Part of Energy Queensland

Substation Standard

Standard for DC Supplies

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Abstract: The purpose of the standard is to define the type and application of DC systems used in Ergon Energy substations for plant protection, control and communications purposes. The DC systems employed for these functions shall be of high reliability design, with whole of life cost considered.

Keywords: Substation, DC Supply, Battery, Battery Charger, Isolation and Test Panel, DC Switchboard, DC/DC Converter, DC/AC Inverter, Safety, Standard Voltages, Application, Design, Installation, Test, Monitoring, Battery Accommodation, Battery Ventilation, SS-1-5.1, Appendix 1.

CONTENTS

FIGURES

TABLES

EQUATIONS

No table of figures entries found.

1 Overview

1.1 Purpose

To define the type and application of low or extra low voltage DC systems used in substations for auxiliary functions such as protection, control and communications purposes. The DC systems employed for these functions shall be of a high reliability design with whole of life operational, maintenance and costs considered. This standard applies to all new works and where practical, major refurbishments and replacements.

1.2 Scope

This standard covers DC systems for use in substations only. It can be used for communications installations in substations where no specific standard for communications equipment exists.

It does not cover:

- Communications only sites
- Battery energy storage systems for grid support
- DC auxiliary supplies integrated as a part of a discrete substation component (e.g. integrated battery of an automatic recloser)
- DC auxiliary systems in distribution plant and equipment
- Management of existing DC auxiliary systems

This standard assumes sealed VRLA batteries are used in the installation. If vented or flooded lead acid batteries are used, refer to the correct subsets of standards such as AS 2676 and AS 3011. If another technology is used (Ni Cad, Li Ion), refer to their relevant standards.

2 References

2.1 Legislation, regulations, rules, and codes

Electrical Safety Code of Practice – Works, 2020 (Queensland Government)

Environmental Protection Act, 1994 (Queensland Government)

Queensland Electricity Act, 1994 (Queensland Government)

Queensland Electricity Regulation, 2006 (Queensland Government)

Queensland Electrical Safety Act, 2002 (Queensland Government)

Queensland Electrical Safety Regulation, 2013 (Queensland Government)

Queensland Work Health and Safety Act, 2011 (Queensland Government)

Queensland Work Health and Safety Regulation, 2011 (Queensland Government)

2.2 Energy Queensland controlled documents

EQL's Fault Management Standard - 11044700

EQL Electrical Safety Rules – 6503074

Energex Commercial and Industrial Substation Manual, 00293 – 3060052

EQL Cyber Securities Controls Guidelines, R201 - 691671

Enterprise Risk Management Standard, R271 – 689958

Risk Management Procedure – 9937852

Management of Hazardous Chemicals, R251 - 692452

Standard for Classifying the Condition of Network Assets - 2948464

Standard for Substation Equipment Identification, STNW3001 - 2947172

Climate and Natural Hazard Resilience, STNW3007 - 3057510

Standard for Cables and Cable Installation, STNW3018 – 12737281

Standard for Panel Wiring, STNW3021 – 2938164

Ergon Energy Standard for Substation Earthing, STNW3028

Ergon Energy Standard for Substation Direct Lightning Strike Shielding, STNW3032

Standard for Substation Fire and Explosion Protection, STNW3035 – 3058013

Standard for Substation Signage, STNW3037 - 2941554

Standard for Substation Lighting, STNW3040 – 2949685

Standard for Substation Ventilation and Air Conditioning, STNW3047 – 3055324

Standard for Substation Metering, STNW3114 - 3061818

2.3 Energy Queensland other documents

Technical Specification for Substation DC Power Systems - EESS-10735-01-0C

TSD0240 - DC Systems Selection Guide

EQL Battery Size Calculator

Battery Space Ventilation Calculator - NA000403R490

SCADA Standard Point List - STNW3106

Standard for Substation Earthing, STNW3028

2.4 Other sources

(AS 2067, 2016), Substation and high voltage installations exceeding 1 kV a.c.

(AS 2676.2, 2020), Guide to installation, maintenance, testing and replacement of secondary batteries in buildings - Sealed cells

(AS/NZS 3000, 2018), Electrical installations (Wiring rules)

(AS/NZS 3008.1.1, 2007), Electrical installations - Selection of cables, Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV - Typical Australian installation conditions

(AS 3011.2, 2019), Electrical installations – secondary batteries installed in buildings – sealed cells

(AS 3015, 2022), Electrical installations - Extra-low voltage power supplies and service earthing within telecommunications networks

(AS 4044, 1992), Battery charges for stationary batteries

(AS 60529, 2004), Degrees of protection provided by enclosures (IP Code)

(AS 62271.1, 2019), High-voltage switchgear and control gear Part 1 Common specifications for alternating current switchgear and control gear.

(AS/NZS 3100, 2022), Approval and test specification – General requirements for electrical equipment

(AS/NZS 3820, 2020), Essential safety requirements for electrical equipment

(AS/NZS 4029.2, 2000), Stationary batteries – Lead acid – Valve regulated type

(AS/NZS 4836, 2023), Safe working on or near low-voltage and extra-low voltage electrical installations and equipment

(AS/NZS 5139, 2019), Electrical installations – Safety of battery systems for use with power conversion equipment

(AS/NZS 60079.10.1, 2022), Explosive atmospheres - Classification of areas - Explosive gas atmospheres

(AS/NZS 61000.1.1, 2000), Electromagnetic compatibility – general – application and interpretation of fundamental definitions and terms

(AS/NZS 61439.1, 2016), Low-voltage switchgear and control gear assemblies – General Rules

(AS/NZS ISO 9001, 2016), Quality management systems - Requirements

(AS/ISO 14040, 2019), Environmental management - Life cycle assessment - Principles and framework

(AS/ISO 31000, 2018), Risk Management - Principles and Guidelines

(IEC 60079-10, 2020) Explosive atmospheres Part 10.1 Classification of areas – Explosive gas atmospheres

(IEC 61643 Series) Low voltage surge protection devices

(IEC 62485-2, 2010), Safety requirements for secondary batteries and battery installations – Stationary batteries

(ENA 018, 2015) Guideline for the fire protection of electricity substations

(IEEE 450, 2020) Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications

(IEEE 484, 2019) Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications

(IEEE 485, 2020), Recommended practice for sizing lead-acid batteries for stationary applications

(IEEE 946, 2020), Recommended practice for the design of DC power systems for stationary applications

(IEEE 1375, 1998), Guide for the Protection of Stationary Battery Systems

(IEEE 1491, 2012), Guide for selection and use of battery monitoring equipment in stationary applications

(IEEE 1635/ASHRAE Guideline 21, 2022), Guide for the ventilation and thermal management of batteries for stationary applications.

(CIGRE TB 777, 2019), Reliability analysis and design guidelines for LV DC auxiliary systems

(QLD Workplace Health and Safety, 2021) Safe design of structures

2.5 Drawings

Ergon Energy Substation Standard Technical Specification Drawings DC System Items - Single Line Diagram Substation Plant Standards – (EESS-10735-11)

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply.

19 in	Nineteen inch, referring to the horizontal mounting dimension for a subrack in a 19 inch rack mount type cabinet. (IEC 60297-3-100, 2008)
Autonomy time	The length of time that the DC Supply System's load should be supported solely by its fully charged battery.
Battery bank / battery	Unit consisting of one or more cells connected in a series, parallel or series-parallel arrangement to supply the voltage and current requirements of the connected load (AS 2676.2, 2020)
Battery case / monobloc	Battery with multiple separate but electrically connected cell compartments each of which is designed to house an assembly of electrodes, electrolyte, terminals or interconnections and possible separators [IEV 482-02-17]
Battery charger	A device to convert AC to DC for charging station batteries and to supply power to dc loads during normal operation (IEEE 946, 2020)
Battery enclosure	An enclosure containing batteries that is suitable for use in an area other than a battery room or an area restricted to authorized personnel (AS 3011.2, 2019).
Battery room	A room specifically intended for the installation of batteries (AS 3011.2, 2019).
Battery string	Batteries or battery modules connected in series (AS 3011.2, 2019)
Battery System Monitor	Legacy Energex monitoring system for DC supply heath with features such as earth leakage detection, load testing and low voltage monitoring.
Bulk Substation	A substation site with system voltages greater than or equal to 100kV
Capacity	Quantity of electricity which a fully charged battery can deliver under specified conditions, measured in ampere hours (A.h) (AS 2676.2, 2020)
C&I Substation	A commercial and industrial substation site with system voltage less than 33kV suppling external low voltage customers and utilised DC Supplies or self-powered devices to drive protection and control at the site.
Cell	Basic functional unit, consisting of an assembly of electrodes, electrolyte, container, terminals and usually separators, that is a source of electric energy obtained by direct conversion of chemical energy [IEV 482-01-01]

DC system	A collection of components that make up a DC supply system, including battery banks, battery charger, isolation, protection, test points and DC switchboard.
Distribution Substation	A substation site with system voltage less than 33kV suppling external low voltage customers with no DC Supplies to drive protection and control at the site (e.g. HV fuse protection).
DC switchboard	An assembly of DC circuit protective devices, switchgear, instruments or connecting devices, arranged and mounted for distribution to, and protection of, one or more submains or final subcircuits or a combination of both (AS/NZS 3000, 2018).
DC/AC inverter	A device to convert a DC voltage to pure sine wave DC voltage to supply power to AC loads during normal operation.
DC/DC converter	A device to convert a DC voltage to another DC voltage to supply power to DC loads during normal operation.
Float charge	Permanent connection of a battery to a voltage-regulated d.c. system so that the battery is maintained fully charged and able to supply power to the system if the normal charging source fails (AS 2676.2, 2020)
Informative	A term used to define the application of the annex to which it applies. An informative annex is only for information and guidance.
Isolation and test panel	A DC switchboard providing battery string isolation and test functions as well as a test point.
Limited Access	Greater than 2 hours from a depot presence with technical capability to address required issues but less than 2 hours from a depot presence that can assist with technical support. Difficult road or access track access. Likely 4 wheel drive access only. Difficult to accessible during/after significant weather events (e.g. cyclone, flood, server storm, bushfire).
Maximum charge voltage	The fully charged battery cell reference voltage compensated for operation at 0 °C
Minimum Discharge Voltage	Minimum allowed voltage across a battery string or bank during the autonomy period which would be considered “discharged”.
N/S/SE	Energy Queensland regions of North/South/South East
Nominal voltage	Suitable approximate value of the voltage used to designate or identify a cell, a battery or an electrochemical system [IEV 482-03-31]
Normative	A term used to define the application of the annex to which it applies. A normative annex is an integral part of a Standard.
Protected extra low voltage	An extra low voltage system that is not electrically separated from earth, but that otherwise satisfies all the requirements for SELV (AS/NZS 3000, 2018).

Restricted Access	Greater than 6 hours from a depot presence with technical capability to address required issues. Requires helicopter, boat or another specialised non-road based vehicle to access within required timeframe. Likely to be inaccessible during/after significant weather events (e.g. cyclone, flood, server storm, bushfire).
Separated extra low voltage	An extra low voltage system that is electrically separated from earth and from other systems in such a way that a single fault cannot give rise to the risk of electric shock (AS/NZS 3000, 2018).
Shall	The word “shall” means mandatory.
Should	The word “should” means advisable.
Switching Station	A high voltage enclosure similar to a bulk, zone or C&I substation but has no voltage transformation and no external low voltage customers.
Temperature compensation coefficient	A co-efficient usually expressed in V/cell/°C to compensate for temperature variations and their effect on the chemical reaction within the battery
Tactical Operational Data	Data such as measurements, status, alarms or other information returned from in service field devices and systems that can be used for planning or managing the operational network. This data includes information sent to the DMS as well as other data repositories like Pi Historian and the Telemetry Hub.
Unrestricted Access	Less than 2 hours from a depot presence with technical capability to address required issues. Sealed roads All weather access Sites that would be fully de-energised prior to a significant weather event and require EQL personal to attend site before re-energisation.
Valve regulated lead acid battery	A secondary cell which is closed under normal conditions, but which has an arrangement which allows the escape of gas when the internal pressure exceeds a predetermined value. The cell cannot normally receive addition to the electrolyte. [IEV 482-05-15]
Zone Substation	A substation site with system voltages equal to or greater than 33kV but less than 100kV.

3.2 Acronyms and Abbreviations

This list does not include well-known unambiguous acronyms and abbreviations, or abbreviations defined at their first occurrence within the text.

AC	Alternating current
ADAS	Alternative Data Acquisition Service

BSM	Battery System Monitor
C	Capacity
C&I	Commercial and industrial
DC	Direct current
DMS	Distribution Management System
HMI	Human machine interface
IED	Intelligent Electronic Device
MTBF	Mean time between failure
MTTR	Mean time to repair
PELV	Protected extra low voltage
SACS	Substation Automatic Control System. Name of SEQEB's/Energex's in-house RTU product family.
SCADA	Substation control and data acquisition
SELV	Separated Extra Low Voltage
SNMP	Simple network monitoring protocol
Vpc	Volts per cell
VLA	Vented lead acid
VRLA	Valve regulated lead acid
VNiCd	Vented nickel cadmium
VRNiCd	Valve regulated nickel cadmium

4 General Requirements

DC systems are installed in substations to supply power for protection, control, communications, and other critical auxiliary circuits like standby/emergency lighting. DC Supplies consists of components such as batteries, battery chargers, switchboards, cables and monitoring equipment. The consequences of failure of the DC system in substation protection applications can be catastrophic, resulting in high risk to both personnel, plant and the general public. As such, DC Supplies are to be highly reliable to ensure safe operation of the high voltage network.

The DC Supply shall align to EQL's overall vision, purpose and values as well as high level documents such as Strategic and Business Plans, Strategic Asset Management Plan and various high level policy documents (e.g. P043 Risk Management Policy).

DC Supplies and associated DC equipment shall:

- Follow the various policies, standards and procedures that make up Energy Queensland's quality management systems (AS/NZS ISO 9001:2016, 2016).
- Identify any risks associated with application of the equipment they supply for the life cycle of that equipment (AS/ISO 31000:2018, 2018).

- Identify any environmental risks associated with the equipment they supply for the life cycle of that equipment (AS/ISO 14040:2019, 2019).

4.1 Functional and Performance Requirements

The installation shall be made as compliant as possible to (AS/NZS 3000, 2018). Where EQL specific standards exist (e.g. Identification), they shall be followed. Any contradictions between EQL standards and (AS/NZS 3000, 2018) are to be escalated to Substation Standards for clarification or confirmation.

Sufficient autonomy, redundancy and segregation shall be implemented to ensure the loss of a single component for either a planned or unplanned reason does not render the DC Supply ineffective or adversely affect the protection and control of the greater electrical network. This requirement must be achieved through the life of the installation including site construction, commissioning, maintenance, asset replacements and eventual de-commissioning. While initial capital investment and ongoing maintenance costs are a consideration for the level of autonomy, redundancy and segregation, they are not the only consideration with aspects such as safe working requirements, National Electricity Rules, network availability and typical response times just a few other considerations to determine appropriate levels.

Sufficient redundancy shall be implemented to ensure the loss of a single component does not render the DC Supply ineffective or adversely affect the protection and control of the greater electrical network. Where redundancy is not implemented, effective controls shall be implemented to limit risk exposure to people and plant. Autonomy time is to be based on credible contingency response times. Sufficient segregation shall be implemented to:

- reduce the likelihood of a catastrophic failure causing cascading damage to the DC Supply,
- reduce the likelihood of safety hazards to workers working on nearby equipment,
- allow easy and efficient replacement of individual components.

The failure or mal-operation of the following major components, sub-components or scenarios shall be considered the minimum credible contingencies. Steps shall be implemented to ensure during any of these events the overall DC Supply remains effective. Credible cascading failures may also need to be considered where one failure may lead to another failure to the point the system becomes ineffective.

- Battery string
- Battery bank
- DC Switchboard
- Battery rectifier
- Battery charger
- Single cable or wire to ground

The system must be able to be safely and effectively operated as per EQL operating and works practices including the (6503074 EQL Electrical Safety Rules) and various Standard Work Practices.

Any components that connect to EQL’s cyber network must comply with EQL’s cyber security policies and standards such as (691671/R201 EQL Cyber Securities Controls Guidelines).

During the design process, if risks are identified that require greater analysis to quantify and manage, a risk analysis can be undertaken to ensure the system is “safe by design” for the life of the installation. A practical example of achieving “safe by design” is the (Safe Design of Structures - Code of Practice, 2021). Assessments are to be completed and documented in line with (689958/R271 Enterprise Risk Management Standard) and (9937852 Risk Management Procedure)

The standard DC supply scheme is shown on (EESS-10735-11).

4.2 Verification, Maintenance and Monitoring Requirements

The design must allow for safe and effective inspection, testing, verification and monitoring during the life of the installation including installation, commissioning, maintenance and diagnostic testing. These activities should be done in line with good industry practice and current EQL standard work practices, commissioning requirements and maintenance standards.

Online condition monitoring that is remotely monitored via SCADA shall be utilised on DC Supplies. Monitoring shall be capable of sufficiently identifying and alarming for abnormal system operation and defects that pose a risk to personal on site and the greater network operation with alarms returned to Operational Control Centres for appropriate action.

4.3 Safety and Risk Management Requirements

DC Supplies and associated DC equipment shall ensure, so far as is reasonably practicable, that the plant, substance or structure they supply is without risks to the health and safety of persons (QLD WH&S Act:2011, 2011). The design, installation and operation shall also be done in a manner “preventing persons from being killed or injured by electricity; and preventing property from being destroyed or damaged by electricity” (QLD Electricity Act:1994).

Risks are to be considered for the life of the installation including the installation, operation, maintenance and disposal. Some plausible hazards associated with DC supplies through their lifecycle include but not limited to:

- Electric shock or electrocution
- Fire and explosion
- Arc blast, arc flash and arc faults
- Hazardous chemicals, toxic fumes, chemical burns or corrosion
- Muscular or skeletal injuries

Some factors that may lead to EQL personal or others being exposed to the hazards can include:

- Gas production during battery charging/discharging or fault.
- Fire during a battery fault or thermal run away.
- Stored energy.
- Working on or near electrical installations.
- Cramped, confined, awkward, hot or wet conditions.
- Defective assets.
- Mechanical failure.
- Significant weather events (e.g. earthquakes, cyclones, floods).
- Poor identification and marking.
- Incorrect wiring or operation.
- Heavy equipment.
- Unintentional de-energisation of DC supplies to in service plant.
- Earth potential rise or transfer potential.
- Induced voltages.
- Lightning or other surges.

The design and components shall consider safe working requirements including those outlined in (AS/NZS 4836, 2023).

4.4 Environmental Requirements

The DC Supply shall be specified, designed and built to operate under the environmental conditions contained in (3057510/STNW3007 Climate and Natural Hazard Resilience). The design shall adequately manage environmental risks that may occur as a result of normal operation, defects or failure which could include acid spills or battery fires. Temperature control is a significant consideration and shall not be overlooked. Management of these risk shall follow the hierarchy of controls and eliminate or substitute risks where possible and practical. Consideration is required for the final de-commissioned assets which should be recycled where possible otherwise disposed of responsibly in line with EQL's policies, standards and processes for plant disposal.

4.5 Lifecycle Management Requirements

The DC Supply design shall consider all aspects of the lifecycle including design, installation, testing/commissioning, operation, maintenance, replacement/decommissioning and disposal. Many parts of the lifecycle management of DC Supplies are documented by various documents including but not limited to:

- Asset Management Plan – DC Supply Systems
- Maintenance Standard for Battery Systems

The overall DC Supply shall be designed to last the life of a typical HV installation before a significant refurbishment project (e.g. 50-60 years). Realistic allowances for future circuits or load growth shall be considered in the design to cater for a site's ultimate arrangement. Design choices should not limit the overall installation or individual component life expectancies (e.g. rooms or enclosures and battery spacing shall not prohibit credible expansions or overheat batteries).

Battery strings will require routine replacement over the life of the DC Supply, with battery chargers likely to be replaced once or twice. Practical replacement of these assets shall be considered in the design while maintaining normal operation of the substation with minimal effort, difficulty or exposure to unsafe conditions. The DC switchboard has a life expectancy similar to most other major substation equipment. As such it has been made the common termination point of the battery strings, battery charger and DC loads. Design consideration is required for an eventual switchboard replacement and how that would be safely and practically carried out.

5 Site Requirements

Site requirements determine attributes such as voltage, autonomy time and redundancy requirements. These requirements must be fit for purpose and manage risks to as low as reasonably practical whilst remaining practical and cost effective.

Refer to Annex C for guidance at brownfield sites where greenfield requirements can be difficult to achieve.

5.1 Voltage

Table 1 outlines the Standard DC voltages that shall be used for new installations or aimed for during brownfield DC Supply replacements. At joint Powerlink / Energy Queensland sites, it is permissible to use Powerlink's standard voltage of 125 V DC which can provide design and operational benefits however 110 V DC is also acceptable and preferred if there is no benefit to EQL using Powerlink's standard.

Component sections must consider the voltages present during a final pulse current to clear a site as batteries reach their minimum voltage. While the DC Supply may be at 1.8 Vpc (AS/NZS

4029.2), the voltages at the end of a trip circuit during the pulse may be as low at 70% with breakers still required to operate as per (AS 62271.1:2019, 2019). As such, any equipment associated with this final trip function shall be able to operate as low as 70% of nominal voltage without mal operation to prevent the trip. Equipment not associated with this function do not need to operate at this reduced voltage however must not mal operate or fail if exposed to this reduced voltage.

The below tables apply for VRLA batteries only – for alternative battery chemistries refer to Substation Standards for voltage settings.

Table 1 - Standard DC Voltages

<table>
<tr><th rowspan="2">Substation Type</th><th rowspan="2">Nominal Voltage[1]</th><th rowspan="2">Typical Float Voltage at 25 °C</th><th colspan="2">Operating Voltage Limits</th></tr>
<tr><th>Minimum (Discharged)</th><th>Maximum (Charged at 0 °C)</th></tr>
<tr><td>Joint Powerlink / EQL sites (where beneficial)</td><td>125 (57 cells)</td><td>129.7</td><td>102.6</td><td>137</td></tr>
<tr><td>Bulk Substation
Or
Substations Connecting NEM Participant</td><td rowspan="2">110 (54 cells)</td><td rowspan="2">122.9</td><td rowspan="2">97.2</td><td rowspan="2">130</td></tr>
<tr><td>Zone Substation</td></tr>
<tr><td>C&I Substation</td><td colspan="4">Refer to (3060052/00293 Energex Commercial and Industrial Substation Manual)</td></tr>
<tr><td>Communication Equipment in Substations</td><td>48 (24 cells)</td><td colspan="3">Not stipulated by this standard.</td></tr>
</table>

Note 1: All voltages are a multiplier of individual cell voltages and number of cells
Nominal Voltage assumes 2 Vpc which may then be normalised to typical system voltages (i.e. 110V systems are actually 108V)
Typical Float Voltage is based on various battery OEM recommendations and standard battery configurations @ 2.275Vp.c.
Minimum Discharge voltage is based on AS 4029.2:2020 with a final cell voltage @ 1.8Vpc
Maximum Charged voltage is based on avoiding gassing cell voltage at 25 deg C set @ 2.35Vpc

Table 2 outlines various legacy and other DC voltages known to exist across the EQL network. Where the installation is determined fit for purpose at the site and not resulting in operational or maintenance issues, these legacy voltages can be retained. Where justification can be provided that the existing voltage is problematic (e.g. difficult to source period contract protection relays for nominal voltage, issues with LV AC spring charge motors, issues with LVAC/DC rectifiers for solenoid driven CB's), the installation can be upgraded to the current standard voltage. Voltage changes would be expected during significant substation rebuilds where significant amounts of auxiliary equipment are being replaced and any remaining aux equipment can either handle the new voltage or is a small additional cost to replace.

Table 2 - Legacy and other DC Nominal Voltages

Substation Type	Nominal Voltage[1]	Typical Float Voltage at 25 °C	Operating Voltage Limits	
			Minimum (Discharged)	Maximum (Charged at 0 °C)
Remote and Islanded Generation Sites BESS Sites	24	Not stipulated by this standard.		
Communication Only Site	48			
Legacy Energex substations.	24 (12 cells)	27.3	21.6	28.2
Legacy Energex and Ergon substations.	30 - Energex 32 - Ergon[2] (15 cells)	34.1	27.0	35.2
Zone substation installations.	48 (24 cells)	54.6	43.2	56.4

Note 1: All voltages are a multiplier of individual cell voltages and number of cells
Note 2: Legacy Ergon "32 V DC" battery strings are made of 15 x 2 V cells DC meaning they are in fact the same as the Energex 30 V DC Supplies.
Nominal Voltage assumes 2 Vpc which may then be normalised to typical system voltages (i.e. 110V systems are actually 108V)
Typical Float Voltage is based on various battery OEM recommendations and standard battery configurations @ 2.275Vp.c.
Minimum Discharge voltage is based on AS 4029.2:2020 with a final cell voltage @ 1.8Vpc
Maximum Charged voltage is based on avoiding gassing cell voltage at 25 deg C set @ 2.35Vpc

5.2 Autonomy

The required autonomy is based on substation type, site access and the ability to restore the network or deploy and maintain a LV AC generator within the expected response time. The overall system voltage should stay above the minimum discharge voltage for the duration of the autonomy time up until the end of the batteries designated life while supplying battery capacity requirements. Where DC Supplies have been duplicated, the autonomy level must be achieved for both independent systems. Where dual strings have been utilised, each string is to provide 50% of the capacity for the overall bank. Where load can be transferred to the other string or DC Supply, autonomy time shall be considered half of the original design requirement while transferred.

Table 3 - Standard DC Autonomy Times

Substation Type	Access Level	Autonomy
Bulk Substation Or Zone Substation	Restricted	20 hours
	Limited	10 hours
	Unrestricted	10 hours
C&I Substation	Restricted	N/A
	Limited	N/A
	Unrestricted	10 hours
Communications Equipment in Substations (if supplied by substation DC Supply)[1]	Match substation autonomy requirements.	
Communications Equipment in Substations (if separate DC Supply to substation)	Not stipulated by this standard.	

Note 1: If communication's equipment requires a longer autonomy time than the substation itself to manage risks to the greater communications network, refer to Section 5.13 Supply for Communications Equipment for options.

The following autonomy exemptions and rules are allowed where justifications can be made and business cases produced confirm the final design meets as low as reasonable practical design principles.

- A standard battery bank can be selected if it is no less than 10% lower in capacity than the calculated requirement, the next standard battery is significantly larger than required (e.g. 50% greater) and there are difficulties installing the next standard battery.
- For restricted sites, a formal risk assessment can be completed considering site specific response times and response mechanisms to determine if a lower autonomy time is reasonable and practical. Autonomy times shall not be less than unrestricted sites.
- For limited and restricted sites, the use of solar panels or standalone power systems may be considered to reduce the autonomy times following a risk assessment to confirm acceptable performance, engineering controls (e.g. trip on low DC voltages) and business response times for the life of the battery cells. Autonomy times shall not be less than unrestricted sites.

Substation LV AC Supplies will cater for the connection of a LV generator to maintain battery charger supply in the event of a full loss of LV AC supply however, a generator will not be left at site as standard. Generators are to be deployed as an operational tool during fault response as required.

Stand Alone Power Systems (SAPS) can be considered a stable AC supply to battery chargers during total loss of AC events at restricted and limited access sites. If used, autonomy times can match unrestricted sites. This will be determined on a case by case basis dependant on site specifics with no standard position at this time for the use of SAPS to provide additional autonomy.

5.3 Redundancy

Redundancy of key components is required to cover components being out of service for planned or unplanned reasons without jeopardising protection and control of the site. At key design locations, the ability to supply the alternative load shall be accounted for.

Table 4 contains the minimum redundancy requirements for new sites, major site refurbishments or DC upgrades.

Table 4 - DC Supply Default Redundancy Requirements

Substation Type	Access Level	Battery Bank	Battery Charger	Distribution Switchboard
Bulk Substation Or Zone Substation	Restricted, Limited or Unrestricted	Duplicated battery banks with dual battery strings	Duplicate chargers with N+1 charging rectifiers per charger	Duplicate switchboards with the ability to switch to the alternative supply.
C&I Substation with DC independent transformer protection*	Restricted, Limited or Unrestricted	Single battery bank with dual battery strings and temporary battery connection at distribution switchboard	Single charger with N+1 charging rectifiers	Single switchboard
C&I Substation with DC dependant transformer protection*	Complete a formal risk assessment to determine if it is reasonable and practical to meet the requirements of a DC independent C&I/distribution substation, zone substation site or implement other controls.			

*For C&I Substations, DC independent protection is considered HV fusing or self-powered relays with spring driven breakers that are not reliant on the local DC Supply to operate for faults. DC dependant protection is considered protection relays and breaker mechanisms reliant on the DC Supply to operate for fault conditions. This differentiation is important to ensure sufficient protection capacity for faults on the 415V side of the transformer.

For greenfield substations, the following exceptions and allowances can be considered where justifications can be made and business cases produced confirm the final design meets as low as reasonable practical design principles.

Table 5 - Greenfield Substation Exceptions and Allowances

Situation	Exception
Greenfield bulk substations with unrestricted access that have physical limitations or site complexities making the installation of dual strings difficult.	Single string battery banks may be used however dual strings should be evaluated as the first preference. Single string battery banks shall not be installed at bulk substations with limited or restricted access.
Greenfield zone substations with physical limitations or site complexities making the installation of dual strings difficult.	Single string battery banks may be used for unrestricted sites. Dual strings should be strongly considered for sites with limited or restricted access.
New zone substations with small transformers utilising HV fuse protection and ACR's for transformer/LV bus and feeder protection.	Single DC Supplies (e.g. single battery bank, single charger, single DC switchboard) may be used provided the battery bank is dual string and the ACR's shall have internal batteries to maintain feeder protection for the loss of the substation DC Supply.
New zone substations with a single power transformer and single modular control room or limited customer numbers where automatic de-energisation of HV assets for loss of DC Supply is preferred against other planning inputs such as Net Present Value, Values of customer reliability or STIPIS when compared to duplication of the DC Supply. This may also be used at sites initially built as a single transformer site with the future second building housing the future second DC Supply.	Install an outdoor DC Supply as the duplicate supply until the second modular building is installed. OR Install a single DC Supply rather than duplicate supplies and implement an automatic de-energisation for Loss of DC Supply scheme. Refer Annex E for more information.
New zone substations that connect a major customer to the EQL network, will likely never have any EQL connected network beyond this site and remote backup protection up to the customers first protection device beyond the connection point can be guaranteed. A backup DC Supply from the customer will not be practical as their batteries will not be sized for EQL asset loads.	Single DC Supplies (e.g. single battery bank, single charger, single DC switchboard) may be used provided the battery bank is dual string. No automatic de-energisation scheme is required as there will be remote end protection up to the connection point for the loss of local DC Supply. If EQL installs any outgoing network in the future, the site must then be upgraded to greenfield zone substation requirements (e.g. implement duplication or automatic de-energisation).

5.4 Segregation

Segregation is required in a number of key components and locations to assist with the overall operation and maintenance of the installation through the whole life of the DC Supply:

- Battery banks, chargers and DC distribution switchboards shall be segregated from one another as discrete components. These components can be installed in the same room however shall have physical separation sufficient to limit damage in the event of failure on the other from credible events. Chargers, batteries and main isolation devices can be combined into a single unit at C&I, distribution or other specialised sites (e.g. NOMAD/Mobile Sub) where space is a premium or reliability and individual part replacements is not as high an importance. If this is completed, all normal considerations (e.g. ventilation, clearances, temperature, maintenance allowances) shall still be adhered to.
- Independent DC Supplies shall be separated from one another as discrete components (e.g. separate chargers, separate cables). These components can be installed in the same room, cable tray, duct etc provided one can be safely removed from service, worked or replaced without impacting or potentially impacting the other and are segregated where practical (e.g. opposite sides of cable trays with separate zip ties or clamps).
- Where dual string batteries have been used, each battery string is to be capable of individual isolation for maintenance, repair or fault condition without affecting the performance of the remainder of the system besides reduced autonomy time. Dual strings can be installed in the same rack or enclosure where practical.
- Unprotected cables between the battery terminals and first protection device shall be segregated from one another to reduce the chance of a positive to negative fault. Refer to Section 12 Cables and Wiring for more information.
- Exposed busbars and cables shall be eliminated wherever possible with the use of appropriate insulation and where required mechanical rather than the use of physical segregation. Refer to Section 12 Cables and Wiring for more information.

5.5 Protection and Control

The majority of protection and control functions are provided by the main components which are specified in (EESS-10735-01-0C Technical Specification for Substation DC Power Systems).

Protection and control requirements of the DC Supply are to be compliant to (AS 2676.2, 2020), (AS/NZS 3000, 2018) and (AS 3011.2, 2019) as well as the following criteria.

5.5.1 Direct Contact Protection

Protection against electric shock from direct contact with parts, otherwise known as basic protection, shall be provided for all low voltage and extra low voltage circuits as detailed in (AS/NZS 3000, 2018). Substations are considering a restricted site allowing the use of obstacles where beneficials.

Barriers and enclosures shall be used as the first preference where access is not required for normal work activities or design choices can eliminate the need for access (e.g. test points). Intermediate obstacles shall be installed directly over any AC supplied terminals in switchboards or panels housing predominantly DC circuits. The obstacles shall have a traffolyte or equivalent label stating ’230V AC’ in white text on a red background. Where multiple sources (e.g LV AC, SELV DC, PELV DC) are within an enclosure, intermediate obstacles should be installed to reduce the likelihood of contact between the different sources and aid in achieving (AS/NZS 4836, 2023) requirements. SELV terminals and assemblies inside panels that are IPXXB or IP2X rating do not need an intermediate obstacle as a single phase to ground connection will not initiate a fault.

5.5.2 Overcurrent protection

Overcurrent protection shall be provided and graded as per (AS/NZS 3000, 2018) requirements. Nominal circuit breaker ratings which form part of the DC Supply are listed later in this document in the relevant component sections (e.g DC Switchboard). Fuses which form part of a protection and control panel are listed in other standards.

Unearthed systems shall have overcurrent protection devices installed on both the positive and negative conductors. Earthed systems only require a protection device on the output conductor.

The short-circuit current rating of a battery consisting of strings of cells in parallel is the sum of the short-circuit current ratings of a group of cells comprising a single cell from each of the parallel branches (AS 2676.2, 2020). Where it can be proven parallel strings will not contribute fault currents in the same conductors under fault conditions, only the contributing strings need to be considered (e.g. cables between battery strings and the point of paralleling).

5.5.3 Overvoltage protection

Overvoltage protection shall be implemented where possible to limit overcharging of batteries which can cause excessive battery gassing or eventual failure. This function is typically managed by the battery charger and shall be set to achieve a “Condition II” charging rate as per (AS 2676.2, 2020) when determining rate of ventilation for rooms and enclosures. If overvoltage protection cannot be implemented in any way, (AS 2676.2, 2020) “Condition I” shall be used when determining ventilation requirements.

5.5.4 Undervoltage protection

Undervoltage protection shall be considered in each design however may be managed in different ways based on installation and site specific considerations. Risks due to undervoltage should not only consider damage to batteries but also damage to equipment supplied by the system and greater electrical network risks such as unprotected network, inability to operate the network or customer reliability. Options for undervoltage protection include:

- Duplicating DC Supplies and all associated AC supply and electrical network to avoid de-energising HV electrical apparatus due to DC Supply undervoltage.
- Automated de-loading of the batteries to limit damage to batteries after being fully drained or damage to voltage sensitive devices.
- Automated de-energisation of HV electrical apparatus to avoid unprotected networks. Refer Annex E for more information.
- Remote monitoring and alarming with manual intervention (not preferred as only mitigation control as administration control in hierarchy). Without intervention, consider batteries run to failure.

5.5.5 Earth Leakage Detection

Earth leakage detection shall be implemented in all unearthed/SELV DC Supplies. Refer to Measuring, Monitoring and Alarms and Appendix B Alarms & Thresholds for detection and alarming requirements.

5.5.6 Isolation Points

The following local isolation points and controls are required at a minimum. Where practical, protection devices should double as isolation or control points with suitable functionality to allow safe working practices (e.g. ability to lock out). Where not practical, a separate control device shall be installed.

- Battery string circuit breaker located on or near the battery string (maximum 2m from battery terminals, outside of any battery enclosure and safely accessible)
- Battery string input isolator located on the DC Main Switchboard
- Battery charger AC mains input circuit breaker located on the battery charger cabinet
- Battery charger DC output circuit breaker located on the battery charger cabinet
- Battery charger DC input circuit breaker located on the DC Main Switchboard
- Incoming circuits to switchboards
- Outgoing circuits from switchboards
- Incoming circuits into panels

Isolation points within protection and control panels is outside the scope of this standard and are covered by (2938164/STNW3021 Standard for Panel Wiring) or plant specifications.

5.6 Earthing / Grounding

Protection and control DC Supplies and circuits shall be unearthed/ungrounded otherwise known as SELV to improve reliability. Earth/ground leakage currents or faults shall be detected by either the battery charger or another device capable of detecting earth leakage currents as per Section 5.5.5 Earth Leakage Detection.

Communication's DC Supplies shall be positively earthed otherwise known as known as PELV to limit electrical interference.

All exposed conductive parts that are not part of the electrical circuitry shall be connected to the substation earthing system as per (STNW3028 Standard for Substation Earthing).

5.7 Electrical noise, lightning, and switching surges

DC Supplies shall be protected from electrical noise as per (12737281/STNW3018 Standard for Cables and Cable Installation).

Electrical devices installed shall be resistant to disturbance from electrical noise, lightning or surges by being compliant to (EESS-10735-01-0C Technical Specification for Substation DC Power Systems).

DC Supplies shall be protected from direct lightning strike as per (STNW3032 Standard for Substation Direct Lightning Strike Shielding).

Negative impacts of lightning shall also be mitigated by ensuring the site is compliant to (STNW3028 Standard for Substation Earthing) to limit earth potential rise to less than DC Supply insulation levels.

Surge protection is not normally required for EQL DC Supplies provided all normal design criteria is achieved. However, if large inductive or capacitive loads are being switched which could produce damaging surges, surge protection should be investigated. Refer to applicable parts of (IEC 61643 Low voltage surge protection devices) for guidance.

5.8 Safe Working and Arc Flash Management

The installation shall consider crews performing routine work on or near the installation, associated safety risks associated with work and how to manage them to as low as reasonably practical as per the hierarchy of controls. (AS/NZS 4836, 2023) should be referenced to ensure these requirements are met.

At a minimum, designs must consider:

- Electric shock, electrocution: Can crews de-energise circuits before approaching them, can they isolate themselves from live components, can insulating barriers (either permanent or temporary) be installed?
- Arc blast and arc flash: Equipment installed shall be as outlined in the appropriate sections of (EESS-10735-01-0C Technical Specification for Substation DC Power Systems) which should achieve this requirement.
- Manual handling: Do crews have sufficient room to use mechanical aids for the installation and removal of heavy batteries.
- Identification: Is there sufficient signage to notify personal of possible hazards? Are all signs outlined in (2941554/STNW3037 Standard for Substation Signage) included in the design?

5.9 Measuring, Monitoring and Alarms

Sufficient monitoring and measuring capabilities are required to ensure safe and reliable operation of the DC Supply and devices at site that rely on it. New installations shall continuously monitor the following analogue measurements:

- AC input voltage to battery charger
- DC output voltage from battery charger
- DC output current from battery charger
- DC main switchboard system voltage
- DC system load current
- Each battery string current
- Each battery string midpoint voltage (50% essential, 25% and 75% optional)
- Ambient temperature
- Battery string temperature (hot spot essential, individual battery cell temperature optional)

New installations shall continuously monitor the following device binary status:

- Battery charger input AC CB status (mandatory where AC input voltage is not monitored and alarmed otherwise not necessary)
- Battery charger output DC CB status
- Battery string CB status
- DC system load CB status (if master load CB installed)

New installations shall continuously monitor and alarm for the presence following conditions (unless optional):

- Earth fault detected/leakage current detected
- Low and high DC voltage
- Failed or open circuit battery cell or battery connection
- AC ripple from the DC charger (preferred if available but optional)
- State of charge of battery strings (optional)
- State of health of battery strings (optional)
- Remaining time at the current rate of discharge to minimum voltage point (optional)
- Cell/battery ohmic measurements (optional)

Refer to Annex B for standard monitoring alarm and threshold values.

The battery charger is expected to monitor and alarm for internal conditions that will affect the operation and performance of the charger, along with other elements of the DC system. Where a charger cannot complete the expected monitoring, measuring or alarming, additional components shall be installed to provide equivalent functionality. Standard monitoring and alarming completed by the charger is outlined in (EESS-10735-01-0C Technical Specification for Substation DC Power Systems):

- Sections 8.2.6 DC Power Management System
- Sections 8.2.7 Local control and indication
- Sections 8.2.8 Metering
- Sections 8.2.9 Alarms
- Sections 8.2.11 Battery Bank Monitoring

Temperature correction probes shall be used by the battery charger for temperature compensation. These shall be installed as close as practical to the hottest location of the batteries to ensure accurate representation of battery temperatures. The standard design is to have a single temperature probe in the middle of each battery string for this purpose. This is deemed acceptable for monitoring battery string temperature however it is recognised discrete in built battery temperature monitoring is the optimal solution for monitoring battery condition.

Current transformers for battery currents can be installed in multiple locations but in order of preference can be installed in battery string isolation panels, on battery rack cables before or after the isolation panels or in the switchboard on the incoming battery cables.

Transducers to measure DC system voltages shall be installed in the main DC switchboard.

5.9.1 Site Requirements

The following monitoring and indications are required at site without the need to connect any device.

- DC main switchboard voltage
- Battery charger output current
- Battery string currents
- Battery charger urgent indication
- Battery charger non-urgent indication
- AC supply un-healthy indication
- Battery temperature

Local indication of alarms is required to ensure crews can easily identify if the DC Supply has concerns that need addressing. Local indication is outlined in Table 15 in Annex B.

Voltage test points are required on DC Distribution switchboards and each battery string to allow voltage readings for routine maintenance and diagnostic testing. These test points shall be protected by their own circuit breaker. The test points must be safely accessible by field personal while live.

5.9.2 DMS/Network Operations Centre Requirements

Monitoring and alarming returned to network operation centres via the DMS requires balancing between adequate notification of changing conditions requiring attention of operational crews, against overloading network operations staff with nuisance alarming. As such, monitoring and alarming returned to the network operations centres shall be based on operational response requirements and bundled accordingly.

The monitoring points listed in Measuring, Monitoring and Alarms shall be returned to the network operations centres via the DMS to allow continuous monitoring and alarming for operational purposes. Some of these monitoring points are to have alarm limits set in SCADA to provide independent failsafe alarming if there is a failure of onsite components. Refer to Annex B for standard monitoring alarms and thresholds. SCADA points shall align to relevant SCADA standards and points lists.

Alarms can be driven from various devices in the DC Supply. Alarms from site to the control room shall be grouped as per Table 6 with alarm level priorities aligned to (2948464 Standard for Classifying the Condition of Network Assets). Refer to Annex B for more specific alarm details.

Table 6 - SCADA Alarm Priority Grouping

Alarm	Priority	Description	Typical DC system conditions
DC Supply Urgent Alarm	P0 / NP	The DC system has a condition or measurement that indicates failure or imminent failure of the DC system.	AC supply failed Battery charge failed DC voltage high/low
DC Supply Non-urgent Alarm	P1	The DC system is operational however has a condition or measurement that if left unaddressed may lead to imminent failure or permanent damage to the DC system.	Battery temperature high Charger rectifier failed or out of tolerance DC earth leakage detected
DC Supply Warning Alarm	P2	The DC system is not working optimally or should have some action taken to ensure high reliability operation. It is expected the condition can remain until the next routine site inspections when it can be addressed. This may also be used to indicate functions that operate under normal conditions but may affect operation while occurring.	System update required
N/A	C3	The DC system is working as intended with no concerns for reduced performance. The system however has recommended actions as per manufacture advice to maintain optimal overall operation. These should not be routed to control rooms as no action from response crews is required. They should however be returned into a centralised database for trending and lifecycle management activities.	Battery discharge test in operation. Battery charger in boost charge mode.
N/A	C4	The DC system is working as intended with no alarms or conditions that need action.	Nil

5.9.3 Tactical Operational Data Requirements

Tactical operational data collected by field devices as part of the remote monitoring shall be captured in the appropriate data repositories as part of EQL's digital transformation (eg. Pi Historian, Telemetry Hub). This information shall be made available to the many parts of the business that operate, maintain and manage devices to assist in tasks such as fault finding, diagnostics, trending and asset management without the need to attend site. This data will be reviewed on a needs basis and is not used to alert for real time operational response needs which are met in the DMS.

5.10 Signage and Safety Data

Equipment identification or naming shall be as per (2947172/STNW3001 Standard for Substation Equipment Identification). In the absences of a unified EQL standard, follow STNW3001 Standard for Substation Equipment Identification for installations in the Ergon Network or Substation Design Standards for installations in the Energex Network.

Identification must sufficiently identify the following components:

- Battery banks
- Battery strings
- Battery cases (a unique number with the manufacturers serial number as the default position)
- Cables
- Chargers
- Distribution switchboards
- CB's, isolators and other protection or control devices
- Battery monitoring units (e.g. Battery System Monitor, MD100m) and accessories (e.g. CT's or transducers) excluding local display (e.g. voltage display points)

Substation signage shall be as per (2941554/STNW3037 Standard for Substation Signage). In the absences of a unified EQL standard, follow STNW3037 Standard for Substation Signage for installations in the Ergon Network or Substation Design Standards for installations in the Energex Network.

Additional signage may be required if alternative battery technology such as Li-Ion is used which should be checked with relevant Australia Standards and industry guidelines during design.

Hydrogen is a hazardous chemical and requires “flammable gas” signs if volumes can exceed 200L but stay below 5000L. It is not expected any room or enclosure properly designed to this standard will be able to hold 200L of hydrogen while remaining below 2% concentration.

Substation batteries contain hazardous chemicals which shall have signage and Safety Data Sheets in line with (692452/R251 Management of Hazardous Chemicals). Safety Data Sheets shall be contained in EQL's computerised internet based SDS database ChemAlert with appropriate QR codes to ensure personal at site can access the required information. At sites with limited or no network access, printed Safety Data Sheets shall be left on site with other site documentation.

5.11 Cyber Requirements

Any device that requires remote monitoring or alarming shall have suitable outputs for connection to SCADA. These shall be either voltage free contacts, or a serial interface supporting DNP3 protocol and IEC 61850. The preference is for DNP3 alarm mapping within the device to be user configurable allowing the user to select the class of each point in addition to the mapping order. Where it is not possible to freely configure the DNP3 map for the battery charger the DNP3 points shall have binary points included in class 0 and class 1. The analogue points shall be included in class 0 and class 2.

Any device that connects or is able to connect to the EQL communications network shall meet all EQL cyber security requirements such as (691671/R201 EQL Cyber Securities Controls Guidelines) and other EQL Information and Cyber Security Requirements.

5.12 Supply for Emergency and Standby Lighting

DC Supplies for emergency and stand by lighting shall be in line with (2949685/STNW3040 Standard for Substation Lighting). Using the substation control and protection batteries as a supply for emergency or stand by lighting is not recommended. Where practical, battery backup emergency or stand by lighting should be used. At sites with larger emergency or stand by lighting requirements greater than 20A or 500 watts total, a dedicated DC Supply (single bank, single charger, single DC Switchboard) shall be installed with capacity for a minimum of 1.5 hours running time. If emergency or stand by lighting is connected to the same battery supplying protection and control equipment, it is to be considered a constant load for 8 hours.

5.13 Supply for Communications Equipment

The source of DC supply to a communications system within a substation is influenced by its power and autonomy requirements for the communications equipment. Where practical, communications systems can be supplied via the substation DC supply with the use of DC/DC converters provided a number of technical and operational requirement are considered. Practical is considered the use of standard designs and standard plant to that used in a substation environment. If not practical (e.g. batteries too large, to many shelves of batteries, misalignment of standards, bespoke design requirements), a separate DC supply for the communications system shall be implemented.

Where there is a shared DC supply, the preference is for the autonomy of both systems to match that of the substation. This will help align with operational response expectations. Communication’s Design is to confirm if this is acceptable for the site or not. If it is an unacceptable risk to the communications network (e.g. site is of high importance of concerns for response time), alternative options are the use of a dedicated DC supply for the Communications equipment or achieve the higher autonomy requirement for the entire site. The DC Supply for a communications system shall at a minimum match all other requirements outlined in this standard unless otherwise directly specified within this standard or a standard specific to Communications systems.

If communications equipment is supplied by the substation DC Supply, it must:

- Electrically separate the substation SELV from the communications PELV supply
- Have separate switchboards for the Communications equipment. Refer to Section 10 DC Switchboard for more information.
- Have sufficient barriers to ensure direct contact between the two supplies is avoided. Refer to Section 5.5.1 Direct Contact Protection for more information.
- Have sufficient redundancy in the DC/DC converters. Refer to Section 11 Inverters and Converters for more information.

6 Battery Room or Enclosure

Battery rooms or enclosures housing VLRA batteries must cover minimum requirements to ensure they are fit for purpose for the life of the DC Supply and be compliant to (AS 2676.2, 2020) and (AS 3011.2, 2019). General requirements to achieve this are outlined in Table 7.

Table 7 – Battery Room or Enclosure Requirements

Attribute	Requirements
Room or enclosure	Options in order of preference are: 1. A dedicated battery room with open racks. 2. A dedicated battery room with indoor enclosures. 3. An outdoor battery enclosure. 4. A control room containing secondary systems only with indoor enclosures. 5. A control room containing both primary and secondary systems with indoor enclosures. 6. A control room containing both primary and secondary systems with open racks. Heat (e.g. chargers) and spark sources (e.g. switches, fans, air conditioning devices) shall be reduced to as low as practical from any battery room or enclosure. For C&I sites, it is recognised that dedicated battery rooms (if not mandated by the National Construction Code), outdoor battery cabinets and secondary system only rooms will often be impractical.
Enclosures - Indoors	Battery enclosures may be used to accommodate batteries if and only if the batteries are unable to be accommodated in a battery room. If sufficient natural ventilation cannot be provided then mechanical ventilation is to be provided. The safety distance when enclosure doors are open shall be maintained. Temperature inside the enclosure should not exceed 2 deg above ambient (IEEE 1635/ASHRAE Guideline 21:2022, 2022). Where a battery enclosure is located in a building it is subject to the building internal environment. The enclosures ventilation arrangement is to be connected a source of fresh air, such that condensation is prevented from forming in the enclosure. Ventilation options are as follows: • For an enclosure in an air conditioned room, the low level inlet vent is to connect to the air-conditioned room. The high level exhaust vent is to connect to the external environment. The air conditioned room itself must have sufficient air inlets or leaks to the natural air environment to ensure the room can replenish vented air. • For an enclosure in a non-air conditioned room, the low level inlet and high level exhaust vents are to connect to the external environment. Where battery enclosures are used within a room to capture hydrogen, the room itself no longer has to comply with the requirements to mitigate the risk of hydrogen explosion.

Attribute	Requirements
Enclosure - Outdoors	Where a battery enclosure is located external to a building it is subject to the outdoor environment including direct sunlight and unimpeded natural ventilation. A double skinned naturally ventilated enclosure installed in a shaded location is preferred. The enclosure shall be designed to meet all structural requirements appropriate to the environment it is installed in. While segregation of batteries and chargers is preferred, for outdoor enclosures containing lower Ah capacity batteries (e.g. 110Ah), it is considered practical to have a combined battery and charger combination with the main switchboard inside the control building. This practicality reduces for larger systems (e.g. 300Ah systems) where larger enclosures, additional hydrogen production and additional heating diminish the benefits in which case separate battery and charger enclosures are preferred. The following additional considerations must be accounted for on top of indoor enclosure requirements: • Manage solar radiation with solar shielding or positioning the enclosure near buildings which can provide shade. The preference is to install them on the southern side of a building followed by the northern side. Do not installed enclosures on the western or eastern side of buildings unless they are shielded from the rising (condensation concerns) or setting (heat concerns) sun. • Maximise passive cooling with double skins, insulation and cross flow ventilation to manage enclosure ambient temperatures. • Allow for additional space between batteries to assist heat dissipation. • The charger and batteries shall be in separate sections in a lockable enclosure. • If mechanical cooling is required, manage condensation by insulating enclosures and ensure sufficient alarming on the cooling system and ambient temperature if cooling stops or is ineffective.
Hydrogen Concentration	Shall be compliant to (AS 3011.2, 2019) and ensure hydrogen concentration is maintained below 2% by volume of the room or enclosure. Exceeding this level may lead to concentrations that may become hazardous (IEC 60079-10:2020, 2020) which is not permitted. Calculations of ventilation requirements shall be as per (AS 2676.2, 2020) Section 3.3 Ventilation. The EQL Battery Space Ventilation Calculator can be used for assistance in calculating ventilation requirements for standard battery banks. Hydrogen concentrations are to consider not only normal charging conditions but also hydrogen production during boost or equalise charge.
Minimum Exhaust Rates	Shall be calculated as per (AS 2676.2, 2020) Section 3.3.2 Rate of Ventilation.

Attribute	Requirements
Charging Rate	Where possible, battery charger settings shall have automatic over voltage cut off enabled to achieve a “Condition II” charging rate as per (AS 2676.2, 2020) when determining rate of ventilation for rooms and enclosures. If overvoltage protection is not implemented, (AS 2676.2, 2020) “Condition I” shall be used when determining ventilation requirements.
Ventilation Methods	Where possible, natural ventilation shall be used to limit maintenance requirements and reduce the chance of mechanical failure. Alternatively, ventilation requirements may be met following (3055324/STNW3047 Standard for Substation Ventilation and Air Conditioning). Ventilation inlets shall be low and outlets high and on opposites sides of the room or enclosure to assist heat transfer and flow. Ventilation must result in enough flow to avoid pockets of hydrogen collecting in the roof space. Overall venting arrangements shall meet the requirements of (AS 2676.2, 2020) Section 3.3 Ventilation. If mechanical aided ventilation is used for a battery room or enclosure, it shall be compliant with (AS 3011.2, 2019) and (AS 2676.2, 2020) requirements. Fans should be flameproof and compliant with AS 1668.
Natural ventilation area	EQL natural ventilation inlets and outlets are sized based on (AS 2676.2, 2020) but also include safety margins to improve staff safety. $A_{EQL} = 100q_v \times Efficiency\ Reduction\ \times FoS$ Where: • A = the minimum area of the apertures, in square centimetres • q_v = the minimum exhaust ventilation rate, in litres per second. • A 50% efficiency reduction if vents are covered (e.g. crimesafe or weather shielding). No reduction is required if the vent is uncovered. • A Factor of Safety (FoS) of 5 for dedicated battery rooms • A Factor of Safety (FoS) of 10 for non-dedicated batter rooms

Attribute	Requirements
Mechanical Ventilation	Where mechanical ventilation is required it shall be provided according to (AS 2676.2, 2020). If a fan is required to ventilate the room the following conditions will apply: • The fan motor must be totally enclosed and suitable for the corrosive electrolytic environment. • The mean air velocity in the duct must be a minimum of 0.5 m/s • An air flow sensor shall be installed to monitor ventilation. Alarms shall be set and raised based on Annex B The charger does not have to stop float charging the batteries should air flow drop below 100% of requirements however boost, equalise and recharging shall be avoided to limit hydrogen production. • The minimum cross sectional area of the exhaust opening must be calculated as per natural ventilation requirements. • The minimum cross sectional area of the supply opening will be twice that calculated for the exhaust opening. • The fan shall be installed to create a positive pressure in the enclosure or room and shall not be installed in the exhaust ducting. The design shall be such that hydrogen can be vented outdoors and not pushed into other rooms due to this positive pressure. The fan control switch will be mounted external to the battery room and adjacent to the battery room door. The switch must be provided with a neon pilot light.
Ducting	Any ducting must be resistant to corrosion by the battery electrolyte. The duct must have a slightly rising gradient over its entire length and areas where gases could be entrapped shall be avoided. The inlet opening of the duct shall be at the highest point of the room to ensure all explosive gases are exhausted from the battery room. The cross sectional area of the duct will be in accordance with ventilation requirements.

Attribute	Requirements
Temperature	The temperature shall be kept as practical as possible to optimal temperatures for battery health of 25 °C. Practical limits will depend on the installation type and location and are considered: • Bulk and Zone Substation (indoors, airconditioned): 20-30 °C range. • Bulk and Zone Substation (indoors, non-airconditioned): 15-35 °C range. • Bulk and Zone Substation (outdoors, airconditioned): 20-30 °C range. • Bulk and Zone Substation (outdoors, non-airconditioned): 15-35 °C range. • C&I Substations: 15-35 °C range. Where other equipment has been installed in the same room (e.g. primary switching plant), competing priorities for battery cooling and switching plant heating shall be addressed to limit plant degradation and condensation in all plant items. Spacings of batteries shall be sufficient to allow the required cooling during operation and should be as per manufacturer recommendations and (AS 3011.2, 2019). Greater spacing shall be considered at sites with greater temperature ranges or outdoor installations to allow better heat dissipation.
Temperature Management	To achieve practical temperature requirements: • The preference is to use passive cooling of battery rooms or enclosures where possible. • If battery enclosures are used they shall account for battery heat generation as per (IEEE 1635/ASHRAE Guideline 21:2022, 2022) for float charge, accelerated charge and discharge modes. • For indoor battery rooms or enclosures, attempt to position low inlet vents from adjacent air conditioned rooms to provide temperature controlled air into the battery room or enclosure. • Avoid installing batteries on unshaded western walls which will be exposed to high levels of solar heat in the afternoon. • For outdoor enclosures, use double skinned or insulated enclosures to limit solar absorption and internal heating. • If mechanical temperature management is used (i.e. air conditioning or fans), alarms shall be implemented if the device fails to sufficiently control the environment temperature.
Moisture and dust ingress	Any room or enclosure housing DC Supplies shall be IP54 at a minimum. Any moisture that is able to enter shall be managed to limit condensation within the room or enclosure. IP55 is preferred for outdoor enclosures.

Attribute	Requirements
Equipment Layout	Minimal physical clearances in the battery room shall comply with (AS 3011.2, 2019) battery room layout and floor area as a minimum. Additional room to assist manual handling shall be included with consideration given to space required for mechanical aids. Batteries, chargers and main switchboards shall be located as close as practical to one another. Consideration shall be given to separate battery rooms and avoiding uneven cable lengths between battery strings. Battery rooms or enclosures shall be positioned to ease battery replacements with consideration given to loading and unloading requirements, mechanical aid requirements, clear route access and minimised transport distances. Batteries shall not be installed in awkward positions that increase the chance of manual handling hazards. Sufficient room is to be included to allow for the ultimate site arrangement.
Safety Distance	Close to a battery, dilution of explosive gases may not always be guaranteed. This arises from the fact that "dispersion of explosive gas depends on the gas release rate and the ventilation close to the source of release" (IEC 62485-2, 2010). "Therefore a safety distance extending through air shall be observed within which flames, sparks or glowing devices are prohibited". In addition any other devices with high surface temperature are also prohibited within the safety distance. For batteries rated up to 600 Ah a minimum safety distance of 500 mm from any battery case can be used. For batteries exceeding this rating but rated up to 1,000 Ah a minimum safety distance of 600 mm from any battery case can be used. A partition wall between battery and sparking or glowing device may be used to achieve the required safety distance, if the specified safety distance, when measured by the taught string method (AS 2067, 2016), is unobtainable.
Electrical equipment in battery accommodation	Electrical equipment application in the vicinity of a battery shall be made in accordance with the requirements of the sealed cell secondary batteries installed in buildings Australian Standard (AS 3011.2, 2019). Telephone and other electronic communication devices may be ignition source hazards that do not meet the equipment safety requirements for use in the vicinity of secondary batteries and shall be excluded from battery accommodation. Air conditioning units should not be installed in battery rooms unless the hydrogen is captured and vented outside the room without entering the room itself.

Attribute	Requirements
Floor Loading, Construction and Finish	Floor loadings shall comply with (AS 2676.2, 2020) and consider (3057510/STNW3007 Climate and Natural Hazard Resilience). Allowance for the ultimate arrangement of the site must be included in the design. For VRLA batteries, there are no special construction or finish requirements. Within battery rooms where vented wet cell battery banks are installed, provision shall be made to hold spilt acid within the room by providing a 20mm recessed floor or a 50mm high bund across doorways. The finish to the battery room floor shall be an acrylic based, pointless flooring composition. The flooring material shall be laid to form a 100mm high coved skirting to all walls. 50mm x 50mm timber coving must be fitted to all floor/wall junctions.
Eye wash facilities	No eye wash facilities are required where sealed batteries such as VRLA are installed. For any other battery types, refer to the relevant standard to confirm requirements. Eye wash facilities are required for vented cells as per (AS 2676.2, 2020).
Fire and Explosion Protection	DC Supplies shall be protected from fire as per (3058013/STNW3035 Standard for Substation Fire and Explosion Protection). This includes the installation of fire extinguishers and room fire ratings. Equipment with arcing contacts shall not be located in a room or enclosure that hydrogen will be captured and vented by. Equipment shall be limited to essential only (e.g. batteries and isolation panels) within a battery room or battery enclosure to limit the exposure to electrical arcs in the presence of hydrogen. Any luminaires in a battery room shall be fully enclosed and other devices installed as per (AS 3011.2, 2019).

7 Battery Bank

For all new installations, batteries shall be as per (EESS-10735-01-0C Technical Specification for Substation DC Power Systems).

VLRA battery technology has been assumed throughout this standard as they are the battery of choice for various reasons. If using other technology such as flooded lead acid, Nickle Cadmium or Lithium Ion, the intent of this document should hold true with relevant industry standards and manufacturer information to be referenced to ensure other requirements are met. Lithium Ion batteries are not standard batteries across the electricity supply industry in the substation space and lack defined Australian or International standards in this regard. If they are installed as a trial or during future standard development, they are to comply as much as practical with this standard, any relevant Australian or International standard as well as any other additional considerations for the specific battery technology.

Battery bank ratings and capacity are to be calculated using the Substation Battery Size Calculator which is based on (IEEE 485, 2020) and EQL knowledge and experiences. Inputs used for capacity and sizing calculations are to reflect the realities of the installation in its current arrangement with future ultimate arrangements and future proofing integrated where possible. The final capacity selected shall provide the required autonomy times outlined in Section 5.2 Autonomy.

A standard duty cycle and loads for capacity calculations is covered in Table 8. These can be altered if the designer can confirm more or less onerous operating conditions however in all instances:

- A credible initial trip load must be considered that could de-energise the site.
- A credible manual reclose load must be considered that could restore the battery charger.
- The largest bus trip load is to be the final load scenario to cover a loss of charger event where the network has to be cleared to prevent loss of protection.

Table 8 - Standard Battery Duty Cycle Load Scenario for Capacity Calculations

<table>
<tr><th>No</th><th>Discerption</th><th>Duration</th><th>Loads</th><th>Rational</th></tr>
<tr><td>1</td><td>Initial Event</td><td>1 min</td><td>Standing load plus load for 2 primary CB’s tripping</td><td>This will cover an initial protection operation and clearing event that leads to the de-energisation of a site. Any auto reclose or CB fail event loads would be covered by the 1 minute duration which (IEEE 485, 2020) states as standard practice.</td></tr>
<tr><td>2</td><td>Standing Load</td><td>15 min</td><td>Standing load only</td><td>This is the Minimum Wait Period in (11044700 EQL Fault Management Standard) prior to any Manual Reclose attempt.</td></tr>
<tr><td>3</td><td>Manual Restoration Attempt</td><td>1 min</td><td>Standing load plus load for 2 primary CB’s closing</td><td>Attempted manual re-energisation of a site.</td></tr>
<tr><td>4</td><td>Standing Load</td><td rowspan="3">As required</td><td>Standing load only</td><td rowspan="3">Additional operational response time in an effort to restore the network before the end of the autonomy time. The duration of this event is until 1 minute before the end of the required autonomy period.</td></tr>
<tr><td>5</td><td>Standing Load</td><td>Standing load only</td></tr>
<tr><td>6</td><td>Standing Load</td><td>Standing load only</td></tr>
<tr><td>7</td><td>Final Trip Load</td><td>1 min</td><td>Standing load plus load for the number of CB’s on the largest primary bus to be tripped</td><td>De-energisation of the site at the end of the battery autonomy period to ensure the site is de-energised before a complete loss of DC.</td></tr>
</table>

Loads are to be classified in line with (IEEE 485, 2020). Standard load currents for typical EQL equipment are provided in the Substation Battery Size Calculator and can be adjusted as required to accurately reflect the loads experienced by the system in its ultimate arrangement. For DC systems with multiple strings in parallel per bank, each string shall be assumed to contribute an equal portion of the total capacity. The battery capacity shall allow for battery degradation to ensure the required autonomy time can be achieved at the end of the battery life.

Standard values for capacity calculations are outlined in Table 9.

Table 9 - Battery Capacity Calculation Standard Values

Attribute	Default Value	Rational
Min volt Vpc	1.8 Vpc	(AS/NZS 4029.2, 2000) Section 3.1.3.
Typical Float Voltage	As per Section 5.1 Voltage.	Based on battery manufacturer advice and number of cells in a string.
Max volt (0 deg C) Vpc	As per Section 5.1 Voltage.	Based on battery manufacturer advice and number of cells in a string.
Autonomy Time	As per Section 5.2 Autonomy.	As explained in Section 5.2 Autonomy.
Number of strings	As per Section 5.3 Redundancy.	As explained in Section 5.3 Redundancy.
Temp factor	1.0	Applicable to batteries with a design temperature of 25 °C in applications where this is the ambient temperature or where the application cycles around this ambient temperature, as is the case of Ergon Energy's substations installed in regional Queensland. For different temperature applications an appropriate temperature factor may be selected after consideration of the battery thermal inertia and the manufacturers information
Design Margin	1.2	During design of new installations to allow for unforeseen additional loads or less-than-optimum operating conditions of the battery due to improper maintenance, recent discharge, or ambient temperatures lower than anticipated, or a combination of these factors that adversely affect a battery's capacity. In existing installations with known loads reduction of this factor to 1.1 is appropriate
Aging Factor	1.25	Allows for normal progressive deterioration in battery capacity until the end of its useful life. (AS 2676.2, 2020) and other international standards (e.g. (IEEE 450, 2020)) recommend replacement at 80% capacity resulting in a 1.25 multiplier (1/0.8=1.25).
Load growth	1.0	Do not account for growth in capacity requirements unless it is foreseeable within the next 15 years with site extensions or equipment upgrades.

Attribute	Default Value	Rational
K factor	As per OEM details for the battery based at a C_{10} rate to Min volt per cell.	(IEEE 485, 2020) Section 6.4.3 Capacity rating factor.
Standard Loads	Calculated as per site ultimate arrangement	Consider all DC loads including protection, communications and emergency lighting if connected. Standing loads will be a combination of continuous, noncontinuous or momentary (IEEE 485, 2020). Refer to the Substation Battery Size Calculator for more information. Standing load cannot be beyond autonomy requirements (e.g. for a 10 hour autonomy time and batteries having a C10 capacity of 200Ah standing load cannot be more than 20A)
Initial Event Load	Calculated as per site ultimate arrangement	Standing load plus the load drawn to trip the largest bus at site.
Manual Restoration Attempt Load	Calculated as per site ultimate arrangement	Standing load plus the load drawn to re-energise the largest bus at site and any other breakers to restore AC supply to the battery charger.
Final Trip Load	Calculated as per site ultimate arrangement	Standing load plus the load drawn for to trip all local breakers required de-energise the site.

From the point of manufacturing, batteries self-discharge while in storage. As a result, batteries should be stored as per manufacturer instructions which may include regular measurements and supplementary charging. Batteries should not be held in storage longer than manufacturer recommendations which is typically 1-2 years. Batteries in storage are more prone to plate sulphation due to self-discharge during storage and will also have reduced service life which may not go beyond periodic replacement periods. Any battery older than 12 months shall not be used unless assessed as acceptable and supplementary charged before installation. Batteries beyond manufacturer recommended shelf life, stored unacceptably or assessed as unacceptable shall be scrapped.

Where a bank has multiple strings, each string shall have its own protection and isolating device. A fault within one string shall not adversely affect the performance of another battery string. Strings shall be arranged to allow the replacement of cells from one string while the other string remains in service supply the load.

8 Battery Charger

For all new installations, battery chargers shall be compliant to (EESS-10735-01-0C Technical Specification for Substation DC Power Systems) including control, indication, metering and alarm facilities.

Other charger types are acceptable for like for like charger replacements where full compliance to (EESS-10735-01-0C Technical Specification for Substation DC Power Systems) is not possible. In these instances, they should be as compliant as practical and all points of differentiation reviewed and addressed as required to meet the general requirements of a DC supply.

The charger should be sized to be capable of:

- Maintaining all continuous loads and supplying a bus trip operation for the largest trip load current with no batteries connected.
- Maintaining all continuous load currents while charging the batteries from fully discharged to 75% capacity at 25 °C within 8 hours and 100% within 24 hours. The battery manufacturers recommended maximum float voltage shall not be exceeded.

Charger settings shall be set to match the batteries installed. For detailed settings, follow in order of preference:

- Specific released EQL Battery Charger Setting Standards or Application Guides
- Annex A for generic charger settings using input from the battery and charger OEM

Temperature compensation shall be enabled in the charger with appropriate settings. Temperature compensation is used to adjust the float voltage to limit damage to the batteries where temperature variation resulting in changes to float voltage. The temperature compensation sensor is to be attached with a suitable means to the side of a battery module as close as practical to the middle of the battery rack that will provide the highest likely temperature. It is preferred to use a thermocouple compound between the sensor and battery to improve accuracy.

The ambient temperature probe is to be installed in the battery room or near battery enclosures to give a true representation of the room temperature. It should be kept away from heat sources (e.g. batteries and chargers) as well as cooling sources and drafts (e.g. next to vents or mechanical fans).

The charger is to have an AC supply CB suitably rated for expected currents considering normal or recharge currents, inrush currents or when a charger is re-energised and fault currents. The CB shall not trip for inrush currents when a charger is re-energised and batteries discharged to minimum operating voltages.

9 Isolation Cubicles

For all new installations, Isolation Cubicles shall be compliant to (EESS-10735-01-0C Technical Specification for Substation DC Power Systems).

One independent isolation cubicle is required for each battery string and shall be installed as close as practicable to that battery string and located outside of the battery and battery charger enclosures. Each isolation cubicle shall be a separate enclosure to ensure the integrity of the DC system reliability. The DC Supply Scheme drawing (EESS-10735-11) shows the arrangement of the isolation and test panels in the DC system.

Installation of isolation cubicles on the side of a battery rack is acceptable provided they can be safely access for operational response requirements.

The battery isolation cubicle shall provide for the following:

- A double pole protection device for a battery string with a normally closed auxiliary contact wired back to a terminal block. The status of this contact will be monitored by EQL's SCADA system. The device must be suitable for a maximum 70mm^2 cable.
- Anderson plug (SB175) and Anderson weatherproof boot (3-6036P1) shall be provided for discharge testing each battery string independently which shall be connected on the switchboard side of the isolating switch (i.e. not connected to the unprotected battery cable).
- Space for a Hall Effect current transducer device for measurement of battery string current by the battery charger for display and monitoring. The transducer will be supplied as part of the battery charger.
- A double pole protection device (2 A) for mid-point monitoring cables.

10 DC Switchboard

For all new installations, DC switchboards and other similar components shall be compliant to (EESS-10735-01-0C Technical Specification for Substation DC Power Systems).

General design requirements include:

- Ensure equipment is rated for current and future operational voltage, continuous currents, short-time withstand currents and making / breaker current for switchgear.
- All components shall be specifically rated for the DC voltage and current. The use of AC rated components for DC circuits is not permitted unless a DC rating has been provided by the manufacturer.
- Polarised DC breakers shall not be used where power flows could be bi-directional or source of supply misrepresented (e.g. solar installations). Where the likelihood of reverse flow on radial cables is not credible, non-polarised DC breakers are preferred however polarised DC breakers are permitted with sufficient checks to confirm correct polarity at time of installation.
- CB's or isolators shall be used for all applications in main and distribution switchboards. Fuses and links are not permitted.
- In control panels, CB's shall be used for incoming DC Supplies for each panel including:
    - Spring charge motor supplies
    - Protection trip and close circuits
    - Protection supply circuits.
- At smaller sites with smaller capacity requirements, typical breaker sizes can be reduced to lower, more practical sizes if beneficial and not likely to cause future constraints.

Protection and control requirements in protection and control panels of substations are outlined in other standards and documents such as (2938164/STNW3021 Standard for Panel Wiring).

10.1 Main Switchboard

A main switchboard will be provided in all substations utilising duplicate supplies. The following equipment will be incorporated in the switchboard as per (EESS-10735-11, 2020):

- Main circuit breaker for the battery charger DC output (100A CB)
- Battery charger auxiliary supply (2A CB).
- Main isolators for each battery string with associated measuring circuitry (250A Isol).
- Supply circuits for supply to distribution switchboards (63A CB).

- One temporary charger connection point (63A CB).
- One temporary battery connection point (63A CB).
- At least one (nominally 2) spare 63A circuit (63A CB).
- Touch proof test points (2A CB).
- Supply to voltage and current transducers for system monitoring (2A CB).
- Supply for an integrated Intelligent Electronic Device (e.g. mini-RTU like MD100m) for monitoring (10A CB)
- Battery system monitor (20A CB, legacy Energex sites only with BSM's still installed).
- Local displays for measured voltages and currents

Substation main switchboards shall allow for a time between any duplicated supplies to allow alternative supplies to protection and control devices. Communication switchboards however shall have no tie with alternative supplies being run directly to each device which will manage alternative supply requirements.

In some instances it may be more practical and beneficial to manage space restrictions by incorporating the main switchboard components into a combined main and distribution switchboard. This is allowable provided all selection criteria can be achieved and no new restrictions are introduced (e.g. difficulty with manual handling, no allowance for future growth). A circuit breaker should be installed between the main switchboard and distribution switchboard sections to allow effective isolation of the distribution switchboard without de-energising the main switchboard components.

10.2 Distribution Switchboard

The DC switchboard selection shall have sufficient capacity to provide all DC circuits necessary for the satisfactory operation of the substation. Selection shall consider future growth of the site and ensure sufficient space is available in the switchboard for additional cables, circuit breakers, etc. when the substation is built to its ultimate arrangement. The switchboard shall be installed inside a control building. Where multiple buildings or multiple floors exist, multiple switchboards shall be installed with each building or floor containing a switchboard with the associated CB's and wiring for the associated building or electrical plant.

Where alternative DC Supplies are available (e.g. DC Supply 1, DC Supply 2), a connection shall be installed to allow the alternative supply to energise the distribution switchboard. This connection shall run normally open at the distribution switchboard to maintain separation of the DC Supplies. This is not required if the devices connected to the system have the ability to manage two supply inputs internally as is common for communication systems.

The following equipment will be incorporated in the switchboard and duplicated switchboard:

- Normal and alternative incoming supply isolator switches (160A Isol).
- Outgoing sub-circuits based on a function level as required (CB ratings as required).
- Touch proof test points (e.g. 4mm banana socket).

Sub-circuits are to be allocated on a functional basis as per the tables below. Circuit breaker ratings shall be confirmed appropriate for the final installation requirements. The supply shall loop between bays or panels with the ability to isolate a bay or panel without affecting the remainder of the downstream bays or panels. Additional circuits shall be added where extra capacity is required. The designer shall add to the list if necessary to allow for any other further requirements.

Table 10 – Typical Sub-circuits on Substation DC Switchboard

Category[Note 1]	Function	DC Supply 1	DC Supply 2[Note 2]
110/132/220 kV Network	Prot 1	32A	
	Prot 2		32A
	Close and Control	32A	32A[Note 3]
	CB Motor Supply	32A	32A[Note 3]
	CB Magnetic Actuator	32A	32A[Note 3]
	Power Transformer Auxiliaries	32A	32A[Note 3]
	Metering	10A	10A[Note 3]
33/66 kV Network	Prot 1	32A	
	Prot 2		32A
	Close and Control	32A	32A[Note 3]
	CB Motor Supply	32A	32A[Note 3]
	CB Magnetic Actuator	32A	32A[Note 3]
	Power Transformer Auxiliaries	32A	32A[Note 3]
	Metering	10A	10A[Note 3]
11/22 kV Network	Prot 1	32A	
	Prot 2		32A
	Close and Control	32A	32A[Note 3]
	CB Motor Supply	32A	32A[Note 3]
	CB Magnetic Actuator	32A	32A[Note 3]
	Metering	10A	10A[Note 3]

Category Note 1	Function	DC Supply 1	DC Supply 2 Note 2
Support Systems	Communication DC/DC converter (if not separate supply)	16A	16A Note 3
	SCADA RTU or SACS	16A	
	SCADA HMI or SACS Interface	16A	
	SICM Bulk Substation or Zone Substation (SE Only)	16A or 4A	
	Fire and Security		10A
	Emergency lighting – 2 circuits maximum		10A
	Touch proof test points	2A	2A
	Minimum 10 spare poles (5 CB's) plus others to make up a standard chassis. At least two spare 16 A CB's fitted.	Designer choice	Designer choice

Note 1: Power transformers are categorised as per their highest voltage winding.
Note 2: DC Supply 2 circuits will be on DC Supply 1 if there is no duplication of DC switchboards.
Note 3: Loads to be shared across DC Supply 1 and 2 where functions are duplicated for redundancy purposes. This applies to things like Building 1/Building 2, Bus 1/Bus 2, Transformer 1/Transformer 2. N/A if a function is not duplicated.

Communication switchboards should be designed as per any communications standard as required. If no standard exists, the following can be used as a guide.

Table 11 - Sub-circuits on Communications DC Switchboard

Category	Function	DC Supply 1	DC Supply 2
Communication Systems	Protection signalling A	10A	
	Protection signalling B		10A
	Communications A	10A	
	Communications B		10A
	Optical isolator 1	10A	
	Optical isolator 2		10A
	HMI		10A
	Two-way radio	10A	
	Telephone isolation		10A
	Minimum five (5) spare poles (5 CB's) plus others to make up a standard chassis. At least two (2) spare 10 A CB's fitted		

10.3 Protection and Control Panels

Table 12 contains typical incoming sub-circuit and associated breaker ratings for supplies to individual protection and control panels. Refer to (2938164/STNW3021 Standard for Panel Wiring) for requirements beyond this incoming circuit breaker.

Table 12 – Sub-circuits entering protection and control panels

Category[Note 1]	Function	DC Supply 1	DC Supply 2[Note 2]
110/132/220 kV Network	Prot 1	10A	
	Prot 2		10A
	Close and Control	10A	10A[Note 3]
	CB Motor Supply, Mag Actuator, Solenoid or similar	16A	16A[Note 3]
	Metering	6A	6A[Note 3]

Category[Note 1]	Function	DC Supply 1	DC Supply 2[Note 2]
33/66 kV Network	Prot 1	10A	
	Prot 2		10A
	Close and Control	10A	10A[Note 3]
	CB Motor Supply, Mag Actuator, Solenoid or similar	16A	16A[Note 3]
	Metering	6A	6A[Note 3]
11/22 kV Network	Prot 1	10A	
	Prot 2		10A
	Close and Control	10A	10A[Note 3]
	CB Motor Supply, Mag Actuator, Solenoid or similar	16A	16A[Note 3]
	Metering	6A	6A[Note 3]

Note 1: Power transformers are categorised as per their highest voltage.
Note 2: DC Supply 2 circuits will be on DC Supply 1 if there is no duplication of DC switchboards.
Note 3: Loads to be shared across DC Supply 1 and 2 where functions are duplicated for redundancy purposes. This applies to functions including Meter 1/Meter 2, Bus 1/Bus 2, Transformer 1/Transformer 2 or Building 1/Building 2. N/A if a function is not duplicated.

11 Inverters and Converters

For all new installations, any inverters, converters or other similar components shall be compliant to (EESS-10735-01-0C Technical Specification for Substation DC Power Systems).

Where inverters and converters are used, they must match or exceed the redundancy requirements of the DC Supply overall. Some general guidance for this is:

- Where functionality has been duplicated (e.g. duplicate protection or communications systems), only a single inverter/converter is required.
- If an inverter/converter is a critical component and its failure could lead to the overall failure of the DC Supply and the loss of the critical functions it provides with no duplication of functionality (e.g. there should be duplicate supplies but there is only a single supply at a legacy site), N+1 redundancy should be considered and implemented if practical.
- Where multiple inverters are required in parallel to achieve current ratings, consideration should be given if one fails and the possibility of cascading failure due to overload. If required to avoid this, install N+1 inverters/converters.

11.1 DC/DC Converters

DC/DC converters may be used in the following situations:

- To supply communications systems as per Section 5.13 Supply for Communications Equipment
- To allow the use of period contract items at sites with legacy DC voltage systems

- To manage sites that are transitioning from legacy DC voltages to current preferred voltages as major plant is replaced.
- To supply legacy circuit breaker closing solenoids where the DC Supply is the incorrect rating. This is more typical for magnetic actuated or solenoid sites that may have 220V DC ratings. This shall not be done at new sites and is also preferred to be avoided at legacy sites where practical.

DC/DC converters should be avoided to integrate single non-standard voltage devices into substation installations. The preference is to install the correctly rated device.

Where DC/DC converters are used as part of the DC Supply the following requirements shall be met:

- Redundancy shall be achieved as per Table 13.
- Each converter requires a watch dog alarm for operational status and malfunctions.
- Each converter is to have separate incoming and outgoing CB's.
- If converters are run in parallel for redundancy purposes, non-directional CB's are required to mitigate the risk of bi-directional fault currents.

Table 13 – DC/DC Converter Redundancy and Segregation Requirements

DC/DC Location	Redundancy	Typical Scenario
Between DC Main Switchboard and Communication Switchboard.	N converters with N+1 rectifiers.	Refer 5.13 Supply for Communications Equipment
Between DC Main Switchboard and Substation Load	N+1 converters with N+1 rectifiers.	RTS projects installing period contract items into legacy voltage sites.
Individual power source to discrete item (e.g. single power relay).	N converters with N rectifiers.	Not preferred but may be most practical for single bespoke device.
Between Battery Charger and remainder of system (e.g. batteries and DC main switchboard).	N converters with N+1 rectifiers.	Not preferred option.

11.2 DC/AC Inverters

DC/AC inverters may be used in the following situations:

- To supply SCADA HMI's or other critical protection, control or communications components that are AC supplied by require the same high reliability of a DC Supply.
- As part of a standalone power system (SAPS) assisting with the LV AC Supply of a substation. If required, this will be specified as per SAPS requirements.
- To supply emergency or standby lighting as per Supply for Emergency and Standby Lighting.

11.3 AC/DC Inverters

AC/DC inverters may be used in the following situations:

- To supply legacy circuit breaker closing solenoids where the DC Supply cannot practically do this. This is more typical at 48V sites which would have excessive current requirements.

This shall not be done at new sites and is also preferred to be avoided at legacy sites where practical.

12 Cables and Wiring

Cables associated with DC Supplies shall be designed as per (12737281/STNW3018 Standard for Cables and Cable Installation).

Wiring associated with DC Supplies shall be designed as per (2938164/STNW3021 Standard for Panel Wiring). In the absences of a unified EQL standard, follow STNW3021 Standard for Panel Wiring for installations in the Ergon Network or 364 Substation Design Standards for installations in the Energex Network.

For management of the risk from high short circuit currents on the unprotected cables and connections between the battery terminals and first protection device the following is required:

- Single core cables.
- As short as practical, preferably less than 2m but no greater than 3m.
- Where installed outdoors, have double brass tape for additional mechanical and termite protection.
- Where installed indoors, either have double brass tape or be double insulated and contained in conduiting as much as practical to provide mechanical protection.
- If double insulated and contained in conduiting, be positioned as close as possible to limit radio interference.
- Battery connections shall be shrouded with removable and reusable insulating covers and all other connections and cables shall be insulated. The preference is for flexible connections to other racks and shelves, allow greater flexibility with arrangement and cover sites with excessive vibration levels as per (AS 3011.2, 2019) Section 3.2. Solid links can be used where legacy standards are installed and it can be confirmed vibration levels will not exceed manufacturer allowances.
- Each centre bridging connection for battery strings greater than 120 V d.c. shall be in a contrasting colour to allow easy identification. This bridge shall be readily accessible for removal to split the bank into two extra low voltage banks.

All cable and wiring selections must be rated for all of the below with standard cables and wiring sizes in Table 14. (AS/NZS 3008.1.1:2018, 2018) should be used for guidance on cable sizing however refer to manufacture specifications as (AS/NZS 3008.1.1:2018, 2018) may not be appropriate for all DC considerations.

- Fault level – Consider dual strings and chargers as fault contribution with no temperature variation beyond 25 °C. Temporary battery connections or alternative LV AC supplies do not need to be considered running parallel to normal supplies.
- Load Currents – Loads are to be calculated using the values used in the battery capacity calculations. Consideration is required for load classifications (continuous, non-continuous, momentary), connected equipment (e.g. spring charge motor or closing solenoids) and realistic maximum currents at a particular time (e.g. currents drawn during a bus protection operation at a site with magnetic actuated circuit breakers).
- Voltage Drop – shall be limited to 5% from the point of supply to the electrical apparatus as per (AS/NZS 3000, 2018) while the batteries are at their minimum (discharge voltage) listed in Table 1 - Standard DC Voltages. It must be confirmed that all devices and circuity will operate as expected to clear the substation via a protection relay, multi trip device and

circuit breaker trip coils/ solenoids/magnetic actuators at this reduced voltage with expected load currents.

The rating of the cable must be greater than the current rating of the CB or fuse suppling the cable as per (AS/NZS 3000, 2018) requirements. Larger conductors shall be used fault current contributions are greater than standard allowances.

Table 14 - Standard Cable/Wire sizing

Location	Cable size	Comments
From battery strings to the main DC switchboard	$35mm^2$ for bulk, zone and C&I substations. $16mm^2$ can be used for C&I sites if confirmed suitable.	Manage risks for unprotected cables listed above. As close as practical identical lengths for all battery strings to the DC switchboard to reduce uneven draw from batteries. Fault current to consider single string fault contribution and battery string isolation cubicle CB operating times.
From battery chargers to the main DC switchboard	$35mm^2$ for bulk, zone and C&I substations. $16mm^2$ can be used for C&I sites if confirmed suitable.	Fault current to consider all string contributions and DC main switchboard CB operating times.
To voltage test points or mid point monitoring	$4mm^2$	Manage risks for unprotected cables listed above where unprotected. Fault current to consider all string contributions test point/midpoint monitoring CB operating times.
From main DC switchboard distribution switchboard	$16mm^2$	To be confirmed based on site specifics using AS 3008.1 and manufacturer specifications. Fault current to consider all string contributions and DC main switchboard CB operating times.
Beyond main DC switchboard to panels and within panels	Refer to the (12737281/STNW3018 Standard for Cables and Cable Installation) and (2938164/STNW3021 Standard for Panel Wiring).	

13 Installation Inspection, Testing and Commissioning

Sufficient inspections and testing shall be completed at the time of installation and commissioning to confirm:

- Individual components are fit for purpose and fit for service.
- The system as a whole is fit for purpose and fit for service.

Refer to EQL's Standard for Minimum Test and Commissioning Requirements, Standard Work Practices, Inspection and Test Plans for further information.

Annex A Generic Battery Charger Settings

Informative

The below generic battery charger settings can be applied at legacy installations if the absence of more prescriptive setting requirements.

Constant Float Voltage Operation:

- Float Voltage
  - As per Table 1 - Standard DC Voltages or Table 2 - Legacy and other DC Nominal Voltages.
- Current Limits:
  - Battery charger as per Table 18 - Battery charger output current alarm thresholds
  - Battery strings as per Table 19 - Battery string current alarm thresholds
- Temperature compensation:
  - As per battery OEM requirements, otherwise
  - -5mV per cell for each 1 deg C above 25 dec C and +5mV for each 1 deg C below 25 deg C (AS 2676.2, 2020)

Constant Current Operation:

- Not covered in this standard.

Functional Settings

- Earth leakage detection
  - As per Table 23 - Earth fault/leakage current monitoring alarm thresholds.
- Battery Discharge test
  - Disable function.
- Boost Charge:
  - Preferred duration of 12 hours.
  - Boot voltage set as per battery OEM specifications, and
  - Disable function.
- Equalise Charge:
  - Preferred duration of 12 hours.
  - Equalise voltage set as per battery OEM specifications, and
  - Disable function.

If there is only a single DC alarm (e.g. general alarm) for a site that alarms for multiple conditions, it shall be urgent priority.

Annex B Alarms and Thresholds

Informative

B.1 Minimum Alarms

The following alarms are the minimum that shall be provided as per Table 15. Battery chargers may have additional alarms or indications possible which should be implemented where practical unless specified otherwise.

Table 15 - Minimum Alarms

DC System Condition	SCADA Alarm Grouping			Local Indication
	Urgent	Non-Urgent	Warning	
AC supply failed	✓ (N/C)			✓
Battery charger failed	✓			✓
Control module failed	✓			✓
DC output CB tripped	✓			✓
Battery temperature high		✓		✓
DC voltage high	✓			✓
DC voltage low	✓			✓
Battery String CB Tripped	✓			✓
Battery charger power module failed		✓		✓
Battery charger power module alarm		✓		✓
Battery strings unbalanced		✓		
DC earth leakage detection		✓		
Battery discharging	✓			✓

DC System Condition	SCADA Alarm Grouping			Local Indication
	Urgent	Non-Urgent	Warning	
Inverter or Converter Failure	✓			
Battery Enclosure/ Accommodation Ventilation Failure	✓			
Battery Enclosure/ Accommodation Cooling Failure		✓		

N/C is a normally closed contact which will alarm if de-energised.

B.2 AC Input Voltage Alarm Thresholds

Table 16 - AC input voltage monitoring alarm thresholds

Nominal Voltage	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
230	N/A	207 V	253 V	N/A
415	N/A	360 V	440 V	N/A

LoLo / LL4: N/A
Lo / LL2: Set based on AS 60038:2022 Section 4 Standard Voltages of -10%.
Hi / HL2: Set based on AS 60038:2022 Section 4 Standard Voltages of +6%.
HiHi / HL4: N/A

B.3 DC System Voltage Alarm Thresholds

Table 17 - DC system voltage monitoring alarm thresholds

Nominal Voltage	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
24 (12 cells)	21.6 V	24 V	N/A	28.2 V
32 (15 cells)	27.0 V	30 V	N/A	35.2 V
48 (24 cells)	43.2 V	48 V	N/A	56.4 V
50 (25 cells)	45.0 V	50 V	N/A	58.7 V
110 (54 cells)	97.2 V	108 V	N/A	126.9 V
120 (26 cells)	100.8 V	112 V	N/A	131.6 V
125 (57 cells)	102.6 V	114 V	N/A	133.9 V

LoLo / LL4: Set based on 0% SOC @ 1.8Vpc.
Lo / LL2: Set based on nominal cell voltage @ 2Vpc

Hi / HL2: Not set
HiHi / HL4: Set based on gassing cell voltage @ 2.35Vpc

Temperature corrected float voltages may approach or exceed HiHi / HL4 alarm limits during cold weather if the voltage monitoring alarms are not also temperature compensated. Where non-temperature corrected high voltage alarms are triggered at the same time as LoLo / LL4 battery temperature alarms, refer to charger and battery specification to determine if the system is operating correctly.

B.4 DC System Load Current Alarm Thresholds

No standard alarm limits set.

B.5 Battery Charger Output Current Alarm Thresholds

Table 18 - Battery charger output current alarm thresholds

Battery Charger	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
10A	N/A	0.2 A	5 A	7 A
16A	N/A	0.4 A	8 A	11.2 A
20A	N/A	0.5 A	10 A	14 A
25A	N/A	0.6 A	12.5 A	17.5 A
32A	N/A	0.8 A	16 A	22.4 A
40A	N/A	1 A	20 A	28 A
63A	N/A	1.5 A	31.5 A	44.1 A
80A	N/A	2 A	40 A	56 A
160A	N/A	4 A	80 A	112 A

LoLo / LL4: N/A
Lo / LL2: Set based on 2.5% of battery charger rated current.
Hi / HL2: Set based on MAC P2 limit for battery charger standing current at 50% of battery charger rated current
HiHi / HL4: Set based on MAC P1 limit for battery charger standing current at 70% of battery charger rated current

B.6 Battery String Current Alarm Thresholds

Table 19 - Battery string current alarm thresholds

Battery Bank	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
75Ah	N/A	N/A	9 A	15 A
80Ah	N/A	N/A	9.6 A	16 A
125Ah	N/A	N/A	15 A	25 A
160Ah	N/A	N/A	19.2 A	32 A
300Ah	N/A	N/A	36 A	60 A
330Ah	N/A	N/A	39.6 A	66 A

LoLo / LL4: N/A.
Lo / LL2: N/A.
Hi / HL2: Set based on 0.12C or 120% of recommended charge maximum current
HiHi / HL4: Set based on 0.2C or 200% of recommended charge maximum current

B.7 Battery String Current Difference Alarm Thresholds

There are no standard alarms limits for battery string current difference.

If implemented:

- The string current difference shall be measured as a percentage and calculated as:

$$Battery\ String\ \%\ Difference = \left\{ \frac{\left| I_{String\ 1} - I_{String\ 2} \right|}{\left(I_{String\ 1} + I_{String\ 2} \right) \big/ 2} \right\} \times 100$$

- Limits should be set based on OEM advice or the MAC if available.
- It is thought Hi/HL2 and HiHi/HL4 alarms would be implemented.
- Alarms should not trigger at times of low string current contribution (e.g. while on float charge) which could exaggerate percentage differences and raise false alarms.

B.8 Battery String Midpoint Voltage Alarm Thresholds

Table 20 - Battery string midpoint measurment alarm thresholds

Temperature	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
Midpoint voltage difference	- 3.0 V	- 1.5V	+ 1.5V	+ 3.0 V

LoLo / LL4: Set to ensure detection of loss of two 2 V cells
Lo / LL2: N/A. Set to ensure detection of loss of one 2 V cell
Hi / HL2: Set to ensure detection of loss of one 2 V cell
HiHi / HL4: Set to ensure detection of loss of two 2 V cells

If only absolute midpoint voltages are provided, only high alarms are to be set with no low alarms required.

For uneven battery strings, it is required to calculate the hypothetical mid-point based on the uneven measured mid-point and total string voltage using the equation:

$$V_{MVD} = \frac{V_{String}}{2} - \frac{Cell_{TMP} \times V_{MeasuredMid}}{Cell_{MMP}}$$

V_{MVD} – Midpoint voltage difference

V_{string} – Total string voltage

$Cell_{TMP}$ – Number of cells at the theoretical midpoint based on the total number of cells in the string (e.g. 27 if there is a total number of cells in the string of 54).

$V_{MeasuredMid}$ – Voltage at the uneven point of measurement

$Cell_{MMP}$ – Number of cells across $V_{MeasuredMid}$

B.9 Ambient and Battery Temperature Alarm Thresholds

Table 21 - Temperature monitoring alarm thresholds

Temperature	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
Ambient (non-air conditioned)	- 5 deg C	0 deg C	+ 40 deg C	+ 45 deg C
Ambient (air conditioned)	- 5 deg C	+ 15 deg C	+ 30 deg C	+ 45 deg C
Battery Cell or String	+ 5 deg C	+ 15 deg C	+ 30 deg C	+ 35 deg C

Ambient (non-air con) based on EQL Standard for Climatic and Seismic Conditions
Ambient (air-con) based on manufacturer recommendation for initial alarms and EQL Standard for Climatic and Seismic Conditions for extremity alarms
Battery String based on manufacturer recommendations

B.10 Circuit Breaker Status Alarm

Table 22 - Circuit breaker status off normal alarms

Device	Normal	Off Normal
AC Charger Input	Closed	Open
Battery charger output DC CB	Closed	Open
Battery string CB	Closed	Open
Temporary Connection CB (e.g. temp charger, temp battery)	Open	Closed

B.11 Earth fault/leakage current Alarm Thresholds

Table 23 - Earth fault/leakage current monitoring alarm thresholds

Nominal Voltage	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
24	N/A	N/A	5 mA	N/A
32	N/A	N/A	5 mA	N/A
48	N/A	N/A	5 mA	N/A
50	N/A	N/A	5 mA	N/A
110	N/A	N/A	10 mA	N/A
125	N/A	N/A	10 mA	N/A

LoLo / LL4: N/A
Lo / LL2: N/A
Hi / HL2: Set based on AS 2676.2:2000 Table 2.1 Earth fault relay operating currents
HiHi / HL4: N/A

B.12 AC Ripple Alarm Thresholds

Table 24 - AC ripple monitoring alarm thresholds

Ripple	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
Voltage Ripple (V)	N/A	N/A	2 %	5 %
Current Ripple (A)	N/A	N/A	N/A	N/A

LoLo / LL4: N/A
Lo / LL2: N/A
Hi / HL2: Set based on AS 4044:1992 Section 6.10 Ripple Voltage with battery connected
HiHi / HL4: Set based on AS 4044:1992 Section 6.10 Ripple Voltage without battery connected

B.13 Stage of Charge of Battery Alarm Thresholds

There are currently no standard alarms limits for stage of charge of battery or battery strings.

Due to a large mix of existing charger technologies, SCADA voltage limits will be used to determine remaining capacity although it is acknowledged, voltage measurements are not the most accurate approach. This can be revised as a greater number of smarter chargers are commissioned into the network.

B.14 State of Health of Battery Alarm Thresholds

Table 25 – State of Health of Battery alarm thresholds

Ripple	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
SoH	N/A	80%	N/A	N/A

LoLo / LL4: N/A
Lo / LL2: N/A
Hi / HL2: Set based on AS 2676.2:2020 Section 7.5.
HiHi / HL4: N/A

B.15 Cell/battery ohmic measurements Alarm Thresholds

There are no standard alarms limits for cell/battery ohmic measurement.

If implemented, limits should be set based on OEM advice and where practical aligned to the MAC Cell impedance measurement change from string average:

- Hi / HL2 and Lo / LL2 limits aligned to MAC P2 limits
- HiHi / HL4 and Lo / LL2 limits aligned to MAC P1 limit

B.16 Mechanical Air Flow Alarm Thresholds

Table 26 - Mechanical air flow alarm thresholds

	LoLo / LL4	Lo / LL2	Hi / HL2	HiHi / HL4
Air Flow	100% of q_v	150% of q_v	N/A	N/A

LoLo / LL4: Set based on calculated ventilation requirements
Lo / LL2: Set based on restricted flow of N-1 mechanical air flow
Hi / HL2: N/A
HiHi / HL4: N/A

Annex C Brownfield Replacement and Upgrade

Informative

C.1 Battery bank only: identical for identical replacement

Where a battery bank is replaced with one of an identical make and model (like for like) it can be considered a “repair” as per (AS/NZS 3000, 2018). As such there is no trigger to upgrade any other part of the installation.

Where a bank is replaced due to defects, the issue should be raised as per normal defect processes to confirm the installation is working properly and fit for purpose. Any rectification work to address issues need to consider implications of their respective design choices which is beyond the scope of this document.

C.2 Battery charger only: identical for identical replacement

Where a battery charger is replaced with one of an identical make and model (like for like) it can be considered a “repair” as per (AS/NZS 3000, 2018). As such there is no trigger to upgrade any other part of the installation. A replacement with similar for similar (e.g. different manufacturer, different model, different plant specifications) is considered an “alteration” and this section is not applicable.

Where the battery charger is to be changed with an identical replacement, the following aspects shall be reviewed and actioned:

- Ensure the battery charge settings are appropriate for the batteries installed and float voltages are set appropriately.
- Confirm temperature compensation settings exist in the charger and temperature sensors are installed in the appropriate location on the battery bank. If not, rectify as required or consult Substation Standards.
- Confirm DC Voltage monitoring (either analogues with alarm limits set in SCADA or SCADA alarms driven by on site monitoring) exists. If not, rectify as required or consult Asset Maintenance to ensure sufficient minimum monitoring.

C.3 DC switchboard only: replacement

Where a DC switchboard is replaced with no other alterations or additions to the circuits it can be considered a “repair” as per (AS/NZS 3000, 2018). As such there is no trigger to upgrade any other part of the installation.

Where the DC switchboard only is to be changed with a non-identical replacement but no other alterations, the following aspects shall be reviewed and actioned:

- The DC switchboard should be procured to meet the current technical specifications,
- Any additional requirements stipulated in (AS/NZS 3000, 2018) for a replacement of a switchboard in Australia shall be met.
- Protection devices installed in the new switchboard will be confirmed appropriate for the connected cables and first up stream and downstream protection devices.

- Confirm DC Voltage monitoring (either analogues with alarm limits set in SCADA or SCADA alarms driven by on site monitoring) exists. If not, rectify as required or consult Asset Maintenance to ensure sufficient minimum monitoring.

C.4 Battery bank only: non-identical replacement

If a battery bank is replaced by one that is different in any way to the one it replaces, this is considered an "alteration" as per (AS/NZS 3000, 2018). This triggers a number of obligations that must be met to ensure the safety and equipment ratings remain appropriate. The batteries themselves while important are not highly integrated into the overall DC Supply making greater changes to the system often impractical based on typical battery bank only replacement drivers (defects, routine replacements).

Where the battery bank is to be changed with a non-identical replacement, the following aspects shall be reviewed and actioned:

- Review redundancy requirements and ability to change single strings to dual strings in line with this standard. Do not change redundancy levels if non-standard batteries are utilised.
- Review capacity requirements to cover any load creep.
- Review battery technology installed and ability to move to current period contract batteries. The charger has to be capable of float voltage operation for this change.
- Ensure the battery charge settings are appropriate for the new batteries installed and float voltages are set appropriately.
- Confirm temperature compensation settings exist in the charger and temperature sensors are installed in the appropriate location on the battery bank. If not, rectify as required or consult Substation Standards.
- Review battery first protection (e.g. type, rating, distance from battery) against current EQL standards and upgrade if not compliant.
- Confirm protection grading has not changed for the new fault current levels. Replace as required.
- Confirm equipment and cable fault current ratings are appropriate for the new fault current levels. Replace as required.
- Confirm battery space requirements can be achieved/maintained.
- Confirm floor spacing requirements can be achieved/maintained.
- Confirm floor loadings for new battery weight is acceptable.
- Confirm ventilation requirements are met. Rectify as required.
- Confirm DC Voltage monitoring (either analogues with alarm limits set in SCADA or SCADA alarms driven by on site monitoring) exists. If not, rectify as required or consult Asset Maintenance to ensure sufficient minimum monitoring.

C.5 Battery charger: non-identical replacement

If a battery charger is replaced by one that is different in any way to the one it replaces, this is considered an "alteration" as per (AS/NZS 3000, 2018). This triggers a number of obligations that must be met to ensure the safety and equipment ratings remain appropriate. The charger is an integral part of the DC supply with greater onus on bringing the system up to current standards.

Where the battery charger is to be changed with a non-identical replacement, the following aspects shall be reviewed and actioned:

- Review the ability to bring the battery bank and its protection and control up to current standards. Complete all requirements for a battery bank only non-identical replacement when batteries are replaced.
- Review voltage requirements and ability to transition the DC Supply to the current preferred voltages with the use of DC/DC converters to maintain supply to legacy loads.
- Review monitoring and alarming requirements and upgrade as required to current standard.

Aspects not brought up to current standard at a brownfield site must show that as much as reasonably practical has been and that the installation still meets the minimum requirements of Australian Standards, good industry practice and alignment to EQL safety, reliability and operational requirements.

C.6 DC Supply Replacement

Where the DC supply (battery bank, battery charger and DC main board) are replaced, this is considered an “alteration” as per (AS/NZS 3000, 2018). In these cases the DC system should be brought up to current standard as much as practical as outlined in this document.

For DC supply replacements, the full DC Supply shall be reviewed and actioned including items such as:

- Voltage, autonomy and redundancy requirements.
- Protection and Control requirements.
- Monitoring and alarming requirements.
- Equipment requirements
- Room or enclosure requirements such as ventilation and temperature control

Aspects not brought up to current standard at a brownfield site must show that as much as reasonably practical has been and that the installation still meets the minimum requirements of Australian Standards, good industry practice and alignment to EQL safety, reliability and operational requirements.

C.7 Brownfield Battery Room or Enclosure Considerations

The first preference is to bring any brownfield site up to greenfield requirements with regards to battery rooms or enclosures housing batteries.

Where the battery room or enclosure requires a review, the following aspects shall be reviewed and actioned:

- Ventilation requirements
- Equipment layout and spacing requirements
- Floor loading requirements

- Fire and explosion requirements
- Signage requirements
- Electrical equipment in the room or enclosure
- Temperature requirements

Table 27 - Brownfield Room or Enclosure Considerations provides some solutions to issues likely to be encountered in existing installations.

Table 27 - Brownfield Room or Enclosure Considerations

Existing Arrangements	Accommodation Options
Lack of ventilation	Install more vents or position them appropriately. Install mechanical ventilation.
Poor temperature control	Improve room insulation levels, especially in roofing, eastern and western walls. Reduce thermal radiation on external western walls. Install air conditioning.
Inability to meet ventilation requirements in a control room	Installed indoor or outdoor enclosed batteries.
Insufficient space or floor loading	Installed outdoor enclosed batteries.

C.8 Brownfield Redundancy Considerations

For brownfield substations that cannot directly apply greenfield requirements, there are many contributing factors to consider. Based on a review and consultation with various Energy Queensland SME's, Table 28 contains some typical selections for redundancy levels in brownfield substations however it is acknowledged not all sites may be covered by these options.

Table 28 - Brownfield Substation DC Supply Default Redundancy Recommendations

Substation	Situation	Battery Bank	Battery Charger	Distribution Board
Bulk Substation	Major refurbishment or rebuild project. New control building	Duplicated battery banks with dual battery strings	Duplicate chargers with N+1 charging rectifiers per charger	Duplicate boards with the ability to switch to the alternative supply.

Substation	Situation	Battery Bank	Battery Charger	Distribution Board
Zone Substations	It is confirmed that all network supplied from the site can be adequately protected for all credible fault scenarios by remote protection schemes	Single battery bank with dual battery strings and temporary battery connection at distribution board	Single charger with N+1 charging rectifiers	Single board
Zone Substations	It is confirmed that all network supplied from the site cannot be adequately protected for all credible fault scenarios by remote protection schemes	Duplicated battery banks with dual battery strings	Duplicate chargers with N+1 charging rectifiers per charger	Duplicate boards with the ability to switch to the alternative supply.
Zone Substations	Implemented auto-trip scheme for loss of DC instead of duplication of batteries and chargers.	Single battery bank with dual battery strings and temporary battery connection at distribution board	Single charger with N+1 charging rectifiers	Duplicate boards with the ability to switch to the alternative supply.
Zone Substations	High levels of embedded generation relying on local protection devices to prevent islanding situations	Duplicated battery banks with dual battery strings	Duplicate chargers with N+1 charging rectifiers per charger	Duplicate boards with the ability to switch to the alternative supply.
C&I Substation with DC independent transformer protection*	Restricted, Limited or Unrestricted	Single battery bank with dual battery strings and temporary battery connection at distribution board	Single charger with N+1 charging rectifiers	Single board

Substation	Situation	Battery Bank	Battery Charger	Distribution Board
C&I Substation with DC dependant transformer protection*	Complete a formal risk assessment to determine if it is reasonable and practical to meet the requirements of a DC independent C&I/distribution substation, zone substation site or implement other controls.			

*For C&I Substations, DC independent protection is considered HV fusing or self-powered relays with spring driven breakers that are not reliant on the local DC supply to operate for faults. DC dependant protection is considered protection relays and breaker mechanisms reliant on the DC supply to operate for fault conditions. This differentiation is important to ensure sufficient protection capacity for faults on the 415V side of the transformer.

Below is guidance for exceptions and allowances that can be considered where justifications can be made and business cases produced confirm the final design meets as low as reasonable practical design principles. It is recognised that what may be practical for greenfield sites will not always be practical for brownfield sites.

Table 29 - Brownfield Substation Exceptions and Allowances

Situation	Exceptions or Allowances
Brownfield bulk and zone substations with limited space to duplicate DC Supplies inside existing control buildings and rooms.	Install an outdoor DC Supply (preferred for bulk substations) OR Implement an automatic de-energisation for Loss of DC Supply scheme. (Requires full development before deployment) Or Complete a formal Risk Assessment to determine appropriate actions and controls (e.g. sufficient alarms, manual intervention, limited exposure to network faults due to network construction).
High duplication costs due to factors such as inter panel looping or civil restrictions compared to customer numbers or reliability requirements that result in a negative NPV position for duplication.	Implement an automatic de-energisation for Loss of DC Supply scheme. (Requires full development before deployment) Or Complete a formal Risk Assessment to determine appropriate actions and controls (e.g. sufficient alarms, manual intervention, limited exposure to network faults due to network construction).
Brownfield bulk and zone substations with physical limitations (e.g. space, weight) or site complexities making the installation of dual strings difficult.	Single string battery banks may be used for unrestricted brownfield sites with duplicated supplies. Dual strings should be strongly considered for sites with limited or restricted access or existing single DC Supplies.

Situation	Exceptions or Allowances
Brownfield C&I substations with physical limitations (e.g. space, weight) or site complexities making the installation of dual strings difficult.	Single string battery banks may be used.
Brownfield zone substations with physical limitations or site complexities making the installation a second distribution board difficult.	Implement an automatic de-energisation for Loss of DC Supply scheme. (Requires full development before deployment) Or Complete a formal Risk Assessment to determine appropriate actions and controls (e.g. sufficient alarms, manual intervention, limited exposure to network faults due to network construction).

Annex D Battery and Charger Sizing Sample Calculation

Informative

D.1 Introduction and background

The design is to be undertaken in accordance with the recommended practice for sizing lead-acid batteries IEEE standard (IEEE 485, 2020), recommended practice for design of DC auxiliary power systems (IEEE 946, 2020) and this standard.

In accordance with the recommended practice for sizing lead-acid batteries IEEE standard (IEEE 485, 2020), Clause 4.1 "The battery must supply the dc power requirements when the following conditions occur:

- Load on the dc system exceeds the maximum output of the battery charger;
- Output of the battery charger is interrupted;
- AC power is lost".

Condition a) will occur as a normal part of the battery life if required currents exceed the charger capabilities, or the impedance of the battery system is lower than that of the charger.

Condition b) will occur on failure of the battery charger and will continue to exist until the charger is repaired. The substation battery capacity is to be designed for a 10-hour autonomy time (ref 8.4), to ensure no loss of function while repair or replacement occurs. Consequently, the charger system must be able to be restored from a contingency within the autonomy time.

Condition c) is the most onerous condition if supply is lost for a time equal to the autonomy time. The absolute worst case is:

- Loss of ac supply (at night)
- DC lights on
- Multiple trips and closes of a number of CB's during the 10 hours
- Rewinding of a number of spring charge motors if applicable
- Finally at the end of the 10-hour period performing a busbar protection trip involving the largest bus in the substation.

D.2 Defining the loads

For Cairns City substation the system details are as follows:

Table 30 - Substation battery nominal voltage 110 V, operating at 122.9 V

	Description	Load (A)	Load type	Comment
a.	Standing load (as measured March 2003)	8.7	Continuous	
b.	Emergency lighting	0	Continuous	
c.	Trip coil	4.0	Momentary	
d.	Close coil	4.0	Momentary	
e.	Trip total no of CB’s 34	136.0	Momentary	
f.	Largest bus for one trip is 10 CB’s (8 on bus plus 2 section CB’s)	40.0	Momentary	
g.	CB spring change motor	0		AC motors
h.	Load growth	0		

Table 31 - Communications battery nominal voltage 48 V, operating at 54.6 V

	Description	Load (A)	Load type	Comment
a.	Standing load (as measured March 2003)	2	Continuous	
b.	Load growth – fibre optic projects	2	Continuous	

D2.1 Assumed operating conditions

Momentary loads are assumed to operate for one minute according to the recommended practice for sizing lead-acid batteries IEEE standard (IEEE 485, 2020) Cl 4.2.3.

All loads are assumed to be a constant current load.

Assumed duty cycle / scenario:

- Loss of ac power
- Turn on emergency lights time zero – continuous 10 hours
- Trip two CB’s at time zero
- Close two CB’s at time 15 minutes

- Trip two CB’s immediately after the close time 16 minutes
- Largest bus trip at time 10 hours (or specified 40 A)

D2.2 Design considerations

Design life – 10 years

End of life at 80% capacity

Average operating temperatures – 25 °C (lower temp results in a longer life but requires a larger capacity)

Nominal voltage – 110 V (54 cells)

Final voltage – 1.80 Vpc at 25 °C, float charge 2.275 Vpc at 25 °C

Voltage range – 97.2 V (@1.80 Vpc and 25 °C) to 122.85 V (@ 2.275 Vpc and 25 °C)

Expected load growth in next 4 years2 – 2 A @ 48 V d.c.

D2.3 Compensation factors

Design factor to be used – 1.2

Cell correction for temperature – nil – operating at 25°C. Refer to manufactures data if lower than 25° C. Shown below are the Yuasa UXL series compensation graphs displaying the Temperature Effects in relation to Battery Capacity.

Aging Factor – 1.25 (based on end of life at 80% of capacity)

Initial Capacity - assumed to be 0.9, which does not require any further compensation, as it is less than aging factor.

8-2 Temperature Effects in Relation to Battery Capacity

At higher temperatures, the electrical capacity that can be taken out of a battery increases. At lower temperatures, the electrical capacity that can be taken out of a battery decreases. Fig.7 and Fig.8 show the temperature effects in relation to battery capacity.

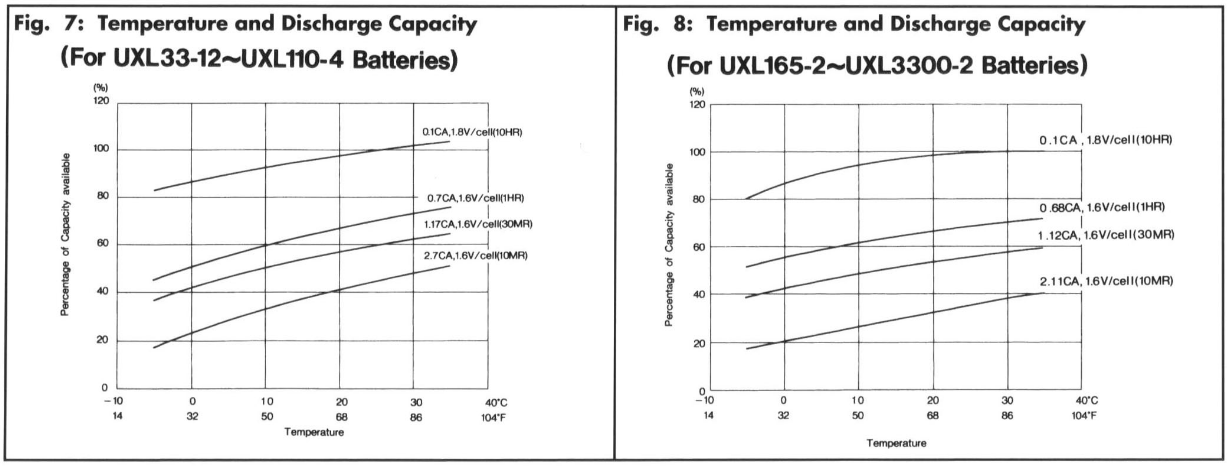


Figure 1 - Temperature effects in relation to battery capacity

D2.4 Other required data

Before any calculations can be made, additional data is required as per below:

- Estimated capacity from section 8.4 table – It is necessary to have an estimate of the required battery size to ensure the correct battery tables are referenced.
- Battery Data Sheet

Select a suitable battery with the required design life and capacity range required.

Locate the battery performance data at the standard temperature of 25 °C and final voltage of 1.80 V / cell. An example from the Century Yuasa 10-year design life UXH series is shown below.

Calculate the K factors from this data sheet

F.V. 1.80 VOLTS PER CELL

Model \ Time		1 min	5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	1 hr	2 hr	3 hr	5 hr	8 hr	10 hr	20 hr
UXH38-12	A	99.2	86.3	63.8	52.8	44.8	38.8	35.0	31.2	28.1	26.2	21.3	12.9	9.5	6.1	4.2	3.5	1.9
	W	179	157	118	99.2	84.7	73.7	66.9	59.7	54.3	50.5	41.4	25.1	18.6	12.2	8.4	6.8	3.8
UXH50-12	A	131	114	84.0	69.5	59.0	51.0	46.0	41.0	37.0	34.5	28.0	17.0	12.5	8.0	5.5	4.6	2.5
	W	236	207	156	131	112	97.0	88.0	78.5	71.5	66.5	54.5	33.0	24.5	16.0	11.0	9.0	5.0
UXH63-12	A	164	143	106	87.6	74.3	64.3	58.0	51.7	46.6	43.5	35.3	21.4	15.8	10.1	6.9	5.8	3.15
	W	297	260	196	164	140	122	111	98.9	90.1	83.8	68.7	41.6	30.9	20.2	13.9	11.3	6.3
UXH75 -6	A	196	170	126	104	88.5	76.5	69.0	61.5	55.5	51.8	42.0	25.5	18.8	12.0	8.3	6.9	3.75
	W	353	310	233	196	167	146	132	118	107	99.8	81.8	49.5	36.8	24.0	16.5	13.5	7.5
UXH100-6	A	261	227	168	139	118	102	92.0	82.0	74.0	69.0	56.0	34.0	25.0	16.0	11.0	9.3	5.0
	W	471	413	311	261	223	194	176	157	143	133	109	66.0	49.0	32	22.0	18.0	10.0
UXH125-6	A	326	284	210	174	148	128	115	103	92.5	86.3	70.0	42.5	31.3	20.0	13.8	11.6	6.25
	W	589	516	389	326	279	243	220	196	179	166	136	82.5	61.3	40.0	27.5	22.5	12.5

Figure 2 - Performance data of the Yuasa UXH series of batteries – 6 and 12 V d.c. cases

The table below, taken from the YUASA 15-year life UXL series battery application manual, shows the current required to reach the final discharge voltage for a number of batteries, assuming constant discharge.

Amperes to F. V. 1.80 Volts Per Cell

Battery Model \ Time	1 min	5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	1 h	2 h	3 h	5 h	8 h	10 h	12 h	24 h
UXL 33-12	93.8	81.1	61.2	50.0	42.9	37.5	33.0	30.0	27.3	24.6	20.0	11.5	8.1	5.4	3.6	3.0	2.6	1.4
44-12	125	108	81.6	66.7	57.1	50.0	44.0	40.0	36.4	32.8	26.7	15.4	10.8	7.1	4.8	4.0	3.4	1.8
55-12	156	135	102	83.3	71.4	62.5	54.9	50.0	45.5	41.0	33.3	19.2	13.5	8.9	6.0	5.0	4.3	2.3
66-6	188	162	122	100	85.7	75.0	65.9	60.0	54.5	49.2	40.0	23.1	16.2	10.7	7.2	6.0	5.2	2.8
88-6	250	216	163	133	114	100	87.9	80.0	72.7	65.6	53.3	30.8	21.6	14.3	9.6	8.0	6.9	3.7
110-6 110-4	313	270	204	167	143	125	110	100	90.9	82.0	66.7	38.5	27.0	17.9	12.0	10.0	8.6	4.6
165-2	300	268	227	195	172	155	142	128	118	111	90.9	54.5	40.5	26.8	18.2	15.0	12.6	6.9
220-2	400	357	303	260	230	206	189	171	157	148	121	72.7	54.1	35.7	24.2	20.0	16.8	9.2
330-2	600	536	455	390	345	309	283	256	236	222	182	109	81.1	53.6	36.3	30.0	25.2	13.8
550-2	1000	893	758	649	575	515	472	427	394	370	303	182	135	89.3	60.5	50.0	42.0	22.9
1100-2	2000	1786	1515	1299	1149	1031	943	855	787	741	606	364	270	179	121	100	84.0	45.8
1550-2	3000	2679	2273	1948	1724	1546	1415	1282	1181	1111	909	545	405	268	182	150	126	68.8
2200-2	4000	3571	3030	2597	2299	2062	1887	1709	1575	1481	1212	727	541	357	242	200	168	91.7
3300-2	6000	5357	4545	3896	3448	3093	2830	2564	2362	2222	1818	1091	811	536	363	300	252	138

Figure 3 - Performance data of the Yuasa UXL series of batteries – 2,6 and 12 V d.c. cases

D.3 Battery calculations

The calculation of the battery size is based on the recommended practice for sizing lead-acid batteries IEEE standard (IEEE 485, 2020) and is worked out using the Battery Size Calculator Excel spreadsheet. All the cells that are highlighted a pale blue are cells requiring data entry from design parameters or data sheets. Cells highlighted orange have default values applied. These may have different data applied according to site specific requirements.

Figure 4 shows a screen shot of the Front Sheet. The data for the Battery Duty Cycle and Compensation Factors are entered here and the final answer is displayed in the cells highlighted green. The assumed operating conditions are added to the Battery Duty Cycle Definition, which is then displayed on the adjacent graph. Each section specifies a change in load and the amount of time that change occurs for. The random section allows for a random event to be added to the calculations and is placed at the worst case position. The compensation factors, Temperature Correction Factor, Design Factor and Aging Factor, are adjusted in the appropriate cells if required.

The final answers are displayed as the Uncorrected Cell Size (uncompensated), Corrected Cell Size and Bank Size, highlighted in green. The two buttons "Clear" the data from the Front Sheet and "Calculate K" factors for the calculations.

D3.1 Case 1 – 110 V d.c. battery bank and converter supplying communications

The data entered into the Front Sheet are as follows:

Standing load of 11.2 Amps for 10 hours

- 8.7 Amps for substation plant
- 1.5 Amp for comms (at 110 V, load is 3 A at 48 V)
- 1 Amp for future comms – increased Fibre Optics (at 110 V, load is 2 A at 48 V)
- 0.6 Amps for converter (assuming 80% efficiency)
- 2 CB's tripped with a load of 8 Amps at time zero for 1 minute
- 2 CB's closed with a load of 8 Amps at time 15 for 1 minute
- 2 CB's tripped with a load of 8 Amps at time 16 for 1 minute
- Largest bus trip with a load of 40 Amps at time 599 for 1 minute

This gives the duty cycle sections over the 10 hours as:

- 19.8 Amps for 1 minute
- 11.8 Amps for 14 minutes
- 19.8 Amps for 2 minutes
- 11.8 Amps for 582 minutes
- 51.8 Amps for 1 minute

As these loads are to be supplied from a dual string battery bank, the loads are halved for the battery string duty cycle.

The Compensation data is added as follows:

- Temperature Factor of 1, since operating at 25 °C
- Design Factor of 1.2 (20%)
- Aging Factor of 1.25, based on end of life at 80% of capacity

All of this data is included on the Front Sheet as shown in Figure 4.

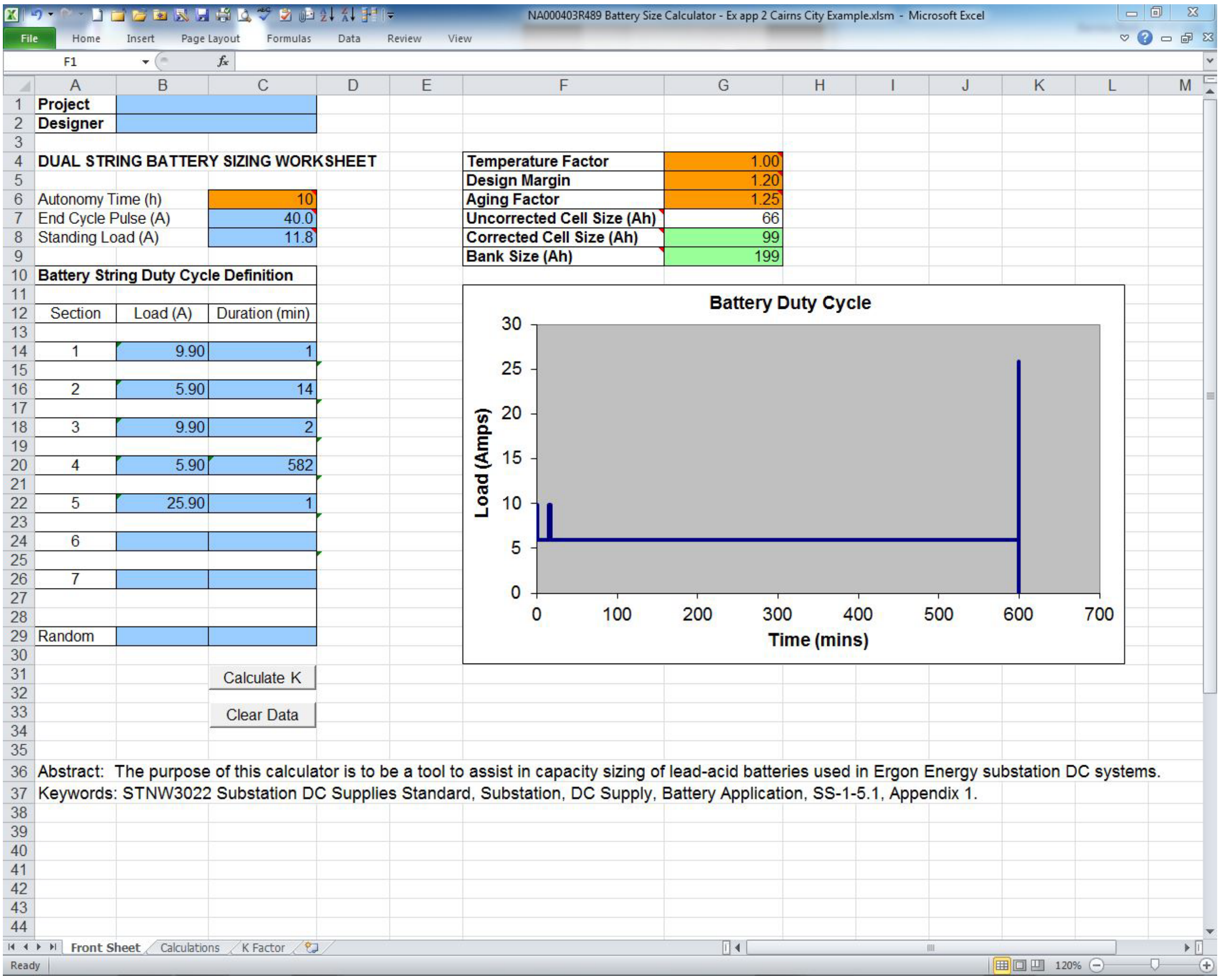


Figure 4 - Front Sheet of the Battery Size Calculator

The Calculations sheet (Figure 5) contains all the mathematics to work out the required cell and bank sizes, as set out in the recommended practice for sizing lead-acid batteries IEEE standard (IEEE 485, 2020). It shows the workings for each of the sections and compensations given on the Front Sheet and the K factors from the battery manufacturer's data sheet.

NA000403R489 Battery Size Calculator - Ex app 2 Cairns City Example.xlsm - Microsoft Excel

	A	B	C	D	E	F	G
1							
2							
3							
4	**Period**	**Load (A)**	**Change in Load**	**Duration of Period**	**Time to End of Section**	**K Factor**	**Required Size**
5							
6	**Section 1 - First period only**						
7		A1	A1 - 0	M1	T=M1	K	
8	1	9.9	9.9	1	1	0.3563218	3.527586207
9						**SUB TOTAL**	**3.527586207**
10	**Section 2 - first two periods only**						
11		A1	A1 - 0	M1	T = M1 + M2	K	
12	1	9.9	9.9	1	15	0.6690647	6.623741007
13		A2	A2 - A1	M2	T = M2		
14	2	5.9	-4	14	14	0.6422652	-2.569060773
15						**SUB TOTAL**	**4.054680234**
16	**Section 3 - first three periods only**						
17		A1	A1 - 0	M1	T = M1 + M2 + M3	K	
18	1	9.9	9.9	1	17	0.712098	7.049770291
19		A2	A2 - A1	M2	T = M2 + M3		
20	2	5.9	-4	14	16	0.689911	-2.759643917
21		A3	A3 - A2	M3	T = M3		
22	3	9.9	4	2	2	0.3683168	1.473267327
23						**SUB TOTAL**	**5.763393701**
24	**Section 4 - first four periods only**						
25		A1	A1 - 0	M1	T = M1 + M2 + M3 + M4	K	
26	1	9.9	9.9	1	599	9.9847902	98.84942292
27		A2	A2 - A1	M2	T = M2 + M3 +M4		
28	2	5.9	-4	14	598	9.9696266	-39.87850634
29		A3	A3 - A2	M3	T = M3 + M4		
30	3	9.9	4	2	584	9.7620714	39.04828551
31		A4	A4 - A3	M4	T = M4		
32	4	5.9	-4	582	582	9.733124	-38.93249608
33						**SUB TOTAL**	**59.08670602**
34	**Section 5 - first five periods only**						
35		A1	A1 - 0	M1	T = M1 + M2 + M3 + M4 + M5	K	
36	1	9.9	9.9	1	600	10	99
37		A2	A2 - A1	M2	T = M2 + M3 +M4 + M5		
38	2	5.9	-4	14	599	9.9847902	-39.93916078
39		A3	A3 - A2	M3	T = M3 + M4 + M5		
40	3	9.9	4	2	585	9.7766097	39.1064389
41		A4	A4 - A3	M4	T = M4 + M5		
42	4	5.9	-4	582	583	9.7475762	-38.99030483
43		A5	A5 -A4	M5	T = M5		
44	5	25.9	20	1	1	0.3563218	7.126436782
45						**SUB TOTAL**	**66.30341007**

Front Sheet | Calculations | K Factor

Figure 5 - Calculations of the Battery Size Calculator

To obtain the final cell size, K factors need to be acquired from the appropriate battery manufacturer data sheet, similar to Figure 2. This data is placed on the K Factor sheet (Figure 6) in the pale blue highlighted cells. For each of the defined times, enter the appropriate time with its current values into columns C and D respectively and the capacity into cell E3. As the current values are added to the table, the K factor is calculated and the K Factor curve is shown on the adjacent graph, which has its K Factor axis on a logarithmic scale.

The K factor is the ratio of rated ampere-hour capacity of a cell, to the amperes that can be supplied by that cell for t minutes at 25°C and to a given minimum cell voltage. K can be calculated with the following equation:

$$K = \frac{Cell\ capacity(Ah)}{Ampere\ for\ a\ given\ time(A)}$$

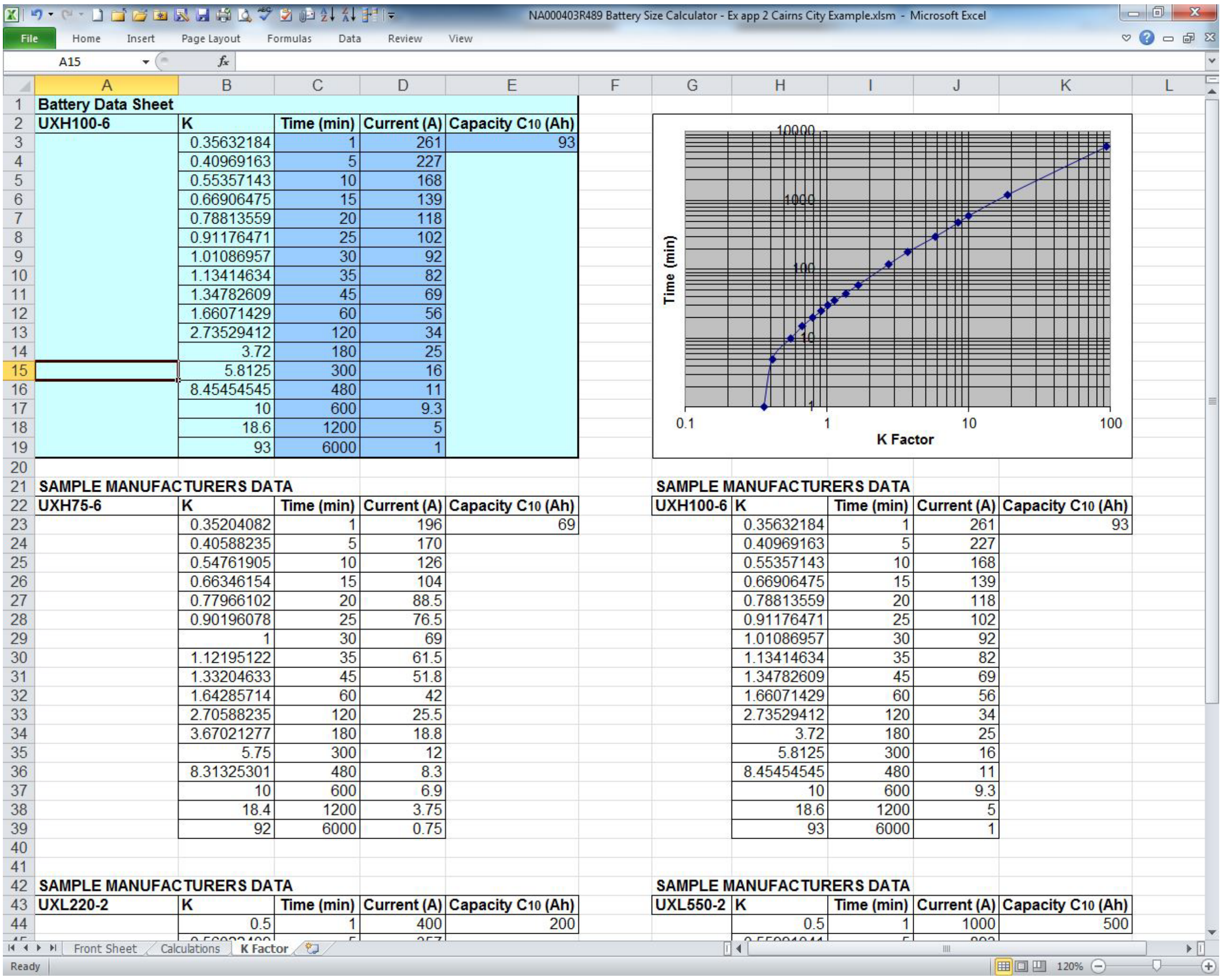
For example, using values from Figure 2, a UXH75-6 monobloc with a C10 cell capacity of 69 Ah and a time of 15 minutes, gives a current of 104 A, thus giving

$$K = \frac{69}{104} = 0.67$$

This can be seen in Figure 6 in position B6

If the manufacturer's data gives the K factors directly without the ampere values, then Equation 1 can be rearranged to calculate these values.

Given on the lower section of the K Factor sheet are sample manufacturer data for the Yuasa UXH and UXL series as taken from the data sheets (Figure 2 and Figure 3 respectively).



Battery Data Sheet				
UXH100-6	K	Time (min)	Current (A)	Capacity C10 (Ah)
	0.35632184	1	261	93
	0.40969163	5	227	
	0.55357143	10	168	
	0.66906475	15	139	
	0.78813559	20	118	
	0.91176471	25	102	
	1.01086957	30	92	
	1.13414634	35	82	
	1.34782609	45	69	
	1.66071429	60	56	
	2.73529412	120	34	
	3.72	180	25	
	5.8125	300	16	
	8.45454545	480	11	
	10	600	9.3	
	18.6	1200	5	
	93	6000	1	

SAMPLE MANUFACTURERS DATA

UXH75-6	K	Time (min)	Current (A)	Capacity C10 (Ah)
	0.35204082	1	196	69
	0.40588235	5	170	
	0.54761905	10	126	
	0.66346154	15	104	
	0.77966102	20	88.5	
	0.90196078	25	76.5	
	1	30	69	
	1.12195122	35	61.5	
	1.33204633	45	51.8	
	1.64285714	60	42	
	2.70588235	120	25.5	
	3.67021277	180	18.8	
	5.75	300	12	
	8.31325301	480	8.3	
	10	600	6.9	
	18.4	1200	3.75	
	92	6000	0.75	

SAMPLE MANUFACTURERS DATA

UXH100-6	K	Time (min)	Current (A)	Capacity C10 (Ah)
	0.35632184	1	261	93
	0.40969163	5	227	
	0.55357143	10	168	
	0.66906475	15	139	
	0.78813559	20	118	
	0.91176471	25	102	
	1.01086957	30	92	
	1.13414634	35	82	
	1.34782609	45	69	
	1.66071429	60	56	
	2.73529412	120	34	
	3.72	180	25	
	5.8125	300	16	
	8.45454545	480	11	
	10	600	9.3	
	18.6	1200	5	
	93	6000	1	

SAMPLE MANUFACTURERS DATA

UXL220-2	K	Time (min)	Current (A)	Capacity C10 (Ah)
	0.5	1	400	200

SAMPLE MANUFACTURERS DATA

UXL550-2	K	Time (min)	Current (A)	Capacity C10 (Ah)
	0.5	1	1000	500

Figure 6 - K Factor of the Battery Size Calculator

Once the Battery Data Sheet section of the K Factor sheet has been completed with time and associated current values as well as the corresponding capacity, the required cell size can be calculated. Returning to the Front Sheet (Figure 4) and clicking on the "Calculate K" button works out all the K factors for the given sections of the Duty Cycle and places them in the "Calculations" work sheet. With all the pale blue and orange cells completed, the required cell and bank sizes are given in the green highlighted cells. The "Clear" button deletes the values in the Battery Duty Cycle Definition.

This then gives an uncorrected cell size of 66 Ah, corrected cell size of 99 Ah and a bank size of 199 Ah. This value would be rounded up to the nearest available bank size, giving the recommended size of 224 Ah battery bank in the arrangement of 2 parallel strings each comprising 18 * 112 Ah 6 V cases.

D3.2 Case 2 – 110 V d.c. battery bank supplying substations loads and 48 V d.c. battery supplying communications loads

The data entered into the Battery Sizing Calculator Excel spread sheet (NA000403R489) were as follows:

For the 110 V d.c. Battery Bank

- Standing load of 8.7 Amps for 10 hours
- 2 CB's tripped with a load of 8 Amps at time zero for 1 minute
- 2 CB's closed with a load of 8 Amps at time 15 for 1 minute
- 2 CB's tripped with a load of 8 Amps at time 16 for 1 minute
- Largest bus trip with a load of 40 Amps at time 599 for 1 minute

This gives the duty cycle sections over the 10 hours as

- 16.7 Amps for 1 minute
- 8.7 Amps for 14 minutes
- 16.7 Amps for 2 minutes
- 8.7 Amps for 582 minutes
- 48.7 Amps for 1 minute

Entering this data into the Battery Size Calculator gives an uncorrected cell size of 51 Ah, corrected cell size of 76 Ah and a bank size of 152 Ah. Rounding up to the nearest available bank size gives a capacity of 180 Ah for the 110 V d.c. battery bank in the arrangement of 2 parallel strings each comprising 18 * 90 Ah 6-volt cases.

For the 48 V d.c. Battery Bank

- Standing load of 5 Amps for 10 hours

This gives the duty cycle sections over the 10 hours as

- 5 Amps for 600 minutes

This gives an uncorrected cell size of 25 Ah, corrected cell size of 38 Ah and a bank size of 75 Ah. Rounding up to the nearest available bank size gives a capacity of 90 Ah for the 48 V d.c. battery bank in the arrangement of 2 parallel strings each comprising 4 * 45 Ah 12-volt cases.

A1.1 Comparison of the two battery arrangements

The two arrangements give the following results:

Table 32 - Comparison of the battery arrangements

	110 V d.c. Battery	**48 V d.c. Battery**
Case 1	Capacity of 224 Ah in the arrangement of two parallel strings each of 112 Ah configured in 18 * 6 V d.c. cases	None
Case 2	Capacity of 180 Ah in the arrangement of two parallel strings each of 90 Ah configured in 18 * 6 V d.c. cases	Capacity of 90 Ah in the arrangement of two parallel strings each of 45 Ah configured in 4 * 12 V d.c. cases

It is recommended that Case 1 be applied with the 110 V d.c. Battery of capacity 224 Ah supplying the 48 V d.c. circuit through a converter. This would eliminate the need to purchase and maintain a second battery system.

D.4 Battery charger sizing

The charger sizing is to be undertaken in accordance with section 8.3. In accordance with the recommended practice for sizing lead-acid batteries IEEE standard (IEEE 946, 2020) clause 4.1 the battery charger is to be capable of supplying normal DC load plus any charging current required by the battery.
With the battery size calculated in previous sections, the charger size and rate can be determined. The requirements are thus as follows:

- to attain a minimum battery capacity of 75% after 8 hours from full discharge
- to attain 100% capacity within 24 hours
- use a maximum float voltage of 2.275 V d.c., temperature compensation to 0 °C
- to maintain the normal DC standing load

Figure 7 shows the charging characteristics of a YUASA UXH Battery at a constant current (0.1C) and a constant voltage (2.275 Vpc) after discharge of 50% and 100% of the 20 h rated capacity.

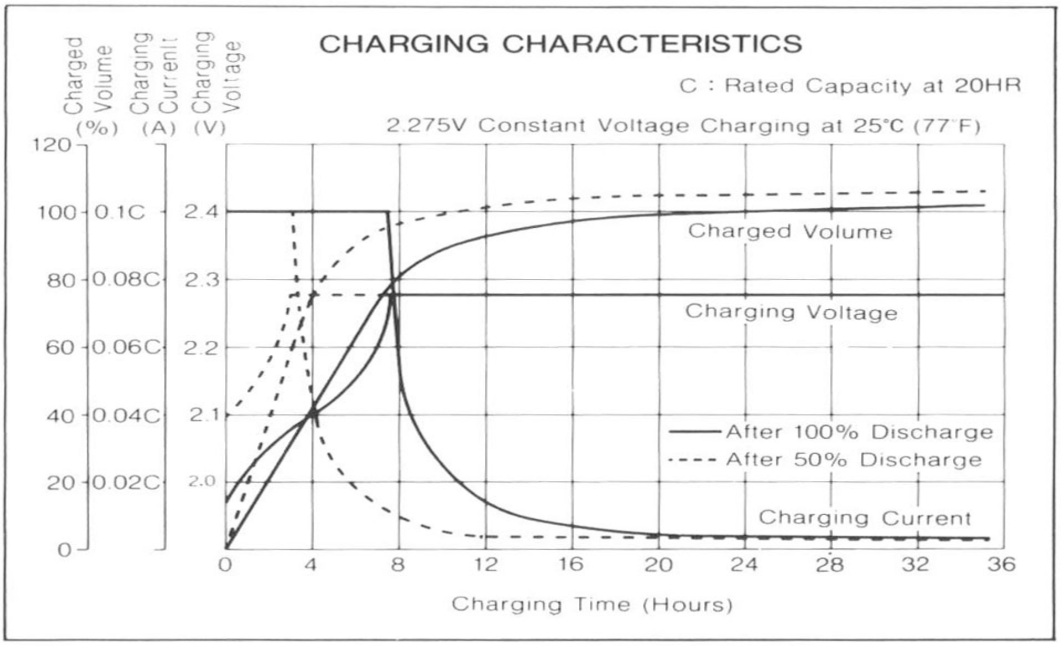


Figure 7 - Yuasa UXH series – charging characteristics at constant current and constant voltage

To meet the above requirements, based on Case 1 the charger needs to supply the following:

- Normal standing load 11.8 Amps
- Battery charging current (IEEE 946, 2020) is given by

$$\frac{1.1 \times C}{Battery\ recharge\ time}$$

For the 224 Ah battery with a 10 h battery recharge time this gives 24.6 A.
The battery charger must therefore be capable of supplying a minimum of 36.4 A at a maximum voltage of 130.0 V d.c.

Annex E Loss of DC Auto De-energisation Scheme

Informative

In some instances, a more cost effective solution to duplication of DC Supplies could be an automated de-energisation scheme which operates if DC supply is lost at the site. This has not been outworked however it is anticipated a MD100m with back up SCADA coding can achieve a suitable solution. This should only be considered a viable option if properly outworked and developed.

General requirements for a "Loss of DC Auto De-Energisation Scheme" include:

- Able to effectively operate when the DC Battery voltage is at Limit 4 Low Level and has suitable fail safes to manage the loss of Local DC Supply or failure to clear.
- Can be enabled and disabled locally and remotely.
- Arms when the DC Battery voltage is less than or equal to the Limit 2 Low Level.
- Initiates an adjustable trip timer (e.g. 60 sec) and adjustable CB fail timer (e.g. 120 sec) when the DC Battery voltage is less than or equal to the Limit 4 Low Level.
- If the trip timer expires, attempts to trip the local power transformer HV and LV CB's. If successful, clear the CB fail timer.
- If the CB fail timer expires, initiate trips at the remote ends supplying the site.
- If possible, if there are prolonged excessive network currents and the DC Battery voltage is less than Limit 4 Low Level or zero, initiate a remote trip after an adjustable CB fail timer (e.g. 10 sec) if fault current still flowing.
- Appropriate notifications to OCC to inform when the scheme is enabled/disabled, armed, triggered or executed.
- Sufficient fail safes to avoid un-necessary network trips due to device malfunction or incorrect operation.

Timers should be adjustable and set based on network requirements to maintain system stability and limit plant damage should a network fault occur during loss of DC Supply. Voltage limits shall be set based on low voltage alarms.

Annex F Portable Temporary DC Supplies

Informative

Portable temporary DC Supplies are often used to manage operational requirements during maintenance, replacements, large projects or defect management. These temporary arrangements are considered tooling and equipment which is outside of the scope of the Substation Standard DC Supplies for however some guidance on reasonable variations from that standard to assist construction, portability and deployment of these installations can be provided.

F.1 Deviations from the Substation Standard for DC Supplies

The following deviation from this standard are deemed reasonable and practical:

- Autonomy: Autonomy/capacity can be reduced based on plausible capacity requirements and to improve portability and standardisation. Capacity should be at least 2 x the maximum expected response time of field crews. For example, if crews are completing maintenance with a response time of 2hr to restore the normal DC Supply, only 4hrs autonomy is required. If crews are completing project work and could be at site within 3hours, only 6 hours autonomy time is required. If autonomy time is reduced, this must be communicated to control rooms and plans in place to ensure response times or next steps should the batteries be fully drained are in place.
- Redundancy: Temporary DC Supplies can have N redundancy for all components including batteries, strings, chargers and distribution switchboards.
- Monitoring: remote monitoring is required on any mobile/temporary supply if it is expected to be left unattended for longer than its autonomy duration. At a minimum, there shall be a watch dog monitoring the charger and battery health. Any temporary supply expected to be in service for longer than 3 months should also include voltage monitoring with alarms.
- Current capacity: A temporary charger shall be able to supply the standing load and provide sufficient current to charge batteries after a discharge event within 24 hours.

F.2 Minimum Specifications

Minimum specifications for portable temporary battery banks and any associated chargers are:

- Chargers shall comply with AS 4044 Battery chargers for stationary batteries with the ability to supply current with or without batteries connected.
- Mixing charger/string voltage with load voltage is not permitted (e.g. do not install a 110V charger and battery which taps out to 48V loads).
- Non-standard, off the shelf, charger and batteries are permitted provided they are fit for purpose. Flooded batteries shall be avoided due to hydrogen production and maintenance requirements and Ni-Cad batteries shall be avoided due to their environmental impacts.
- Non-standard alternative battery technologies can be provided it is suited to the application of a portable substation battery supply, is suitable for the battery charger and battery technologies are not mixed (e.g. not half VRLA and half Li-Ion).
- Integrated battery and charger configurations or modular configurations are allowed provided they are of acceptable reliability for 12 months operation.
- Temporary chargers shall have a temperature compensated float charge voltage with a probe that can be installed in a suitable location for the battery bank.
- Temporary charger should have a general alarm that can be fed into existing site SCADA alarms which will raise when the charger either stops working properly or entirely.

- If using the existing onsite charger for portable batteries only, the charger settings are to be reviewed and adjust as required. Sufficient local and Power On notes are to be recorded to ensure settings are changed back when the normal bank is restored.
- The charger does not have to be of rectifier or modular design philosophy however it is preferred provided it is robust enough to handle its portable nature.
- Chargers shall not output AC ripple beyond allowed limits in Annex B. Any that do shall be quarantined to be repaired or replaced.
- Must be able to operate in constant voltage mode applying applicable float voltage.
- Constand current mode is not essential but desired to assist boost charging after a battery drain or allow equalisation charging if required.
- Must consider manual handling requirements. This may include the ability to move sub-components individually or the ability to use pallet jacks, trolleys, forklifts or cranes.
- Use universal plugs and adaptors across EQL with Anderson plugs the plug of choice.
- Sufficient voltage ranges should be available within each region for systems installed in that region. To reduce the number of units:
  - For portable chargers only, it is preferred to have multiple voltage selections of 24V, 32V, 48V, 110V and 125V on a single charger or alternatively one charger to cover 24V/32V/48V and another charger for 110V/125V.
  - For portable charger and battery combinations, it is considered practical to have a single 48V or 110V system and use N+N DC/DC converters to supply any substation load at other voltages.

F.3 Installation and commissioning requirements

- The first time a portable temporary charger or battery is deployed, if shall undergo all standard commissioning inspections and tests. This may be done prior to deployment for operational response.
- Any charger that has been thorough previous initial commissioning inspection and testing and has had routine maintenance, only basic checks are required to confirm the installation has been successfully completed and is fit for service. This may include but not limited to:
  - Confirm there are no visual defects or concerns with the temporary arrangements.
  - Confirming all connections are tight and correct.
  - Confirming system and charger voltages are correct and appropriate for the installation.
  - Confirming any temporary equipment is properly connected and supplying the substation load.
  - Confirming SCADA alarming and any operational response requirements (e.g. autonomy times, response for loss of capacity).

F.4 Storage and maintenance requirements

- Any portable battery bank shall be stored in an appropriate location to manage hydrogen and temperature requirements and left on float voltage charge to ensure batteries remain fit for service. Refer to manufacturer advice or the relevant Australian Standards for further details (e.g. AS 2676.2 and AS 3011.2 for VRLA batteries).
- Temporary battery banks and chargers shall be registered in corporate asset databases as tooling and equipment with sufficient routine maintenance applied.
- Any battery charger that fails routine maintenance shall be quarantined and either repaired or scrapped.
- Any battery bank that fails routine maintenance shall be quarantined and scrapped.

Annex G Rationale Statements

Informative

G.1 Redundancy Requirements

G1.1 Previous Loss of DC Supply Incidents

A review in 2023 of previous incidents across EQL covering the loss of DC components, systems and on occasions, complete substation de-energisation has confirmed these as credible events occurring across EQL. This is across a fleet of over 600 bulk and zone substations and over 500 C&I substations and has occurred at sites with and without alarming. Using available data previous incidents involving DC supply failures within EQL, Ergon and Energex have varied frequency and consequences including:

- Loss of protection schemes.
  - For Energex approx. 2-3 per year.
  - For Ergon approx. 2-3 per year.
  - For EQL approx. 5-6 per year.
- Loss of protection and customer outages.
  - For Energex approx. 1 per 2-3 years.
  - For Ergon approx. 1 per 1-2 years. (Although improvements made since battery voltage monitoring introduced)
  - For EQL approx. 1 per year.
- Loss of protection and customer outages greater than expected due to a network fault.
  - For EQL between “1 per 10 years or less frequent” but more frequent than 1 per 100 years.

While rare and not well documented, two known instances in the Australian electricity industry have occurred where a network fault has coincided with a DC Supply failure. This resulted in significant clearing times (many minutes) for the fault to propagate until upstream protection clears, causing extensive primary plant damage and significant prolonged customer outages due to plant damage. One of these happened to be on EQL assets at Glenmore Substation in 1998.

A third similar event occurred in Ergon in 2017 where a loss of DC to a single protection relay coincided with a lack of upstream backup protection resulting in a significant clearing period and large amounts of conductor damage to the overhead network by the time the network was cleared. A fourth incident occurred in Energex in 2017 where back up protection was required to clear a network fault due to a DC supply failure however there was not massive plant failure due to the backup protection (not duplicate) in that instance.

G1.2 National Electricity Rules

The National Electricity Rules outlines that credible contingency events for protection systems shall consider loss of any single components (N-1). Other events or events that would cause a domino effect of failures can be considered credible if considered plausible. Sufficient protection (primary or back-up as defined in NER) is the ability to detect and clear a network fault in line with National Electricity Rules (e.g. S5.1a.8, S5.1.9). NER Clause S5.1.2.1 (d) states "The Network Service Provider must ensure that all protection systems for lines at a voltage above 66 kV, including associated inter-tripping, are well maintained so as to be available at all times other than for short periods (not greater than eight hours) while the maintenance of a protection system is being carried out." The availability of the Substation DC Supply is critical to achieving these requirements.

G1.3 Changing Network, Electric Life and the Energy Transition

Historically, the network has been a one way flow of power with supply flowing from bulk substation to zone substations then distribution loads. This has assisted the ability for non-unit protection to provide some level of backup protection in case of loss of local DC Supplies. EQL forecasts indicate a major shift in distributed generation which introduces complexities such as weak in feeds and islanded networks which erodes or completely eliminates this capability.

Table 33 - Energex Substations (242 forecast nodes) with Zero Demand

Minimum Demand	2022	2025	2032
Less than 0	129 (53%)	180 (74%)	201 (83%)
Greater than 0	113 (47%)	62 (26%)	41 (17%)

Table 34 - Ergon Substations (273 forecast nodes) with Zero Demand

Minimum Demand	2022	2025	2032
Less than 0	101 (37%)	200 (73%)	228 (84%)
Greater than 0	172 (63%)	73 (27%)	45 (16%)

EQL's Electric Life outlines key drivers for business change in the future and external driving factors. This also assists EQL's position to achieve targets set by the Queensland Energy and Jobs Plan. For 2023, the "four pillars" are empowered customers, development in renewables, digitisation and data and market disruption. The emphasis on renewable distributed generation reinforces this upward trend of distributed renewable energy and the importance of functioning DC Supplies at substations to allow EQL to safety and reliably achieve its goal of #keepingthelightson. A large amount of network data that is part of the pillar for digitalisation and data comes from substations and also benefits from a high reliability DC Supply.

G1.4 Workplace Health and Safety and Electrical Safety Code of Practice

The WH&S and Electrical Safety Code of Practice "requires persons who have a duty to ensure health and safety to 'manage risks' by eliminating health and safety risks so far as is reasonably practicable, and if it is not reasonably practicable to do so, to minimise those risks so far as is reasonably practicable." This means, if a solution is practical to eliminate or minimise a risk, it should be implemented. There is no defence if an effective control was rejected or not implemented on the assumption a risk score was low enough. Any legal litigation or ESO actions brought against EQL for failing to achieve this requirement will include hindsight making it imperative that due diligence is completed to achieve SFAIRP and ALARP in designs and installations.

EQL takes these requirements seriously with #safebydesign encapsulated in EQL's Business Plan for 2023/24 to drive proactive improvements from a design perspective. To balance competing requirements, the EQL Risk Framework can be used to cover risk scenario's, consequences and likelihoods. This framework also outlines "hierarchy of control" similar to the WH&S and Electrical Safety Act highlighting the importance to implement more robust controls where reasonable and practical. These tools are also helpful when evaluating competing safety aspect such as reduction of batteries to reduce manual handling requirements compared to duplication of systems to allow systems to be de-energised to avoid working live on DC Supplies.

G1.5 Financial Considerations

All network assets have direct capital and operational costs during their lifecycle including procurement, design, installation, commissioning, operation, maintenance, replacement and disposal. To be #financially stable, these should all be considered as well as how the individual asset contributes to cost in the context of the greater network costs and operational responses and flexibility.

DC supplies can cost over a hundred thousand dollars while also requiring routine maintenance and periodic replacements of batteries throughout its life. However, when compared to other assets in the Asset Management Plan for DC Supply Systems. DC Supplies are the lowest cost asset covered by an asset management plan and significantly cheaper than the bulk of the assets which are poles and wires related. Comparing the cost of a single DC supply as part of a greenfield substation is also of negligible consequence when considering additional material costs, design effort or installation effort which feeds into a reasonable or practical solution. There are however significant costs and complexities when considering various brown field applications or changes to sites built to a legacy design philosophy that make costs a far greater consideration.

G1.6 Failure Mode and Effect Analysis

In 2023 Substation Standards in conjunction with Substation Design, Protection and Grid Project Engineering completed a failure mode and effects analysis on DC Supplies in the Energy Queensland electrical network. It was this FMEA that determined appropriate redundancy levels and alternatives for DC Supplies in EQL Substations. Anyone wanting to review the FMEA can consult

G.2 Ability to select alternate supply

The preference is to have completely independent DC supplies with no cross over throughout the DC supply. However, during maintenance, contingencies and replacement projects, the normal supply may not be available. This would leave secondary assets de-energised for this duration reducing redundancy in the system.

This issue is resolved in many communication's devices which have the ability to take two supplies and automatically transfer internally in the device when the nominal supply is lost. This option however is not available or practical for many protection and control functions of electrical assets. As such, the best practical alternative is to have the ability to switch between DC Supply 1 and DC Supply 2 so with one out of service, all protection and control will remain functional.

G.3 Blocking Diodes on Paralleling Circuit Breakers

The system shown on the DC supply scheme drawing (EESS-10735-11) shows both battery strings in parallel via CB's without blocking diodes. There is a small risk of sustaining a short circuit in a battery bank, with consequent loss of protection grading leading to total loss of DC supply, however blocking diodes present a greater risk of failure due to their inherent unreliability. It is because of this risk that blocking diodes have not been used.

G.4 Unprotected Cables

The preferred length of unprotected cables between the battery terminals and the first protection device of 2m has been taken from AS/NZS 5139 2019 Electrical Installations – Safety of battery systems for use with power conversion equipment, Section 5.3.1.2.5 Location of overcurrent protection devices.

The maximum length of unprotected cables between the battery terminals and the first protection device of 3m has been taken from AS/NZ311.1 2019 Electrical Installations – Secondary batteries installed in buildings Part 1: Vented cells, Section 3.3.5 Main isolating switch.

G.5 Fault Current Ratings For Dual Strings

AS3000 requires installations to have sufficient protection against overcurrent during faults before any thermal damage occurs.

AS 2676.2 states "The short-circuit current rating of a battery consisting of strings of cells in parallel is the sum of the short-circuit current ratings of a group of cells comprising a single cell from each of the parallel branches." It also defines prospective fault current as "highest level of fault current that can occur at a point in a circuit".

Dual strings installed in line with this standard will have individually protected strings that parallel at the main DC switchboard. This will be the first location the prospective fault current will be the combination of the two strings.

Prospective currents for various faults on the DC system and associated protection are outlined in Table 35 (excludes unprotected cables). From this is can be confirmed cables between battery strings and the DC Main Switchboard only need to consider a single string's fault current cleared by the circuit breaker in the battery isolation cubicle. All equipment and other cables shall consider the dual string fault current contribution.

Table 35 - Dual String Fault Level Considerations

Fault location and details	Fault current paths and considerations	String contribution for protection against overcurrent
Fault between battery string and main DC switchboard. Common point for strings is the main DC switchboard. Each string has its own graded protection for its own fault current contribution.	Each string will provide fault current to the fault however the two currents will never flow in the same conductive path except for at the location of the fault.	Cables between a string and main DC switchboard only need to consider fault current contributions from one string. Fault current and clearing times will be based on each battery string carrying its own fault current and clearing via it's respective 250A isolating cubicle CB.
Fault internal to the main DC switchboard. Each string has its own graded protection for its own fault current contribution.	Both strings will contribute fault current within the switchboard. The protection devices for each string will allow full fault contribution into the switchboard.	DC switchboards must consider all strings connected to the DC system contributing to fault currents. Each battery string only needs to consider its own fault current. Fault current and clearing times will be based on each battery string carrying its own fault current and clearing via it's respective 250A isolating cubicle CB.
Fault downstream of the main DC switchboard. Faults will be downstream of a circuit breaker that will provide overcurrent protection.	Both strings will contribute fault current to the fault. Circuit breakers can provide protection of cables.	Any fault downstream of the main DC switchboard must consider all strings connected to the DC system contributing to fault currents. Fault current and clearing times

Annex H Revision History

Informative

Revision date	Version number	Author	Description of change/revision
08/10/07	1.0	Substation Standards	Approved for issue
12/12/17	2.0	Substation Standards	General review and copied to new template in preparation for publishing to the process zone. SS-1-5.1 Appendix 1 incorporated as Annex C. Approval by General Manager Asset Standards
3/7/23	3	Substation Standards	Update template for ECM audit, update references
14/12/2023	4	Matthew Ridgley	Major revision to EQL standard, update redundancy requirements, brownfield considerations, housing and ventilation brought up to current standards
15/12/2023	5	John Lansley	Update incorrect references