A Technical Overview of Wilton Substation 33 kV Outdoor to Indoor Conversion

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1 Introduction

Transpower is in the process of replacing their 33 kV outdoor switchyards with indoor 33 kV GHA switchgear. This is due to the existing plant reaching the end of its economic life, resulting in safety, reliability, and maintenance issues. Indoor switchgear provides a safer, more reliable and more environmentally-friendly solution, while reducing maintenance requirements.

This paper provides an overview of the 33 kV outdoor to indoor conversion conceptual and detailed design conducted for Transpower's Wilton Substation.

2 Concept Design

2.1 Site Layouts

Initially conducting a site visit to familiarise ourselves with the site, multiple 33 kV switchroom locations were considered, and 33 kV cable routes drawn up for each option. Three options were considered and draughted; to the north of the 33 kV switchyard, to the west, and to the south.

The north and south options resulted in excessive cable lengths, and compressing the incomer and feeder cables through narrow corridors. This would have resulted in excessive cable route costs, both in length and in needing to upsize the cables to allow for the narrow corridors.

The option to the west was superior in cable length and corridor width, although it did have the potential to impact on the footprint of a possible future static VAR compensator that Transpower was considering. However, close liaison with Transpower found this not to be the case.

With the preferred option decided, a site visit was arranged between Mitton ElectroNet Ltd (MEL), Transpower, the maintenance contractor Transfield Services Ltd (TSL) and the lines company Wellington Electricity (WE*) to discuss the concept and gain feedback from all stakeholders. This site visit proved invaluable, as all stakeholders requirements and preferences could be incorporated into the concept design, well ahead of the detailed design commencing.

The preferred switchroom location and cabling arrangement is shown below in Figure 1.

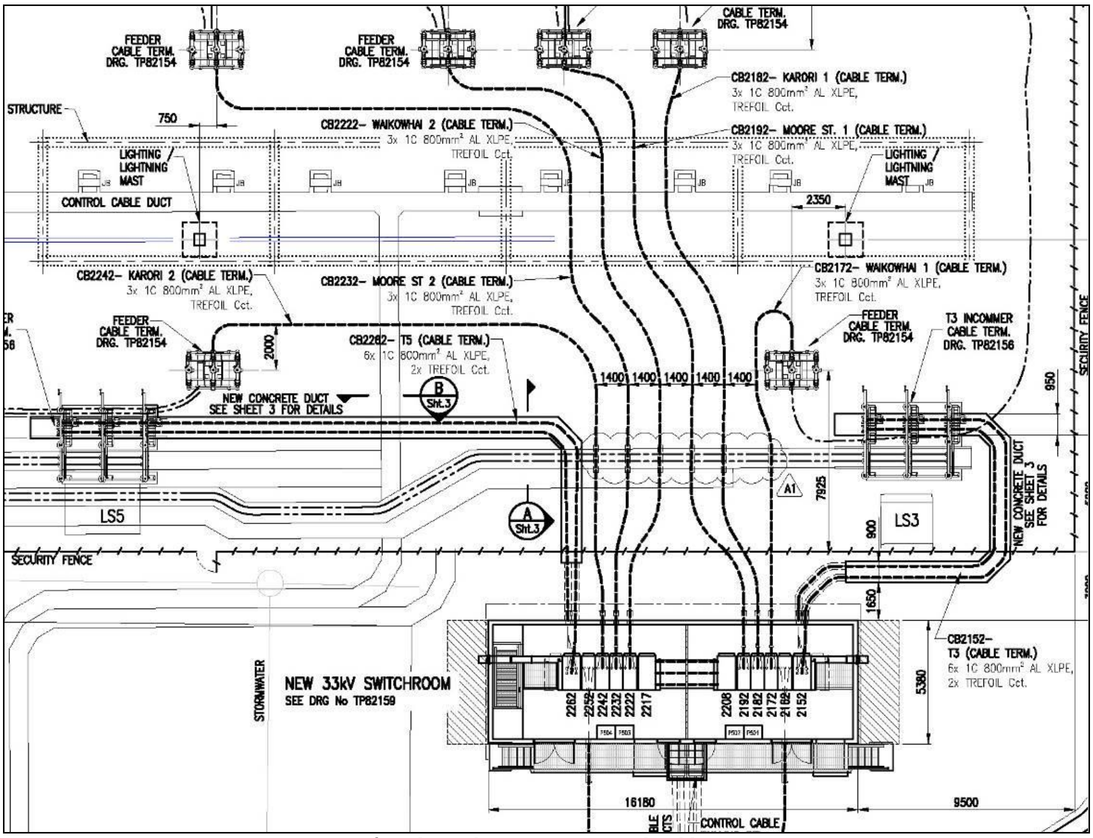

Figure 1: Preferred Switchroom Location and Cabling Arrangement

2.2 33 kV Switchroom

Each concept design option has a unique single line diagram, with feeders ordered to firstly ensure complimentary feeders are on different buses, and secondly to minimise cable crossings. These single line diagrams are used as the basis for modifying the Transpower 33 kV standard switchroom for each specific option.

The 33 kV switchroom layout for Wilton is shown below in Figure 2.

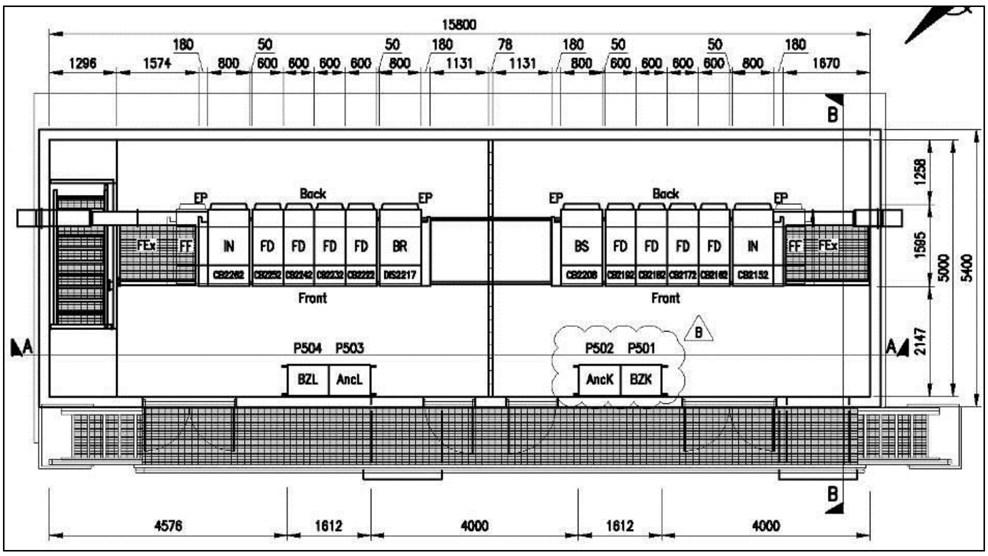

Figure 2: 33 kV Switchroom Plan

It is Transpower standard to allow space on each end for one future feeder per bus, which has been allowed for here. The switchroom is also designed to be further extended at each end by removing the end walls and extending the building.

A bus zone panel is included for each bus section, to prevent long current transformer (CT) cable runs back to the control room. Ancillary panels are also included for each bus section, to house DC fusing and communications equipment for SCADA and remote engineering access.

A perspective view of the switchroom is shown below in Figure 3.

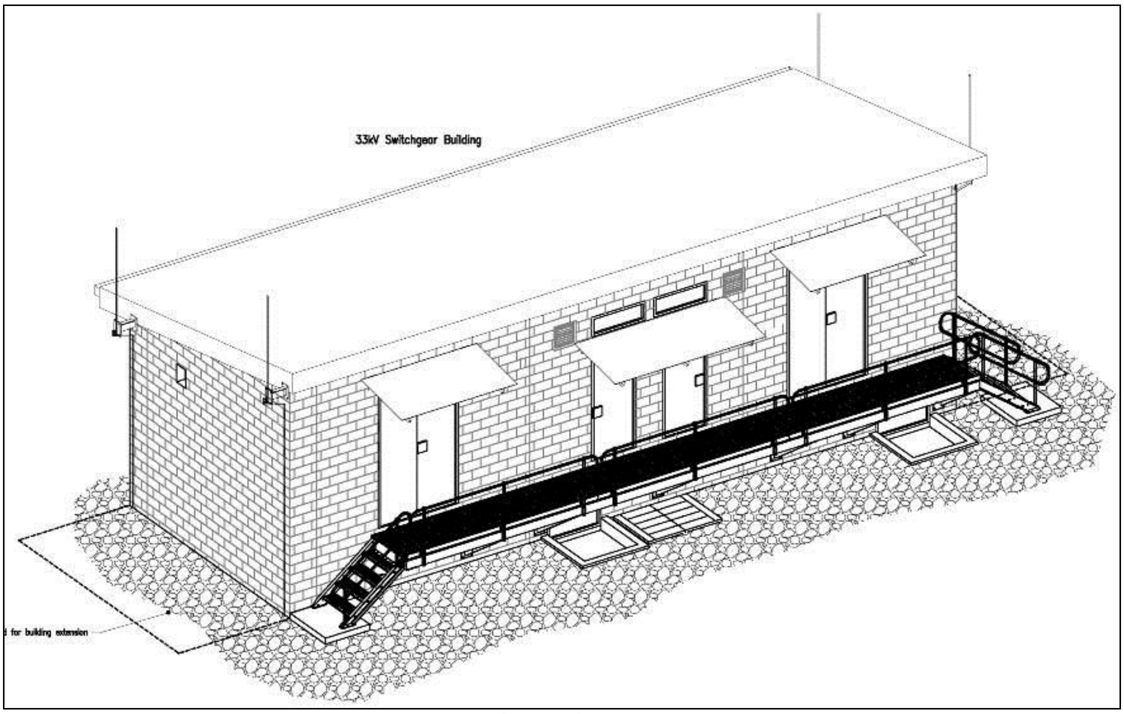

Figure 3: 33 kV Switchroom Perspective

2.3 Cutover Sequence

The cutover sequence needed to be considered at the concept design phase to establish a means of retaining N-1 contingency, as well as ensuring the feeders are cutover in a sequence which prevents the need for temporarily crossing live cables.

There are two ways of retaining N-1 security during the feeder cutover sequence; installing a temporary tie cable, or paralleling of the indoor and outdoor 33 kV buses. Refer to Figure 4 below for both options.

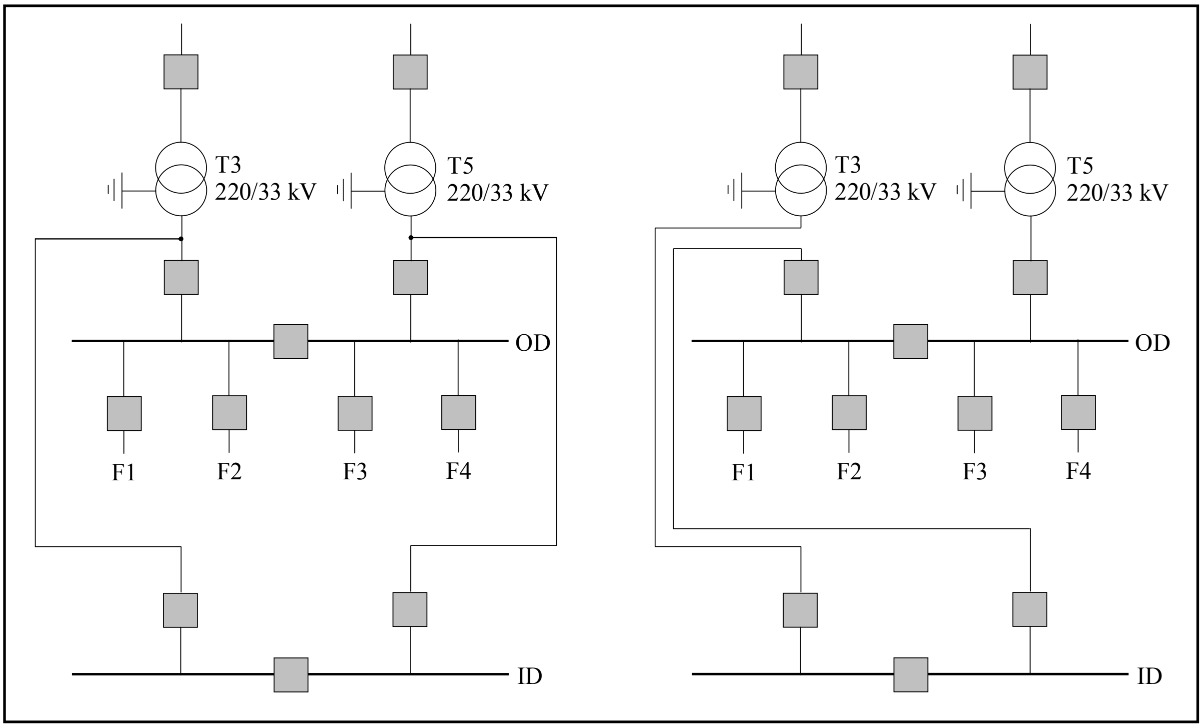

Figure 4: Paralleling Arrangement (left) and Temporary Tie Arrangement (right)

Paralleling involves two initial outages to parallel the two supply transformers with both the indoor and outdoor 33 kV buses. The feeders are then individually cutover, followed by two more outages to remove the supply transformer connections to the 33 kV outdoor bus (de-paralleling).

The temporary tie cable arrangement involves an initial outage to cutover the first supply transformer to the 33 kV indoor bus (T3 in this case) and install a temporary tie cable from the old T3 outdoor incomer circuit breaker (CB) to the new T5 indoor incomer CB. The feeders are then individually cutover, followed by a final outage to remove the temporary tie cable and cutover T5 to the 33 kV indoor bus.

Both arrangements allow either supply transformer to supply the existing outdoor 33 kV bus and the new indoor 33 kV bus, maintaining N-1 security during the feeder cutover sequence.

Generally, paralleling is the preferred option and always chosen if the primary arrangement allows. This is for the following reasons:

- A temporary tie cable requires temporary protection (such as differential) to protect the cable. In some cases, paralleling does not require temporary protection. The LV incomer CBs have their CTs paralleled, and both trip coils operated via auxiliary relays.

- The temporary tie cable results in cable wastage, which can be significant as the temporary tie cable needs to be capable of supplying the full GXP load.
- The de-paralleling outages are of a far shorter duration, and shorter recall time, than the final temporary tie removal outage. Generally, the de-paralleling outage simply involves removing primary jumpers, and removing CT paralleling links and trip coil auxiliary relays. Whereas the temporary tie removal outage involves a significant protection cutover of the indoor incomer CB protection, from the temporary tie differential protection to the transformer LV protection.

Transpower preference is to always utilise a paralleling arrangement if the primary arrangement allows. At Wilton, this was easily achievable and therefore the chosen option.

3 Detailed Design

The detailed design involved a combination of employing Transpower standard designs as well as site specific innovative designs as appropriate, to provide a design considering key aspects such as safety by design, constructability, ongoing asset maintenance, and continuity of supply.

3.1 Incomer Cabling

The existing 33 kV T3 & T5 incomer arrangements consisted of cables run in natural convection ventilated ducts from the T3 & T5 LV cable boxes to incomer cable termination stands within the 33 kV switchyard. Jumpers from these stands connect the local service transformers, and the outdoor incomer circuit breakers.

The average cable run for each of the existing incomer circuits was 225 m, so the preference was to modify the existing incomer cable termination stands to accept additional cables to extend the incomer cable circuits to the new switchroom, rather than run entire new lengths of incomer cables.

This was achieved by extending the existing incomer cable termination stands, and installing additional natural convection ventilated troughs from the extended stands to the new switchroom. This arrangement also allowed the jumpers to the outdoor incomer circuit breakers to be re-instated to achieve a temporary parallel connection.

See Figure 5 and Figure 6 below:

Figure 5: T3 33 kV Incomer Cable Termination Stand (before)

Figure 6: T3 33 kV Incomer Cable Termination Stand (after) – Extended with Additional XLPE Cables

The additional incomer cables needed to match or exceed the current rating of the existing incomer cables, to ensure the existing incomer thermal chain was not compromised. The preference was to utilise aluminium cables, as the aluminium equivalent of a copper cable is approximately a third of the price.

The existing incomer cables consisted of two sets of 630 mm^2 Cu paper insulated lead covered (PILC) per phase, which have a maximum permissible operating temperature of 65°C. This type of cable has a comparable current rating to 630mm^2 Al XLPE, which has a maximum permissible operating temperature of 90°C.

In order to allow the use of 630mm^2 aluminium cable, the additional concrete ducts needed to be ventilated as adequately as the existing. The existing natural convection ventilated concrete ducts consisted of a complex design. Sheet metal "chimneys" were cast within the walls of the ducts to allow cool air to flow into the duct beneath the cables, and rebates were cast within the duct lids to allow the hot air to escape.

A cheaper, simpler design was developed for the additional ventilated concrete ducts installed. This design allowed standard precast concrete ducts to be used, with only the duct lids requiring modification to allow natural convection ventilation.

The duct lids were designed to include a rebate for the hot air to escape, with a hole cast in the middle of the duct lids to allow the insertion of a drain and PVC pipe. This pipe extended into the duct so that the pipe opening was beneath the power cable cleats, to allow cool air entry. The drain and attached PVC pipe could be easily be extracted to allow the duct lids to be removed.

The size of the rebates and cast holes were designed to ensure the hot and cool air ventilation surface area matched the existing ventilated ducts per unit length.

Refer to Figure 7 below.

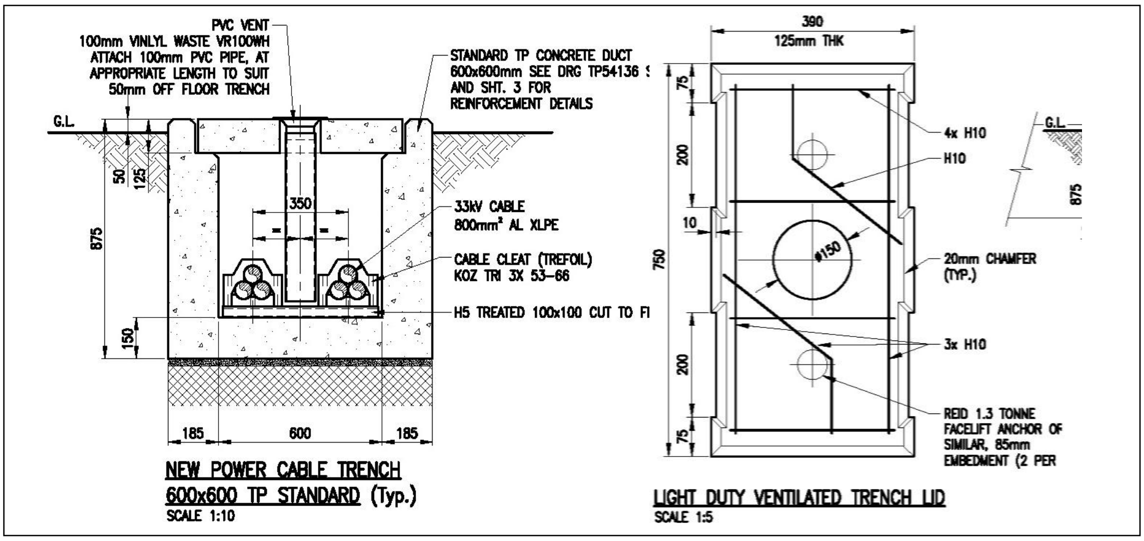

Figure 7: Incomer Cable Ventilated Duct Design

3.2 Feeder Cabling

The existing feeder circuits at Wilton were cabled off-site from cable termination stands within their respective feeder bays of the 33 kV outdoor switchyard. The preference was to not disturb or join any existing power cables if possible to improve safety during installation, and reliability of the final arrangement.

The design modified the existing cable termination stands to accept the feeder cable tails from the new switchroom, by running the new cable tails up the opposite side of the structure to the existing power cable. Jumpers could then be installed to connect the two cables. Refer to Figure 8.

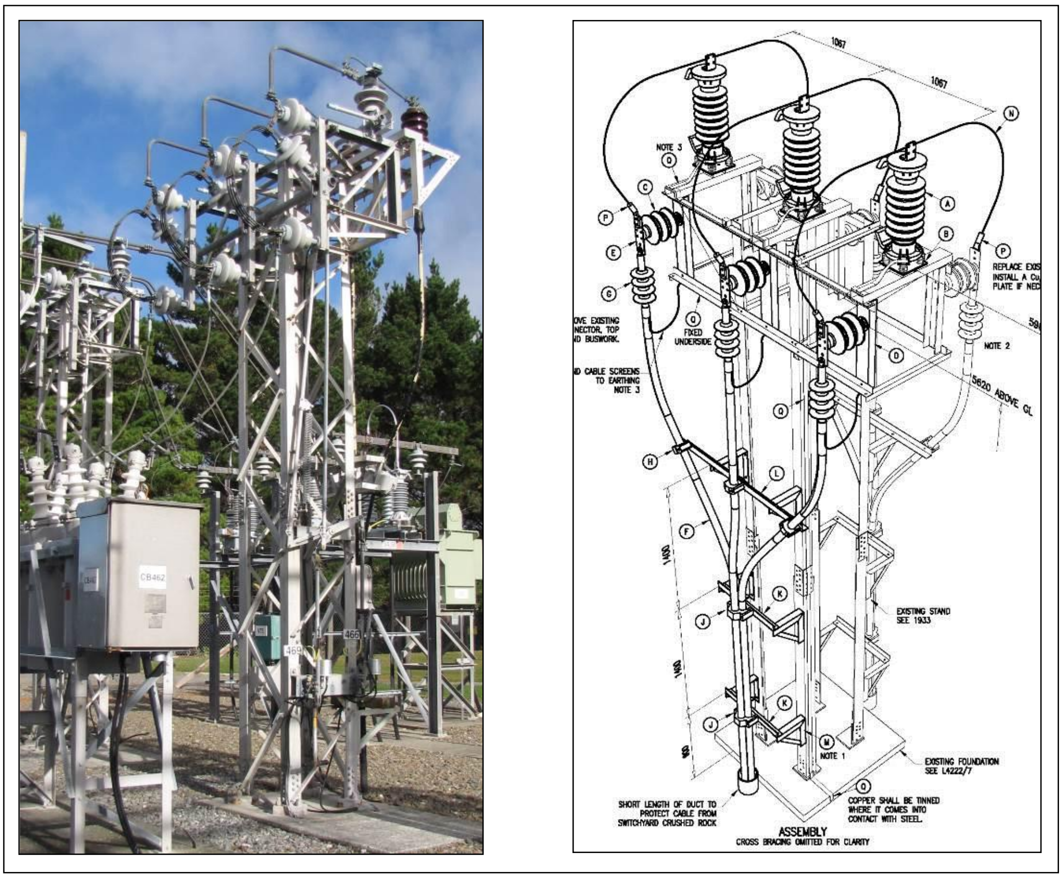

Figure 8: Feeder Cable Termination Stands – Existing (left) & Design (right)

The required feeder cable ratings were specified by WE* based on their peak summer/winter loads, while allowing for future load growth. The most onerous cable corridor was the point in the 33 kV outdoor switchyard where six feeder cables were direct buried at a spacing of 1.4 m.

Although the feeder cabling spacing is set at 600 mm as they enter the switchroom basement (due to the width of the switchgear), this is not considered the most onerous corridor, as the heat can dissipate down the short length of cable to the air conditioned environment of the switchroom cable basement.

The corridor was modelled based on the following parameters:

a) A native soil thermal resistivity of 2°C.m/W in the summer and 1.2 C.m/W in the winter. This information was provided by WE* based on soil thermal resistivity tests previously conducted.
b) An imported backfill thermal resistivity of 1.0 °C.m/W. This is a conservative average of 1.2 °C.m/W 100 mm above/below the cable, and the remainder being 0.8°C.m/W GAP40. These values were obtained from testing and assumed 100 % dry out.
c) A phase conductor fault rating of 25.9 kA for 3 sec, and a screen conductor fault rating of 1 kA for 3 sec.
d) A maximum permissible operating temperature of 90°C.

Figure 9 shows a screenshot from CYMCAP, modelling all six feeders in service for the most onerous cable corridor in summer conditions, using 800mm^2 Al XLPE. This screenshot shows that 800mm^2 Al XLPE, buried with improved thermal backfill, can supply 38.2 MVA per feeder, exceeding WE*s requirement of 36 MVA.

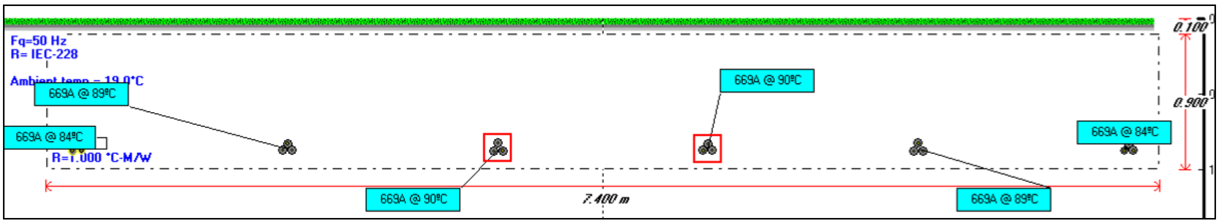

Figure 9: CYMCAP Feeder Model, Showing All Feeders In Service (Summer Conditions)

Similar models were conducted to ensure WE*s winter requirements were met, and their requirement to supply more power down fewer cables during a half bus outage.

The incomer cables were uprated to 800 mm^2 Al XLPE to rationalise all 33 kV cable used for the project, and save cable supply costs.

3.3 Protection

The existing 33 kV feeder protection consisted of Multilin SR760 relays, located in protection panels within the control room. These were replaced with Transpower standard SEL-351S relays, mounted on the front of the switchgear LV cubicles. In this case, WE* provided a second feeder protection in the form of Siemens 7SD610 line differential.

The vintage of the existing supply transformer protection, consisting of SEL-351S relays for HV & LV overcurrent/earth fault (OC/EF) protection, and a GE 745 relay for differential, did not justify replacement.

The most complex portion of the protection design was the temporary paralleling. In some applications, it is possible when paralleling to simply parallel the indoor and outdoor incomer CB CTs, and trip both trip coils in parallel via auxiliary trip relays. While this could be done for transformer differential protection, the same was not true for the transformer OC/EF protection.

In this case, a legacy overcurrent (OC) fast bus blocking (FBB) scheme existed on the outdoor bus, which needed to remain operational during the feeder cutover sequence to provide a safer working environment.

A FBB scheme works by feeder relays sending blocking signals to the supply transformer incomer relays and the bus section relay if they “see” an OC fault. This signal prevents the incomer relays and bus section relays from tripping. In the event of an OC on the outdoor bus, the feeder relays do not “see” a fault condition, and therefore do not send a blocking signal, and the incomer and bus section relays clear the bus fault quickly.

In the case of a paralleled outdoor and indoor connection with the LV OC/EF incomer CTs paralleled, if there is a fault on a cutover indoor feeder, the outdoor incomer relays will “see” a fault condition, not receive a blocking signal, and trip both supply transformers.

The option of temporarily connecting the new feeder relays into the existing fast bus blocking scheme was considered, but the new feeder relays did not have the required spare I/O.

To solve this issue, a temporary protection scheme was designed which consisted of connecting the indoor LV OC/EF incomer CTs and trip circuits to their respective permanent supply transformer LV protection relays, while installing temporary SEL-351S relays for the outdoor LV OC/EF incomer CTs, trip circuits and fast bus blocking signals to connect to.

This allowed the LV outdoor relay receiving the fast bus blocking signals to only “see” faults associated with the outdoor bus and outdoor connected feeders, allowing the fast bus blocking scheme to remain operational during the feeder cutover sequence.

The unacceptable arrangement of paralleling incomer OC/EF CTs and trip coils, as well as the acceptable temporary relay solution, are illustrated below in Figure 10. Note that only the T3 FBB signals are shown for clarity.

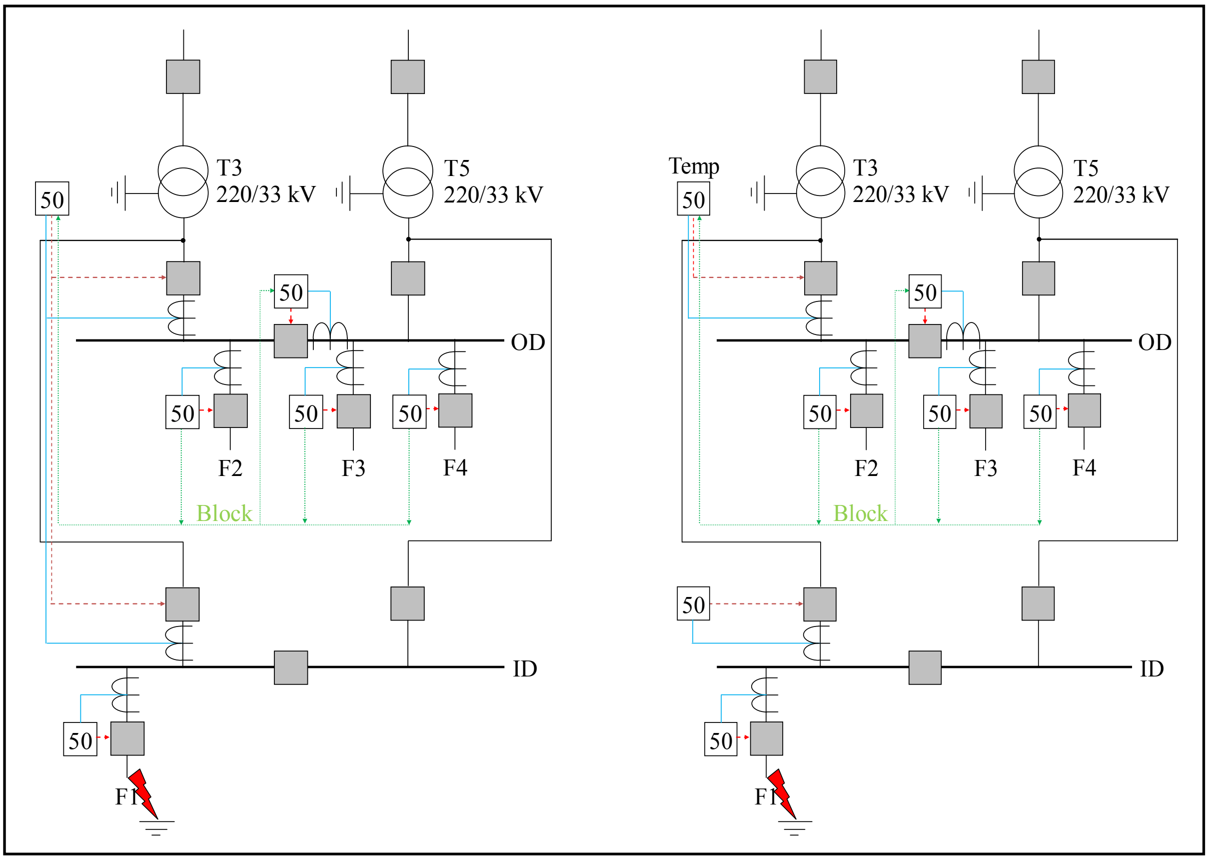

Figure 10: Paralleled Incomer OC/EF CTs & Trips – Unacceptable (left), Temporary relay solution - Acceptable (right)

3.4 Lightning Shielding

The ultimate removal of the 33 kV outdoor gantry meant that the lightning shielding for the remaining cable termination stands needed to be reviewed, as well as shielding for the new 33 kV switchroom, in accordance with Transpower standard TP.DS 07.01, "Shielding against direct lightning strikes to station equipment."

Since 10 kA surge arrestors were installed on transformer bushings, the critical current for the 220 kV, 110 kV & 33 kV equipment lightning shielding was 10 kA. This equates to a rolling sphere radius of 43 m.

A sphere of 43 m is rolled around all lightning masts, overhead earth wires, and any other earthed metallic objects that can provide lightning shielding. A piece of equipment is said to be protected from direct lightning strikes of 10 kA or above if it remains below the curved surface of the 43 m radius rolling sphere.

Although not shielded from direct lightning strikes of 10 kA or less, 10 kA surge arrestors installed on the transformer bushings and cable terminations provide protection.

It was determined that the standard design lightning masts in each corner of the new switchroom roof were sufficient for shielding the new switchroom, and that two lightning 18.4 m high lightning masts were required within the 33 kV outdoor switchyard to protect the remaining feeder and incomer cable termination stands.

3.5 125 V DC System

The 33 kV outdoor to indoor conversion (ODID) resulted in additional 125 V dc load due to additional protection and communication relays. Therefore, the capacity of the existing battery banks needed to be assessed to ensure the additional load did not jeopardise the standard Transpower carry over period of 8 hours, in the event of a loss of local service supply.

Transpower standard requires the voltage across the 125 V battery banks to remain above 100 V after supplying the standing load for 8 hours, and the maximum momentary load for 1 minute.

To determine the new standing load, the existing 125 V dc standing load was measured on-site, and the additional standing load determined by tallying up the datasheet standing load values of all additional protection and communications equipment installed as part of the ODID conversion (some devices have actual measured standing load currents, available in Transpower standard document TP.PP 01.10, "Application guide to approved protection relays.").

To determine the worst case momentary load, the current draw for each voltage's worst case bus zone trip was calculated, referring to the circuit breaker manufacturer's manuals to obtain trip coil currents for each type of circuit breaker on-site. The worst case momentary load was determined to result from a fault within the 110 kV bus coupler circuit breaker, causing the simultaneous tripping of two 110 kV bus zones and drawing 100 A.

Using the standard Transpower battery sizing spreadsheet, the effect of the new standing load for a carryover period of 8 hours, followed by the worst case momentary load for 1 minute, was determined to result in 92% discharge towards 1.85 V per cell (100 V across the battery terminals).

It was determined that the existing 125 V battery banks had sufficient capacity for the 33 kV ODID conversion.

4 Conclusions

This paper has provided a technical overview of the Wilton Substation 33 kV outdoor to indoor conversion. This paper has discussed considering multiple site layouts during the concept design, how to integrate these layouts into an existing site, how to consider feeder cutover sequences, including temporary protection, and what needs to be considered regarding lightning shielding and auxiliary systems.

It is essential to involve all stakeholders at an early stage throughout the conceptual design stage, including Transpower, the maintenance contractor, and the lines company, in order to record their requirements and preferences well before the detailed design.

It is important to consider multiple switchroom locations to ensure access and cabling is optimised, while considering future plant footprints. Interfacing to the existing incomer and feeder structures is safest done without disturbing legacy cables, regardless of their vintage.

The cutover sequence needs to be carefully designed to determine whether a temporary tie cable or parallel arrangement is best, and the feeder cutover order chosen to avoid temporarily crossing live power cables.

Whenever existing structures such as 33 kV gantries are removed, the lightning shielding of the site needs to be reassessed, and lightning masts installed where required.

It is important to consider the effect of additional standing load, and the potential of introducing higher momentary loads (i.e. bus zone protections), on the 125 V DC system.