Network Configuration Framework – Selection for New Substations

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1. INTRODUCTION

1.1 Purpose

This framework provides functional specifications 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 in accordance with AEMO requirements and the performance standards specified in the Rules.

While some layouts may already exist in Powerlink's network that differ from those listed in this framework, these are the result of historical network development and if they are 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 will 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 the 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 established 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. This assessment must be undertaken with input from Real Time Network Operations to minimise unintended operational issues placing unnecessary complexity into operational activities.

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 the desired levels of reliability and availability.

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

This document lists standard network and busbar configurations for the 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 on 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
- Operational complexity
- 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 reduce social impact, minimise connection costs and the 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 existing network assets which are identified as reaching the end of service life or where there are plans which change its configuration in the future 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 proposed 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.

1.3.4 Connections in general

For connections to Powerlink's network, the following criteria must be met in the configuration of the connection:

- No credible customer outage should result in an outage of the regulated shared (prescribed) network to which it is connected.
- 110kV and 132kV connections within 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 or other constraints. An exemption would be required to allow a new substation within 10 km of an existing 110kV or 132kV substation.
- 275kV and 330kV connections within 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 an earthing perspective). This can be re-assessed for sites with space or other constraints. An exemption would be required to allow a new substation within 15 km of an existing 275kV or 330kV substation. Generally, the exemption will require provision for the proposed substation effectively to be an extension of the nearby substation.

Table 1: Standard Configurations

Voltage	Application	Recommended Configuration
275kV, 330kV & 500kV	Main grid	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 & 330kV	Lesser availability and generally lower cost than Standard Configuration.	3 and 4 breakers meshed configuration (in 1½ CB layout) for AIS only
132kV & 110kV	Lesser availability and generally lower cost than Standard Configuration.	Switchable transformer ended feeders (no bus arrangement) where load or generation capacity is small and Point-on-Wave switching is assessed as not required.
132kV & 110kV	Lesser availability and generally lower cost than Standard Configuration.	Teed feeder arrangement (three ended feeder) – one connection per feeder.
132kV & 110kV	Higher availability and generally higher cost than Standard Configuration	Breaker and half for both AIS and GIS

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 are monitored through the 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 the Materials group regarding new equipment types and technologies available on the market.

4. Construct and Install
    - Ensure construction and installation are completed as per design and final check that design is in accordance with the principles set in this framework.
    - Seek feedback on space and costs required for each standard and non-standard configuration
5. Commission
    - Ensuring that protection settings align with the principles set in this framework.
6. Operate
    - Ensuring that operational requirements including outage management are not impacted by the configurations.
    - Seeking feedback to ensure improvements for safe, secure and 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 the 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. 110KV / 132KV 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 busbar 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.

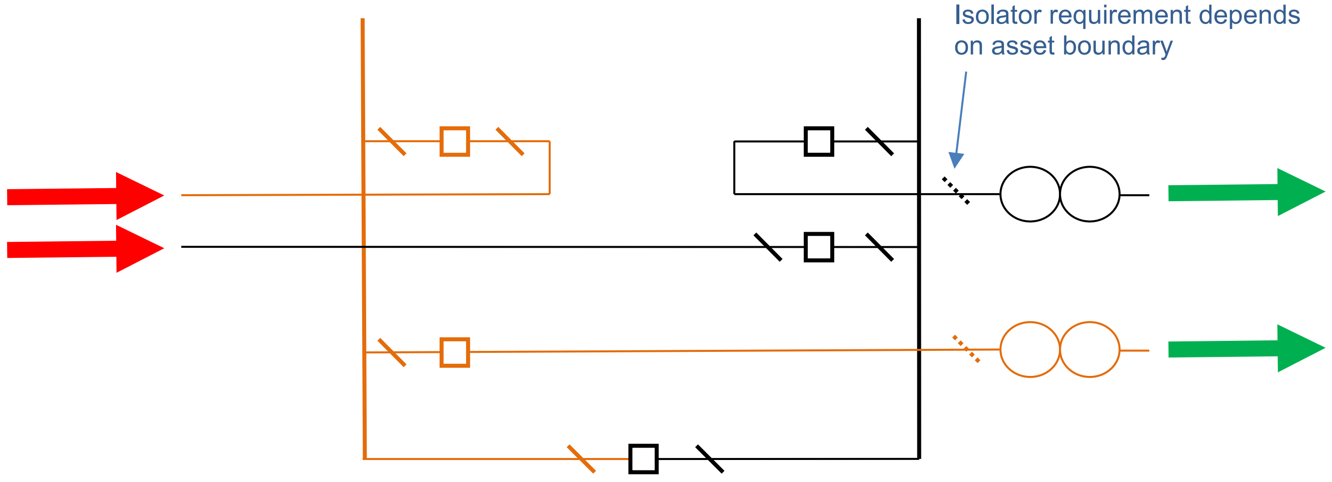

Figure 1: Typical U Bus Configuration (Folded Bus)

[1] To have shorter current paths and avoid all the power going through the bus coupler circuit breaker, & busbar itself. 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

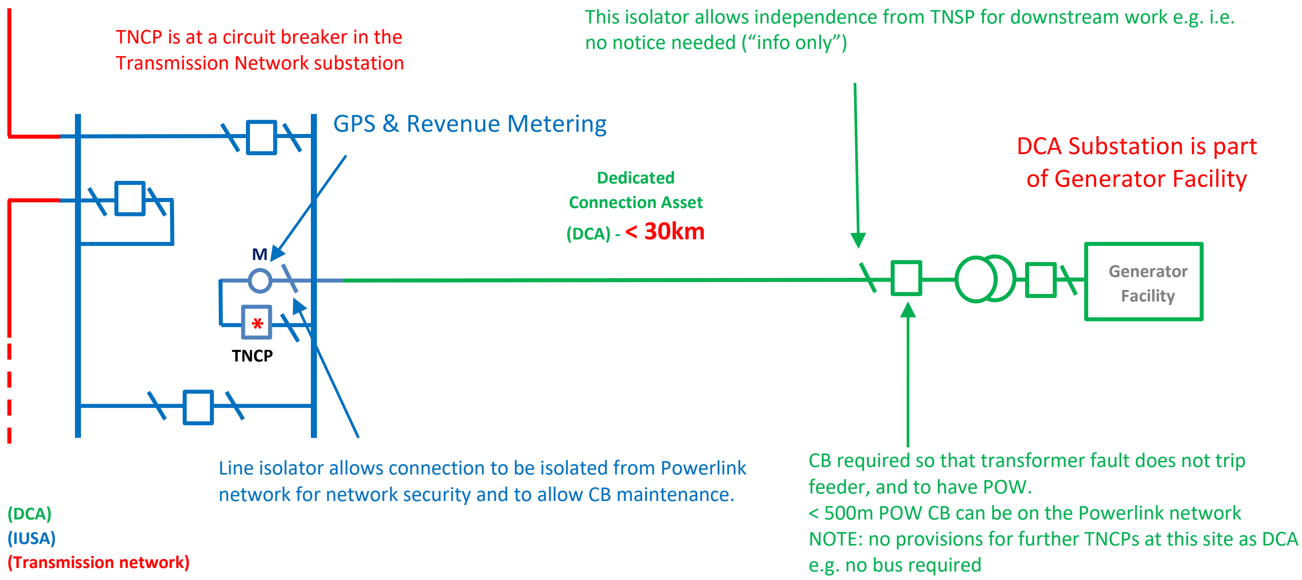

Figure 2: Simplest connection is single circuit radial as DCA with "N" level of reliability

Apart from requirement to have one 110kV/132kV circuit breaker (either feeder or transformer) and a 110kV/132kV 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). Outages will be required periodically to maintain equipment. The busbar configuration at a DCA substation can be any that will meet the customer's reliability and availability requirements.

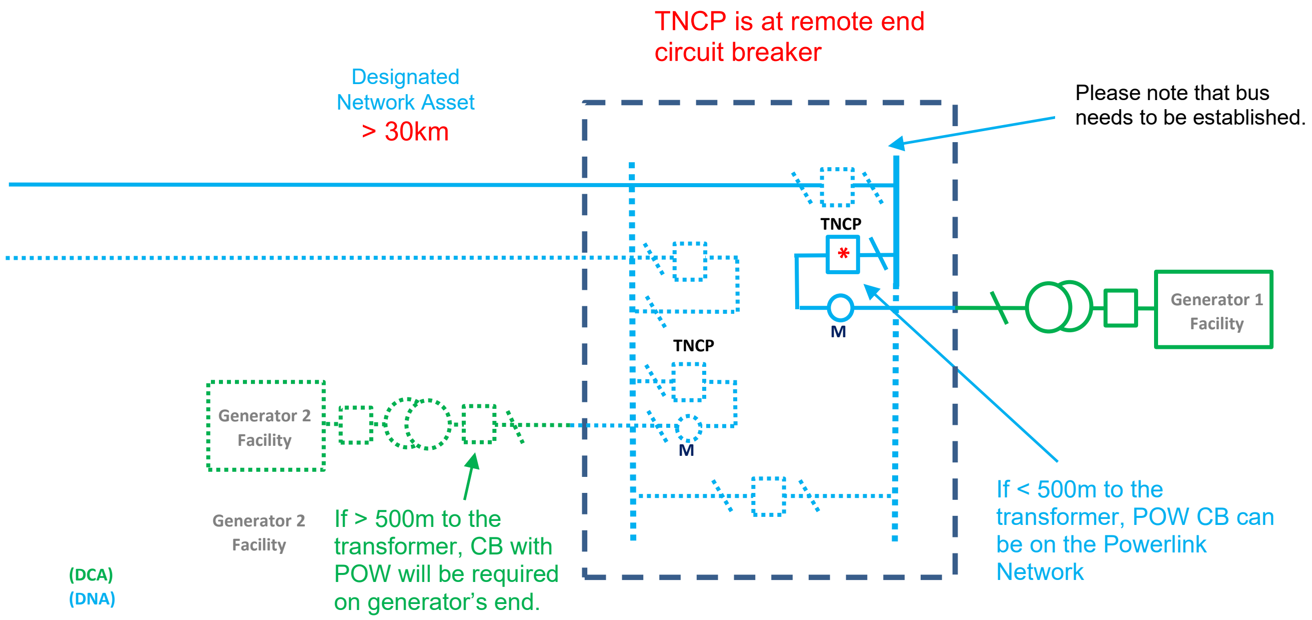

Figure 3: Typical DNA connection allowing for future expansion

If the remote end substation is 30 km or more from the existing transmission network the connection is required to be classified as DNA. There may be circumstances where a connection under 30 km from the transmission network is also treated as a DNA, where the asset owner has entered into a Network Operating Agreement with Powerlink, as the Primary TNSP, under the National Electricity Rules.

A DNA is required to comply with the minimum functional specification provided by Powerlink, as the Primary TNSP, which will be consistent with this Framework.

Whilst able to be built in stages, the substation needs to be planned in such a way as to allow for a U-bus configuration and have provisions for future connections, including a future second supply circuit.

If a customer is adjacent to a Powerlink substation and would like the POW CB on the Powerlink network, then they must accept responsibility for the following:

- Appropriate disconnection points are to be established at the asset boundary.
- The trip signal at the interface kiosk must be received from the customer transformer relays in sufficient time after fault inception to meet the NER 110kV/132kV fault clearing time. This requirement needs to be demonstrated by the customer during design reviews and commissioning tests.

2.3 110kV / 132kV Increased Reliability Configuration

Where a number of critical connections exist, it may be preferable to utilise a selectable disconnector arrangement to increase the operational availability and reliability of the substation. (Refer to Figure 4 below). Each transformer or feeder is to be established utilising a disconnector to each busbar, with a single CB. This allows the connection to be transferred across to either bus. A bus coupler breaker is still required. Reactive plant elements can be connected to a single busbar without needing to be selectable.

The use of this configuration will be assessed on a case-by-case basis. This configuration provides increased reliability to maintain supply capacity to a customer, including during planned bus outages. A disconnector selectable configuration is generally only considered where the extra cost is outweighed by the benefits of increased reliability and operational availability against a folded bus arrangement. This configuration requires a different protection system.

For 110kV/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.

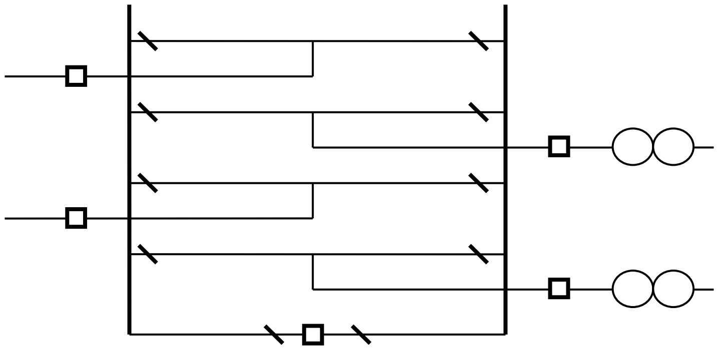

Figure 4: Isolator selectable bus

The exceptions are those supplying major customer loads (separately negotiated) in which case a 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, operational flexibility and maintenance requirements with the potential to reduce availability and reliability for customers connected to all three ends. A tee connection is only permissible on the 110kV/132kV network where it meets the following criteria:

- For customer connections, where loads or generating capacities are small (defined as less than 100 MVA) and POW switching has been assessed as not required[3]
- The new section of feeder will become part of the Transmission Network.
- Only one customer/tee connection point permitted per feeder[4].
- 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 30 km, whichever is less. [5]
- Customer accepts reduced transmission network reliability of 'N'.

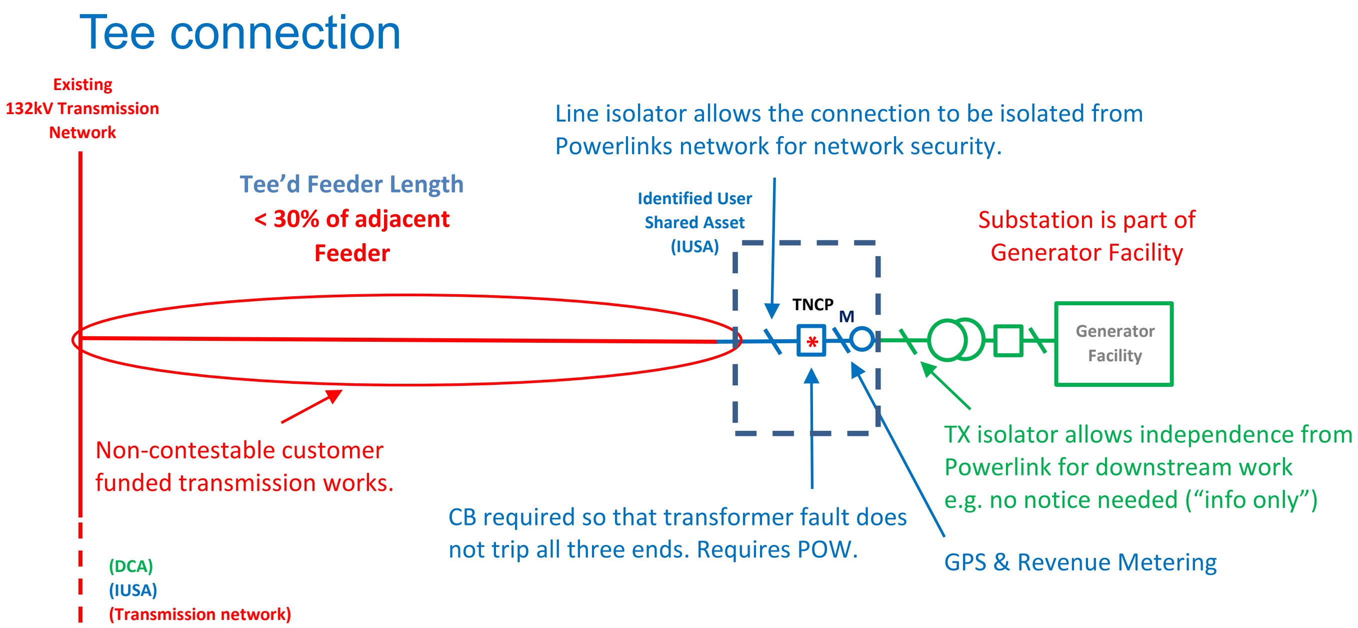

Figure 5: 110kV / 132 kV Tee Connection

[3] Energising transformers can reduce the bus voltage unacceptably. POW switching takes into account pre-existing flux levels to switch 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.
[4] NER does 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.
[5] 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 selectable (Figure 4 above, or CB selectable Figure 6 or Figure 7).

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

OR have additional bus couplers

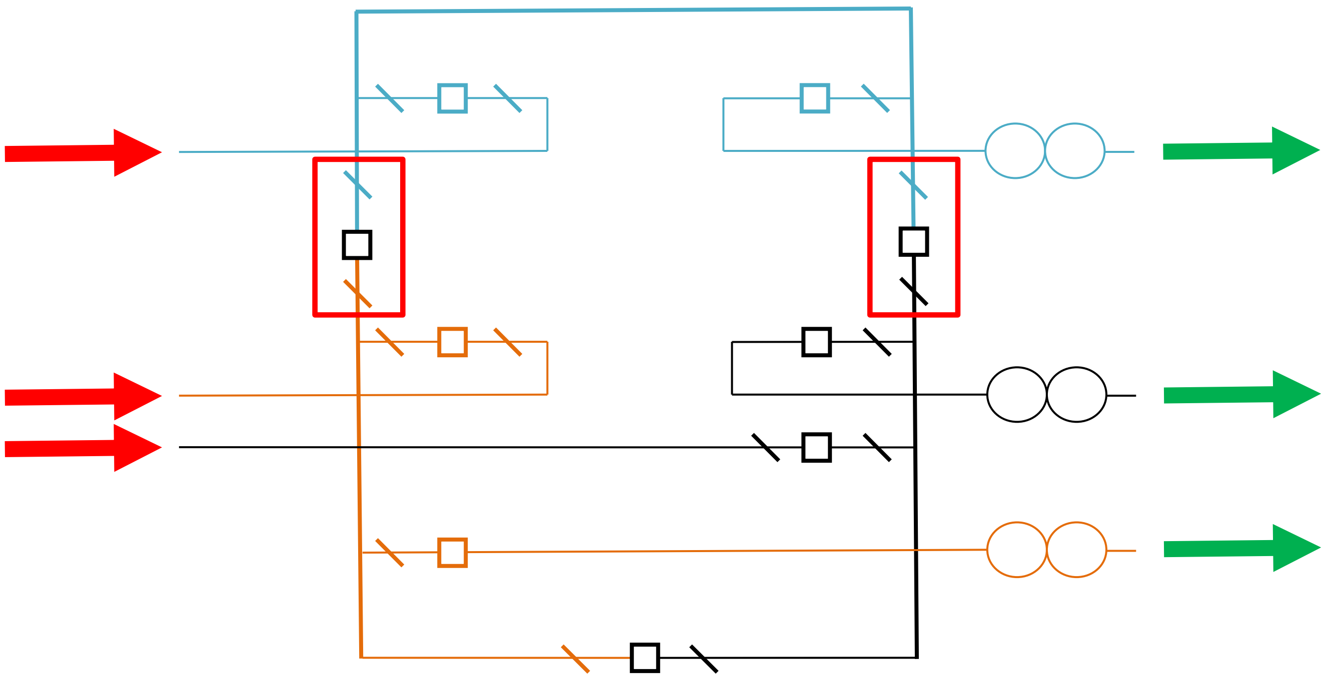

Figure 7: U Bus Layout (more than 2 feeders from the same source and/or more than 2 Transformers)

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

For negotiated customer connections, where load or generating capacities are small (defined as less than 100 MVA) and POW switching has been assessed as not required[6], then it may be acceptable to omit the HV transformer circuit breakers as shown in Figure 8. In this case, TNCPs and metering points will be at the transmission network substation.

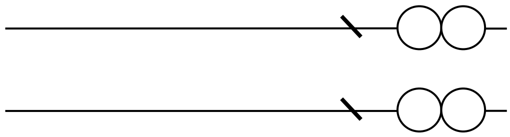

Figure 8: Transformer Ended Layout (feeders from the same source)

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).

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

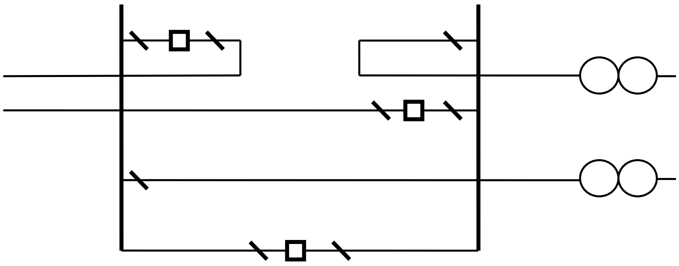

Figure 9: U Bus Layout (feeders from the same source) with no transformer breakers-bus coupler is required

[6] Energising transformers can reduce the bus voltage unacceptably. POW switching takes into account pre-existing flux levels to switch 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, 330KV AND 500KV NETWORK CONNECTIONS AND BUSBAR LAYOUTS

3.1 275kV / 330kV / 500kV Standard Configuration

The standard configuration for a 275kV, 330kV or 500kV substation is a breaker and a half arrangement, comprised of two busbars with 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 a feeder or transformer) from service.

Connections via tees to the 275kV, 330kV and 500kV network are **NOT** considered as an acceptable arrangement. This is because higher reliability and availability is required at higher voltages as fault consequences impact on a much wider area of supply, more customers and can affect network stability.

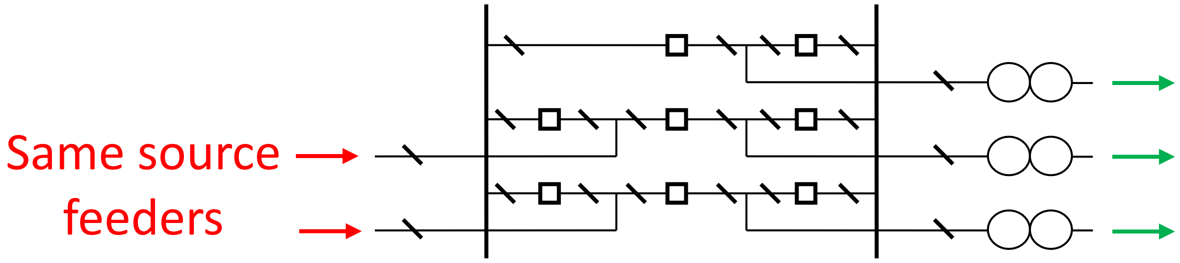

Figure 10: Typical 1½ CB (Breaker and a Half) Bus Configuration – Radial supply

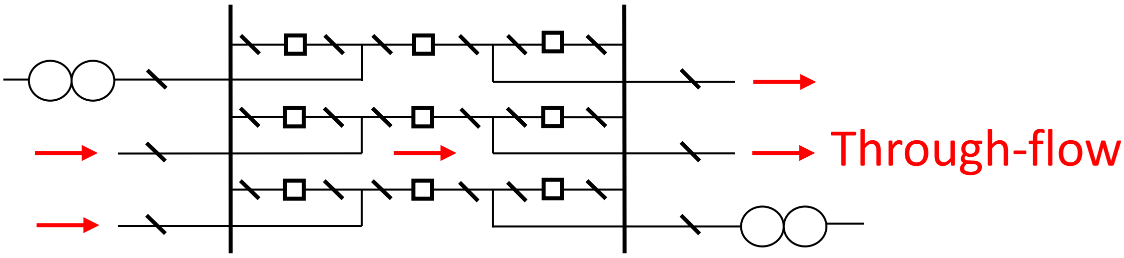

Figure 11: Typical Breaker and a Half Configuration

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 busbar. It also allows through-flow to be maintained even if the substation is bypassed, for example during a planned bus outage followed by a bus fault.

Similarly, efforts are made to avoid arranging transformers, or connections from the same source, back-to-back within a substation. Planned outages of either feeder bay will leave both connections at risk of being lost together as a single credible contingency i.e. loss of the opposite feeder opens the remaining circuit breakers and both connections are de-loaded. The same can be said with CB fail operation of the coupler CB. Exemptions may be considered where the combined capacity of such connections does not impact network security and stability. For dispatchable load or generation, this still may result in capacity constraints during these outages.

3.2 275kV / 330kV Customer Connections

3.2.1 3CB & 4CB Mesh Layouts (in 1½ CB layout)

Whilst a 1½ CB configuration, is Powerlink's standard for HV substations, 3CB and 4CB mesh (in 1½ CB layout) have been permitted to provide an economic start-up option for new connections where the customer is trying to reduce costs. These options must prioritise power flow in the main transmission network path, and the customer will be exposed to more network outages than the full 1½ CB layout. Due to the complicated protection modifications required, this configuration will require significant additional investment in secondary systems and network outages if or when it is required to expand into a full 1½ CB configuration.

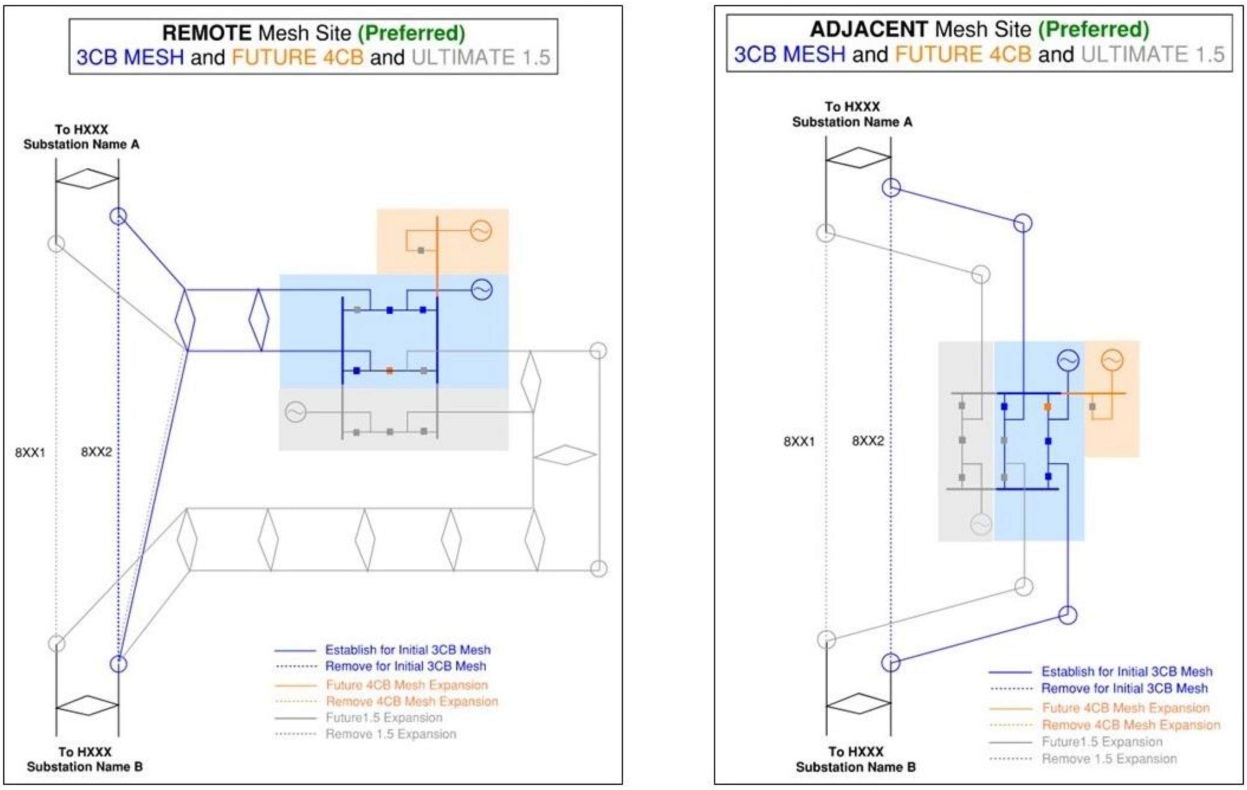

Figure 12: 3CB and 4CB Mesh Configurations[7]

The 3 and 4 CB mesh options inherently offer lower reliability and availability.

[7] The use of poles or towers represented in Figure 12 are only for illustration of the connections, but detailed design will determine what transmission structure type is the most suitable.

In case of DCA connections, an example of a 3 CB mesh connection is presented below including the TNCP, the metering point and a few additional explanations.

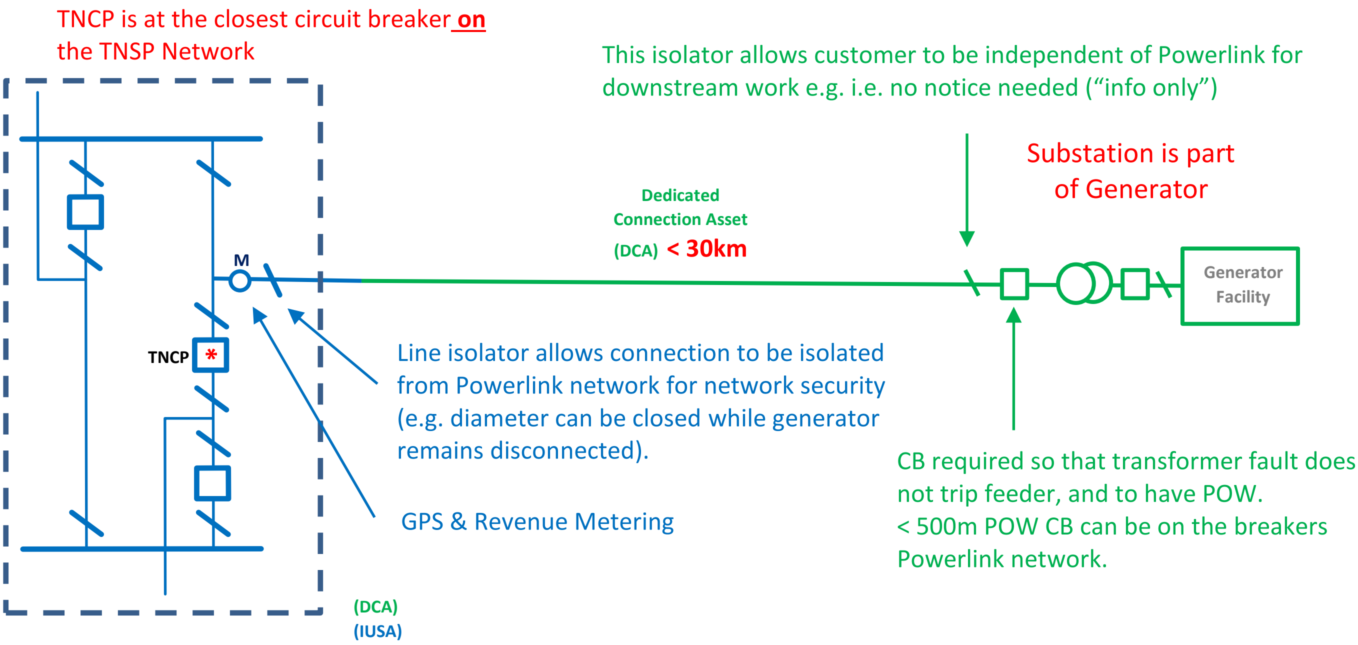

Figure 13: Simple connection is single circuit radial as DCA with "N" level of reliability

If the customer's connection is 30 km or more from the existing transmission network, then it will be classified as DNA. There may also be circumstances where a customer is seeking a DNA for a connection less than 30 km from the transmission network, and this can be discussed with Powerlink on a case-by-case basis.

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

If a customer is adjacent to a Powerlink substation and would like the POW CB on the Powerlink network, then they must accept responsibility for the following:

- Appropriate disconnection points are to be established at the asset boundary.
- The trip signal at the interface kiosk must be received from the customer transformer relays in sufficient time after fault inception to meet the NER 275kV/330kV fault clearing time. This requirement needs to be demonstrated by the customer during design reviews and commissioning tests.

3.2.2 Single Bus Connections

If plant size is assessed as small enough to be on a single circuit radial, then it may also be acceptable to only connect to a single busbar provided that the connection accepts a reduced level of connection reliability. The overall backbone network security and performance should remain uncompromised.

Single-bus connections will only be considered where it can be demonstrated that the resulting risk to the transmission network (including consideration of bus outages) is acceptable. Where multiple single-bus connections are proposed, their cumulative capacity shall be assessed on a combined basis.

Where single-bus connections are located across the diameter from other sources or loads, the bus coupler is required to maintain acceptable system performance and contingency outcomes.

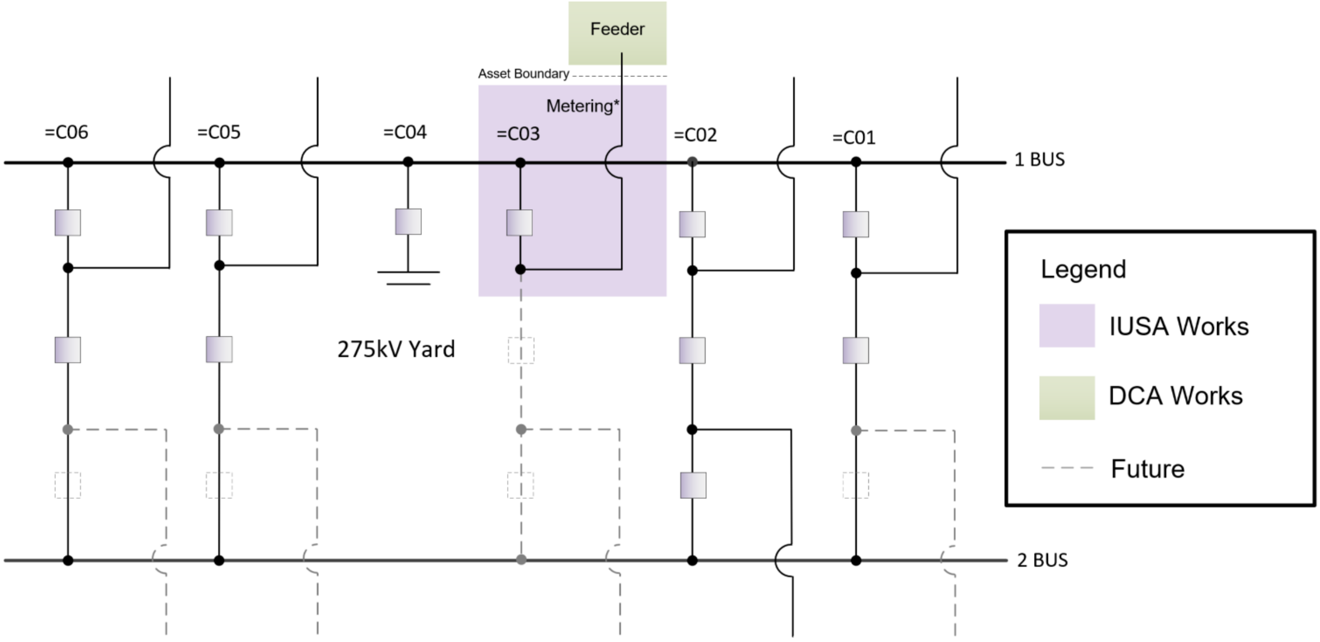

Figure 14: Single bus connection in breaker and a half substation

For a single-circuit radial, the connection need only connect to one bus.

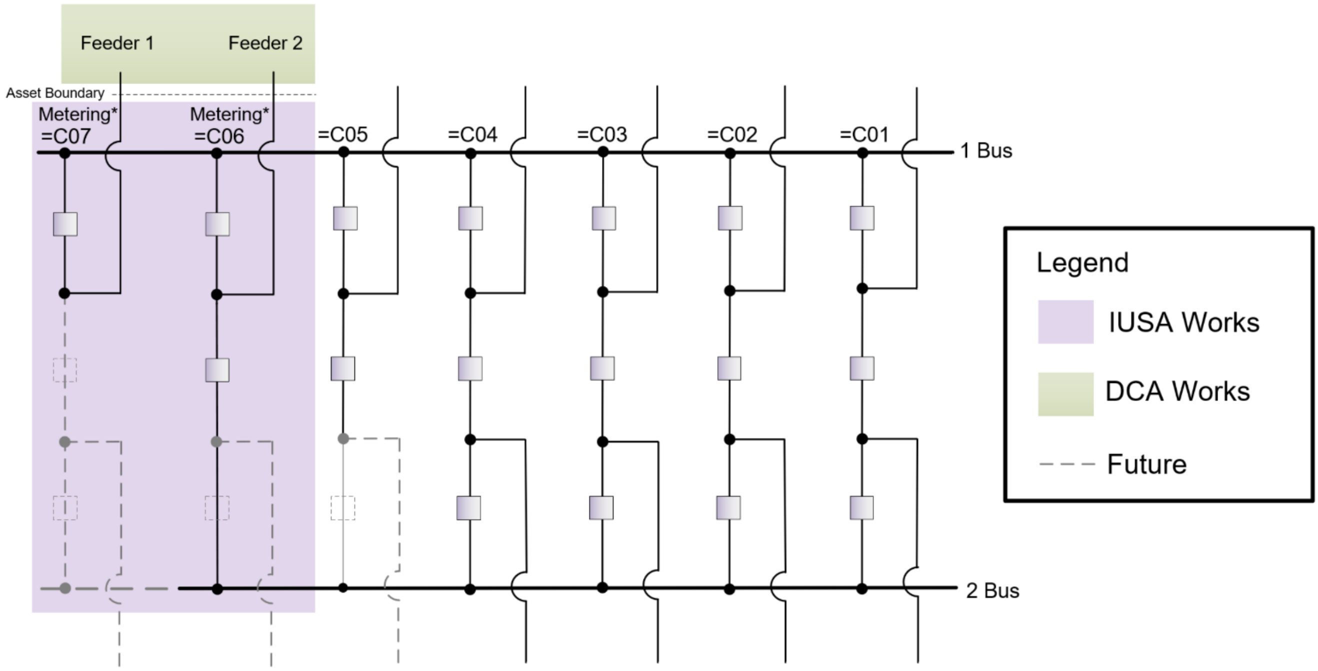

Figure 15: Double circuit radial connected onto single bus and one closed diameter.

For a double-circuit radial, one of the radials needs to be in a closed diameter. This is consistent with N-1 expectations in that one source of supply for essential loads can still be maintained, even under bus outage conditions.

4. 275/33 KV POWER TRANSFORMERS AND CONFIGURATION OPTIONS

This section is not a reference for circuit breaker layouts; however, it is included to provide guidance for transformers that are typically used with IBR plant.

4.1 IBR Generator Connections

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

Generating capacities have also increased. This is why standard ratings for widely available 36kV equipment starts to be a limiting factor from a cost efficiency perspective. The 36kV rated equipment has continuous current ratings from 1250A to max 5000A (disconnectors only) and fault current ratings typically ranging from 25kA up to 40kA (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 ratings, it is assumed that any limitations associated with these will be managed by the customer with 33kV reticulation design.

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

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

- Multiple transformers
- Transformers with dual 33kV windings

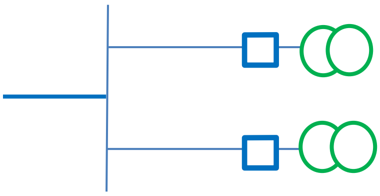

Figure 16: Multiple transformers option

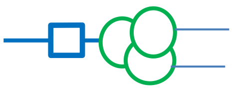

Figure 17: Single transformer with dual secondary windings

Whilst both options are acceptable, Powerlink recommends the option with multiple transformers, as the benefits typically 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 offline (open circuit), if necessary, when both LVs are loaded, the loading of the two LVs must be kept balanced in order to maintain the full transformer LV rating.
- The two 33kV LV buses must never be electrically connected 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 a replacement organised unless an investment is made in obtaining a spare transformer (which then disadvantages this lower lifecycle cost option compared to the two-transformer option).
- Any transformer fault results in a full loss of production for the generator.

There are several benefits to using a 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 the 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 the multiple transformer option is the higher cost (transformers, site infrastructure and high-voltage switchgear requirements) and the additional 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 inverters 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.

APPENDIX A: PREVIOUS SMALL DNA ALTERNATIVE CONFIGURATION

Prior to the introduction of DNAs (Designated Network Assets) into the NER, the rules referred to two types of DCAs (Dedicated Customer Assets): small and large. The differentiation offered by the 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 NER now classifies radial connections of 30 km or more as DNAs and allows for connections of less than 30 km to be classified as DNA under certain circumstances. The primary aim of a DNA is that it provides for other customers to connect in the future and is built and operated to TNSP standards.

Powerlink previously offered a "Small DNA" configuration consisting of a single feeder (transmission line) and a single bus limited to two TNCPs (see Figure 18 below) providing that the "Small DNA":

- is 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 other additional connections *(to be advised by Powerlink at Connection Enquiry)* i.e. there is no need for a new hub substation AND
- combined generation is small enough to be lost as a 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 as shown below) in a transmission network substation that has a full 1½ CB layout i.e. minimum of 3 closed diameters.

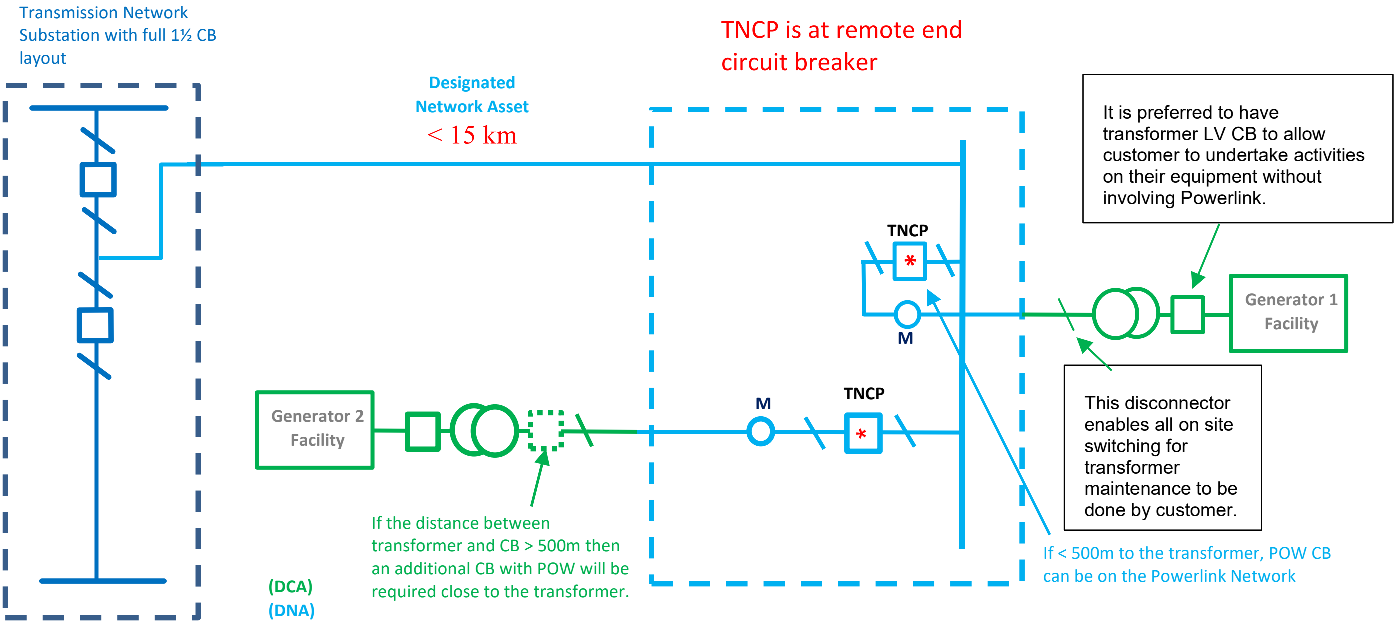

Figure 18: SMALL DNA Specification