Network Configuration – Selection for New Substations - Framework

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1. INTRODUCTION

1.1 Purpose

This framework provides functional specification for standard network and busbar configurations and consequent layouts to be used for Powerlink substations and for network and substations classified as designated network assets (DNA) and Identified User Shared Asset (IUSA).

Establishing these configurations ensures Powerlink's consistency with good electricity industry practice, enables provision of services at acceptable levels of security, reliability and availability whilst maintaining the safe operation of the power system as per AEMO requirements and to the performance standards specified in the Rules.

While some layouts may already exist in the Powerlink's network that differ from those listed in this framework, these are the result of historical network development and if not listed in this document it means that the experience is such that these are not to be propagated in the network.

Any network and busbar configurations not provided for in this Framework will be treated as non-standard and require exemption approval.

1.2 Scope

The requirements of this framework apply to all new transmission network developments, any additions/reconfigurations and new connections to it including connections to DNA and IUSA, as these are to be treated as part of the transmission network in accordance with National Electricity Rules.

1.2.1 Existing Network Applications

This framework is not applied retrospectively. However where a full rebuild of an existing substation or construction of a new substation is necessary, the busbar configuration shall be in accordance with this framework. Where a partial replacement or addition is required, the existing substation busbar configuration requires assessment on a case-by-case basis and unless proven that it does not meet present and future customer/network requirements, the existing busbar configuration will be maintained.

1.2.2 DCA Connections

Under the National Electricity Rules, Powerlink as the primary TNSP in Queensland has no obligation to provide functional specifications for DCA substations. It is a requirement that each customer with a DCA connection to the transmission network has determined desired levels of reliability and availability. Powerlink provides information about requirements for planned routine (scheduled) maintenance in Table 3 of ASM-FRA-A542372 (Substation Asset Methodology-Framework) and in Appendices "A" of ASM-FRA-A537590 (Transmission Line Asset Methodology-Framework) and ASM-GDL-A2930690 (Secondary Systems and Telecommunications Equipment Maintenance Schedule - Guideline documents as a guide for availability and reliability assessment.

In addition, Powerlink has also provided information about standard equipment ratings including fault levels in ASM-SPE-A515948 Substation Ratings-Specification. Both documents and most high voltage equipment strategies are available on Powerlink's web site.

1.3 General Network & Busbar Configurations Principles & Overview of Standard Configurations

This document lists standard network and busbar configurations for transmission network operated by Powerlink Queensland.

Application of any other network configurations are assessed against a number of criteria, including but not limited to:

- Customer availability and reliability requirements
- Impact on network stability

- Impact of planned and unplanned contingencies for all new and existing customers (there should not be any impact on regulated network customers for any contingencies apart from load being put at risk for normal state)
- Complexity and reliability of protection systems
- High level investment cost
- Maintainability (incl. availability of spare equipment)
- Expandability

1.3.1 Outages

Access to customer outages should be such that there is not a significant impact on the backbone-shared network. That is, disconnectors should be installed to facilitate the outage without needing to take the shared network element out of service.

1.3.2 Connection of Hub Substation

Where multiple parties are connecting in close proximity, Powerlink may consider and suggest the connection of multiple parties to a single substation to minimise connection costs and potential impact on the other parts of the network.

1.3.3 Connection to end-of-life assets

If a customer proposes to connect to the existing network assets which are identified to be reaching the end of service life or there are plans which change its configuration in the future (e.g. in the latest Asset Management Plan), then the customer will be provided with information and high level estimated costs involved for either extending asset service life (if feasible) or estimated cost of replacement. In addition, an alternative connection point will be made available for customer consideration.

Where the expected end of service life, or configuration change, for the asset is not known, and outages are required by Powerlink for the asset renewal, Powerlink reserves the right to arrange outages and undertake the works without penalty unless formally agreed in a Connection and Access Agreement.

Additionally, for connections to Powerlink’s network, the following criteria must be met in the configuration of the connection:

- No credible outage on a customer’s network should result in an outage of the regulated shared (prescribed) network to which it is connected.
- 110kV and 132kV connections within 5 to 10 km of an existing regulated, IUSA or DNA substation will typically be connected back to the nearby substation (Powerlink’s experience has shown this to provide the lowest combination of cost, complexity, operability and electrical safety). This can be re-assessed for sites with space constraints, however if a new substation is proposed in close proximity to the existing substation, the procedure for exemption needs to be used.
- 275kV and 330kV connections within 10 to 15 km of existing substations will typically be connected back to the nearby substation. Powerlink’s experience has shown this to provide the lowest combination of cost, complexity, operability and electrical safety (from earthing perspective). This can be re-assessed for sites with space constraints, however if a new substation is proposed in close proximity to the existing substation, the procedure for exemption needs to be used.

Table 1: Standard Configurations

Voltage	Application	Recommended Configuration
275kV & 330 kV	Main grid and major customers	Breaker and half for both AIS and GIS
132kV & 110kV	Sub-transmission	U–bus for AIS & bus disconnector selectable for AIS where low impedance protection exists Bus disconnector selectable for GIS

Table 2: Specific Case Standard Configurations

Voltage	Application	Recommended Configuration
275kV & 330 kV	Lesser availability acceptable, have to be agreed by customer.	3 and 4 breakers meshed configuration (in 1½ CB layout) for AIS only
All voltage levels	Lesser availability acceptable, have to be agreed by customer.	Switchable transformer ended feeders (no bus arrangement) where load or generation capacity is small and point of wave switching is not required.
132kV & 110kV	Lesser availability acceptable, have to be agreed by customer.	Teed feeder arrangement (three ended feeder) – one customer per feeder.
132kV & 110kV	Customers that require high reliability	Breaker and half for both AIS and GIS
All voltage levels	Small DNA	Single feeder and single bus for maximum of two connection points.

1.4 Defined terms

Terms	Definition
DCA	Dedicated Connection Asset
DNA	Designated Network Asset
IUSA	Identified User Shared Asset
POW	Point-On-Wave (switching)
RIT-T	Regulatory Investment Test for Transmission
TNCP	Transmission Network Connection Point

1.5 Monitoring and compliance

The implementation and improvements of this framework is monitored through asset lifecycle:

1. Planning and Investment
   - Through feedback from existing customers and potential proponents.
   - Ensuring the appropriate network and busbar configuration is included in the project scope report.
2. Design
   - Ensuring the design of network and busbar configuration is in accordance with the principles of this framework.
   - Seeking feedback from designers regarding the level of difficulty for substation expansions or modifications and complexity of the protection systems.

3. Acquire/Procure
   - Ensuring that equipment purchased is in accordance with relevant equipment strategies as the principles of this framework rely on reliability of the equipment.
   - Seeking feedback from Materials group regarding new equipment types and technologies available on market.
4. Construct and Install
   - Ensure construction and installation completion is as per design and final check that design is in accordance with the principles set in this framework.
   - Seek feedback on space and costs requires for each standard and non-standard configurations
5. Commission
   - Ensuring that protection settings align with the principles set in this framework.
6. Operate
   - Ensuring that operations including outage management are not impacted by the configurations.
   - Seeking feedback to ensure improvements for reliable operation are realised.
7. Maintain
   - Seeking feedback on access to equipment and any other maintainability aspects.
   - Seeking feedback to ensure that any replacement or augmentation project considers any required improvements.
8. Modify/Refurbish
   - Ensuring any future expansions and refurbishments meet principals set in this framework.
9. Dispose/Decommission
   - Ensuring that end of life decisions do not affect other customers.
   - Prior to initiation of replacement and augmentation projects, the existing network and busbar configuration is assessed considering existing and new customer requirements, stability of the network and maintainability of the equipment.

2. 110/132 KV NETWORK CONNECTIONS AND BUSBAR LAYOUTS

2.1 110kV / 132kV Standard Configuration

The standard configuration used for 110kV and 132kV networks is a “U bus” or folded bus configuration. This consists of two busbars, with a bus coupler breaker, and breakers on each transformer / feeder / reactive plant. Where any even number of elements provide connection to the same location or function, then half of these should be connected to one bus bar and the other half to the opposite busbar[1]. Refer to Figure 1. With any odd number of elements, the last one should typically be selectable in some way[2]. Refer to Figure 6.

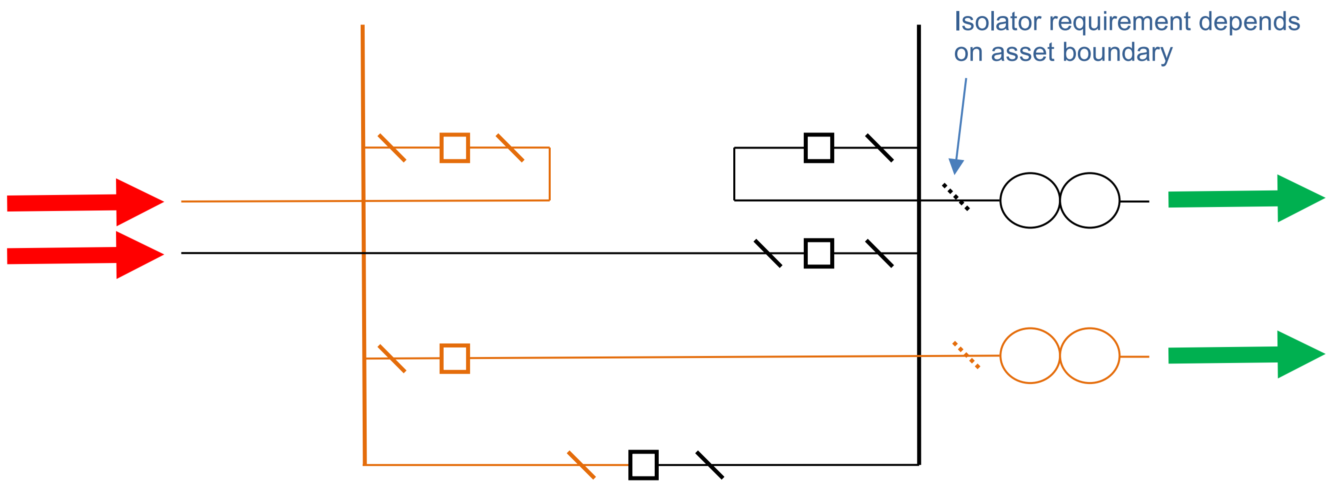

Figure 1: Typical U Bus Configuration (Folded Bus)

[1] To have shorter current paths and avoid all of the power going through the bus coupler circuit breaker.
It also allows single busbar outages, with sufficient supply maintained.

[2] To allow single busbar outages (which would otherwise take 2 of the 3 supplies out of service). If sufficient outage window exists where load can be supported by only 1 feeder, then selectability could be discretionary.

2.2 110kV / 132kV Connections

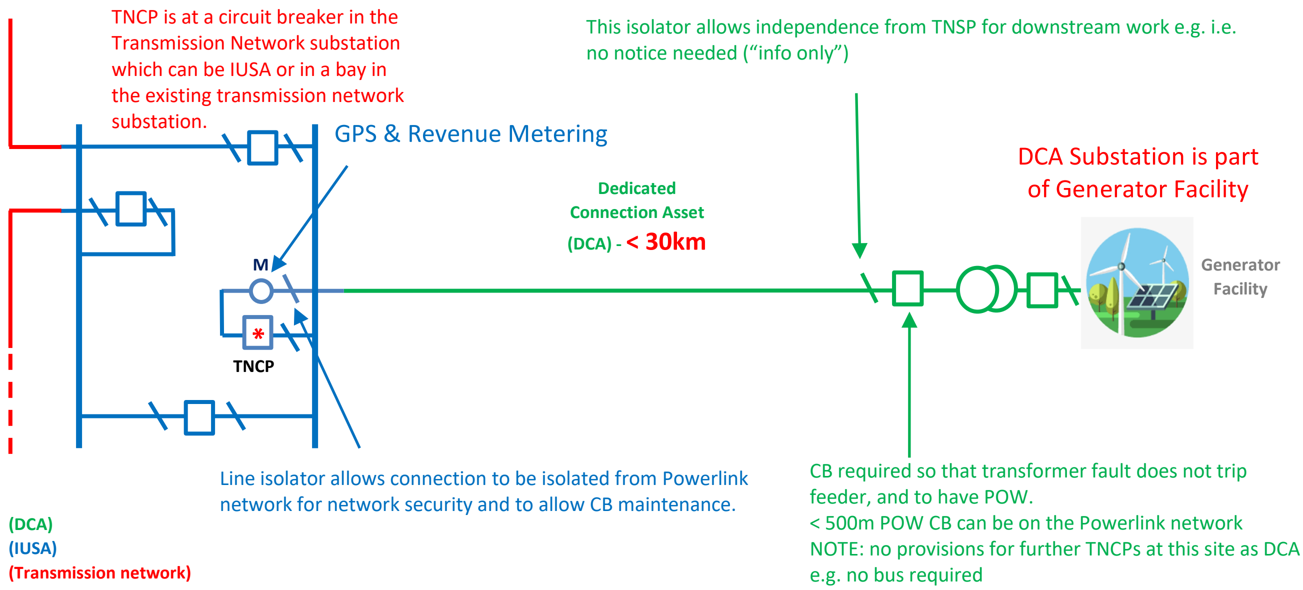

Figure 2 - Simplest connection is single circuit radial as DCA with "N" level of reliability

Apart from requirement to have one 132/110 kV circuit breaker (either feeder or transformer) and a 132/110 kV disconnector at customer substations, there are no other requirements for DCA substations. This connection will be limited by maximum available standard equipment ratings (type test for going above this involves significant costs). The outages will be required periodically to maintain equipment. Their busbar configuration at DCA substation can be any that will meet a customer reliability and availability requirements.

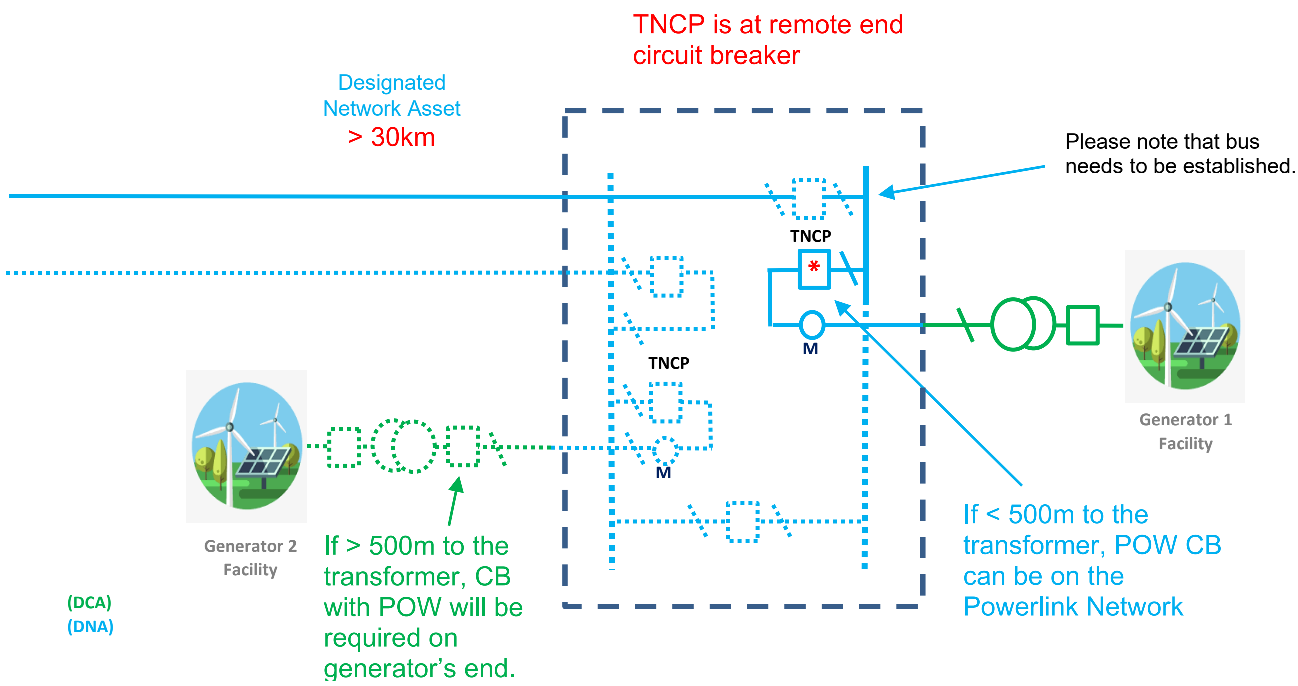

Figure 3 - Typical Large DNA connection allowing for future expansion

If remote end substation is likely to have more than one TNCP, then it will be classified as either SMALL or LARGE DNA. If it is likely to have more than two TNCPs, then it will be LARGE DNA and needs to be to Powerlink Standard, which is a U bus for 132kV or 110kV. Whilst able to be built in stages, the substation needs to be planned in such way to allow for U bus and having provisions for future connections, including a future second supply circuit.

2.3 110kV / 132kV Increased Reliability Configuration

Where a number of single or multiple connections exist, it may be preferable to utilise a selectable disconnector arrangement to increase the operational reliability of the substation. (Refer to Figure 4 below). Each transformer or feeder is to be established utilising a disconnector to each busbar, with single CB. A bus coupler breaker is still required. Reactive plant elements can be connected to a single busbar and not being selectable.

The use of this configuration will be assessed on a case-by-case basis. Disconnector selectable configuration and only considered where it is cost effective against a folded bus arrangement. This configuration requires different protection system.

For 110/132kV gas insulated substations (GIS), this is the preferred busbar configuration and is combined with additional gas barriers allowing any element to be taken out of service using existing isolators/ disconnectors for their isolation.

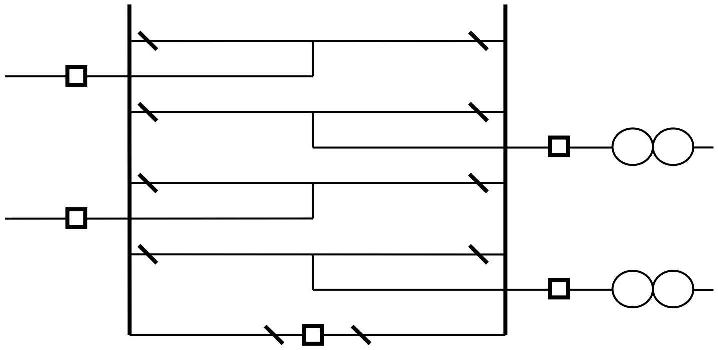

Figure 4 - Isolator selectable bus

The exceptions are those supplying major customer loads (separately negotiated) in which case breaker and a half-busbar configuration can be used for both AIS and GIS applications.

2.4 110kV / 132kV Tee Connection

A tee connection creates a three-ended feeder, increasing the complexity of protection systems and maintenance requirements and reducing availability and reliability for customers connected to all three ends. A tee connection is only permissible on the 1100/ 132kV network provided it meets the following:

- The new section of feeder will become part of the Transmission Network.
- Only one customer/ tee connection point permitted per feeder[3].
- The feeder must have duplicate high-speed communications available to facilitate duplicate differential protection.
- The length of the entire tee connection must not exceed 30% of the feeder length into which it is tee'd, or 30km, whichever is the lesser. [4]

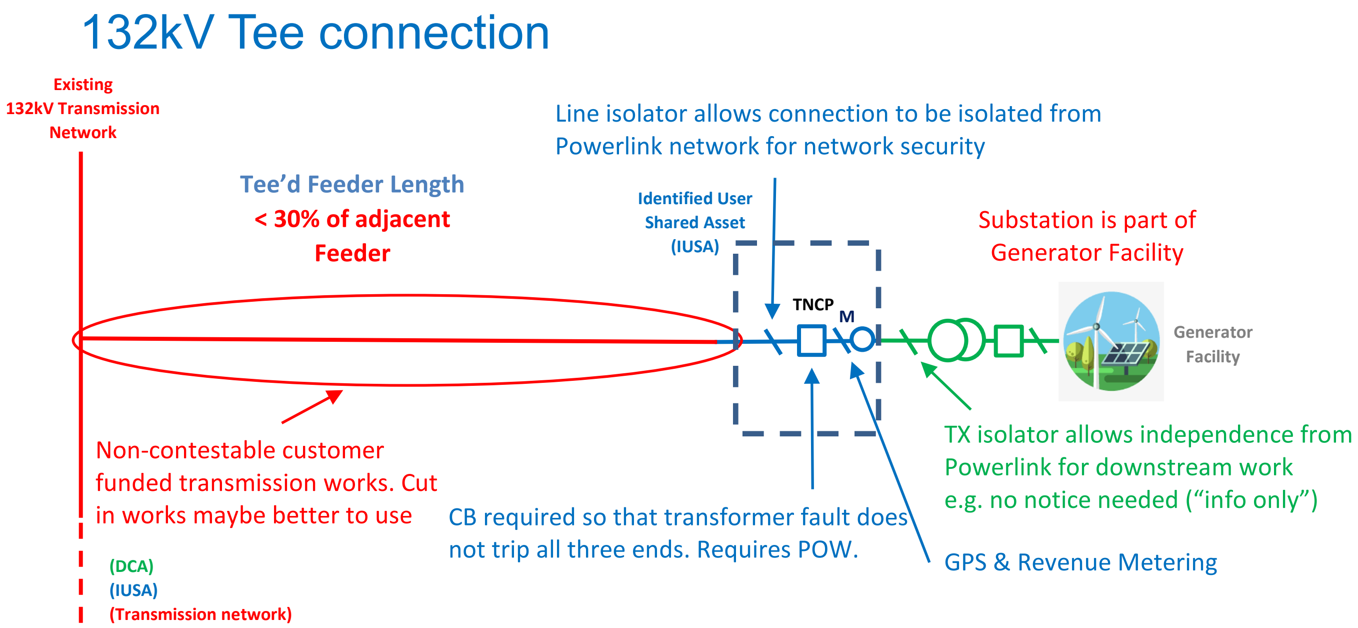

Figure 5: 132 kV Tee Connection

[3] NER Rules do not permit outages of one customer to have an adverse impact on another customer. The market availability for protection relays with 4 inputs is limited.

[4] 30% reflects an effort to keep costs down and minimise impact on reliability/availability of existing customers

2.5 110kV / 132kV Large loads or through flows

Where a third transformer (and/or third feeder) from the same source, is required (e.g. for a large load), it is to be made bus CB selectable (Figure 6).

Figure 6: U Bus Layout (more than 2 feeders from the same source and/or more than 2 Transformers)

OR have additional bus couplers

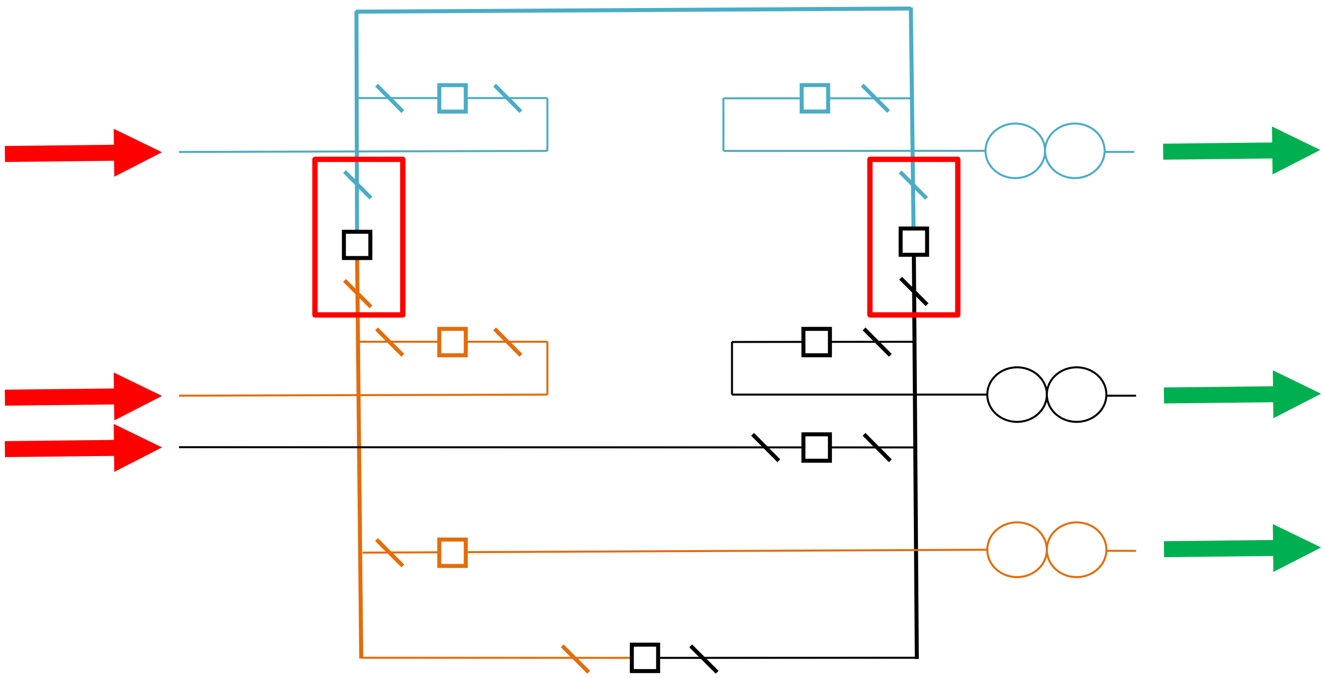

Figure 7: U Bus Layout (more than 2 feeders from the same source and/or more than 2 Transformers)

2.6 110kV / 132kV When HV Transformer CBs are not required

For negotiated customer connections, where loads/generating capacities are small (defined as less than 100 MVA) and POW switching is not required[5], then it may be acceptable to omit the transformer circuit breakers as shown in Figure 8. In this case, TNCPs and metering points will be at transmission network substation.

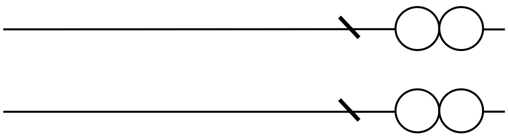

Figure 8: Transformer Ended Layout (feeders from the same source)

This is typically only acceptable with simple configurations such as:

- two feeders supplying two transformers, or
- one feeder supplying one transformer, and
- where through flows are not critical e.g. both feeders are from the same source.

Transformer Ended Feeders are not to be combined with tee'd feeders (to avoid impact on other customers).

Layout shown in Figure 9 is only possible where transformers are located at the same substation as bus and have the same ownership.

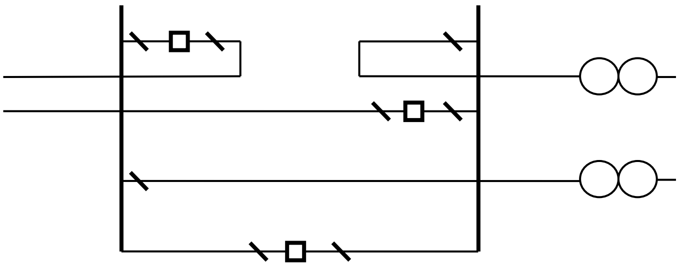

Figure 9: U Bus Layout (feeders from same source) with no transformer breakers-bus coupler is required

[5] Energising transformers can reduce the bus voltage unacceptably. POW switching takes into account pre-existing flux levels at switches at the optimum point of the sine wave, and is required on each transformer. If the fault level is high, and the transformer size small, POW may be assessed as unnecessary, subject to detailed network studies and approval.

3. 275KV AND 330KV NETWORK CONNECTIONS AND BUSBAR LAYOUTS

3.1 275kV / 330kV Standard Configuration

The standard configuration for a 275kV or 330kV substation is a breaker and a half arrangement, comprised of two busbars with 275kV diameters for connection of elements. This configuration provides high reliability, allows for maintenance outages and maximises operational flexibility.

For GIS substations at these voltage levels gas barriers shall be provided such that any faulty circuit breaker can be removed and replaced without having to interrupt the associated element (for example feeder or transformer) from service.

Connections via tees to the 275kV and 330kV network are NOT considered as an acceptable solution and will require exemption approval. This is because higher reliability and availability is required at higher voltages as fault consequences have impact on much wider area supply, more customers and sometimes can affect network stability.

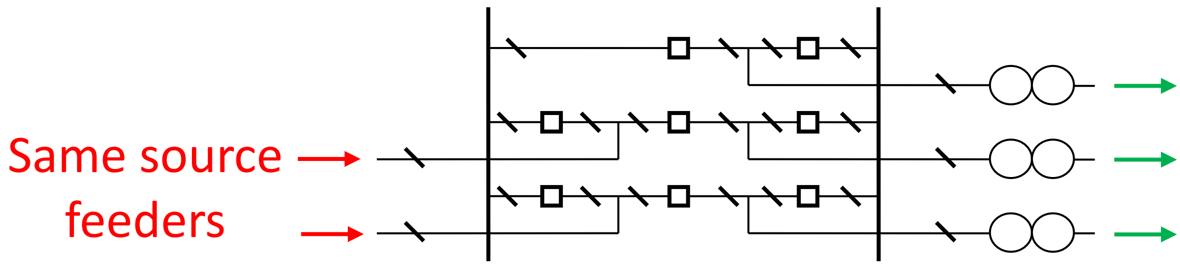

Figure 10: Typical 1½ CB (Breaker and a Half) Bus Configuration – Radial supply

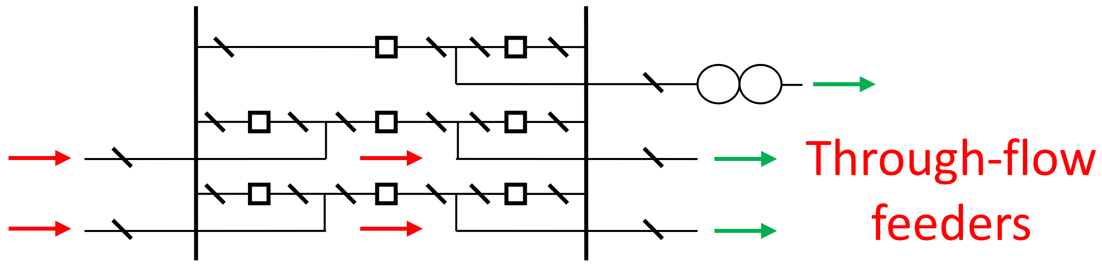

Figure 11: Typical Breaker and a Half Configuration – cut into through flows

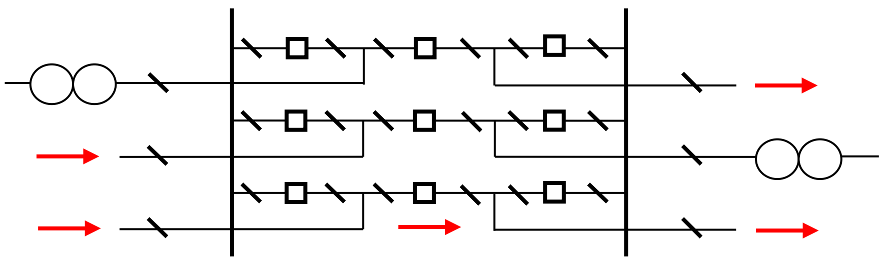

Figure 12: Typical Breaker and a Half Configuration
(Reduced Diameters by only requiring a single through-flow interconnecting circuit)

At least one through flow should be maintained in the same diameter (i.e. back to back) – to have shorter current paths and minimise the power going through the bus bar. It also allows through flow to be maintained even if substation is bypassed e.g. planned bus outage followed by bus fault.

In addition to 1½ CB configuration, a 3CB and 4CB mesh (in 1½ CB layout) is acceptable where power flow in main transmission network path can be maintained and is subject to Powerlink's Network Operation's endorsement. Due to the costs associated with protection modifications required, this configuration will require significant additional investment in secondary systems if it is required to expand it into 1½ CB configuration.

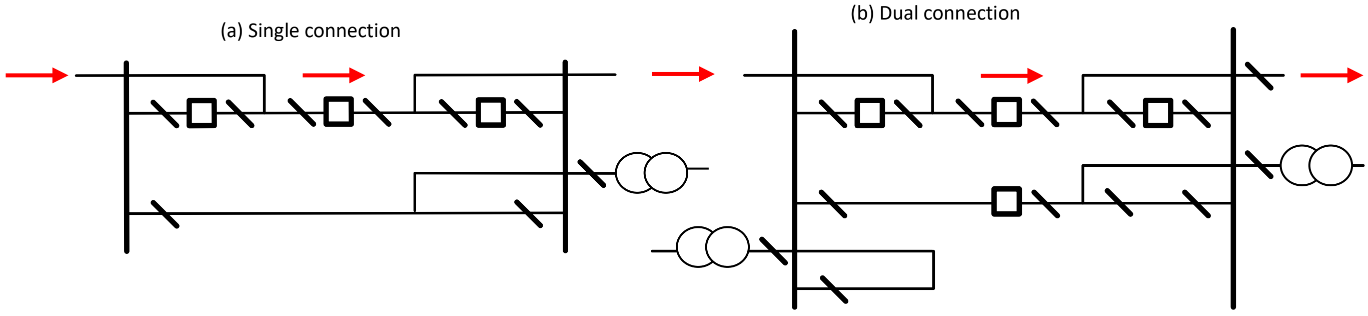

Figure 13: 3CB and 4CB mesh configurations

The above options (3 and 4 CB mesh) have inherently lower reliability and availability and customers that take these options have to consider this and accept it.

3.2 275kV / 330kV Generator Connections

In case of DCA connections, 3 CB mesh connection is presented below including TNCP and metering point and few additional explanations. This option is subject to Powerlink's Network Operation's endorsement.

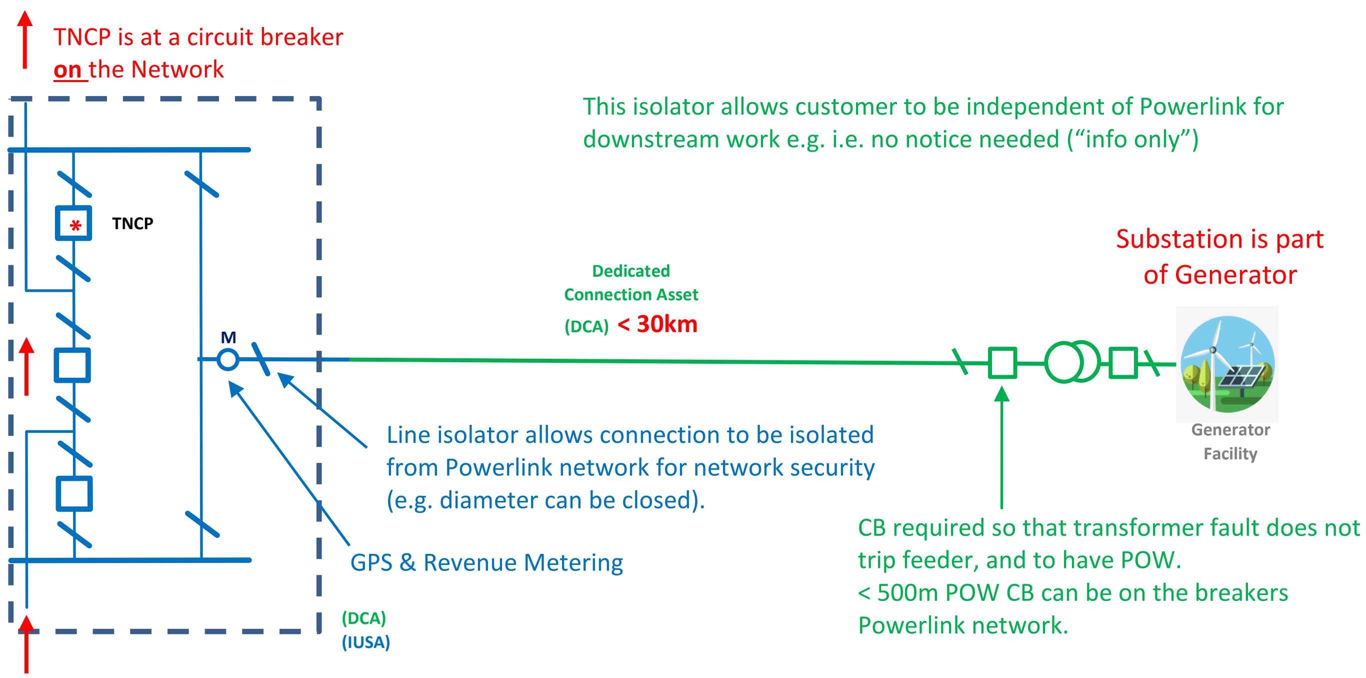

Figure 14 - Simple connection is single circuit radial as DCA with "N" level of reliability

If remote end substation is more than 30 km away from the existing transmission network substation, or there is intention to have more than one TNCPs at remote end substation, then remote end substation will be LARGE DNA (>30 km) or SMALL DNA substation.

If it is LARGE DNA then it needs to be planned in a 1½ CB layout allowing for a staged implementation, starting with “N” reliability and single TNCP.

This is required to allow for future connections including a future second supply circuit once N-1 reliability is required for future connecting customers.

For SMALL DNA, in addition to 1½ CB configuration (preferred), there is another option described in Section 5 of this document.

4. SMALL DNA ALTERNATIVE CONFIGURATION

Prior to the introduction of DNAs into the NER, the rules referred to two types of DCAs (small and large). The differentiation offered by NER related to the distance (length) of the connecting transmission line to the shared transmission network. Small DCAs were limited to transmission lines less than 30 kilometres long. The DNA rule introduction mandated all large DCA to become DNA (keeping the 30km transmission line length as differentiation) and left the option to small DCAs (<30 km) to opt-in to becoming DNA.

Powerlink is offering a "Small DNA" configuration consisting of a single feeder (transmission line), single bus with two TNCPs (see Figure 15 below) providing that the "Small DNA":

- are located in close proximity to the existing transmission network substation (<15 km) AND
- will not have more than 2 TNCPs in the future AND
- the connecting transmission network substation has viable options for additional connections *(to be advised by Powerlink at Connection Enquiry)* AND
- combined generation is small enough to be lost as single contingency *(to be advised by Powerlink at Connection Enquiry)* AND
- the feeder must have duplicate and diverse high speed communications to facilitate duplicate protection AND
- proponents formally accept significantly lower reliability and availability

To make this reduction in availability and reliability as small as possible for routine maintenance, "Small DNA" connections with this single feeder, need to be connected to a complete diameter (i.e. connected via two circuit breakers to two different buses) in transmission network substation (as shown below).

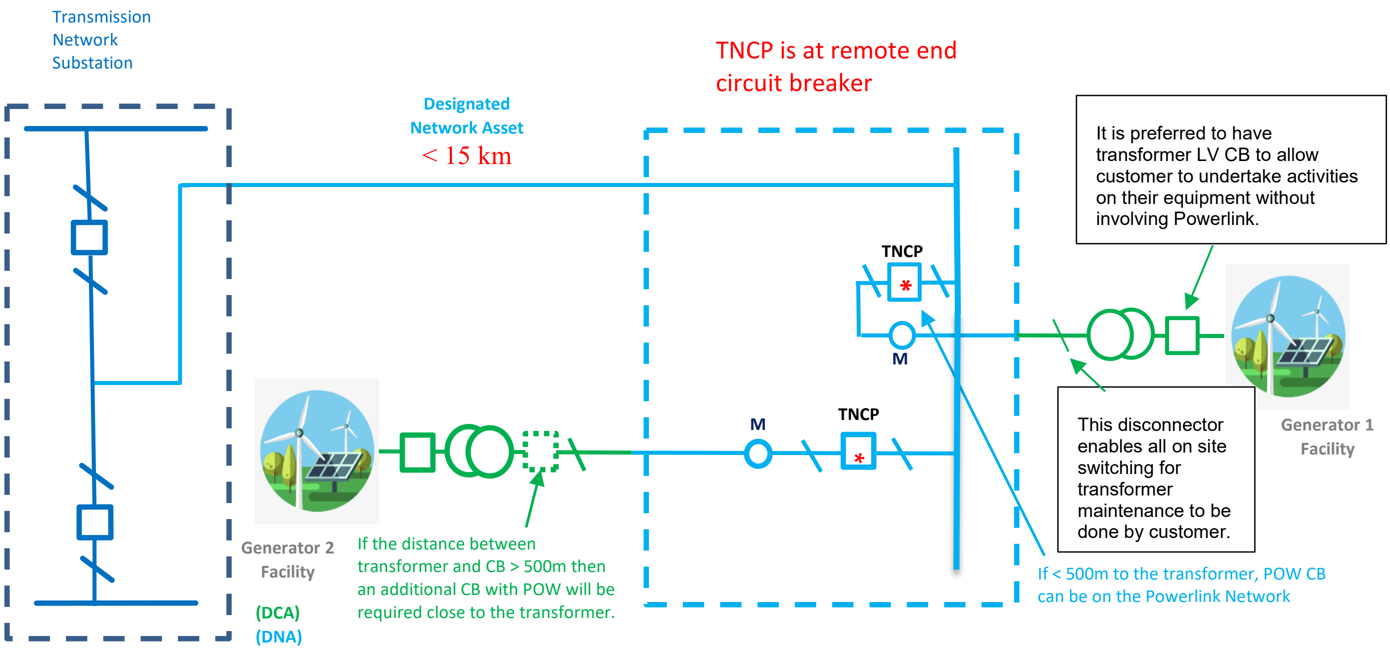

Figure 15 – Alternative SMALL DNA Specification

5. 275/33 KV POWER TRANSFORMERS AND CONFIGURATIONS

5.1 Renewable Generator Connections

Whilst older coal fired and gas generator transformer secondary voltage was 11kV, renewable generator transformer secondary voltage is typically 33kV. As they are often connecting to high voltage transmission network the voltage ratio for generator transformers required is either 132/33 kV (or 110/33kV in SE Queensland) and 275/33kV (or 330/33kV in south-west parts of Queensland).

Generating capacities have also increased. This is why standard ratings for 36kV rated widely available equipment starts to be limiting factor from cost efficiency perspective. The 36kV rated equipment has continuous current ratings from 1250A to max 5000A (disconnectors only) and fault current ratings typically being 25kA up to 40kA (later at much higher cost and lower market availability). In addition 33kV switchboards also have rating limitations (typically up to 2500A and 31.5kA). While it is understood that inverters and associated ring main units (RMU) also have continuous and fault current rating, these data was not considered and it is assumed that any limitations associated with these will be managed with 33kV reticulation design.

The 36kV switchgear-rating limitations have an impact on a number, type and size of power transformers for renewable generator connections along with reliability and availability requirements and required 33 kV busbar configurations.

Typically, two options can be considered for larger MVA requirements. These are:

- Multiple transformers
- Transformers with dual 33kV windings

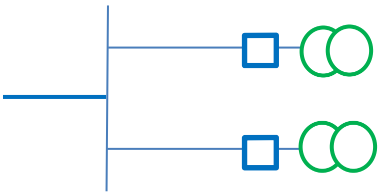

Figure 16 –Multiple transformers option

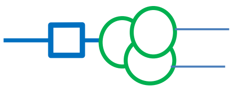

Figure 17 – Single transformer with dual secondary windings

Whilst both options are acceptable, Powerlink recommends option with multiple transformers as the benefits outweigh its higher lifecycle cost.

This recommendation is based on a number of disadvantages of using power transformers with dual secondary windings:

- Whilst one LV can be fully loaded with the second LV off line (open circuit) if necessary, when both LVs are loaded, two LVs loading must be kept balanced in order to maintain full transformer LV rating.
- The two 33kV LV buses must never be electrically connected together because this would cause the LV prospective fault level to double.
- These are typically custom-built transformers and in case of failure, typically take longer to have the replacement organised unless the investment is made in obtaining a spare transformer (which then disadvantages this lower lifecycle cost option compared to two-transformer option).
- Any transformer fault means full loss of production for the generator.

There are a number of benefits for using multiple transformer configuration:

- Increased availability and reliability, due to the failure of a single transformer, the generator would be able to generate at half capacity until failed transformer is sourced.

- Having just one 33kV collector bus, the Customer does not have to contend with keeping the load on both transformer LVs balanced when both LVs are in operation.
- Easier and faster transformer manufacturing. Less exposure to potential design and manufacturing imperfections.
- Simpler protection.

The main disadvantage of multiple transformer option is the higher cost (transformers, site infrastructure and high voltage switchgear requirements) and more space required for substation development.

Whilst increasing transformer impedances can assist with fault current limitations it can have an adverse impact on meeting generator performance standard (GPS) requirements and resulting in an increased number of invertors being required.

Based on observed limitations, if required capacity is above 140MVA but less than 250MVA, negotiation is required with designers and owners of 33kV substation to understand if they are able to purchase switchgear rated above 25kA and 2500A (up to 40kA and 5000A for 250MVA).

For required capacity exceeding 250MVA, only multiple transformers or transformers with dual secondary windings options are available.