Part of Energy Queensland

Substation Standard

Standard for Switchgear Selection

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Approver	Carmelo Noel General Manager Asset Standards
If RPEQ Sign-off required insert details below.	
Certified Person Name and Position Title	Registration Number
John Lansley Manager Substation Standards	RPEQ 6371

Abstract: The purpose of the standard is to assist with selection of circuit breakers for substation applications.

Keywords: Substation, Circuit breaker, Gas Insulated Switchgear, Disconnector, Switchboard

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EQUATIONS

1 Overview

1.1 Purpose

To provide direction on the selection of switchgear to be used with Energy Queensland Substations. The standard also provides rating specific to switchgear which is not covered in other standards. The standard is manufacturer agnostic. Details of the actual switchgear on contract can be found in the relevant technical instructions.

1.2 Scope

This standard applies to all circuit breakers for zone substation application. It includes reclosers, ring main switchgear, medium voltage (MV) air insulated and gas insulated switchgear, high voltage (HV) gas insulated switchgear and outdoor MV and HV circuit breakers.

2 References

2.1 Legislation, regulations, rules, and codes

Electrical Safety Code of Practice – Works, 2020 (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

Standard for Climate and Natural Hazard Resilience, STNW3007 – 3057510

2.3 Energy Queensland other documents

Standard for HV Equipment Ratings, STNW3015

Substation Technology Comparison, TSD0207

2.4 Other sources

AS 62271.1, 2019 (Standards Australia) High-voltage switchgear and controlgear, Part 1: Common specifications for alternating current switchgear and controlgear (IEC 62271-1:2017, MOD)

AS 62271.100, 2019 (Standards Australia) High-voltage switchgear and controlgear - Part 100: High-voltage alternating-current circuit-breakers (IEC 62271-100, Ed. 1.2 (2006) MOD)

AS 62271.102, 2019 (Standards Australia) High-voltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthing switches (IEC 62271-102, Ed.1.0(2003) MOD)

AS 62271.200, 2019 (Standards Australia) High-voltage switchgear and controlgear - Part 200: A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV

AS 62271.203, 2012 (Standards Australia) High-voltage switchgear and controlgear - Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV

3 Definitions and abbreviations

3.1 Definitions

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

Cable charging breaking capacity	Breaking capacity for which the specified conditions of use and behaviour include the opening of an insulated cable operating at no-load (AS 62271.100)
Line charging breaking capacity	Breaking capacity for which the specified conditions of use and behaviour include the opening of an overhead line operating at no-load (AS 62271.100)
loss of service continuity category LSC	Category defining the possibility to keep other compartments and/or functional units energised when opening an accessible high-voltage compartment (AS62271.200)
Category LSC2	Functional unit having at least an accessible compartment for the high-voltage connection (called connection compartment), such that, when this compartment is open, at least one busbar can remain energized and all other functional units of the switchgear and controlgear can be operated normally (AS 62271.200)
Category LSC2A	Functional unit of category LSC2 such that, when any accessible compartment (other than the busbar compartment of a single-busbar switchgear and controlgear) is open, at least one busbar can remain energised and all other functional units of the switchgear and control can be operated normally (AS 62271.200)
Category LSC2B	Functional unit of category LSC2A, where the high-voltage connections (e.g., cable connections) to the functional unit can remain energized when any other accessible high-voltage compartment of the corresponding functional unit is open (AS 62271.200)
Category LSC1	Functional unit having one or more high-voltage compartments, such that, when any of these accessible high-voltage compartments is open, at least one other functional unit cannot remain energised (AS 62271.100)
Circuit-breaker class C1	Circuit-breaker with low probability of restrike during capacitive current breaking as demonstrated by specific type tests (AS 62271.100)
Circuit-breaker class C2	Circuit-breaker with very low probability of restrike during capacitive current breaking as demonstrated by specific type tests (AS 62271.100)
circuit-breaker class E1	Circuit-breaker with basic electrical endurance not falling into the category of class E2 (AS 62271.100)
Circuit breaker class E2	Circuit-breaker design so as not to require maintenance of the interrupting parts of the main circuit during its expected operating life, and only minimal

	maintenance of its other parts (circuit-breaker with extended electrical endurance) (AS 62271.100)
Circuit-breaker class M1	Circuit-breaker with normal mechanical endurance as demonstrated by specific type tests (AS 62271.100)
Circuit-breaker class M2	Frequently operated circuit-breaker for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests (AS 62271.100)
Multiple (parallel) capacitor bank Back to back capacitor bank	Bank of shunt capacitors or capacitor assemblies each of them switched independently to the supply system, the inrush current of one unit being appreciably increased by the capacitors already connected to the supply (AS 62271.100)
Peak (making current)	Peak value of the first major loop of the current in a pole of a circuit-breaker during the transient period following the initiation of current during a making operation NOTE 1 The peak value may differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage. NOTE 2 Where, for a polyphase circuit, a single value of (peak) making current is referred to, this is, unless otherwise stated, the highest value in any phase.
Primary switchgear	Switchgear with a nominal current rating of 1250A or more
Secondary switchgear	Switchgear with a nominal current rating of less than 1250A
Shall	Indicates that a statement is mandatory
Should	Indicates a recommendation advisable (non-mandatory)
Single capacitor bank	Bank of shunt capacitors in which the inrush current is limited by the inductance of the supply system and the capacitance of the bank of capacitors being energised, there being no other capacitors connected in parallel to the system sufficiently close to increase the inrush current appreciably (AS 62271.100)

3.2 Abbreviations

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

AC	Alternating current
CB	Circuit breaker
CT	Current transformer
DC	Direct current
EQL	Energy Queensland Limited
GIS	Gas Insulated Switchgear
IAC	Internal arc classified switchgear and controlgear
MV	Medium voltage (11-33kV)

LSC	Lloss of service continuity category
STATCOM	Static Synchronous Compensator
SVC	Static var Compensator
VT	Voltage transformers

4 Authorities and responsibilities

The responsibility for substation switchgear selection at EQL is shared as follows:

Table 1: List of teams and associated responsibilities substation ratings

Authority	Responsibilities
Asset Standards	Standard for Substation Ratings
Asset Standards	Providing equipment options able to meet this standard
Grid Planning	Ensure EQL meets this standard during planning activities
Substation Design	Electrical and Civil Engineering RPEQ Site-specific application of this standard

5 Switchgear selection

5.1 Ratings to check

Before switchgear can be selected for an application the following ratings shall be considered:

- Voltage
- Current rating
- Fault ratings
    - Review X/R for substations with high fault levels
- Wind ratings (outdoor only)
- Operating sequence
- Suitability for special applications (where applicable)
- Instrument transformers are suitable (where applicable)
- Control and motor voltage
- Line \ Cable charging
- Bus rating (where applicable)
- Cable entry (where applicable)
- Number of cables per phase (where applicable)

5.2 Where to use what technology

5.2.1 Live v dead tank circuit breakers

Where an outdoor AIS bay is used dead tank circuit breakers should be used. For all new installations dead tank circuit breakers shall be used (except at 245kV).

Dead tank circuit breakers have the following improvements compared to live tank circuit breakers:

- Included current transformers (eliminates maintenance associated with post type current transformers)
- CT marshalling box not required
- Over lapping protection zones

Replacement of existing live tank circuit breakers may necessitate using a live tank breaker to fit back in the same space.

5.2.2 GIS

Gas insulated switchgear shall be used for indoor applications of 66kV and above. Gas insulated switchgear may also be used at 33kV in built up areas, where space is restricted, or where an indoor option is preferred. For outdoor applications at 66kV and above, GIS should be used where there are space constraints or where the number of bays required makes it cost effective to install GIS. TSD0207 has further information and a technology cost comparison tool.

GIS shall be installed in line with the standard for GIS (STNW3045). The climatic requirements of the installation shall be checked against the rating of the GIS. Where the GIS does not meet the climatic requirements, it shall be installed indoors, or a different technology used.

5.2.3 Hybrid switchgear

Hybrid switchgear can be used for single bay customer connections only at this stage.

5.2.4 MV switchgear

Secondary switchgear may be used within substations as the main switchgear in cases where the required rated nominal current is less than 630A. The protection schemes shall be as per the standards and advice from the protection team. Where a higher rating is required, primary switchgear (2000A rated nominal current) shall be used.

Substation auto reclosers are available for use within substations. These are suitable for outdoor applications typically for single bay substations or retrofitting into existing outdoor substations.

Fixed pattern switchgear shall be used in lieu of withdrawable switchgear to eliminate potential hazards during circuit breaker racking.

5.2.5 Considerations for staging of switchgear

The preferred option to extend switchgear (MV switchboards and GIS) is to use the same switchgear from the original manufacturer. Where it is not possible to get the same switchgear (e.g. switchgear is no longer manufactured) a joggle panel can be used. Where a joggle panel is used additional space is required for the extension. Typical width required for joggle panels is shown in Table 1, note these values are a guide only; manufacturer specific details will be required for each project.

Table 2: Typical joggle panel sizes

Voltage (kV)	Typical width (mm)
11	500
22	800
33	800

Another extension option is to cable from an existing CB to a panel on the new switchgear (typically a circuit breaker panel). Circuit breaker panels are preferred as these are an EQL standard product and are rated for the cable charging currents. Note this option will create an additional bus section and will require appropriate bus protection schemes.

When planning the ultimate arrangement of switchgear, the timing of the extensions shall be considered. Typical switchgear contracts are a minimum of 5 years with possible extensions. Additional space for a joggle panel shall be included be included in the ultimate layout, where it is expected that the construction of the ultimate stage of the switchgear is outside the contract period, or expected availability of the switchgear.

5.2.6 Typical outage requirements

Typically, an outage will be required during the design stage for the manufacturer to measure up the location of the bus bars.

Bus outages are required to install new and commission new panels.

5.2.7 Considerations with joggle panels

The following must be taken into consideration with using a joggle panel:

- Outage during design stage
- Matching arc fault ratings
- Matching gas pressures (GIS)
- Fault ratings
- Space requirements

5.2.8 Consideration with cable connection options

The following must be taken into consideration with using a cable connection to extend switchgear

- protection scheme across the cable
- Additional bus section created
- Rating of existing CB and suitability of the CTs
- Design transfer load to be allowed for in the event of a transformer outage
- Maximum cable size to connect to existing CB

5.3 Special operations

5.3.1 Capacitor bank switching

For capacitor bank switching a circuit breaker with a C2 classification shall be used. The capacitive current, inrush current and frequency shall be checked against the ratings of the circuit breaker.

The Calculator bank Inrush Calculator has been developed to calculate the in-rush currents and frequency; calculations are as per Figure H.3 from AS 62271.100. Refer to Annex A.

5.3.2 Reactor bank switching

For reactor bank switching a transient switching study shall be completed to determine the suitability of the circuit breaker for the switching case.

5.3.3 Charging currents

Where long cable or line sections with no intermediate loads are installed the applicable cable or line charging rating of the switchgear shall be checked. Typically, higher voltage switchgear has higher charging ratings and may be required where long cables \ lines are installed. Section 8.1.6 lists the standard rated charging currents. The Switchgear Selection tool can estimate the charging current for 11kV and 22kV cables.

5.3.4 Single pole switching

Single pole switching shall be used where three pole switching is identified as unsuitable for the switching application.

Where a study identifies that single pole switching is required, a single pole circuit breaker with a point on wave controller shall be used to reduce the effect of transformer inrush currents.

To match legacy installations single pole mechanism circuit breakers should be installed at 245kV.

Staggered pole operating mechanisms are not standard and are not considered for greenfield installations.

5.4 Environmental factors

Switchgear shall meet the requirements of the Standard for Climate and Natural Hazard Resilience (STNW3007). The manufacturer’s requirements for indoor switchgear shall be compared to the site conditions (particularly for existing sites).

6 Switchgear available

Energy Queensland has multiple types of switchgear on contract. Table 3 shows the types of switchgear available at each voltage. Refer to the associated technical instructions for specific details of the switchgear.

Table 3: Switchgear Available

	11 kV	22 kV	33 kV	66 kV	145 kV	245 kV
Recloser		X	X			
Indoor RMU	X		X			
Outdoor RMU	X		X			
Primary Switchboard	X	X	X			
Live tank CB (3 pole)				X	X	
Live tank CB (single pole)				X	X	X
Dead tank CB (3 pole)			X	X	X	
Dead tank CB (single pole)				X	X	
GIS				X	X	
HIS (3 pole)				X	X	
HIS (single pole)				X	X	

Table 4: Relay Operated C&I Substations

	11kV C&I Sub LV Connection to customer	11kV C&I Sub HV Connection to customer (single bus)	11kV C&I Sub HV Connection to customer (multiple buses)
Indoor RMU	X	X	
Primary Switchboard			X

6.1 Current transformers

The standard current transformers included with the switchgear have been selected to work with the period contract relays (at the time of the tender process). Preference is to integrate with existing systems via low impedance protection, alternatively non-standard CTs can be investigated by Substation Standards.

For bus differential schemes interfacing current transformers are an option, however the cost of the CTs enclosure and wiring shall be considered against the cost of replacing the scheme with a low impedance scheme. Other factors to consider are the common point of the differential scheme.

6.2 Voltage transformers

Where voltage transformers are required, and the switchgear type supports their installation as part of the switchgear then the voltage transformers should be installed as part of the switchgear.

6.3 Standard relay locations

The preference is for feeder protection relays to be installed on MV switchgear. For relays to be installed onto new switchgear the switchgear must meet the following requirements:

- AFLR rated
- Duplicate feeder protection installed
- High speed bus protection installed (installed off switchgear)
- Isolation and test facilities are to be installed on the front of the switchgear

For GIS (66kV and above) the protection relays should be installed separately from the GIS.

7 Ratings

Primary ratings are detailed in the Equipment primary rating standard. This section provides additional rating information not included in the STNW3015.

7.1 Circuit breakers

The following ratings apply to circuit breakers

7.1.1 Peak withstand current

In addition to fault ratings described in STNW3015 the following shall apply to circuit breakers.

The standard time constant of 45ms is used for the ratings of the standard circuit breakers to be included on contract.

Where the maximum fault level is 80% or greater than the rating of the circuit breaker then the time constant shall be checked. In cases where the time constant is greater than 45ms a circuit breaker with the next short circuit rating from the R10 series shall be used.

R10 series is 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80 and all ten-fold multiples thereof.

The time constant can be calculated using the X/R ratio as shown in Equation 1

$$\tau = \frac{1}{2\pi f}\left(\frac{X}{R}\right)$$

Equation 1: Time constant

The international standard for High-voltage switchgear and control gear – part 1 common specifications (IEC 62271-1) states that a time constant of 45ms covers the majority of cases and corresponds to a peak withstand current of 2.5 times the rated short-time current. With a 25kA short time withstand current the peak withstand current shall be 62.5kA.

The international standard for High-voltage switchgear and control gear – part 1 common specifications (IEC 62271-1) further states that for a time constant up to 120ms a peak withstand current should be 2.7 times the rated short-time current. Using a factor of 2.7 and backward calculating from a peak withstand current of 62.5kA the maximum allowable fault current is 23.1kA where the time constant is between 45-120ms.

7.1.2 Operating sequence

All substation circuit breakers (excluding C&I subs) shall have an operating sequence suitable for auto reclosing.

O - t - CO - t' - CO – AS 62271.100

For all applications the value of t shall be 0.3 seconds.

For MV applications the value of t' shall be 15 seconds, for HV applications t' of 15 seconds is preferred but 3 minutes is accepted.

For applications where the network is all underground (e.g., commercial and industrial substations) a mechanism not rated for auto reclose is acceptable. Where switchgear has multiple use cases the switchgear shall be rated for auto reclose as defined at the start of this section.

7.1.3 Electrical endurance

Circuit breakers rated =< 52kV have an electrical endurance rating. These circuit breakers shall be rated to E2.

7.1.4 Mechanical endurance

Circuit breakers used to switch reactive plant used for network support, capacitor banks, reactors, Statcom and SVCs shall be M2 class. Circuit breakers not used to switch reactive plant should be rated to M2 class.

7.1.5 Transient recovery voltage

As a minimum the circuit breakers shall meet the values of Table 25 or Table 1b of AS62271.100 with respect to the rated voltage of the circuit breaker. Table 24 for indoor switchboards 12-36kV

For circuit breakers rated less than 100kV there are class S1 and S2. Class S1 is for breakers switching cable networks and S2 is for lines networks.

7.1.6 Charging currents

The rated cable and line charging breaking currents of the CB shall meet or exceed.

Table 5: Charging currents

Voltage (kV)	Line (A)	Cable (A)
12	10	25
24	10	31.5
36	10	50
72.5	10	125
145	50	160
245	125	250

7.1.7 Requirements for simultaneity of poles

The maximum difference between contacts touching or separating during three pole operations shall be as per

Table 6: Simultaneity of poles

Operation	Single Interrupter	Multiple Interrupters in series
Closing	<1/4 of a cycle	<1/6 of a cycle
Open	<1/6 of a cycle	<1/8 of a cycle

7.2 Disconnector and earth switch requirements

7.2.1 Disconnector mechanical endurance

The disconnector mechanical endurance has been selected as M1 (2 000 operations). This is to align with the M1 circuit breaker endurance.

7.2.2 Earth switch electrical endurance

To reduce the impact of switching errors earth switches shall be rated for fault make (electrical endurance E1 or higher). There are 3 classes of electrical endurance, E0 no making capacity, E1 2 making operations and E2 5 making operations. With current technology it is not possible achieve a rating greater than E0 for outdoor AIS.

A typical GIS bay has 3 earth switches, bus side CB earth switch, line side CB earth switch and line earth switch. The line earth switch shall have fault making capability (E1 or greater), while it is possible for the CB earth switches to be fault making rated this would significantly increase the cost and size of the switchgear. As both these earth switches are interlocked with the circuit breaker disconnectors it is not possible to close the earth switch onto energised plant as such E0 earth switches are acceptable for this application.

7.3 MV switchgear

7.3.1 Arc fault ratings

All MV switchgear shall be IAC classified with the following requirements:

- Duration 1 second
- Accessibility type A and FLR (front lateral and rear)
- Prospective fault current shall equal the rated short time current of the switchboard

7.3.2 Loss of service continuity class

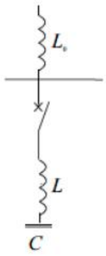
For secondary switchgear (RMUs) Category LSC1 is acceptable.

For primary switchgear LSC2 shall be used, LSC2B is preferred.

Annex A

Informative

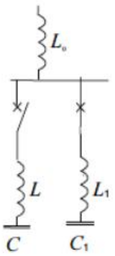
Capacitor bank switching inrush calculations



a) Connection of a single bank

$$\hat{i} = U_r\sqrt{\frac{2}{3}\frac{C}{L_0+L}} \approx U\sqrt{\frac{2}{3}\frac{C}{L_0}} \qquad L_0 >> L$$

$$f_{ib} = \frac{1}{2\pi\sqrt{C(L_0+L)}} \approx \frac{1}{2\pi\sqrt{CL_0}}$$



b) Connection when one bank is already connected

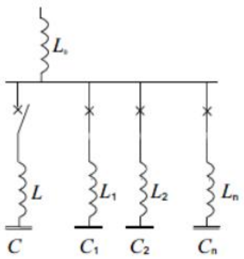
$$\hat{i} = U_r\sqrt{\frac{2}{3}\frac{C_1C}{(C_1+C)} \times \frac{1}{(L_1+L)}}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{\frac{C_1C}{(C_1+C)}(L_1+L)}}$$

$$S = \frac{U_r}{L_1+L}\sqrt{\frac{2}{3}}$$

When $L_1 = L$ and $C_1 = C$ then:

$$\hat{i} = U_r\sqrt{\frac{C}{6L}} \quad \text{and} \quad f_{ib} = \frac{1}{2\pi\sqrt{LC}}$$



c) Connection when n banks are already connected

$$L' = \frac{1}{\frac{1}{L_1}+\frac{1}{L_2}+\cdots\frac{1}{L_n}} \quad \text{et} \quad C' = C_1 + C_2 + \cdots C_n$$

If $L_1 = L_2 = \ldots = L_n = L$ and $C_1 = C_2 = \ldots = C_n = C$, then

$$L' = \frac{L}{n} \quad \text{and} \quad C' = nC$$

$$\hat{i} = U_r\frac{n}{n+1}\sqrt{\frac{2C}{3L}} \quad \text{and} \quad f_{ib} = \frac{1}{2\pi\sqrt{LC}}$$

L' and C' substitute L_1 and C_1 in figure H.3 b).
The calculation is correct if $L_1 \times C_1 = L_2 \times C_2 = \ldots = L_n \times C_n$; in other cases it is an approximation.

Components

U_r	rated voltage	L	inductance in series with switched capacitor bank
$\hat{i}$	inrush current peak	C	capacitance of switched capacitor bank (equivalent star value)
f_{ib}	inrush current frequency	$L_1, L_2 \ldots L_n$	inductances in series with capacitor banks on source side
S	inrush current rate-of-rise	$C_1, C_2 \ldots C_n$	bank capacitances (equivalent star values) on source side
L_0	source inductance		

Figure H.3 – Equations for the calculation of capacitor bank inrush currents

Revision History

Revision date	Version number	Author	Description of change/revision
6/6/2023	1	A.Gabriel	Initial issue