	ELECTRICITY NETWORKS Asset Strategy and Performance Functional Scope	

Functional Scope Created	07-06-2017	**By**	Chris McCallum		
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Project Title	Geelong (**GL**) REFCL Installation				
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Protection and Control Engineer	Prateek Mann				
Plant and Stations Engineer					
Asset Strategy Engineer					
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Revision History:

Version	Date	Changes	Responsible Officer
1.0	07/06/2017	Original	C.McCallum
2.0	19/06/2017	Merged the existing protection and control scope with the primary plant scope	P.Mann
3.0	27/07/2017	Minor wording and balancing unit estimates. Amended auto-changeover requirements.	V.Hadya

1 Project overview

This project scope covers the migration of the Geelong zone substation (**GL**) system to a resonant earthed network. Migration to a resonant network requires the installation and operation of a ground fault neutraliser (**GFN**). This changes the electrical operating characteristics of a zone substation and its distribution network as follows:

- full voltage displacement occurs on the system for operation of the GFN
- this significantly stresses equipment on the system and may lead to failure
- this equipment has been identified and included in this scope for replacement as part of the GFN installation
- other limitations will dictate part of the operational protocols that will be developed by Electricity Networks.

The GFN provides potential benefits to single-phase-to-ground faults on the 22kV three phase system. It provides no benefit on the following:

- the 12.7kV Single Wire Return System (**SWER**)
- the 66kV sub-transmission system
- the low voltage (**LV**) system.

1.1 Background

The Victorian Government has introduced changes to the Bushfire Mitigation Regulations that require distribution businesses with high voltage (**HV**) overhead assets in high bushfire consequence areas to meet new performance standards for detection and limiting of arc fault energy. These standards can only be achieved using rapid earth fault current limiters (**REFCLs**).

A REFCL is a network protection device, normally installed in zone substations that significantly reduce the arc fault energy generated during a phase to ground fault. The reduction in arc fault energy can be so effective that earth fault fire ignition on 22kV three phase networks is almost eliminated.

The Bushfire Mitigation Regulations mandate that REFCLs must provide the required capacity—required capacity means, in the event of a phase-to-ground fault on a polyphase electric line, the ability:

- to reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for high impedance faults to 250 volts within 2 seconds
- to reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for low impedance faults to:
  - 1900 volts within 85 milliseconds
  - 750 volts within 500 milliseconds
  - 250 volts within 2 seconds
- during diagnostic tests for high impedance faults, to limit:
  - fault current to 0.5 amps or less
  - the thermal energy on the electric line to a maximum I^2t value of 0.10

  where:

- high impedance faults means a resistance value in ohms that is equal to twice the nominal phase-to-ground network voltage in volts
- I^2t means a measure of the thermal energy associated with the current flow, where I is the current flow in amps and t is the duration of current flow in seconds

- low impedance faults means a resistance value in ohms that is equal to the nominal phase-to-ground network voltage in volts divided by 31.75
- polyphase electric line means an electric line comprised of more than one phase of electricity with a nominal voltage between 1 kV and 22 kV.

1.2 Geelong zone substation

The Geelong 66/22kV zone substation is encompassed between the Midland Highway (Ballarat Road), Ebden Street and Gibb Street. It is a switched station consisting of two 20/40 transformers and a 12MVAr capacitor bank. It supplies nine distribution feeders which supply mostly urban residential areas, and some rural areas to the west as well as part of the Geelong CBD on Corio Bay.

Table 1 GL: existing characteristics (zone substation)

Zone substation	Volume
Feeders	9
Zone substation transformers	2
22kV buses	2
Capacitor banks	1
Station service transformers	2
22kV circuit breakers (switching configuration)	13 (switched)

Table 2 GL: existing characteristics (network)

Network	Volume
Total route length (km)	602
Underground cable length (km)	41
Overhead line length (km)	561
Underground network (%)	6.8
Overhead single phase	243
Estimated network capacitance (A)	149
Distribution transformers	1464
HV regulator sites	6
Fuses	1677

Network	Volume
ACRs	9
Surge arrestor sites	1,206
HV customers	1

2 ZSS requirements

This functional scope sets out the GL zone substation requirements, including the following:

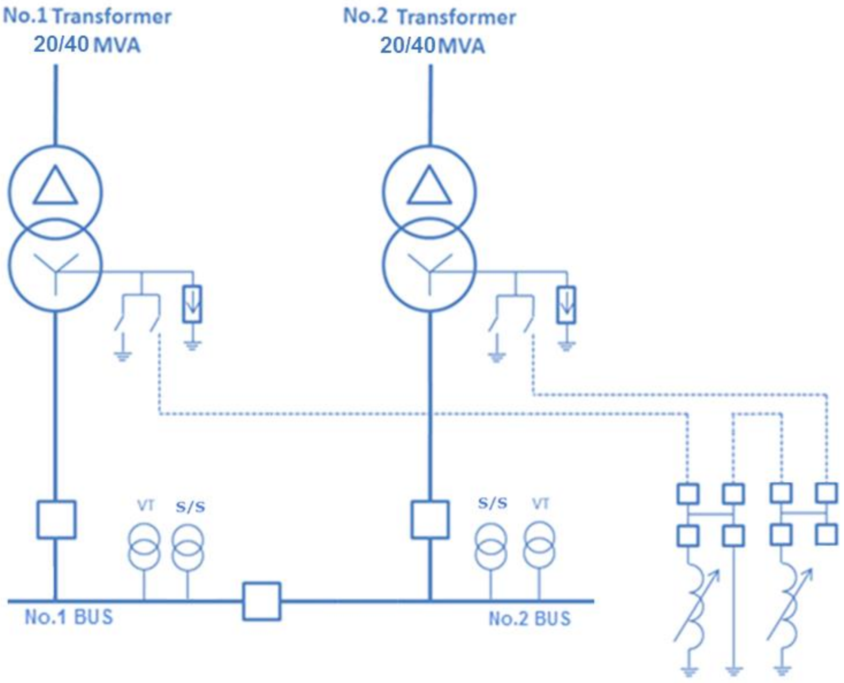
- establish ASC bunds for two (2) REFCLs
- installation of two (2) Swedish Neutral GFN Arc Suppression Coils
- modification of the 66/22kV transformer earthing arrangement
  - installation of Transformer Neutral Isolators and Direct Earth Switches
  - installation of 19kV surge diverters on transformer neutrals
  - installation of Neutral Bus Systems
    - bus CB's
    - direct earth terminations
    - ASC Terminations
    - neutral VT Installation
- 22kV bus modifications
  - swap the GL015 and GL024 feeders
  - decommission and disestablishment of the existing outdoor No.1 22kV bus, No.1 transformer CB, disconnect switch and earth switch
  - installation of 22kV Switch Room to house and facilitate the No.1 22kV bus and No.1 transformer CB
- upgrade existing station service supply to two (2) new 500kVA kiosk transformers with changeover board
- upgrade of the station service supply cabling and installation of new AC distribution board
  - install current limiting fuses on AC distribution boards
- replace two (2) existing 22kV VTs with two (2) new 22kV VTs
- replace all substation surge arrestors with new 22kV continuous voltage units for resonant network compatibility and 10hr 24kV TOV capability
- install the Station Earth Fault Management control relay
  - GFN Interface control
  - operating mode management
- install the Neutral Bus Management and X MEF Relay
  - adoption of existing MEF function
  - neutral voltage supervision
  - neutral bus CB management functions
- install and commission two (2) GFN control and two (2) RCC inverter cubicles
- review and modify secondary systems to accommodate split bus arrangement
  - install new independent transformer and voltage control schemes
- replace existing Transformer No.1 & No.2 X differential relays with differential protection relays with REF protection.
  - modify the configuration of existing delta connected LV Transformer No.1 & No.2 X Diff CTs to star connected

- retire existing X MEF relay
- modify existing backup earth fault protection scheme
- modify existing HMI and HMI RTU
- install one (1) Elspec Power Quality Meters
- extend station yard and earth grid as required to accommodate ASC
- install weather station.

2.1 Primary plant requirements

The works associated with the installation of the GL ASC and NER arrangement is summarised in the following single line diagram.

Figure 1 GL single line diagram



2.1.1 Arc suppression coil

Install 2 off (2x) Swedish Neutral – Ground Fault Neutraliser's Arc Suppression Coil (ASC) component. The arc suppression coil is a paper wound copper coil wrapped around a solid iron core and immersed in oil. This arc suppression coil is of fixed reluctance but contains an array of capacitors in parallel that are switch as part of the tuning process of the coil. The coil also features an LV winding for coupling of these capacitors and the Residual Current Compensator.

Primary neutral and earth connections are via elbows.

As oil filled device, it shall be installed in a bunded area in accordance with current standards. The total volume of oil will be made available once the coil size has been confirmed.

The GFN ASC shall be installed in the location of the existing No.1 22kV Bus:

- install Ground Fault Neutraliser comprising of 2 x 200A ASC and residual current compensation module with maximum available tuning steps onto the provided pad mount within a newly established bunded area
- the footing of the ASC shall reside on the installed 150mm steel beams fixed to the concrete pad
- install cable connections to and from the Neutral System.

2.1.2 Zone substation surge arrestors

The operating principle of the GFN uses a tuned reactance to choke fault current in the event of a single-phase-to-ground fault. As a result, displacement of the line-to-ground voltage occurs in the healthy phases. Whilst line-to-line voltages remain at 22kV, the line-to-ground voltage rises to 22kV, phase-to-ground, on the two healthy phase's subsequently stressing substation and distribution equipment. In the case of surge diverters, this displacement cannot be tolerated and as such the diverters require replacement.

To accommodate the GFN installation:

- replace all sub-standard zone substation surge arresters with a station class 22kV continuous voltage arrestor
- install station class 19kV surge arresters across the transformer neutrals.

2.1.3 Zone substation capacitor bank

The existing No.2 22kV Capacitor Bank is connected in grounded star. The Capacitor Bank also requires modification works to take it from a grounded star connection to an ungrounded star with an insulation rating of not less than 13kV.

To facilitate GFN installation, the earth must be removed from this Capacitor Bank:

- the neutral structure shall be modified such that the earth connection be removed and the neutral point floating with a continuous insulation rating of not less than 13kV
- install overvoltage protection (surge diverters) as per WND REFCL project.
- remove the Cap Bank Neutral CTs.
- install single phase 22kV VT on the neutral point of the capacitor bank.

2.1.4 Neutral system arrangement

A new kiosk type ground mounted Neutral Bus system shall be installed with the ASC. The neutral bus system allows for integration of the ASC and NER onto the transformer neutral.

The purpose of this arrangement is to provide a simple switching configuration that offers the following combinations within one kit:

- solid grounding
- ASC in service (Solid ground CB Open) on a common bus
- ASC in service (Solid ground CB open) on a split bus (Bus Tie Open)
- install 2 x Neutral Bus Modules – alongside the Arc Suppression Coils.

Neutral Bus

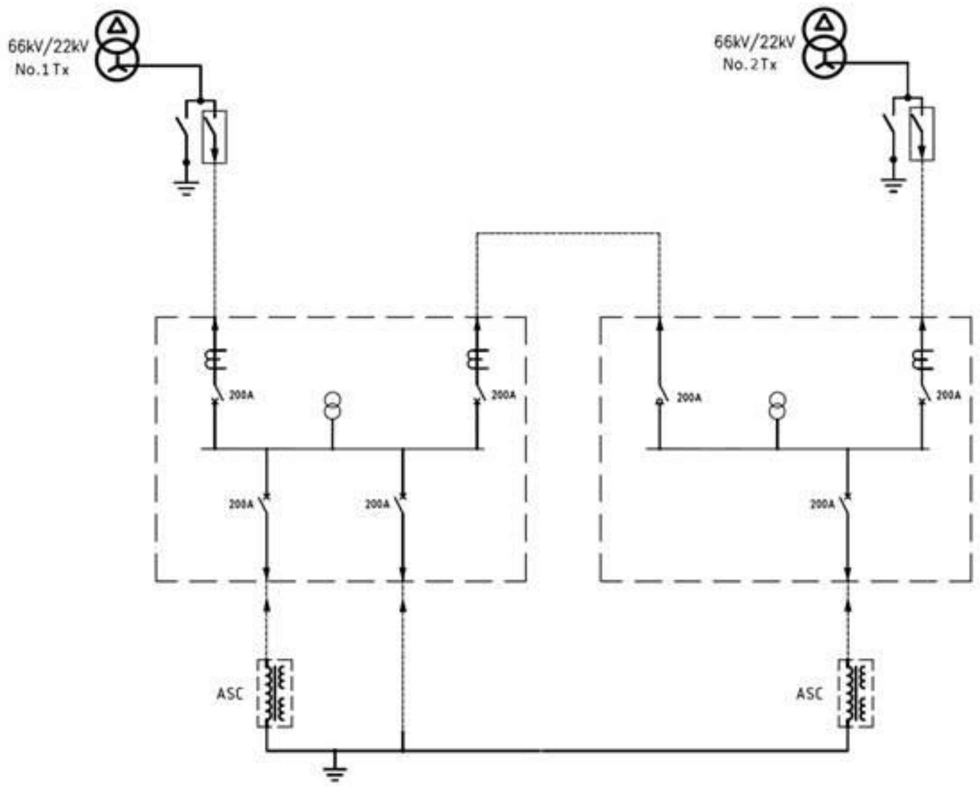
The connection to the Neutral Bus module shall be via elbow connections. Four (4) elbows are required per module for:

- transformer neutral connection
- ASC connection
- solid ground connection
- bus-tie connection.

Neutral Voltage Transformer

A neutral VT shall be included in each of the Neutral Bus modules. The neutral VT shall be 0.5M 1P at 15VA.

Figure 2 Proposed GL neutral system single line diagram



2.1.5 Transformer Earthing

The three 66/22kV transformers in service at GL are delta/star connected with the neutral of the star windings directly earthed.

The neutral earthing arrangement shall be modified to incorporate the new earthing arrangement with connection to the ASCs. The transformer neutral shall have a new HV insulated single phase cable installed underground from the new Neutral Bus isolator (enclosed in a lockable cage) through to HV elbow connections on the Neutral Bus modules.

External earth receptacles are required if any air cable boxes are used.

2.1.6 Neutral surge diverter

As the 22kV network is now operating as a resonant circuit, neutral surge diverters are to be installed to protect the ASC, Transformer Neutrals and 22kV network from overvoltages.

Install and connect a Station Class 19kV surge diverter between the transformer neutral bus and the substation earth grid. The surge diverters should be connected as close to the transformer neutrals as possible.

2.1.7 22kV Bus Arrangement

GFN Sensitivity

The GL 22kV Network consists of an estimated 561km of overhead line and 41km of underground cable. This leads to a network charging current of approximately 149 amps. To meet the sensitivity requirements of the GFN, it is recommended that the network be limited to 108 amps. This is a result of a sensitivity analysis surrounding a number of unknown parameters in the GL network. In order to achieve this, the 22kV network must be rearranged, to cater for the ability to 'split' the buses.

The following requirements are necessary to split the GL 22kV buses

- the existing 22kV Bus Tie Circuit Breaker between each of the 2 22kV Buses to physically split the 22kV buses and provide CT measurements for bus protection zones required for the GFN fault detection schemes in a split bus arrangement
- the existing 22kV Transformer Circuit Breakers are required in order to complete the transformer and bus protection zones
- 2 x 22kV VT's are required for transformer parallel control and GFN operation with the buses split
- 2 x Station Service Transformers are required to ensure that the GFN Inverter is available following any single fault. To prevent de-sensitising the bus protection scheme, these station service transformers shall be connected beyond circuit breakers where possible or contain 22kV CT's to remove contribution from bus protection schemes. In cases where the station service transformer is connected to the bus, it is to be protected by HV fuses.

22kV works

In order to arrange the substation in such a way that the 22kV bus can be split, appropriate protection zones exist for the GFN fault detection schemes the following works are required.

<u>22 kV Feeder rearrangement</u>

To balance the charging current among the 2 split buses the following feeders need to be rearranged at the feeder exit:

- GL015 swap with GL024.

New arrangement will be as follows:

- bus 1 will have GL011, GL012, GL013, GL014 and GL024
- bus 2 will have GL015, GL021, GL022 and GL023.

Note: if any of the feeder exit cables require replacement 300mm^2 3/c 22.c.epr.hc.v. underground cable is to be installed.

<u>GFN Inverter Room and Indoor Switch Room</u>

- Decommission and disestablish the existing No.1 22kV outdoor bus and No.1 22kV transformer CB, disconnect switch and earth switch to make the required space to install the REFCL equipment (design to confirm that this is the most appropriate arrangement to install the appropriate REFCL equipment of 2 x ASCs, GFN inverter equipment, 2 x neutral bus systems and 2 x 500kVA station service kiosk transformers).
- Install a new GFN inverter room and indoor 22kV switch room with 22kV switchboard:
  - switchboard is to be sourced with 10 positions to cater for the existing No.1 22kV bus of 5 feeder CBs, the No.1 transformer CB, a riser, a cable termination and 2 spare positions for a future No.1 Cap Bank and No 1-2 bus tie (design to consider whether bus tie to be installed as part of this scope).
- Switchboard is to be similar to current or recent standards for 22kV switchboards, refer Technical Standards Group.
- Inverter Room/Switch Room is to be designed and located in the yard such that it can be extended at a future date to accommodate the No.2 22kV bus.
- All 22kV feeder exits that may need to be replaced as part of the rearrangement into the new indoor switch room are to be 300mm^2 3/c 22.c.epr.hc.v. underground cable.

<u>Station Service and Capacitor Banks</u>

- The existing No.2 22kV Capacitor Bank is connected in grounded star. The Capacitor Bank also requires modification works to take it from a grounded star connection to an ungrounded star with an insulation rating of not less than 13kV. In addition to this, install a single phase VT on the neutral point of the capacitor bank. Refer Technical Standards for the VT specification.

- Replace the existing 25kVA 22kV No.1 Station Service Kiosk Transformer with a new 500kVA 22kV Station Service Kiosk Transformer:
  - station Service Kiosk to include 22kV CT's to allow for removal from 22kV Bus protection zones
  - connect beyond future 22kV feeder CB in new indoor board
  - refer Technical Standards for specification
  - connect to AC Changeover Board within GFN Inverter Room.
- Replace the existing 25kVA 22kV No.2 Station Service Kiosk Transformer with a new 500kVA 22kV Station Service Kiosk Transformer:
  - station Service Kiosk to include 22kV CT's to allow for removal from 22kV Bus protection zones
  - connect to No.2 22kV bus beyond HV fuses
  - refer Technical Standards for specification
  - connect to AC Changeover Board within GFN Inverter Room.

22kV Bus VT

Replace existing two 22kV VTs with new 22kV Voltage Transformers (one in new indoor switch room for No.1 22kV bus and the other on the existing outdoor No.2 22kV bus with HV fuses) with a VT with the following specification (SAP ID 310661):

- 3-Phase 5 Limb construction
- frequency – 50Hz
- ratio - 22,000/110/110V
- connection - STAR/STAR/STAR
- vector group - YNyn0yn0
- output - 100VA per phase per secondary winding
- accuracy class - CLASS 0.5M1P per secondary winding.

Transformer and Bus Tie

- Install new 22kV cable (2 x 630mm^2 1/c Cu XLPE underground cable per phase) from the No.1 transformer to the new No.1 transformer CB in the new 22kV switchboard.
- Install new 22kV cable (2 x 630mm^2 1/c Cu XLPE underground cable per phase) from existing No.2 Bus to the new 22kV switchboard.

22kV Insulators

- Replace all existing unrated 22kV pin insulators with station post insulators.

22kV Bus Naming

Any large scale changes to the 22kV yard require that consideration is given to the naming of plant in the substation from an operational perspective. This is critical from a healthy and safety perspective as well as from an operational

Nameplates in the 22kV Yard shall be reviewed and any that do not conform with the new naming of primary plant must be replaced:

- review nameplates of all 22kV Circuit Breakers, Buses, Isolators, Disconnect Switches, Earth Points and Cables.

All Primary and Secondary drawings shall be reviewed and any that do not conform with the new naming of primary plant must be updated:

- review all drawings with references to 22kV Circuit Breakers, Buses, Isolators, Disconnect Switches, Earth Points and Cables
- update SCADA system to conform with the new station asset naming.

2.1.8 22kV Feeder CT's

The ability to detect 25.4 kΩ faults requires a high level of accuracy in measurement to optimise network balancing. Perform diagnostic testing to confirm 25.4 kΩ faults while releasing less than 0.10 I^2T, as mandated by the Regulations, also requires very accurate current measurements.

The existing feeder CT specifications are outlined below.

Table 3 Feeder CT information

Feeder	CT Spec	Required Action
GL0011	0.2PX100R0.15	Suitable for sensitivity requirements
GL0012	0.2PX100R0.15	Suitable for sensitivity requirements
GL0013	0.2PX100R0.15	Suitable for sensitivity requirements
GL0014	0.2PX100R0.15	Suitable for sensitivity requirements
GL0015	0.2PX100R0.15	Suitable for sensitivity requirements
GL0021	10P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
GL0022	10P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
GL0023	10P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
GL0024	10P100 300/5	Not suitable for sensitivity requirements, require new CT installation.

At GL zone substation, four (4) feeder CT's need to be installed and will require associated modifications of the 22kV bus structures and civil works to facilitate their installation. An alternative option to avoid modification to bus structures was considered, this option involved complete replacement of 22kV circuit breakers and was found to be a more expensive solution.

- Review fault levels, wiring length and relay burdens and define required specification to procure PX class CT's:
  - note: Factory acceptance of CT's requires non-standard testing to confirm accuracy of zero sequence measurement through full range of load.
- Relocation of existing bus structure to facilitate the installation of a new 22kV structure in each feeder bay that requires new CT's.
- Installation of new 22kV CT mounting structure in each feeder bay that requires new CT's.
- Install CT's and modify secondary relay settings for new CT ratio's and test CT polarity.

2.1.9 Earth Grid Resistance

Experience from our REFCL trial substations and Camperdown zone substation has shown that the earth grid impedance in multiple REFCL substations negatively impacts on the ability to achieve 25.4 kΩ fault detection. In our desired range of network size (less than 108A) an earth grid impedance of 0.45 Ω will result in a neutral voltage developed in the unfaulted bus up to 1.5kV which is greater than the fault detection threshold for required capacity.

At GL zone substation, the following works are required to reduce the earth grid impedance to below 0.2 Ω:

- site survey, earth grid and soil resistivity testing
- detailed analysis and modelling of earth grid and soil conditions
- design of earth grid modification works
- additional earth stakes and earth grid installation
- retesting of earth grid.

2.2 Civil works requirement

For Neutral Systems:

- install concrete foundation pad for neutral system modules
- install neutral cable conduit, control cable conduit and provision for solid earth grid connections
- install neutral cable conduits from transformers to neutral system modules
- install conduits to ASCs and solid earth grid connection
- install conduits for secondary circuits

For ASCs:

- install neutral cable conduit, control cable conduits and solid earth grid connections
- pour concrete foundation
- install steel beam, 150mm high at a width designed to accommodate the placement of the GFN Arc Suppression coil
- install bunding to EPA requirements

For Station Service Supplies:

- install concrete foundation for new station service transformers
- review station service transformer foundations and enclosure for upgrade to 500kVA. Note the existing station service is 25kVA

For new 22kV No.2 Bus VT review the suitability of existing footings and control cable conduits. If unsuitable:

- install concrete footings for new structures
- install control cable conduits for No.2 22kV VT

For Extended GFN Inverter/Switch Room:

- remove any existing foundations, footings or apparatus from the decommissioned No.1 22kV outdoor bus, No.1 transformer CB, disconnect switch or earth switch that impede on the new 22kV yard arrangement.
- install concrete footings for new GFN Enclosure and switch room
- land new GFN Inverter and Switch Room
- install HV cable conduits for No.1 Transformer Cable, 1-2 Bus Tie Cable, Station Service Transformer Cable
- install control cable conduits to Control Room.

For new single phase 22kV Capacitor Bank No.2 neutral VT install the following:

- install concrete footing for the new structures
- install control cable conduits for the new VT

2.3 Secondary works

The following outlines the Protection and Control requirements.

All secondary drawings shall be in the wiring schematic format consistent with the existing suite of drawings for the station.

2.3.1 Protection Schemes

Cubicle 4 - 22 kV Trans No1, Trans No2 and Bus tie 1-2 CB Management

SEL-351S CB management configuration and firmware:

- relays shall have the current Z104 firmware version upgraded to version Z106
- relays shall be reconfigured to provide external protection trip initiations via IEC61850 GOOSE
  - these GOOSE initiations shall drive auto reclose functionality direct to lockout through the internal 79DTL function.

Cubicle 6, 7 and 8 - 22 kV Feeder Protections

SEL-351S Feeder Protection configuration and firmware:

- relays shall have the current Z104 firmware version upgraded to version Z106
- relays shall be reconfigured with directional control capability for all phase, neutral and earth fault elements
- relays shall be reconfigured to provide external protection trip initiations via IEC61850 GOOSE
  - these GOOSE initiations shall drive auto reclose functionality direct to lockout through the internal 79DTL function.

22kV Feeder CT contributions are required by the GFN zero sequence bus admittance calculations.

To facilitate the GFN connection, install an extra set of neutral links on feeder link rack to permit the installation of the I_0 connection off to the GFN controller.

Cubicle 9 – No.2 Cap Bank 22 kV Protection

SEL-351S X OC and EF Protection and CB management configuration and firmware:

- relays shall have the current firmware version Z104 upgraded to version Z106
- relays shall be reconfigured with directional control capability for all phase, neutral and earth fault elements
- relays shall be reconfigured to provide external protection trip initiations via IEC61850 GOOSE
  - these GOOSE initiations shall drive auto reclose functionality direct to lockout through the internal 79DTL function
- connect the single phase Cap Bank No 2 neutral VT to the relay VS for a voltage protection scheme.

22kV Cap No.2 CT contributions are required by the GFN zero sequence bus admittance calculations.

To facilitate the GFN connection, install an extra set of neutral links on feeder link rack to permit the installation of the I_0 connection off to the GFN controller.

Panel 13 – Trans 1 & 2 X Diff, Gas and T/C Protection

The existing D202-2790 Trans 1 & 2 X Diff relay shall be replaced with a modern IED to allow for Diff, REF and GFN integration. SEL 787-3 relays shall be installed as a replacement and configured as X Transformer Diff and REF relay.

The relay will execute and manage the following functions:

- trans diff

- REF protection
- transformer zone tripping via GFN.

The GFN control system requires a residual current measurement from the 22kV side of the transformer - which requires a CT connection in star formation. The existing protection relay does not have the modern capability to account for angular shifts and as such the CT connection is wired in delta. This relay is to be replaced to allow the CT connection to be remade to facilitate GFN installation. An additional benefit is this modern protection relay can also be used to trip transformer zone faults of the GFN without requiring installation or replacement of 66kV CB management devices.

If due to constraints replacement of the top half of the steel panel is required the following changes shall be undertaken.

The existing ARTVC-2165 x Diff trip relay shall be replaced with RMS 2HSM513 and Gas Velocity and tap changer surge trip relay shall be replaced with RMS 3A30K51 trip relay. Additionally the existing Gas Velocity and tap changer surge test switch shall be reinstalled as part of the steel panel replacement.

Design Notes:

- The Delta connected CTs for the Trans 22kV breaker for the diff contribution shall be reconfigured to be Star connected.
- The REF CT to be utilised shall be the 1800/5 ratio CTs within the neutral bus module for the individual transformer.
- Summated 22kV Trans CB CTs and REF contributions from Trans No.1 and No.2 are required by the GFN zero sequence bus admittance calculations. To facilitate the GFN connection, install an extra set of neutral links permit the installation of the I0 connection off to the GFN controller.

Panel 15 – Station Earth Fault Management, X MEF & Neutral Bus Management

Install a SEL-451 Station Earth Fault Management relay in order to perform the automated control of the GFN's installed at the substation.

The relay will manage the following functions:

- operating mode selection
- GFN remote controls
- automate fault detection handling
- request fault confirmations consistent with operating mode
- trip faulted zones consistent with operating mode
- bypass ASC
- provide local controls and indications.

Install a GE F35 relay configured as the X MEF and Neutral Bus Management relay. The relay will execute and manage the following functions;

- master Earth Fault relay for direct earth in service applications
- neutral Voltage Supervision
- neutral CB Management.

Cubicle 18 – 22kV Bus Diff, X MEF, Comm BUEF & Y MEF

Retire the existing RMS 2C137 relay in cubicle 18, currently performing X Master Earth Fault. The new X MEF is installed in Panel 15. Additional links shall be added to the No.1 & No.2 bus distance relay to allow for the individual transformer and bus tie summations required by the GFN for the zero sequence bus admittance calculations.

The No.2 Cap Earth CT contributions shall be removed from No2 Bus BUEF scheme.

2.3.2 Ground Fault Neutraliser

Cubicles 20-22 – New GFN Control Cubicles

The GFN control unit is a single cubicle comprising of;

- GFN Master Control module
- GFN Slave Control Module
- Windows based PC utilising proprietary NM Term software
- all VT & feeder I_0 CT terminations
- all trip link outputs
- RCC Inverter and ASC Interface
- panel Meters.

Notes:

- Geelong (GL) Zone substation will require two (2) of these controllers to permit split bus operation
- Powercor will request through their specification process that the control unit be constructed within a standard cubicle. The cubicle will contain an interface controller in the form of a SEL-2440 DPAC control unit in the top 2U of this cabinet. This control unit will be used to interface controls to the Station Earth Fault Management relay
- The GFN specification will be developed separately from this scope.
- The GFN cubicles shall be in cubicles 20-22 position (refer to Appendix C for proposed location of the GFN control cubicle).
- VT Supplies (R, W, B & VN) are required from bus into the GFN controller along with Feeder and Transformer neutral summation (IN) circuits.

2.3.3 VT supplies

VT supplies from the new No.1 & No.2 Bus VT's are required to the GFN control units. For earth fault detection, an open delta (U_N) input is required from the 22kV bus VT at 110V secondary. Swedish Neutral install internally to their control cubicle an open delta connected auxiliary transformer, as such no works beyond providing normal star connected VT supplies is required:

- connect No.1 Bus VT to No.1 GFN
- connect No.2 Bus VT to No.2 GFN.

2.3.4 Protection settings

A protection review shall be undertaken by Network Protection & Control of all schemes within GL zone substation with particular reference to earth fault schemes on the 22kV network.

SEL-351S relays will have configuration changes done by Network Protection and Control to introduce:

- GOOSE (via GFN) tripping capability

- auto Reclose integration of GFN initiated trips
- GOOSE message isolation function.

An application for backup Voltage Displacement shall be implemented in the X-MEF and Neutral Bus Management Relay.

2.3.5 Protection relay configurations

Powercor Network Protection and Control will make standard relay configuration files available to the Service Provider where appropriate. Given the nature of this project, the service provider must expect that this project will have non-standard requirements.

2.3.6 Weather Station

A weather station is to be installed at GL in order to provide monitoring of temperature, solar radiation, wind speed and humidity in the area. This provides an indication of REFCL sensitivity as it will fluctuate as the network damping (resistive leakage to earth) will vary with weather conditions. Care is to be taken when earthing the weather station to ensure there is no risk of damage to the control room from lightning strikes.

2.3.7 Metering requirements

Cubicle 1 – Existing Power Quality Meter

In a split bus arrangement station summation metering is required of the individual bus groups. The existing ION 7650 Power Quality Meter in Cubicle 1 is to be modified to meter the No.1 Bus Summation, removing the contributions from the No.2 Transformer.

A new ION 7400 Power Quality Meter shall be installed in Cubicle 1 as the No.2 Bus Summation PQM. The CT circuits are to be wired such that this new PQM is provided No.2 bus currents only. This PQM is to be connected to the existing ION 7650 which will make available via DNP the individual bus metering as well as a station summation.

Cubicle 19 – New ELSPEC Power Quality and Data Recorder

Install one (1) of ELSPEC Power Quality and Data recorders. The meter provides the following functionality:

- this recorder is capable of recording 16 analogue & 32 digital channels of data at a sampling rate of 1000 samples per second, 12 months of data can be captured and stored internally using a patented algorithm
- the ELSPEC shall be installed to capture bus voltage, neutral voltage and bus incomer currents (i.e. transformer currents). The purpose of this recorder is to aid with GFN commissioning and long term monitoring
- connectivity to the ELSPEC meter to be fibre 100BASE-FX Ethernet to a new RSG2100 switch.

2.3.8 Transformer Control

The existing Transformer Control RTU and RMS-2V164-S Relays will not be able to handle the split bus arrangement required at Geelong Zone Substation in order to meet the sensitivity requirements of earth fault detection. A SEL-451 Programmable Automation Controller shall be configured to perform independent voltage control of each bus in the split bus arrangement or traditional voltage control with the 22kV 1-2 Bus Tie closed. It will require installation of additional relays to provide the statuses, analogues as well as a pathway for controls.

In order to enable the split bus arrangement, the following items will be required:

- 1 x SEL-451 Programmable Automation Controller (VRR & TX Parallel Control)
- 2 x SEL-2440 DPAC (Transformer Interface)
- 2 x Winding Temperature Transducers.

Cubicle 5 – New VRR, Trans Controls and Station HMI

The existing SCD5200 Transformer Control RTU and all associated transformer control wiring and relays including Trans OLTC supply MCBs shall be retired and a new cubical No.5 shall be established with a SEL-451 Programmable Automation Controller, 2 x 2440 Transformer interface controller, Trans OLTC MCBs, winding temperature transducers and Trans DC Controls MCB. This will allow control of the two transformers at GL in either the traditional or split bus arrangement.

The existing RedLion G315C shall be relocated to the new cubicle.

2.3.9 Station HMI and HMI RTU

The existing Human Machine Interface (**HMI**) is to be relocated to new cubicle 5 and modified to accommodate new station controls:

- single line diagram updated to match Substation Configuration
- new transformer controls
- GFN controls.

2.3.10 Control and monitoring requirements

Remote control and monitoring of new:

- X MEF, neutral voltage & neutral system CB management relay UR F35
- station earth fault management SEL-451
- GFN controllers SEL-2440 (2 off)
- ELSPEC power quality recorder (2 off)
- transformer diff & REF SEL 787-3 (2 off)
- VRR and transformer control relay SEL-451
- transformer interface control relays SEL-2440 (2 off).

The remote controls and monitoring of the new IEDs shall be via DNP 3.0 with DNP Maps provided to the SCADA group and produced by the service provider in conjunction with Network Protection & Control.

Powercor SCADA group are responsible for developing a suite of ENMAC control pages in conjunction with the Network Operations group and Network Protection & Control.

2.3.11 Communications Requirements

Ethernet Connectivity

All communications shall be over 100 BASE-FX (optic fibre) Ethernet back to the zone substation Sub-LAN RSG-2100 Ethernet switches. Preferably, devices maintain duplicated Ethernet connectivity either through an internally “switched” architecture or a preferred and failover arrangement.

Tripping from the GFN to the feeder CB’s will be over IEC 61850 via an interface module built into the GFN control cubicle. For this reason, the architecture for Ethernet communications shall change to eliminate “loops” that emanate from the sub-LAN switch for devices that are involved in this scheme.

Based on this architecture three additional RuggedCom RSG-2100 will be required. The proposed location for these switched have been outlined below:

- GL-RSG2100-12: at the top of Cubicle No.6 GL 11, 12, 13 & 14 22kV Feeder Management relay
- GL-RSG2100-13: at the top of Cubicle No.8 GL 22, 23 & 24 22kV Feeder Management relay

- GL-RSG2100-14: at the top of Cubicle No.15 Station Earth Fault Management, X MEF & Station Earth Fault Management.

Additionally, install two identical new Fortigate 60C firewalls (redundant firewalls must be identical).

Engineering Access

Powercor SCADA shall ensure remote engineering access is available to select members of the Network Protection & Control group. Remote access is required to all sub-LAN connected devices including protection relays, data recorders and GFN controller.

Time Stamping

Install new Tekron TCG-01 GPS clock, antenna and ensure that earthing is performed carefully using the standard enclosure. This is to be used for time stamping all equipment. All NTP capable equipment shall synchronise with the GL GPS NTP server.

All non NTP capable equipment is to be left as is.

2.3.12 415/240 AC Supplies

The existing station service supply transformer is located on the 22kV service bus. The sizing of this station service transformer is inadequate for the RCC inverters used to drive faulted phase voltage to zero via the Arc Suppression Coil. As the size of GL network requires a split bus arrangement and two Arc Suppression Coils, one for Transformer No.1 and one for Transformers No.2, the AC Supplies must ensure capacity and reliability requirements are fulfilled.

Install two (2) new 500 KVA kiosk type station service transformers.

Upgrade existing station AC board, incoming mains and change over schemes such that they are compliant with existing standards:

- configure new auto-changeover board to only restore to Supply 1 for loss of Supply 2, i.e. not changing over immediately after Supply 1 is restored, interrupting the REFCL supply unnecessarily.

Install AC supplies for the GFN inverter to meet its specifications.

2.3.13 DC Supplies

The battery capacities shall be verified as being of adequate capacity to supply the station standing load and any CB operations that could occur within a 10 hour period following loss of AC Station Service supplies.

Documentation must be provided that demonstrates the battery amp-hour rating chosen has been sized for the load and the duty of the load. Calculations and appropriate documentation must be provided to demonstrate compliance with IEEE – 485 “IEEE Recommended Practices for Sizing Lead Acid Batteries for Stationary Applications”.

2.3.14 Station Design

As a minimum the secondary design documentation shall include:

- 22kV Station Schematic Diagram
- protection, control, instrumentation and alarm data schedules
- control room layout and elevation of cubicles
- cubicle layouts
- wiring schematics/diagrams for individual protection, control and metering schemes
- DC supply schematics
- remote control equipment and associated data schedules
- labelling for cubicles and all slide link terminals

- manufacturer and interface drawings for the Ground Fault Neutraliser equipment.

The latest modular design concepts shall be used as far as practical for this project.

2.3.15 Powercor control centre SCADA works

A new series of Control System Pages shall be created for the GFN interface. Consultation between SCADA, Operations and Network Protection and Control is required to establish these pages.

2.3.16 Fibre Optic Cable

Fibre optic patch leads are required for Zone Substation Sub-LAN Ethernet communications.

These optic fibres shall be of OM1 62.5/125um type.

2.3.17 Radio

No radio communications are required.

2.3.18 Building and Property Considerations

Yard lighting

Switch yard lighting shall be reviewed to ensure adequate coverage of the ASC, Neutral System.

Fire suppression

The ASC winding is immersed in oil. A review of its design and the amount of contained oil is required to determine if any fire suppression assets are required.

3 22 kV distribution feeder requirements

3.1 Surge diverters and insulation limitations

The operating principle of the GFN uses a tuned reactance to choke fault current in the event of a single-phase-to-ground fault. As a result, displacement of the line-to-ground voltage occurs in the healthy phases. Whilst line-to-line voltages remain at 22kV, the line-to-ground voltage rises to 22kV, phase-to-ground, on the two healthy phase's subsequently stressing substation and distribution equipment. In the case of surge diverters, this displacement cannot be tolerated and as such the diverters require replacement.

To accommodate the GFN installation, replace approximately 3,152 surge diverters across the 22kV three phase and single phase system.

This covers all feeders ex GL ZSS as well as surge arrestors beyond inter-station open points shall also be upgraded to permit transfer of loads with the GFN in service.

The replacement diverters should be of 22kV continuous rating with a 10 hour 24kV TOV rating such as the ABB POLIM D 22kV arresters.

CitiPower and Powercor previous standard surge diverters were the ABB MWK 20 and POLIM D 20 arresters.

These, and all previous types except Bowthorpe 'Type A' arresters do not meet the overvoltage requirement needed for use with a GFN and therefore the higher rated arresters are required.

These surge diverters will be a new standard, applicable to distribution systems with a GFN installed.

3.2 Distribution transformers

Operation of the GFN displaces the neutral voltage of the entire 22kV system from the bus to the outer extremities of the feeders. This is different from an NER arrangement, when displacement is at its highest for a fault on the 22kV bus, and decreases for faults occurring down the feeders.

During GFN commissioning, voltage offset testing will simulate the voltage displacement that will occur for a single-phase-to-ground fault (22kV phase-to-ground):

1. some distribution transformers may not be in a condition to withstand the overvoltage and will subsequently fail during the voltage offset testing
2. some distribution transformers may fail following repeated subjection to sustained over-voltages caused post commissioning due to normal operation of the GFN.

At this time, experience from network resilience (voltage stress) testing at GSB and WND does not support a proactive replacement of any distribution transformers.

3.3 Line insulators

As is the case above for distribution transformers, line insulators are also susceptible to premature failure caused by the repetitive over-voltage stresses.

At this time, experience from the network resilience testing does not support a proactive replacement of any line insulators.

3.4 Line regulators

Single phase open-delta-connected Cooper regulators displace the system neutral voltage by regulating line-line voltages on two phases as opposed to three.

Closed-delta independent regulator control schemes tap each regulator independently, a similar displacement to the neutral voltage occurs, as per the open-delta mode.

All regulator works shall be compliant with current CitiPower and Powercor standards for 22kV regulators.

The GL distribution network contains seven (7) 22kV regulating systems.

Table 4 GL regulating systems

Feeder	Name	Manufacturer	Phasing	Issue
GL012	HAMILTON HWY P154A REG	Cooper – 2 x 100A	RWB	No work as regulator is to be retired in early 2018.
GL012	SHELFORD B/BURN RD P24 REG	Cooper – 2 x 100A	RW	Require a 3rd unit or rebuild of regulating site to operate in 'closed delta'
GL012	SHELFORD P98 REG	Cooper – 1 x 50A	RW	Single phase line with single phase regulator – this must be addressed as part of balancing works
GL012	HAMILTON HWY – P142 REG	Cooper – 3 x 300A	RWB	New control box required to tap all phases together
GL015	BALLARAT RD P219 REG	Cooper – 2 x 200A	RW	Require a 3rd unit or rebuild of regulating site to operate in 'closed delta'
GL015	MOORABOOL VALLEY REG	Wilson – 1 x 3 5MVA	RWB	No issues
GL015	ROBERTSONS RD P6 REG	Cooper – 2 x 100A	RB	Require a 3rd unit or rebuild of regulating site to operate in 'closed delta'

The following regulators require modification in order to meet the requirements for installing the GFN.

3.4.1 Shelford B/Burn Rd P24 Regulator

Shelford B/Burn Rd P24 regulator is an open delta connected regulator; this artificially moves the neutral point of the line beyond it. This must be either replaced with a 3-phase ground type regulator, or a third single phase regulator installed on a neighbouring pole and a control scheme installed to ensure that all 3 phases tap in unison.

3.4.2 Hamilton Hwy – P142 Regulator

Hamilton Hwy – P142 regulator has 3 single phase regulators. They will need to tap in step with each other, which will require a new CL7 control box as a minimum. If it is not possible for this to be fitted, a new 3 phase regulator may be required.

3.4.3 Ballarat Rd P219 Regulator

Ballarat Rd P219 regulator is an open delta connected regulator; this artificially moves the neutral point of the line beyond it. This must be either replaced with a 3-phase ground type regulator, or a third single phase regulator installed on a neighbouring pole and a control scheme installed to ensure that all 3 phases tap in unison.

3.4.4 Robertsons Rd P6 Regulator

Robertsons Rd P6 regulator is an open delta connected regulator; this artificially moves the neutral point of the line beyond it. This must be either replaced with a 3-phase ground type regulator, or a third single phase regulator installed on a neighbouring pole and a control scheme installed to ensure that all 3 phases tap in unison.

3.5 Admittance balancing

The ground fault neutraliser uses a tuned inductance (Petersen Coil / Arc Suppression Coil) matched to the capacitance of the distribution system. The 3 phase 22kV distribution system ex GL zone substation contains approximately 561km of overhead conductor length (excluding SWER). Of this, 243km (43 per cent) is single phase. Whilst planning philosophies have always attempted to balance the single phase system, inevitably this is difficult to achieve. In order to balance the capacitance of the three phase system such that the ASC can be correctly tuned, balancing substations will be placed at nodes on the system that utilise low voltage capacitors to inject the missing capacitance onto the system.

Note: Balance does not refer to the balancing of load. System balance is required from a capacitance-to-ground perspective and affected by route length and single phase connected distribution equipment.

A reconciliation (survey) of all 22kV overhead and underground lines routes shall be conducted to assess the scope of the network balancing requirements.

The following steps shall be outworked prior to GFN installation:

1. Consolidate all “Single Phase” and “unknown” conductor into the “BR”, “RW” or “WB” categories:
   (i) validate “Single Phase” and “unknown” conductor where required
   (ii) spot check the validity of current phasing information.
2. Consolidate all single phase transformers on the 22kV system and assign to one of the “BR”, “RW” or “WB” categories.
3. Ascertain the construction types for all sections:
   (i) indicate whether LV subsidiary exists.
4. Consolidate all “1 Phase” and “unknown phase” 22kV cable and assign phase information
5. If single phase circuits are used underground, ascertain the design principles behind the single phase underground sections:
   (i) conductor type, two or three core?
   (ii) treatment of the unused core (earthed or phase bonded)—if bonded, to what phase?

The course balance shall look at sections of the system in 'switchable blocks' and for any re-phasing and finite admittance balancing opportunities in order to balance out the single phase route lengths and large single phase spurs where the capacitance is fairly easy to approximate.

A tuneable balancing approach shall then look at the system again in switchable blocks for the application of 3-phase admittance balancing substations.

The use of 3-phase admittance balancing substations will provide accurate capacitive balancing in each section. Admittance balancing substations shall be placed at the following locations to enable switching of balanced blocks of the system.

The blended approach to admittance balancing is designed to cater for the historical use of single phase spur lines, single phase cable and the variability in capacitive balancing. The number of re-phasing sites, single phase balancing units and 3 phase balancing units are also informed by experience of GSB and WND and scaled to the relative network parameter of this substation.

Table 5 Balancing requirements summary

Balancing concept	Number of sites
Re-phasing Sites	16
Single Phase Balancing Units	20
3 Phase Balancing Units	43

3.6 Automatic Circuit Reclosers (ACRs) and remotely controlled gas switches

Each RVE or VWVE ACR on the GL network should be replaced with the current standard Schneider N27 ACR which has inbuilt voltage measurement.

Table 6 ACR replacements

Name	Operating voltage	Phase code	ACR model
BANNOCKBURN P25 ACR	22kV	RWB	VWVE27
LETHBRIDGE P179 ACR	22kV	RWB	VWVE27

Each ACR or remote controlled gas switch requires a modern control box which has required programmable functions and up to date firmware. ACR and gas switch control box replacements are required (for CAPM5 or GCR300 control boxes) in order to:

- automatically detect REFCL operation and prevent incorrect operations de-energising customers
- provide advanced fault locating algorithms capable of detecting REFCL fault confirmation tests
- continue to operate in the traditional manner automatically when REFCL is not in operation.

Table 7 Control box replacements

Name	Control box model
HAMILTON HWY P79 ACR CTRL	PTCC (CAPM5)
SHANNON AVE P54 ACR CTRL	PTCC (CAPM5)
ELIZABETH ST P38E ACR CTRL	PTCC (CAPM5)
LETHBRIDGE P179 ACR CTRL	ADVC-C

Table 8 ACR and control box requirements summary

Units	Number of sites
ACR replacements	2

Units	Number of sites
Control box replacements	4

3.7 Fuse savers

HV Fuses pose a difficulty in operating a network with a REFCL. Maintaining capacitive balance is critical in the network, and scenarios that result in 1 or 2 out of 3 fuses blowing in a 3 phase section, such as phase-phase faults can result in large capacitive imbalances. These imbalances can result in loss of REFCL sensitivity, REFCL maloperations resulting in widespread outages or REFCL backup schemes operating to remove the REFCL from service.

Fuse Savers are to be installed as a 3 phase ganged unit such that when any individual phase operates for a fault, all 3 phases open in unison de-energising a balanced section of the network regardless of the fault type.

Fuse Savers are required to operate for any fused section with a downstream network capacitive charging current of 540 mA or greater.

In some locations where the network fault levels are high, Fuse Savers cannot be used as they do not have the appropriate fault breaking capacity. In these situations, an ACR is required to clear faults as a three phase device else the feeder will be tripped on days of high sensitivity.

Table 9 Fuse saver requirements

Units	Number of sites
Fuse savers	37
ACRs	2

3.8 HV underground cable

Experience from REFCL testing has shown that a percentage of HV underground cable is likely to experience failure due to elevated phase to earth voltages experienced in a resonant network. An allowance for cable failure is to be made for the transition to resonant earthing.

Table 10 HV underground cable requirements

Location	Length (m)
Cable failure length	2,568

3.9 Distribution switchgear

Overhead distribution switchgear has been shown to be largely resilient to the phase to earth over-voltages experienced in a resonant network. There is no planned replacement of these assets.

Resilience testing has shown that Felten and Guilleaume ground mounted kiosk switchgear is not capable of withstanding 24.2kV phase to earth voltages. The inherent design and construction of these units preclude them from any repair works and as such must be replaced.

Table 11 Felten and Guilleaume switchgear replacements

Location	Kiosk size (kVA)
BURNS-McPHILLIPS	750
THOMPSON-BALLARAT	500

3.10 HV customer isolation substations

The Electricity Distribution Code stipulates that at the point of connection to a customer on the 22kV network, the phase to earth voltage must be no greater than 80 per cent for up to 10 seconds.

In order to maintain compliance with the code, the installation of HV isolation substations is required.

The service provider is to ensure that the detailed design of these installations considers:

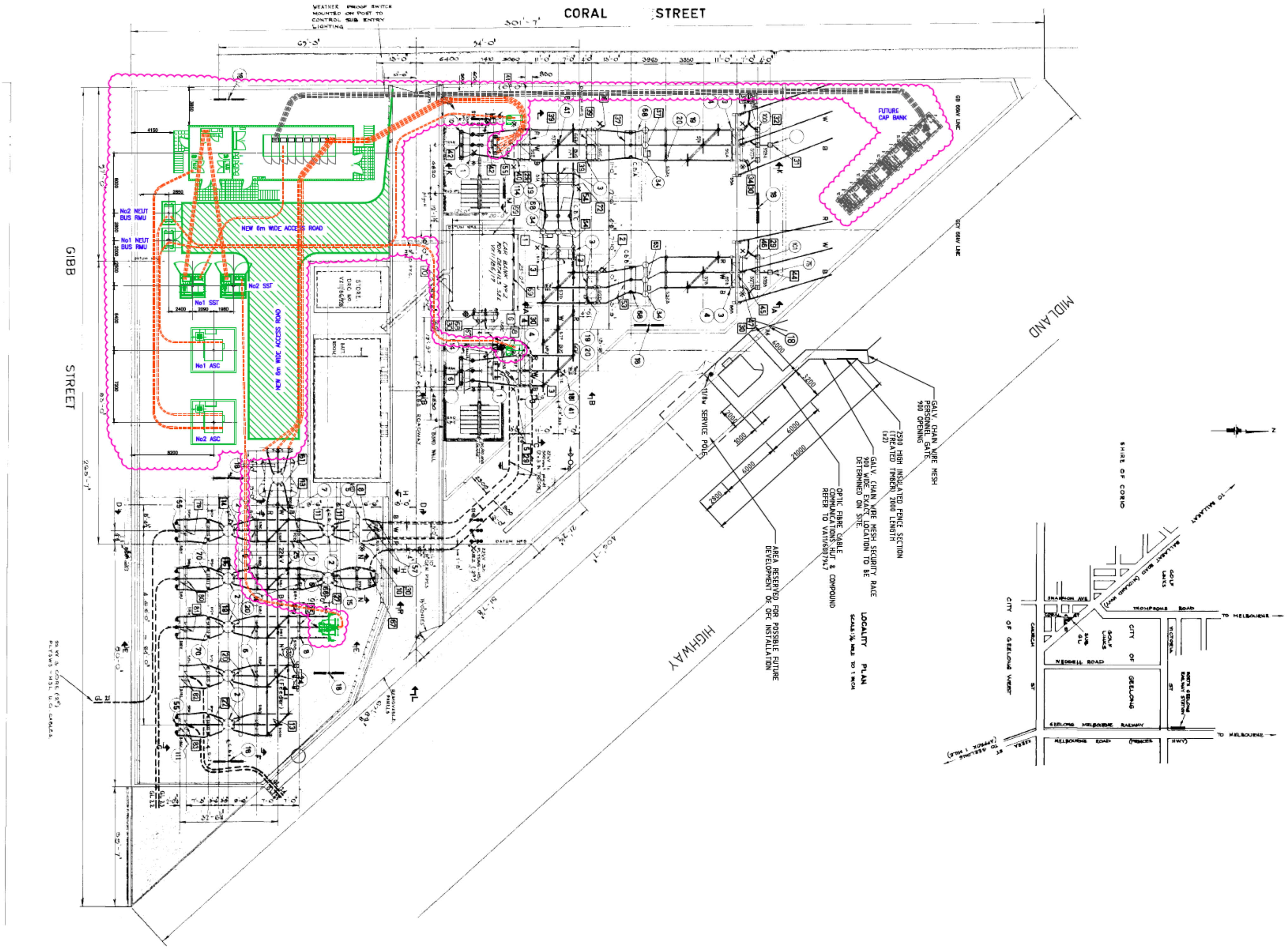
- a delta zig-zag (Dzn0) vector group transformer is required to provide the isolation
- isolation substation to be sized appropriate for the total size of the customer's load, taking into account any generation
- voltage control requirements for the customer is likely to require tap changing capability for larger customers
- station service supply via the tertiary winding to provide supply to protection, metering and control circuitry
- appropriate HV source side protection to protect for faults in the substation transformer
- appropriate HV load side protection to protect for faults between the substation and customer protective devices
- note that customer protection is in some cases not at the point of connection and there is a risk of sensitive earth faults
- bunding and other environmental considerations for substations
- undergrounding of any electrical conductor between the isolation substation and customer connection.

HV customer connection sizes are set out in table 12.

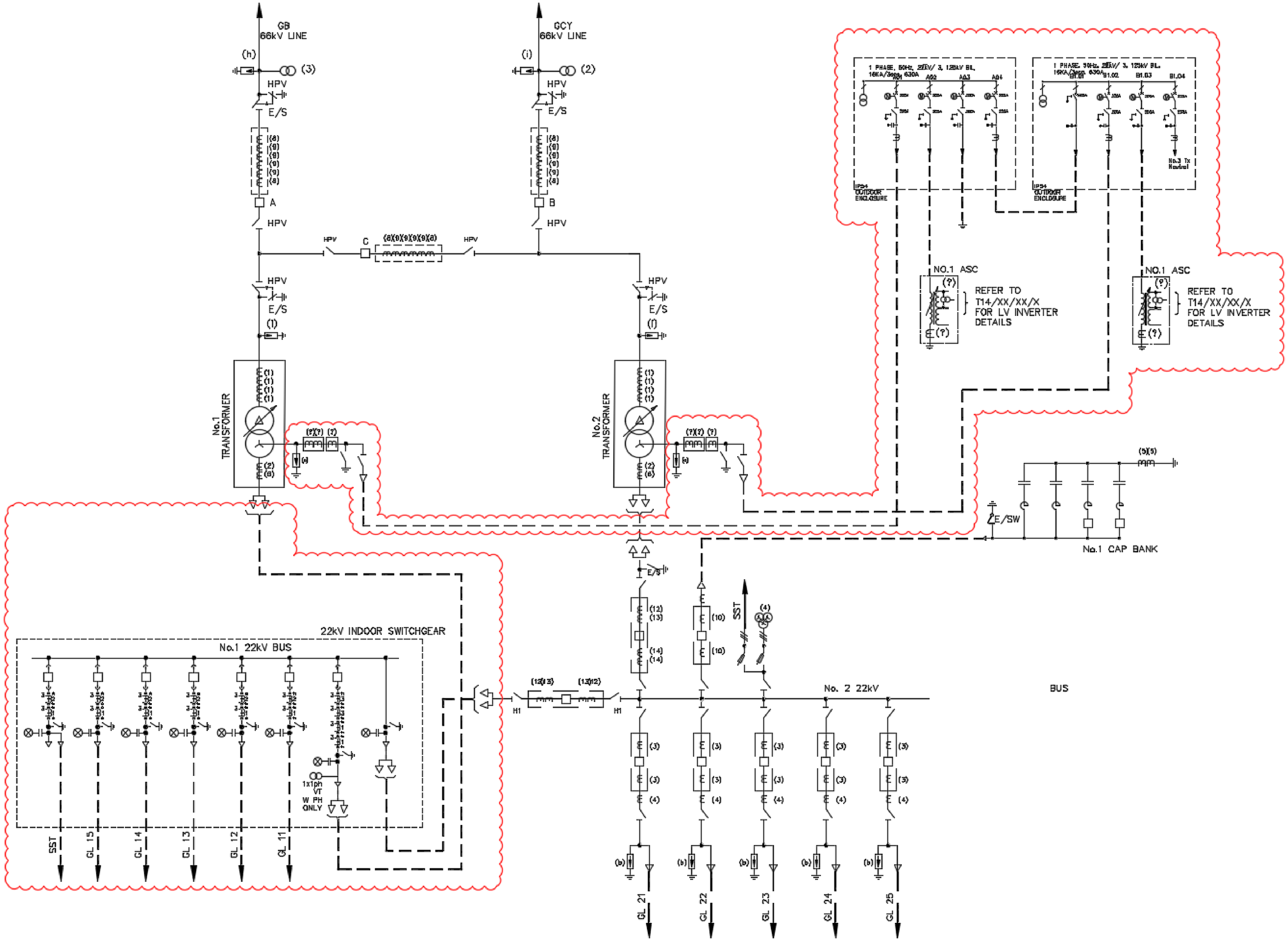
Table 12 Isolation substation requirements

Size	Quantity
3 MVA	1

Appendix A: proposed site general arrangement



APPENDIX B: proposed plant datasheet



APPENDIX C: Ethernet connectivity