is provided in Table 8:

<table>
<thead>
<tr>
<th>Tap changer position</th>
<th>33 kV HV</th>
<th>66 kV HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34485</td>
<td>68970</td>
</tr>
<tr>
<td>2</td>
<td>33990</td>
<td>67980</td>
</tr>
<tr>
<td>3</td>
<td>33495</td>
<td>66990</td>
</tr>
<tr>
<td>4</td>
<td>33000</td>
<td>66000</td>
</tr>
<tr>
<td>5</td>
<td>32506</td>
<td>65010</td>
</tr>
<tr>
<td>6</td>
<td>32010</td>
<td>64020</td>
</tr>
<tr>
<td>7</td>
<td>31515</td>
<td>63030</td>
</tr>
</tbody>
</table>
8.15.2. Tap-changer control

Normal control of the tap changing operation will be from a remote location through the SCADA system. Local operation via pushbuttons shall also be possible. A two position selector switch with positions 'Local' and 'Supervisory' shall be provided on the tap-changer control cabinet for the selection of mode.

The tap-changer control circuit shall operate at 125 V dc which will be supplied from the substation 125 V dc distribution board.

A 415 V, three-phase and neutral, 50 Hz supply will be provided for the operation of the tap changing equipment. In the event that the transformer is required to operate at a substation without such a supply, details of the alternative supply will be included in the RFT.

The tap-changer control circuit shall be designed to receive remote enable, raise and lower commands through voltage free contacts.

The raise and lower contacts (normally open) are from the substation SCADA and the enable interlock is derived from a normally closed contact from the rectifier transformer HV ACCB. The enable contact is to prevent tap changing in either local or supervisory mode when the HV ACCB is in the closed position.

The enable signal will be a maintained signal, whilst raise and lower commands will be fleeting of 1 second duration.

The tap-changer shall be designed to index one step at a time only, either up or down, when a remote raise or lower is received.

Indication of the tap position shall be available to the remote operator by means of individual N/O contacts for each position of the tap-changer.

Provision shall be made for remote indication that the tap change sequence is in progress when the tap changer is changing position. This signal shall comprise a voltage-free relay contact that is normally closed and which opens whilst a tap change is in progress. The actual tap change shall commence not less than one second after the indication signal goes to the 'changing position' state.

A fault signal shall also be available for remote indication and shall incorporate all fault conditions that may reasonably be monitored, together with loss of motor and control power supply. This signal shall be a contact that is normally closed and which opens upon a fault.

The functionality and interfaces shall be consistent with EL 0269500 General Substations, rectifier transformer tapchanger control circuit and auxiliary schematic diagram.
8.16. System earthing

The RailCorp 33 kV and 66 kV HV systems are not effectively earthed.

The secondary side of the transformer is not earthed under normal service conditions so that over-voltages due to the capacitances between windings, and between windings and earth shall be allowed for in the transformer design.

The rectifier negative terminal is not deliberately earthed; however is normally close to earth potential and may be connected to earth under some conditions. Refer to EP 12 10 00 10 SP System Substation Earthing for further details.

8.17. Temperature indicators

The temperature of the transformer shall be monitored with both local indication and remote indication to SCADA provided as follows:

- top oil temperature indication contacts (two contacts required) for liquid immersed
- top oil temperature local visual indicator
- top oil temperature remote analogue transducer
- winding hot-spot temperature indication contacts (two contacts required)
- winding hot-spot temperature local visual indicator
- winding hot-spot temperature remote analogue transducer

The temperature at which each set of indication contacts operate shall be independently adjustable over the range of 70 °C to 150 °C for liquid immersed and 70 °C to 240 °C for dry type in 10 °C increments. The operating point shall be able to be set within ±2 °C without the need for additional instruments. The instrument shall be capable of operating in ambient conditions as specified in EP 00 00 00 13 SP, for auxiliary equipment located near heat emitting equipment.

One set of indication contacts shall be used to provide remote alarms of abnormal temperatures and that the second set of contacts shall be set to operate at a higher temperature and be used to trip the transformer HV ACCB.

Winding hot-spot temperature local visual indicator shall be provided with a re-settable maximum indicator and shall have accuracy of not less than ±2 °C.

The device shall be fixed on a flexible mounting to minimise the effects of transformer vibration. All set points shall be labelled according to their use (for example, ‘alarm’ or ‘trip’). Winding temperature indicator location shall be based on hot spot gradient after consideration of harmonics.
8.18. **Fibre optic temperature sensors**

Liquid immersed transformers shall have a minimum of four (that is, two for the HV winding and one in each LV winding) fibre optic sensors to monitor the winding hot spot and the top oil (liquid immersed) temperature. The manufacturer is responsible for the recommendation and justification of the proposed locations.

The options for dry type transformers shall be discussed with the Lead Electrical Engineer, ASA during the design stage.

The fibre optic sensors shall be brought out to the marshalling box where a data logger can be placed while the transformer is in service.

Fibre sensors shall be used with a direct winding temperature monitoring system; alternatives to this will require approval by the Lead Electrical Engineer, ASA.

8.19. **Gas and oil actuated relays - liquid immersed**

The transformer shall be equipped with earthquake proof devices which are actuated by the generation of gas or pressure in the transformer unit and have similar characteristics to a float and flap type Buchholz relay. If reed switch type relays are used, then they shall not be affected by magnetic fields associated with fault levels stated in Table 5.

Each device shall be fitted with two independent sets of contacts which will perform the following functions:

- One set of normally open contacts to trip the HV ACCB controlling the transformer unit in the event of major faults.
- One set of normally open contacts to operate an alarm system in the case of faults of a minor nature that is not sufficiently serious to warrant isolation of the transformer unit. The contacts shall be wired back to the marshalling box.

The Buchholz relay operating mechanism shall be removable without the need to disconnect the relay casing from the pipe work.

Provision shall be made to enable gas from the relay to be sampled at ground level.

The gas pressure relay shall be fitted with a test valve to facilitate the injection of air onto the relay vane to prove trip operation under simulated fault conditions.
8.20. Transformer liquid

Section 8.20.1 and Section 8.20.2 provide requirements for the use of mineral oil and synthetic ester as the cooling medium.

8.20.1. Mineral oil

If mineral oil is used, then the transformer oil shall be naphthenic, corrosive sulphur free, non-inhibited, not passivated, and be compliant with IEC 60296 Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear.

Detection of sulphur shall be in accordance with IEC 62535 Insulating liquids – Test method for detection of potentially corrosive sulphur in used and unused insulating oil.

Oil shall be polychlorinated biphenyl (PCB) free and any deliveries (including the transformer) shall be accompanied by a National Association of Testing Authorities (NATA), Australia certificate confirming this requirement.

8.20.2. Synthetic ester

At the time of publishing this standard there are no rectifier transformers installed in the RailCorp network with synthetic ester. The Lead Electrical Engineer, ASA shall be consulted if a rectifier transformer with synthetic oil is proposed at the concept design stage of the project.

In addition to specific transformer technical requirements to determine suitability, other non-technical issues shall be addressed as follows:

- interchangeability
- identification of the transformer with synthetic ester
- system spares
- operation and maintenance requirements (including specific maintenance equipment requirements)

8.21. Finish - liquid immersed

The transformer tank and cover shall remain corrosion-free for the life of the transformer.

The main tank shall be shot blasted internally and externally to remove rust and scale in accordance with Class SA2½ ‘near white’ blast cleaning which is in accordance with AS 1627.4 Metal Finishing – Preparation and pre-treatment of surfaces Part 4: Abrasive blast cleaning of steel.

The internal and external surfaces shall be prepared and coated strictly in accordance with the manufacturer’s instructions. The preparation and method of application for the finish shall ensure that the transformer is corrosion-free for its design life.
Any surface that has the potential to come into contact with oil shall not be galvanised.

8.21.1. Internal surfaces

The main tank, tap changer enclosure, conservators and pipework internal steel surfaces shall be painted with an oil resistant paint immediately after abrasive cleaning.

The internal surfaces of the control box and marshalling box shall be finished with an oil resistant full gloss white coating, colour N° N14 in accordance with AS 2700 Colour standards for general purposes. This requirement does not apply to stainless steel or aluminium marshalling box with a natural finish.

8.21.2. External surfaces

The external steel surfaces shall be painted with an inorganic zinc-rich paint immediately after abrasive cleaning. The preferred colour for dry type and mineral oil transformers is storm grey, colour N° N42 in accordance with AS 2700.

8.22. Finish - dry type

The internal and external surfaces shall be prepared and coated strictly in accordance with the manufacturer’s instructions. The preparation and method of application for the finish shall ensure that the transformer is corrosion-free for its design life.

The enclosure shall be constructed of Galvabond steel (G2 Z275) or equivalent with minimum thickness of 3 mm for base and lid, 2 mm for other panels. Alternative steel products require approval from the Lead Electrical Engineer, ASA.

The internal and external surfaces of the transformer enclosure shall be powder coated, colour N° N42 in accordance with AS 2700.

The internal surfaces of the control box and marshalling box shall be finished with an oil resistant full gloss white coating, colour N° N14 in accordance with AS 2700. This requirement does not apply to stainless steel or aluminium marshalling box with a natural finish.
8.23. **Rating plate**

A rating plate made of pacified stainless steel in accordance with the requirements of AS/NZS 60076.1 *Power Transformers, Part 1: General* shall be firmly attached to a bracket externally on the transformer enclosure. The plate shall not be attached to any removable cover.

In addition to the requirements of AS/NZS 60076.1, the rating plate shall also include the following:

- a diagram of connections
- type of insulating liquid (for liquid immersed transformers)
- the TfNSW specification number and version

The rating plate shall be located such that it can be easily read from ground level with the naked eye.

8.24. **Provision for safe access - liquid immersed**

Section 8.24.1 through to Section 8.24.5 details requirements for the safe access provisions to enable maintenance and commissioning activities.

8.24.1. **General**

Guard rails shall be provided around the perimeter of the top of the tank to facilitate safe access for installation and commissioning tasks, and all maintenance actions identified in the equipment manual on the top of the transformer.

Where a task is to be undertaken at a greater height such that it cannot be carried out by a person standing on top of the tank within the hand rails anchorage points, then other fixings suitable for an industrial fall-arrest system to permit a safe system of work for such tasks shall be fitted.

8.24.2. **Guard rails**

Guard rails shall comply with AS 1657 *Fixed platforms, walkways, stairways and ladders – Design, construction and installation*.

Guard rails shall be de-mountable (bolted connections or similar) from the tank to facilitate transport of the transformer.

The toe-board and mid rail may be omitted from the area adjacent to the LV bushings to provide clearance for the LV cables.

In the case of transformers fitted with HV bushings, the top rail, or top rail and mid rail, may be omitted adjacent to the HV bushings as necessary to provide the required electrical clearance.
8.24.3. **Ladder access point**

A ladder access point shall be provided clear of radiators and LV bushings. The ladder access point shall be clearly identified. The ladder access point shall provide positive location and support for a portable extension ladder. A tie-off point shall be provided to secure the foot of a ladder placed at the ladder access point. A gate or similar shall be provided in the hand-rails at the ladder access point.

8.24.4. **Fall-arrest anchor points**

If the use of an industrial fall-arrest system is required to facilitate any task that is required to be done by a person standing above the top of the tank, a safe system of work for all such tasks shall be designed and documented.

The safe system of work shall comply with AS/NZS 1891.4 *Industrial fall-arrest systems and devices - Selection, use and maintenance*. Suitable fall-arrest anchorage points shall be nominated. Suitable structural elements should be nominated as anchor points for use with an anchor sling of similar, rather than the provision of dedicated fall-arrest system anchor points.

8.24.5. **Documentation of safe systems of work**

The maintenance manual shall include details of any safe systems of work required to facilitate any task that shall be done by a person standing above the top of the tank.

9. **Tests**

All tests conducted shall be carried out in accordance with a prepared test program which shall detail the sequence of tests, the duration of tests and the relevant standard.

The transformer shall be completely assembled in the factory with all protection devices and cubicles. TfNSW reserves the right to witness any of the tests. The manufacturer shall provide TfNSW with six weeks’ notice of the test commencement date.

All test results including the routine test results of bushings and the tap changer shall be included in the maintenance manuals.

A transformer test report for each transformer shall include the following information as a minimum:

- specific transformer details
- test personnel names, date of tests, ambient conditions
- index of test results
- statement of measurement uncertainty for each test
• tabulated results of each test with guaranteed and the specific ASA requirement as applicable
• test engineers comments and acceptance of test results as being satisfactory and meeting the specific ASA requirement

9.1. **Routine tests**

Routine tests as listed in AS/NZS 60076.1 and the following tests shall be carried out on each transformer:

• transformer winding resistance
• transformer voltage ratio and check of phase displacement and polarity
• transformer load loss and short cct impedances: HV and (LV1+LV2 short cct), HV and (LV1 short cct), HV and (LV2 short cct)
• transformer no load loss and current
• transformer insulation resistance
• dielectric loss angle (DLA) and capacitance of winding
• separate source ac withstand voltage test
• induced withstand voltage test
• CT tests, resistance, polarity, ratio (liquid immersed transformer)
• Tapchanger functional checks
• auxiliary circuits insulation test
• leak test with pressure (liquid immersed transformer)
• frequency response analysis

In addition, the following tests shall also be carried out on each transformer:

• An extended no-load loss and current test in which the transformer shall be energised continuously at rated no-load voltage for at least six hours after which time the no-load watts and current shall be measured. If these losses are greater than those measured in the routine test, they shall be used in the evaluation of losses.

• After a liquid immersed transformer has been delivered to site and any oil added as may be necessary, the manufacturer shall arrange for the oil to be tested for PCB content and a certificate issued to TfNSW showing the PCB content.
9.2. **Type tests**

Section 9.2.1 through to Section 9.2.3 details requirements on the type tests to be performed.

Type test certificates for each of these tests will be accepted where it can be demonstrated that the transformer supplied is of an identical design and manufacture to a previously type tested transformer.

9.2.1. **Sound level test**

A sound level test shall be performed in accordance with AS/NZS 60076.10 *Power transformers: Part 10: Determination of sound levels*.

9.2.2. **Temperature rise test**

A temperature rise test shall be performed for rated power, 150% and the 200% overload conditions specified in T HR EL 90003 ST. The 300% and 400% overload conditions shall be verified by calculation.

The test shall be in accordance with the following standards:

- AS/NZS 60076.2 *Power transformers – Part 2: temperature rise for liquid-immersed transformers*
- AS 60146.1.3 for dry type transformers

In conjunction with the temperature rise test the fibre optic sensors shall be calibrated against the temperature rise test results.

The temperature rise test report shall include the following:

- calculations
- shutdown curves for HV, LV1, LV2
- tabulated data such as current, losses, ambient temperature, top oil temperature, top pipe winding temperature, fibre optic sensor temperature, measurement time

9.2.3. **Lightning impulse test**

A full wave lightning impulse test as specified in AS/NZS 60076.3 *Power transformers: Part 3 Insulation levels, dielectric tests and external clearances in air* shall be performed.

9.3. **Transport delivery and tests after installation**

The transformer shall be equipped with a time stamped data logging impact recorder immediately after factory testing. This shall remain operational until final installation of the unit at site. The data log shall be provided to TfNSW on delivery of the unit.
Tests shall be carried out by the contractor to demonstrate readiness for service. These tests shall include (but not be limited) to the following:

- measurement of winding resistance on all taps and all windings
- measurement of voltage ratio and check of voltage vector relationship on all taps
- insulation resistance of all windings
- dielectric dissipation factor (DDF) tests of all winding configurations
- oil dielectric test and test for water content (liquid immersed transformer)
- frequency response analysis

Inspection and test plans (ITPs) and associated test sheets showing completion of all site tests and test results shall be provided to a TfNSW representative. The contractor is responsible for ensuring that the transformer is ready for service.

10. **Human factors**

The transformers shall be designed in accordance with the human factors principles outlined in T MU HF 00001 ST *Human Factors Integration – General Requirements*.

The design of the transformer shall allow for good access and visibility to items that require access for operation and maintenance. The design shall include the following:

- height of Buchholz gas sampling device
- location and height of breathers
- location and height of manual tap changer control
- location and height of marshalling box (AS 3000 requirements also apply for location of 240 V isolator)
- location, visibility and legibility of signage
- location and visibility of temperature indicators (shall be visible from ground level)
Appendix A  Whole-of-life cost

This appendix is provided for AEOs to assess the whole-of-life cost as required by T MU AM 01001 ST Life Cycle Costing.

The selection of the most suitable rectifier transformer shall be made on the basis of minimising the whole-of-life cost. The following factors shall be considered in determining the whole-of-life cost:

- cost of changes to the Technical Maintenance Plan and Service Schedules or the creation of new manuals and schedules
- cost of decommissioning and disposal
- cost of installation
- cost of inventory spares
- cost of maintenance
- cost of manuals
- cost of modifications to other parts of the installation
- cost of replacement parts
- cost of special tools
- cost of staff training
- discount rate
- electrical losses
- environmental costs
- initial purchase price
- lifetime of equipment
- reliability and cost of consequential damage after failure

If this transformer has not previously been type approved by ASA in accordance with T MU MD 00005 GU, the costs for this process shall be included in the whole-of-life cost.
Appendix B  Data set associated with the equipment

Section B.1 through to Section B.4 lists the data that shall be supplied by the manufacturer and maintained for the rectifier transformers. This data will remain the property of TfNSW.

B.1. Drawings and information

All drawings shall conform to the requirements of T MU MD 00006 ST Engineering Drawings and CAD Requirements. The following drawings are required:

- Transformer arrangement drawings. Arrangement drawings shall be drawn to scale with the following details:
  - complete details of the transformer with views of all sides of the transformer and detailed sections as required
  - dimensions, including overall size, position of HV connectors or bushings and the LV bushings relative to the centre lines of the tank and the level of the foundations, marshaling box height from base
  - position of the centre of gravity
  - mass of the transformer complete both with and without oil
  - mass of main tank (including tank fitted with accessories) and filled with oil
  - quantity of insulating oil required in each oil-holding compartment
  - jacking points to be identified
  - complete listing of all fittings, accessories and parts with the associated manufacturer, part or model number and relevant ratings

- Where the transformer is required to be shipped in a dismantled state, a separate outline drawing shall be produced detailing the dimensions and weight of the separated components.

- Drawings of any special slinging arrangement required for handling the transformer during shipment or erection.

- Foundation drawings showing detail of base for the main tank.

- Schematic and wiring diagrams as follows:
  - schematic diagrams of the transformer windings showing connections, tappings and tabulations of current and voltage rating of all windings
  - schematic and wiring diagram of the tap changer control
• schematic diagram of alarm and trip circuits
• schematic diagrams of control of auxiliary systems

- Marshalling cabinet arrangement drawing showing details of all components. This shall include an item list detailing the components, the manufacturer, part or serial number and rating (where applicable).
- Marshalling cabinet terminal layout.
- Drawings of the rating plate required in Section 8.23. Details shown on these drawings shall not vary from that shown on the plates fixed to the transformer.
- Bushings and cable box drawings showing details of all bushings including profile drawings and full details of the cable box where supplied.
- Drawing showing the location of the fibre optic probes.

Note: This list does not include component drawings which are required as part of the integrated support requirements and inclusion in the operations and maintenance manual.

B.2. Technical schedule

The information listed in the technical schedule in Appendix C shall be supplied by the manufacturer and maintained for each rectifier transformer.

B.3. Life cycle costing

All the data and assumptions pertaining to the determination of the whole-of-life cost calculations shall be recorded, including transformer loss calculations as detailed in EP 02 00 00 01 SP Transformer Loss Evaluation. This is prepared by the AEO.

B.4. Test results

The results of all tests, including routine, type, special, acceptance, periodic and corrective maintenance tests shall be recorded and provided.

Routine tests certificates showing the results of each test performed shall be supplied in English, and maintained for the life of the transformer.

Type tests certificates showing the results of each test shall be supplied in English, and maintained for the life of the equipment.
Appendix C  Technical schedule

This appendix has the technical schedule which is required to be completed at the time of tender and details the descriptive information that is required to be submitted at the time of tender.

C.1. Transformer technical schedule

The manufacturer shall provide transformer information listed as follows:

<table>
<thead>
<tr>
<th>Transformer Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of manufacturer</td>
<td></td>
</tr>
<tr>
<td>Type of transformer (dry/mineral oil/synthetic ester)</td>
<td></td>
</tr>
<tr>
<td>Rated primary voltage</td>
<td>V</td>
</tr>
<tr>
<td>Rated secondary voltage</td>
<td>V</td>
</tr>
<tr>
<td>Rated power of primary winding</td>
<td>MVA</td>
</tr>
<tr>
<td>Rated power of secondary star winding</td>
<td>MVA</td>
</tr>
<tr>
<td>Rated power of secondary delta winding</td>
<td>MVA</td>
</tr>
<tr>
<td>Connection symbol</td>
<td></td>
</tr>
<tr>
<td>No-load current with rated voltage applied to the principal tapping</td>
<td>A</td>
</tr>
<tr>
<td>No-load current with 110% rated voltage applied to the principal tapping</td>
<td>A</td>
</tr>
<tr>
<td>No-load loss</td>
<td>W</td>
</tr>
<tr>
<td>Load loss at 75°C</td>
<td>W</td>
</tr>
<tr>
<td>Thermal time constant – Tank</td>
<td>Hrs</td>
</tr>
<tr>
<td>Thermal time constant – Winding</td>
<td>Mins</td>
</tr>
<tr>
<td>Reactance at rated primary MVA on principal tap</td>
<td></td>
</tr>
<tr>
<td>• with secondary No 1 short-circuited</td>
<td></td>
</tr>
<tr>
<td>• with secondary No 2 short-circuited</td>
<td></td>
</tr>
<tr>
<td>• with secondary windings short-circuited</td>
<td></td>
</tr>
<tr>
<td>Mean sound level</td>
<td>dB(A)</td>
</tr>
</tbody>
</table>

Harmonic enhancement factors (refer to Section 8.4)

| Enhancement factor for HV winding | |
| Enhancement factor for LV windings | |
## Construction details

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of core steel - hot or cold rolled</td>
<td></td>
</tr>
<tr>
<td>Brand or trade name and grade of core steel</td>
<td></td>
</tr>
<tr>
<td>Maximum flux density on net cross-section of steel with rated volts at rated frequency applied to the centre tapping</td>
<td></td>
</tr>
<tr>
<td>• limbs</td>
<td></td>
</tr>
<tr>
<td>• yoke</td>
<td></td>
</tr>
<tr>
<td>Material used for HV winding</td>
<td></td>
</tr>
<tr>
<td>Material used for LV windings</td>
<td></td>
</tr>
<tr>
<td>Details of insulation on windings</td>
<td></td>
</tr>
<tr>
<td>Maximum dielectric stress on winding insulation</td>
<td>V/mm</td>
</tr>
<tr>
<td>Dry type (outdoor) IP rating</td>
<td></td>
</tr>
<tr>
<td>Dry type (indoor) IP rating</td>
<td></td>
</tr>
</tbody>
</table>

## Oil details

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td></td>
</tr>
<tr>
<td>Type of oil</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
</tr>
</tbody>
</table>

## Temperature rise details (load conditions refer to Section 8.1)

<table>
<thead>
<tr>
<th></th>
<th>Winding (°C)</th>
<th>Top oil (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150% for 2 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200% for 30 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300% for 1 minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400% for 10 seconds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Winding hot spot temperature details (maximum ambient temperature as per EP 00 00 00 13 SP)

<table>
<thead>
<tr>
<th></th>
<th>Winding (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum ambient temperature</td>
<td></td>
</tr>
<tr>
<td>Full load</td>
<td></td>
</tr>
<tr>
<td>150% for 2 hours</td>
<td></td>
</tr>
<tr>
<td>200% for 30 minutes</td>
<td></td>
</tr>
<tr>
<td>300% for 1 minute</td>
<td></td>
</tr>
<tr>
<td>400% for 10 seconds</td>
<td></td>
</tr>
</tbody>
</table>

## Tapchanger details

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Motor supply voltage</td>
<td>V</td>
</tr>
<tr>
<td>Power requirement of motor</td>
<td>W</td>
</tr>
<tr>
<td>Continuous rating of tap-changer</td>
<td>A</td>
</tr>
<tr>
<td>Overload rating of the tapchanger and</td>
<td></td>
</tr>
<tr>
<td>information to show that it is capable of</td>
<td></td>
</tr>
<tr>
<td>carrying the overload specified</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transformer dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall dimensions</td>
<td>mm x mm</td>
</tr>
<tr>
<td>Extreme height from foundation level</td>
<td>mm</td>
</tr>
<tr>
<td>Extreme height from foundation level when</td>
<td>mm</td>
</tr>
<tr>
<td>dismantled for transport</td>
<td></td>
</tr>
<tr>
<td>Projected floor area</td>
<td>mm x mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transformer mass (oil immersed)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of transformer complete with oil</td>
<td>kg</td>
</tr>
<tr>
<td>Mass of transformer core and windings only</td>
<td>kg</td>
</tr>
<tr>
<td>Mass of windings only</td>
<td>kg</td>
</tr>
<tr>
<td>Volume of oil to fill transformer</td>
<td>Litres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transformer mass (dry type)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of complete transformer</td>
<td>kg</td>
</tr>
<tr>
<td>Mass of transformer core and windings only</td>
<td>kg</td>
</tr>
<tr>
<td>Mass of transformer without enclosure</td>
<td>kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HV separable connectors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td></td>
</tr>
<tr>
<td>Manufacturers model number</td>
<td></td>
</tr>
<tr>
<td>Voltage rating</td>
<td></td>
</tr>
<tr>
<td>Continuous current rating</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HV bushing details (where applicable)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td></td>
</tr>
<tr>
<td>Manufacturers model number</td>
<td></td>
</tr>
<tr>
<td>Insulator material</td>
<td></td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>kV</td>
</tr>
<tr>
<td>Lightning impulse voltage</td>
<td>kVp</td>
</tr>
<tr>
<td>Creepage distance</td>
<td>mm</td>
</tr>
<tr>
<td>Continuous current rating</td>
<td>A</td>
</tr>
<tr>
<td>Minimum air clearance between phases</td>
<td>mm</td>
</tr>
</tbody>
</table>
### HV bushing details (where applicable)

<table>
<thead>
<tr>
<th>Minimum air clearance between phase to earth</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm dimensions</td>
<td>mm x mm</td>
</tr>
</tbody>
</table>

### 600 V bushing details

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturers model number</td>
<td></td>
</tr>
<tr>
<td>Insulator material</td>
<td></td>
</tr>
<tr>
<td>Voltage rating</td>
<td>V</td>
</tr>
<tr>
<td>Lightning impulse voltage</td>
<td>kVp</td>
</tr>
<tr>
<td>Creepage distance</td>
<td>mm</td>
</tr>
<tr>
<td>Continuous current rating</td>
<td>A</td>
</tr>
<tr>
<td>Minimum air clearance between phases</td>
<td>mm</td>
</tr>
<tr>
<td>Minimum air clearance between phase to earth</td>
<td>mm</td>
</tr>
<tr>
<td>Palm dimensions</td>
<td>mm x mm</td>
</tr>
</tbody>
</table>

### Miscellaneous items

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buchholz relay</td>
<td></td>
</tr>
<tr>
<td>Temperature indicators</td>
<td></td>
</tr>
<tr>
<td>Overpressure relay</td>
<td></td>
</tr>
<tr>
<td>Winding temperature CT</td>
<td></td>
</tr>
<tr>
<td>Transformer leakage CT</td>
<td></td>
</tr>
<tr>
<td>Transducer</td>
<td></td>
</tr>
<tr>
<td>Type of conservator airbag</td>
<td></td>
</tr>
<tr>
<td>Conservator bag rupture relay</td>
<td></td>
</tr>
</tbody>
</table>

### Protective treatment applied to tank:

<table>
<thead>
<tr>
<th>Internal surfaces</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>External surfaces</td>
<td></td>
</tr>
</tbody>
</table>

## C.2. Reliability data

The transformer reliability data is required to be submitted. Refer to T MU AM 01002 MA Maintenance Requirements Analysis Manual for details of TfNSW requirements. This manual supports the TfNSW Asset Management Policy with detailed processes for undertaking a maintenance requirement analysis.
Transformer reliability data (use separate sheet if necessary):

Design life (years):  

Failure modes (for early, normal life, and wear out periods):  

Mean operating hours between failures:  

Time to repair:  

C.3. Additional descriptive transformer details and information

In addition to the technical schedule, the following information shall also be provided with the tender:

- Outline drawings - fully dimensioned outline drawings showing all fittings, terminal arrangements, radiator equipment, tap changer equipment, marshalling box, required maintenance access. The general arrangements and layouts shall be adhered to in the final design unless written approval is obtained from Lead Electrical Engineer, ASA.

- Core material characteristics - typical curves of flux density versus ampere turns per metre for the core material.

- Core information - drawing and detailed description of core type, methods of making joints, insulation between laminations, treatment of edges, core bolt insulation and method of minimising hot spots in limbs.

- Details of the proposed method of verifying core hot spot temperature.

- Details of core earthing method.

- Features of the transformer design as follows:
  - Winding and short circuit design. Provide detailed design features of winding and winding supports to withstand frequent short circuit conditions associated with normal operation as a railway traction duty transformer.
  - Overload allowances to comply with Section 7.
  - Harmonic assumptions, allowances and type testing methodology.
  - Voltage ratio. provide details on turns and error (mismatch) on LV.

- Temperature indicators - a full description of temperature indicators and transducers including detailed design information on the type of pocket to be used.
• Tap-changer details - a full description of the tap-changer proposed including type test certificates.

• Conservator sizing - provide detailed calculations for the sizing of the conservator.

• Fall-arrest system - provide details of the proposed method for the industrial fall-arrest system.

• Component data sheets - data sheets for the Buchholz relay, temperature monitors, conservator membrane, and pressure switch shall be provided.

• Other information - any other information considered necessary by the manufacturer.

• Departure from standard: are there any departures from the requirements of this standard? If there are departures include the details on a separate sheet.

• Special delivery requirements - any special requirements that are envisaged for the safe delivery of the rectifier transformer to the specified site shall be stated at tender stage, for example, removal of bushings due to low bridge on delivery route. These costs shall be provided separately at tender stage.
Appendix D  Options to be priced at tender

The items listed in Section D.1 through to Section D.3 should be priced at the time of tender and recommended to the ASA for inclusion based on a life cycle assessment and their functional requirements.

D.1.  On load tap-changer

On-load tap-changer in lieu of the off-circuit tap-changer as specified in Section 8.15 should be provided.

D.2.  Fibre optic monitoring system

A direct monitoring 6 channel fibre optic monitoring system for transformers should be provided.

D.3.  Reduced sound level

Reduced sound level in accordance with AS 60076.10 should be provided.
Appendix E  Integrated system support requirements

E.1. Integrated support objectives

The transformer manufacturer shall establish and provide the information required to operate and maintain the equipment throughout its operational life. This shall be done in a cost effective manner and to a level that is consistent with the planned operational performance and usage of the rectifier transformer.

This includes the following:

- specifying maintenance requirements
- spares support (availability of spares - timeframe, where they are held)
- operations and maintenance manuals
- training
- support equipment and tooling

The Integrated support requirements are a significant deliverable in the procurement of a new rectifier transformer. Manuals, training, documentation and other support deliverables shall be in accordance with T HR EL 00002 PR Electrical Power Equipment – Integrated Support Requirements.

E.2. Operation and maintenance manual

An operation and maintenance manual shall be provided for the equipment in accordance with T HR EL 00002 PR. The requirements for the scope of the operation and maintenance manual are as detailed in T HR EL 00002 PR. The following additional content is also required:

- Photographs showing the following details:
  - winding and core taken during manufacturing of the transformer
  - overview of assembled transformer (all sides)
  - marshalling box (inside and outside)
  - HV and 600 V dc cable interfaces
- Detailed description and overall transformer oil system diagram (with valves identified) including the required plant for the vacuum and oil filling procedure.
- Detailed step-by-step instruction for sampling gas from the Buchholz relay.
- Detailed step-by-step instruction for obtaining oil samples.
• Drawings necessary to install, maintain, dismantle, reassemble or adjust the transformer and fittings and to repair or replace all parts liable to wear and failure. In particular, this applies to fixed and moving contacts of the tapchanger unit and auxiliary switches and special gaskets (being those that cannot be hand cut from sheet materials such as moulded gaskets and 'O' rings).

• Procedure to open the tank.

• Tapchanger operation and maintenance manual.

• All operation instructions and associated descriptions of equipment shall be accompanied by colour photos of the actual equipment installed on the transformer that is being described.
Appendix F  Guide to information requirements for RFT

Section F.1 and Section F.2 provides guidance for preparing a request for tender for traction rectifier transformers.

**F.1. Information to be sought from the tenderer**

Tenderers should complete and submit the technical schedule provided in Appendix C.

**F.2. Information to be supplied at the time of tender**

Technical information for the procurement of the rectifier transformer should be supplied and specific site information should be provided.

Table 9 provides technical details of the traction rectifier transformer to include in the RFT.

<table>
<thead>
<tr>
<th>Transformer item</th>
<th>Technical details to include in the RFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer type</td>
<td>Indicate whether the transformer is a dry type or liquid immersed (miner oil or synthetic ester)</td>
</tr>
<tr>
<td>Transformer electrical ratings</td>
<td>Indicate the MVA rating, primary voltage</td>
</tr>
<tr>
<td>Transformer HV configuration</td>
<td>Indicate whether the configuration is bushing or separable connection and whether a neutral busing is required</td>
</tr>
<tr>
<td>Tap changer ac motor supply</td>
<td>Indicate whether 415 V ac or 220 V ac (unearthed)</td>
</tr>
</tbody>
</table>

Table 10 provides site specific information to be considered for including in the RFT.

<table>
<thead>
<tr>
<th>Site specific information</th>
<th>Information to include in the RFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site specific limitations on size or arrangement</td>
<td>Indicate whether there are size limitations imposed by surrounding infrastructure</td>
</tr>
<tr>
<td>Foundation</td>
<td>Type of foundation (plinth or slab)</td>
</tr>
<tr>
<td>Access and transportation limits</td>
<td>Access road weight limit</td>
</tr>
<tr>
<td></td>
<td>Maximum road width</td>
</tr>
<tr>
<td></td>
<td>Maximum standard height above road</td>
</tr>
<tr>
<td>Access road alongside operating railway</td>
<td>Provide details of whether or not the access road to the site is within the rail corridor and adjacent to an operating railway track</td>
</tr>
</tbody>
</table>