Equipment Strategy for Synchronous Condensers & Auxiliaries

Table of contents

1. Introduction

1.1 Purpose

The purpose of this document is to provide high level functional requirements for synchronous condenser installations to enable Powerlink and its suppliers to have consistent planning and project management platforms for the life of the strategy, considering all aspects of lifecycle costs. This document expresses Powerlink's vision in terms of equipment performance requirements but does not constitute a detailed contract nor technical specification.

This strategy applies to both regulated and non-regulated synchronous condensers and associated equipment to be installed in the transmission network operated by Powerlink over lifetime of this strategy. It has been developed with input from relevant Powerlink teams. Additional support was also received from an external subject matter expert and from potential suppliers.

It is envisaged that the Equipment Strategy for Synchronous Condensers will have a life of ten (10) years. Review of this equipment strategy is required in the eighth (8th) year to enable inclusion of new technologies and new requirements that may mature over that period. It will be reviewed earlier if there is a specific business need or significant technology change identified.

The objective of this equipment strategy is to achieve economical and reliable operational life for Synchronous Condensers and its major auxiliary equipment of forty (40) years whilst minimising required major plant overhauls.

1.2 Scope

This document covers synchronous condenser(s) and associated auxiliaries, with capability to deliver a nominal total output (at point of connection) of up to 240MVA (at Point of Common Coupling). Review of the strategy would be required if higher capacity installations are required.

It includes switchgear, the step-up power transformer and all associated control systems, protection and monitoring systems associated with synchronous condenser, synchronous condenser auxiliary equipment such as lubrication systems, pony motor, excitation system, cooling banks, etc.

In addition, each synchronous condenser installation is required to meet the specific transmission network requirements of inertia, system strength and stability support, as defined in the relevant planning report forming part of tender documentation.

The scope of this strategy excludes the high voltage transmission bay (≥110 kV), associated protection systems and any other equipment beyond Point of Common Coupling of synchronous condenser installation to the transmission network. The functional requirements for these are covered by the existing relevant equipment strategies.

1.3 References

Document code	Document title
IEC 60034-1:	Rotating electrical machines – Part 1: Rating and performance.
IEC 60034-3:	Rotating electrical machines – Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines and for synchronous compensators.
IEC 60034-4:	Rotating electrical machines – Part 4: Methods for determining synchronous machine quantities from tests.
IEC 60034-4-1:	Rotating electrical machines – Part 4-1: Methods for determining electrically excited synchronous machine quantities from tests.
IEC 60034-16-1:	Rotating electrical machines – Part 16-1: Excitation systems for synchronous machines – Definitions.

Document code	Document title
IEC 60034-18-1:	Rotating electrical machines – Part 18-1: Functional evaluation of insulation systems – General guidelines.
IEC 60034-18-32	Functional evaluation of insulation systems – Test procedures for form-wound windings – Evaluation by electrical endurance.
IEC 60034-27-1	Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines
IEC 60034-27-3	Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines.
IEC 60034-27-4	Measurement of insulation resistance and polarization index of winding insulation of rotating electrical machines.
IEC 60068-1	Environmental testing – Part 1: General and guidance
IEC 61850	IEC (2013) Communication networks and systems for power utility automation
ISO/IEC 17025	ISO (2005) General requirements for the competence of testing and calibration laboratories
IEC 60909-0	Short-circuit currents in three-phase a.c. Systems, Part 0: Calculation of currents
IEC/IEEE 62271-37-013	High-voltage switchgear and control gear – Part 37-013: Alternating current generator circuit-breakers
IEC 62477-1:	Safety requirements for power electronic converter systems and equipment – Part 1: General
IEEE 115-2019:	IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis.
IEEE 433:2022	IEEE Recommended Practice for Insulation Testing of AC Electric Machinery with High Voltage Rating up to 30 kV at Very Low Frequency.
IEEE P1719:2020	IEEE Draft Guide for Evaluating Stator Cores of AC Electric Machines Rated 1 MVA and Higher
IEEE Std 43™-2013	IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery
IEEE Std 95™-2002 (R2012)	IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and Above) with High Direct Voltage
IEEE Std 434™-2006 (R2013)	IEEE Guide for Functional Evaluation of Insulation Systems for AC Electric Machines Rated 2300 V and Above
IEEE Std 522™-2004 (R2009)	IEEE Guide for Testing Turn Insulation of Form-Wound Stator Coils for Alternating-Current Electric Machines
IEEE Std 111-2007	IEEE Guide for Synchronous Generator Modelling Practices and Applications in Power System Stability Analyses
IEEE C50.13 - 1989	Cylindrical-rotor 50 Hz and 60 Hz Synchronous Generators 10 MVA and Above
IEEE 551-2002	Calculating Short-Circuit Currents in Industrial and Commercial Power Systems
IEEE Std. 432-1992	IEEE Guide for Insulation Maintenance for Rotating Electric Machinery
ASM-FRA-A542372	Substation Asset Methodology – Framework

Document code	Document title
ASM-STR-A2903094	Equipment Strategy for DC Power Supplies, Quality Procedures and Documentation
ASM-STR-A2902407	Equipment Strategy for Auxiliary Transformers
ASM-STR-A3127128	Equipment Strategy for Power Transformers
ASM-PLN-A1142336	Equipment Strategy for Substation Buildings, Panels and Enclosures
ASM-PLN-A1122202	Equipment Strategy for Substation Secondary Systems Cables
ASM-SPE-A515948	Substation Ratings - Specification
ASM-SPE-A4630234	TDS-263 Cyber Security Requirements for Operational Technology Equipment Specification
INF-SPE-A5626751	Cyber Security Framework – Specification
-	Electrical Safety Act 2002 (Qld) and all associated and applicable Codes of Practice
-	Electrical Safety Regulation 2013 (Qld)
-	Work Health and Safety Act 2011
A2720172	

1.4 Defined terms

Terms	Definition
SynCon	Synchronous Condenser
SCADA	Supervisory, Control, and Data Acquisition
SAP	Computerised maintenance management system used by Powerlink
RPM	Rotation per minute
VSD	Variable Speed Drive
SFC	Static Frequency Converter
TNSP	Transmission Network Service Provider

1.5 Monitoring and compliance

The successful implementation of this strategy is monitored through review of technical specification and tender outcomes.

In addition, the success of this strategy is measured by monitoring life cycle costs as well as reliability, availability and service history associated with Synchronous Condensers and associated auxiliaries.

The minimum records required are:

- Technical Specification
- Design review reports
- Tender evaluation report
- Period contract (if used)
- Equipment Drawings

- Operation and maintenance manuals
- SAP equipment records (details to be specified by Asset Strategies)
- Factory Acceptance Test Results
- Site Acceptance Test Results
- Commissioning report

2. Strategy

2.1 Projected use of equipment

Synchronous Condensers are intended to be used for improving network system strength (short circuit capability), inertia and voltage control.

2.2 Strategy Requirements

The vision presented in this equipment strategy is based on historical experience, research and investigations into products available on the market. It has been supported by an external expert with the goal of achieving a minimal lifecycle cost over the expected service life of the equipment, whilst ensuring maximum availability and reliability of synchronous condensers.

The basis of this equipment strategy is to have expected reliable service life for synchronous condensers and major ancillary components (such as pony motor) for a minimum of 40 years. It is expected the reliable service life for components within the systems below will be less than 40 years:

- Bearings
- SFC
- Cooling plant
- Lubrication plant

In addition, reduced reliable service life for vacuum pumps, secondary systems (including protection and control), AC pumps and AC fans of 20 years is also acceptable, assuming some redundancies exist and are part of design.

The main requirements for synchronous condensers are as follows:

General:

- The synchronous condenser will **NOT** be hydrogen cooled.
- The unit and auxiliaries such as pony motor (if used) must be housed **indoor in a purpose-built industrial style building with internal gantry crane** to enable major synchronous inspection as well as replacement of major parts if required (such as bearing, pony motor, etc.).
- The rooms housing the electronic equipment will be air-conditioned
- Annual operation and maintenance cost: Less than 0.6 – 0.8 % of asset value.
- Availability of 99% (includes all synchronous components covered by this equipment strategy)
- Remote monitoring capabilities integrated with SCADA.
- Manufacturer support in Australia for installation, testing, commissioning, major services and life cycle product support (like for like spare parts).
- Modular designs for synchronous condenser, auxiliaries and controls to minimize site assembly and optimize factory pre-assembly.

- Preference for a Synchronous Condenser that can deliver inertia requirements without a flywheel.
- Preference is to adopt standardized auxiliary equipment available off the shelf in Australia in accordance with the power industry standards to eliminate the necessity for customization.
- Low as reasonably practical level of intrusive maintenance requirements to achieve availability requirements.
- Noise level to comply with the relevant standards including the Work Health and Safety Regulation 2011 and the Environmental Protection Act. Additionally, the sound pressure level at the boundary of the synchronous condenser switchyard should not exceed 55 dBA. To avoid need for additional protective measures the noise level should be kept below the exposure standard for noise as defined in the Work Health and Safety Regulation 2011 as $L_{Aeq,8h}$ of 85 dB(A) or an $L_{C,peak}$ of 140 dB(C) including details related to tonality and frequency of noise.

Sub Systems:

Main Condenser (synchronous machine):

- Stator frame design to contain components for at least 200% of expected life of 40 years.
- Stator core of suitable assembly and magnetic construction to withstand mechanical stresses and core end heating during operation within the SynCon capability.
- Stator insulation system of suitable di-electric material to withstand thermal, mechanical, operational and environmental stresses for the duration of design life and that its condition can be monitored.
- Neutral connection points to be available in frame mounted dedicated termination box. Access to line connection also required.
- A durable rotor design that can endure both steady-state and transient mechanical forces throughout the condenser's operational lifespan.
- Preference is to have rotor mass of a quantity that provides sufficient inertia to meet performance requirements without flywheel.
- Rotor field insulation system of suitable di-electric material to withstand thermal, mechanical, operational and environmental stresses for the duration of design life.
- Bearings suitable for supporting rotor up to maximum design RPM.
- Bearing sealing arrangement to prevent ingress of oil into stator enclosure and machine surrounds.
- Shaft Oiling rings fitted integrated in bearing for emergency rundown lubrication.
- Bearing protection against shaft currents.
- On-line continuous monitoring of the following:
    1. Temperature (bearings, stator winding, ambient);
    2. Bearing and Shaft vibration (Proximity Probes);
    3. Rotor earth fault;
    4. Rotor shorted turns (Flux Probe);
    5. End winding vibration (2 pole machines);
    6. Airgap monitoring (Salient Pole);
    7. Stator winding (Partial Discharge).

Exciter:

- Brushless excitation system is preferred if it meets response requirements and damping control.
- Rotor insulation system of suitable di-electric material to withstand thermal, mechanical, operational and environmental stresses for the duration of design life.
- Deliver precise voltage regulation and excitation current to maintain stability during grid disturbances
- Deliver consistent excitation response to system requirements within SynCon capability for the duration of the design life.
- The excitation system shall have two (2x100%) AVR channels including complete independent power supplies and controls. Each channel shall be equipped for ‘Auto Operation’ with the facility for selecting either channel in ‘Auto’ or ‘Manual’ mode.
- Expected reliable service life without major refurbishment of minimum 40 years (preference to be 60 years). This excludes any electronic components within exciter system.

Pony Motor:

- Squirrel cage induction motor.
- TEFC (Totally enclosed fan cooled) system.
- Capable of smooth acceleration during run-up of SynCon.
- Rated for condenser mass startup under varying conditions.
- Controlled by Variable Speed Drive (VSD) for run-up, controlled synchronization and run down braking (alternatives such as SFC are also acceptable).
- Capable of multiple starts per hour.
- Suitable insulation and winding design and co-ordinated for High Voltage windings.
- Bearings that are frictionless, force lubricated.
- Expected reliable service life without major refurbishment of minimum 40 years, preference to be 60 years.

Variable Speed Drive (VSD)/Static Frequency Converter (SFC):

- Ensures smooth speed control and efficient startup operations.
- Braking of main condenser rotor during cycling or trip.
- Heat management. Air/Water cooling.
- Remote monitoring for control, thermal and electrical performance.
- Expected reliable service life without major refurbishment of minimum 30 years, preference to be 40 years.

Lubrication System:

- Dual oil pumps (primary and standby).
- Emergency DC Pump back-up.
- Mounted on dedicated skid.
- Hydraulic jacking of rotor shaft capability.
- Lubrication cooling system.
- Replaceable in-line filters.
- Oil sampling point.

- Inlet and outlet lubricant temperature monitoring.
- Pressure and flow measurement.
- Expected reliable service life without major refurbishment of minimum 30 years, preference to be 40 years.

Braking System:

- Braking with sufficient torque capacity to transition the SynCon from synchronous speed to standstill.
- Ensure smooth deceleration.
- Auxiliary braking system for emergencies.
- Expected reliable service life without major refurbishment of minimum 40 years.

Cooling System:

- Forced air on water-cooled systems (TEWAC).
- Cooling tower designed and configured with 120% capacity allowing 20% built in redundancy.
- Inlet and outlet temperature monitoring.
- flow sensors for real-time monitoring.
- Expected reliable service life excluding AC fans of minimum 30 years, preference to be 40 years.

Synchronous Condenser High Voltage Generator Circuit Breaker:

- The selection criteria for GCB are standardised and reported in the IEC/IEEE 62271-37-013.
- The Generator Circuit Breaker (GCB) must be capable of interrupting system source short circuit fault current, generator source short circuit fault current and out-of-phase switching fault current, in compliance with IEC/IEEE 62271-37-013.
- The Generator Circuit Breaker (GCB) is designed to have a reliable service life of at least 40 years with service intervals not being shorter than 12 years.
- The preference is for SF6 spring operated circuit breaker with spring used as energy storage medium.
- The vacuum type of circuit breaker with spring operated mechanism and spring used as energy storage medium is also acceptable (pressure vessel must be registered).
- Circuit breaker control cubicle and auxiliaries must be maintainable as per existing Powerlink's owned circuit breakers.
- It is assumed that this circuit breaker will require service at the same interval as major overhaul of synchronous condenser and therefore it will be maintained only when synchronous condenser is out of service.
- As per above any circuit breaker, service and repairs (condition based and corrective) will require synchronous condenser outage and will have significant impact on synchronous condenser availability.
- The circuit breaker will have provisions to be adequately isolated and earthed in safe manner and within allowable approach distance.

Synchronous Condenser Step Up Power Transformer:

- It is envisaged that synchronous condensers can be connected into transmission network on 275 kV or 330 kV voltage level.
- All other requirements will be as per ASM-STR-A3127128.
- It is acceptable to use isolated phase bus (air insulated preferably with no pressure /vacuum requirements) as a connection between generator circuit breaker and step up power transformer.

- It is expected that step up power transformer will have adequate overvoltage protection (switching and lightning over voltages).
- It is not acceptable to use porcelain housing for any equipment that has potential catastrophic failure mode.

Protection and Control System:

- An integrated control system must be provided to undertake control and supervision of all plant systems and equipment.
- The systems shall consist of well-proven, high-quality components and be constructed to have long operating life and product support with minimum maintenance.
- The systems must not become obsolete within 10 years from the date of tender. Additionally spares and product support must be available from at least 15 years from the commissioning date.
- PCs/servers, LAN devices, operating systems and software may have shorter life expectancies than the main P&C equipment but shall be easy to upgrade with new compatible hardware and/or software.
- Redundant protection and control systems must be implemented as per Powerlink's Protection Design – Standard (ASM-STD-A637457).
- The control system must be designed for fail-safe operation.
- SCADA-enabled remote control and monitoring.
- The secondary systems must comply with the cyber security requirements specified in the Cyber Security Framework Specification (INF-SPE-A5626751) & TDS-263 Cyber Security Requirements for Operational Technology Equipment Specification (ASM-SPE-A4630234).

Auxiliary Supplies:

- AC secondary voltage and DC voltage of auxiliary systems should be consistent with existing Powerlink standard voltages (415V and 125V DC).
- Main AC auxiliary supply source will be synchronous condenser step up transformer secondary or tertiary, capable of supporting full maximum load that the whole synchronous condenser installation requires. An alternate AC supply will be sized to supply only essential synchronous condenser loads and if possible, will be derived from the closest established transmission substations owned and operated by Powerlink (from its AC change over panel to provide required redundancy).
- The supplier will list the essential loads and their power requirements.
- The supplier will specify auxiliary supply requirements for construction purposes.

Safety and Environmental:

- The risk of explosive failure kept to "So Far As Reasonably Practicable" principle (SFAIRP).
- The design of the unit allows for safe and environmentally appropriate disposal.
- Cooling fluids to be recyclable or recoverable.
- Meeting standard requirements for noise (environmental and health and safety) and radio interference voltage (RIV).

Maintenance:

- Minimal maintenance requirements to achieve availability target.
- Availability calculation with all input data to be provided by the supplier.
- Simple and reliable design.
- Spares to be held by Powerlink are to be determined by the relevant teams within Powerlink during the procurement process (in consultation with the OEM) but as a minimum shall include:

    - Bearing shells and seal kit;
    - Vacuum pump;
    - AC pumps;
    - AC fans;
    - Rotor field coil (if synchronous condenser is with Salient rotor);
    - Bearing shells and seal kit for pony motor;
    - Heat exchanger fan motors for pony motor.
- Special tools required for the synchronous condenser maintenance shall be supplied by the OEM and securely stored on site.

2.3 Technologies available now

There are a number of technologies available now across the main synchronous condenser unit and its various components.

For example these include the type of machine rotor design (i.e salient pole or cylindrical rotor).

Another example are different technologies available for start-up (pony motor or SFC).

There are also various technologies available for cooling and various excitation technologies.

This equipment strategy nominates the preference for such components, with further explanatory information found in the Section 4. Appendix of this document.

The other technologies such as batteries have been explored and will continue to be monitored.

2.4 Concurrent investigations

No concurrent investigations are underway at this time.

3. Appendix

Further details regarding strategic choices and preferences documented within this strategy are provided below.

Indoor Synchronous Condenser

A dedicated building for the synchronous condenser provides the following benefits against an outdoor system:

- Ability to control the indoor operating temperature to ensure optimal operating conditions and avoid the derating of synchronous condenser during periods of high ambient temperatures (temperatures for outdoor installation are further increased by solar radiation).
- The building creates a safer, more controlled space for maintenance, making it easier for technicians to work in addition to reducing the chance of damage or contamination during repairs.
- Better protection against atmospheric conditions (i.e moisture, salt, solar radiation and dust), which can shorten asset lifespan.
- Improved ability to control noise and avoids the need for noise containment enclosures around the synchronous condenser and associated plant.
- Reduced construction and commissioning delays due to weather once erected.

Flywheels

Since inertia is a function of the mass and diameter of the rotor, it would be more desirable if the required inertia could be met by the mass of the SynCon rotor alone, without having to add additional mass through a flywheel. Flywheels introduce an additional layer of system complexity including:

- System design and alignment of shaft.
- Additional couplings and bearings.
- Additional auxiliaries such as vacuum pumps, lube circuit and control circuits.
- Additional maintenance activity.
- Additional mitigation actions to ensure safety.

In addition, flywheel adds additional potential safety risks in case of any failures impacting fly wheel braking system.

Excitation System

Two main types of excitation system exist for synchronous condenser equipment; static excitation and brushless excitation. When compared with static excitation systems, brushless excitation systems require less maintenance and result in increased system availability. As the static excitor is transferring large excitation currents from a stationary component to a rotating winding through carbon brushes, carbon wear and contamination requires regular and intense maintenance when compared with a brushless exciter configuration.

The preference for a brushless exciter but will be contingent on the following:

1. The brushless excitation system can meet voltage control and system damping requirements.
2. Condenser design can be sourced that will deliver the required excitation current.

Rotor Design

Compared to a Cylindrical rotor SynCon, the salient pole SynCons have:

1. Higher inertia,
2. Simpler maintenance, since there is no need to remove rotors to undertake intrusive inspections and local repairs and
3. Run at a lower speed so less mechanical stress and improved reliability.

Conversely, high speed cylindrical 2 pole SynCons have:

1. Lower inertia support and require the addition of flywheels to achieve required inertia,
2. More complicated and intense maintenance requirements,
3. Higer mechanical stress at 2 pole speed compared to the low-speed Salient Pole SynCon and

4. Complex construction when compared to Salient Pole SynCon.

In addition to the above, Salient Pole Machines have superior grid frequency support whereas, Cylindrical rotor high speed Syncons typically have a faster dynamic response.

Cooling System Design

One of the key drivers for H2 cooling is to permit to run machines at voltages well above 33,000 Volts since hydrogen under pressure has a superior breakdown voltage when compared to air. As we are operating a SynCon at < 33,000 Volts breakdown strength of air is not an important consideration.

An additional benefit of H2 cooling is the efficient transfer of heat characteristic of H2 when compared to air cooled. In specifying TEWAC as the cooling arrangement and considering the design of SynCon H2 is not preferred.

The final advantage that H2 design has is reduced windage losses, normally much higher in high speed Syncons. The efficiency trade off against additional cost of Hydrogen cooled machines makes it difficult to trade off on smaller H2 cooled machines.

Further to the above deploying H2 cooling to SynCon plant introduces a whole layer of complexity that comes with the introduction of explosive gases. This includes:

1. The construction of a gas handling plant.
2. Designation of hazardous areas around the SynCon plant.
3. Maintaining of hazardous area dossiers..
4. Additional safe working practices when working in or around the hazardous area
5. Seal oil system to maintain the hydrogen gas pressure inside the machine.
6. Management of H2 leakage.
7. Safety management of purging of H2 from machine for maintenance and inspection.

Taking into account all of the above the preference is for an air cooled SynCon.