CITIPOWER	**ELECTRICITY NETWORKS** **Asset Strategy and Performance** **Functional Scope**	Powercor AUSTRALIA

Functional Scope Created	**14 June 2017**	**By**	Frank Argus		
		Ex:	5726		
Project RO	Joe Vinci	**Ex:**	8284		
Project Title	Bendigo (BGO) REFCL Installation				
Network No. and F/C	5108025				
Last Update	1 August 2017	**By**	Vikram Hadya	**Version**	1.3
Related Scopes					
Project Engineer					
System Planning Engineer	Frank Argus				
Protection and Control Engineer	Geoff Squires				
Plant and Stations Engineer					
Asset Strategy Engineer					
Required Quote Date					
System Requirement Date	TBA				

Revision History:

Version	Date	Changes	Responsible Officer
1.0	14/06/2017	Original	F. Argus
1.1	27/07/2017	Added Protection & Control Requirements	G.Squires
1.2	31/07/2017	Yard extension revised Appendix E a.	F. Argus
1.3	01/08/2017	Reviewed balancing unit and AC changeover requirements	V.Hadya

1 Project overview

This project scope covers the migration of the Bendigo zone substation (**BGO**) 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 Bendigo zone substation

BGO zone substation is located in central Victoria and consists of two transformers and seven 22kV feeders. The two transformers are in a fully switched arrangement. The existing BGO network consists of 480km of overhead line and 34km of underground cable, yielding an estimated charging current of 125 amps. Two REFCLs are to be installed at BGO zone substation.

Table 1 BGO: existing characteristics (zone substation)

Zone substation	Volume
Feeders	7
Zone substation transformers	2
22kV buses	2
Capacitor banks	1
Station service transformers	2
22kV circuit breakers (switching configuration)	3 (Fully Switched)

Table 2 BGO: existing characteristics (network)

Network	Volume
Total route length (km)	514
Underground cable length (km)	34
Overhead line length (km)	480
Underground network (%)	6.6
Overhead single phase	229
Estimated network capacitance (A)	125
Distribution transformers	1226
HV regulator sites	4
Fuses	1346

Network	Volume
ACRs	6
Surge arrestor sites	758
HV customers	3

2 ZSS requirements

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

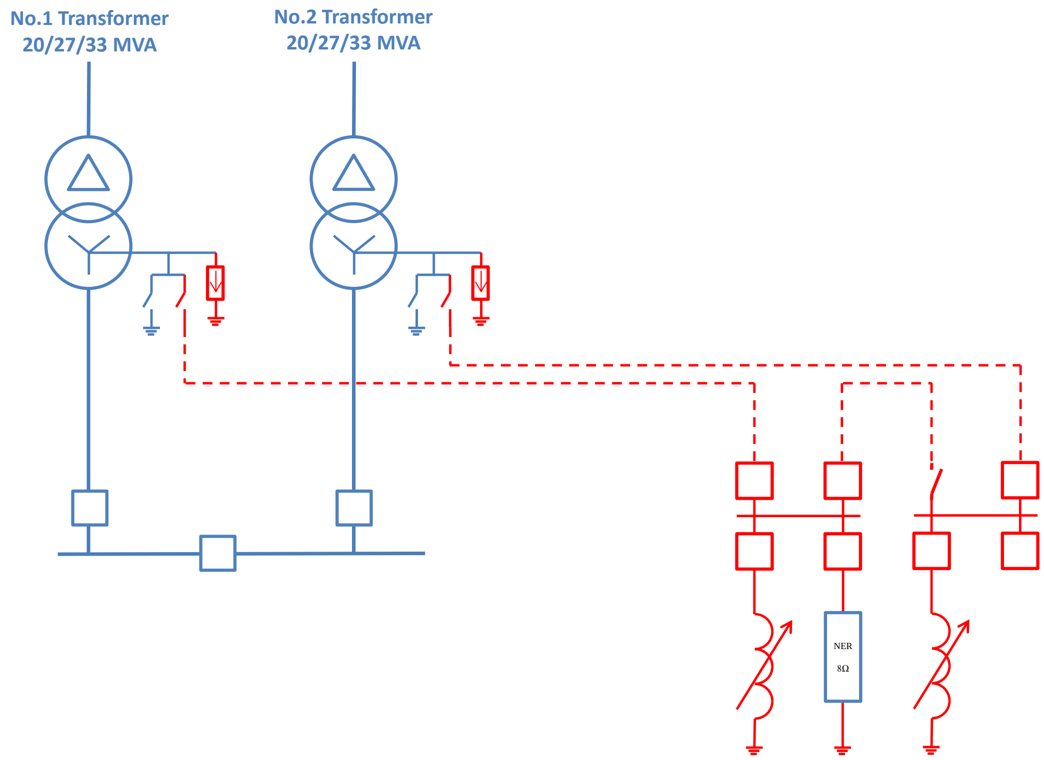
- establish ASC bunds
- install two (2) Swedish Neutral GFN arc suppression coils
- install & Commission two (2) GFN control and RCC inverter cubicles
- modification of the 22/66kV transformer earthing arrangement
  - installation of two (2) Neutral Bus Systems
    - 1 X Type A & 1 X Type B2 (Z0081)
    - transformer neutral
    - ASC termination
    - NER termination
    - neutral VT
    - bus tie CB
  - installation of 19kV surge arresters across transformer neutrals
- replace two (2) station service supply transformers with two (2) new 500kVA kiosk transformers.
- upgrade station service supply cabling and installation of new AC distribution board with auto-changeover scheme
- replace all substation surge arrestors with new 22kV continuous voltage units for resonant network compatibility and 10hr 24kV TOV capability
- Station Earth Fault Management
  - retire Group-2630 Master E/F
  - install GE-F35 Earth Fault Management Relay
    - MEF function
    - Neutral Voltage supervision
    - Neutral Bus CB Management functions
  - retire BUEF relays
  - install GE-F35 BUEF Relay
- replace seven (7) SEL-351S 22kV feeder protection relays to IEC compatible units
- replace four (4) Group-2753 ‘X’ CB Fail relays with SEL-351S CB management relays
- replace two (2) Group-2819 transformer 1 & 2 ‘X’ Differential Protection Relays with SEL-787-3 Differential & REF Relays
- reconfigure CT connections in two transformer 22kV CB’s
- transformer Gas & T/C Protection
  - retire Group-2598 Gas & T/C Protection
  - install two (2) SEL-2414 Gas & T/C Protection Relays
- transformer Voltage Control

  - retire two (2) 2V161-2203 VRR’s
  - retire group-2654 Transformer Parallel Control
  - retire DED-466 (Modified) Air CB, Fuses & Setpoint
  - retire group-2634 Transformer Alarm & Prot Inhibit Aux
  - install SEL-451 as VRR
- transformers
  - retire existing OLTC controls
  - install two (2) transformer control interface boxes
- station U/V & O/V
  - retire group-2506 U/V & O/V relay
  - utilise SEL-2440 relays in transformer control interface boxes, with alarms visible on HMI
- modification of existing Capacitor Bank
  - install new current neutral balance CT’s
  - retire M1AM-3238 Cap OC & EF Protection
  - retire group-2749 Neutral Balance Protection
  - retire capacitor controls on mimic
  - retire DED-1488 capacitor control
  - retire group-2932 interposing relays
  - retire DED-0753A var sensing
  - install SEL-351S CB Management relay incorporating Overcurrent & Earth Fault Protection
  - install GE-F35 Step Switch Management and Neutral Current Balance Protection Relay
  - install SEL-2411 Capacitor Control
- install new Elspec Power Quality Meter
- modification of existing substations communications network configuration
  - install six (6) new RSG 2100 Sub-LAN Ethernet Switches
  - install two (2) new Fortigate 60 Firewall units
  - install SEL-3530-4 station RTAC RTU
  - install Tekron GPS Clock
  - install TPC-1551WP station HMI
- install weather station
- extend station yard and earth grid as required to accommodate ASC

2.1 Primary plant requirements

The works associated with the installation of the BGO ASC's is summarised in the following single line diagram:

Figure 2.1 BGO neutral diagram



2.1.1 Arc suppression coil

Install 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 capacitor bank:

- install 2 off Ground Fault Neutralisers comprising of 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 phases 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

BGO has one 22kV capacitor bank.

The existing No.1 22kV Capacitor Bank comprises of four (4) 3.0MVAR internally fused banks with earthed neutrals. There is existing neutral balance protection. CTs on the neutral feed into the MEF and BUEF relays.

To facilitate GFN installation, the earth must be removed from the No. 1 22kV Capacitor Bank and the neutral must have sufficient insulation to allow for a neutral voltage rise during REFCL operation on ground fault. No. 1 22kV Capacitor Bank neutral shall be modified and made suitable for a sustained 13kV voltage.

- The star point shall be reconfigured as a floating neutral, and the neutral structure re-designed with a continuous insulation rating of not less than 13kV
- Install voltage protection (surge diverters) ABB MWK 22L
- Remove the earth connection CTs and disconnect from the earth fault protection schemes
- Install new current neutral balance CTs
- Reconfigure current balance protection.

2.1.4 Station Service Transformers

Retire the two existing 50kVA 22kV Station Service Transformers.

Install a new 500kVA 22kV No. 1 Station Service Kiosk Transformer and a new 500kVA 22kV No. 2 Station Service Kiosk Transformer to replace the existing station service transformers.

- Connect the No. 1 Station Service transformer to the No.1 22kV bus via HV fuses supplied from the BGO11 CB as is the existing arrangement
- Connect the No. 2 Station Service transformer to the No.2 22kV bus via HV fuses supplied from the BGO24 CB as is the existing arrangement.
- Connect to AC changeover board located within the 22kV switch room

2.1.5 Neutral system arrangement

Two (2) new kiosk type ground mounted Neutral Bus modules shall be installed alongside the NER or ASC. The neutral bus module comprises of circuit breaker or isolation switches to facilitate selection of transformer neutral earthing or earthing via the NER while the ASC is out of service and as independent isolation of transformer neutrals in case of an internal fault.

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 and NER CB Open)
- NER in service (Solid Ground CB open and ASC CB Open)
- independently isolating each transformer neutral.

Neutral Bus Arrangements

Refer to Figure 2 for connections.

Transformer 1

Transformer 1 Neutral Bus will be a Type A module. This shall consist of four (4) circuit breakers and a bus VT.

The four CB's shall be arranged as follows:

- Transformer 1 Neutral
- ASC 1
- Neutral Bus Tie to Transformer 2 Neutral Bus
- NER

Transformer 2

Transformer 2 Neutral Bus will be a Type B2 module. This shall consist of three (3) circuit breakers, an isolation switch and a bus VT.

The three CB's shall be arranged as follows:

- Transformer 2 Neutral
- ASC 2
- Spare

The isolation switch shall be arranged as follows:

- Neutral Bus Tie to Transformer 1 Neutral Bus

Neutral Bus Connections

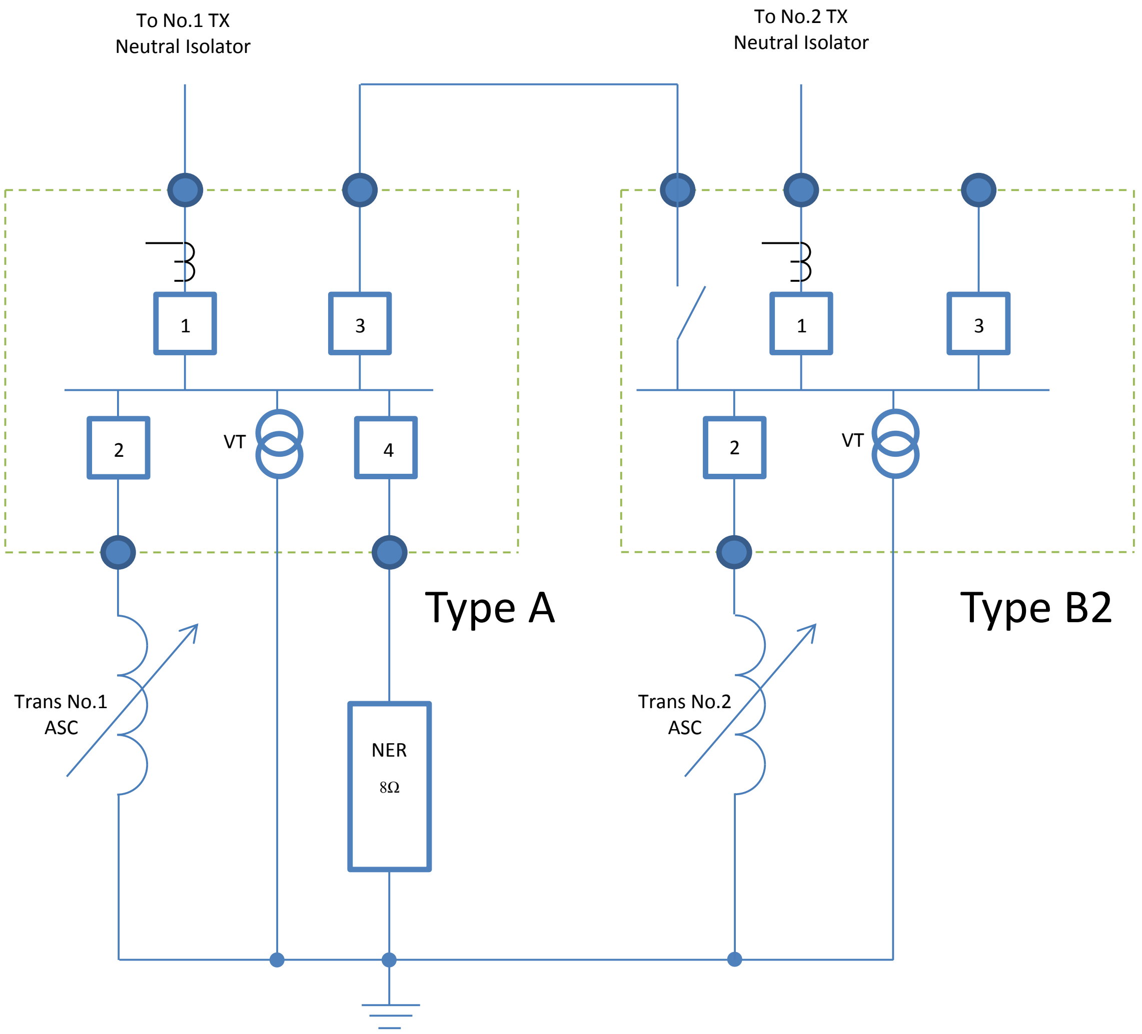
The connection to the Neutral Bus module shall be via elbow connections. Four (4) elbows are required at one module and three (3) at the other for;

- Transformer Neutral connection (2 transformers)
- Neutral Bus Tie
- ASC Connection
- NER Connection

Neutral Bus 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 2.2 Proposed BGO neutral system single line diagram



2.1.6 Transformer earthing

The two (2) 66/*22kV transformers* in service at BGO are delta/star connected with isolators to allow the neutral of the star windings to be either solidly earthed or earthed via a NER.

The neutral earthing arrangement for each transformer shall be modified to incorporate the following parallel connections as shown in Figure 1:

- Surge diverter rated at 19kV (must be able to withstand 12.7kV neutral voltage under earth fault conditions)
- Retire the direct cable connection from the neutral of each transformer to the NER
- HV single phase cable connection to a Neutral Bus module via isolation switch at transformer end
- Neutral bus module connection via circuit breaker at the Neutral bus Module

The transformer neutrals from each transformer shall be connected to a Neutral Bus module using a HV insulted single phase cable installed underground from the existing transformer neutral earthing point to the HV CB (via the elbow connections) on the Neutral Bus modules (RMU).

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

2.1.7 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.

2.1.8 Neutral Earth Resistor

The existing Neutral Earthing Resistor (NER) is connected to each transformer neutral via an isolating switch at each transformer. This existing connection is to be retired and the NER is to be connected to a neutral bus module as shown in Figure 2

2.1.9 66kV yard

It is expected that an extension of the BGO 66kV yard onto the Stanley St side of the property will be required to fit two ASCs along with the two neutral bus modules. There is space on the property for an extension in the area presently used for vegetation to screen the station. Determine if a yard extension is required and if so extend the station yard, earth grid and security fence on Stanley St side to accommodate the ASC.

Plant screening trees on the property to replace the screening from any removed to extend the yard.

2.1.10 22kV feeder CTs

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 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
BGO011	10P30	Not suitable for sensitivity requirements, require new CT installation.
BGO012	10P30	Not suitable for sensitivity requirements, require new CT installation.
BGO013	10P30	Not suitable for sensitivity requirements, require new CT installation.
BGO021	10P30	Not suitable for sensitivity requirements, require new CT installation.
BGO022	10P30	Not suitable for sensitivity requirements, require new CT installation.
BGO023	10P30	Not suitable for sensitivity requirements, require new CT installation.
BGO024	10P30	Not suitable for sensitivity requirements, require new CT installation.

At BGO zone substation, 7 (seven) feeder CTs are required to be installed. As the 22kV switchboard houses these CTs, an appropriately sized set of CTs is to be installed, similar to those installed at WND zone substation.

- 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

- Install CT's and modify secondary relay settings for new CT ratio's and test CT polarity.

2.1.11 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 BGO 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 bus
- Install neutral cable conduits from NER to neutral bus
- Install conduits for secondary circuits

For ASC:

- Extend station yard, earth grid and security fence on Stanley St side as required to accommodate the ASC.
- 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.
- Install blast wall

For station service supplies:

- Install concrete foundation pad for a two (2) 500kVA kiosk transformers.

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 drawings for the station.

2.3.1 Protection Schemes

Master Earth Fault, Neutral Overvoltage & Neutral Bus Management

The Group-2630 Master Earth Fault relay shall be retired.

A GE-F35 relay shall be installed and configured with the sensitive ground CT option and provide the facility for a Master Earth Fault relay scheme. The relay shall also incorporate the station 22kV and neutral VT's and be configured to provide neutral voltage protection & supervision. This relay will also incorporate CB Management functions of the Neutral & ASC CB arrangement.

Station X MEF and Neutral Bus Management relay (GE-F35)

- The relay will execute and manage the following functions:
  - X Master Earth Fault relay for low impedence earth in service applications
  - Neutral Voltage Supervision
  - Neutral Bus CB Management

Station Earth Fault Management

Station Earth Fault Management relay (SEL-451 Control Relay configured for Station Earth Fault Management).

- The relay shall provide 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
  - provides remote and local controls, and indications

22 kV feeder protection

The existing SEL-351S feeder management relays do not have IED Ethernet functionality. The relays shall be replaced in the existing locations with IED compatible SEL-351S relays. All existing wiring is to remain, apart from SCADA and engineering access that will be replaced with fibre Ethernet connection.

Feeder Protection & CB Management relays (SEL-351S)

- Install 7 off relays, 1 per 22kV feeder
- The relays shall provide the following functions:
  - OC & EF protection
  - Auto reclose
  - CB management, including local and remote controls
  - Integration with GFN protection for detecting compensated earth faults

66kV & 22 kV CB management

The GFN control system requires relays with IED functionality for GOOSE signalling on the following CBs:

- Transformer 1, 22kV CB
- Transformer 2, 22kV CB
- 1-2 22kV Bus-Tie CB

The existing ‘X’ CB Fail relays for each of these CB’s are in a cubicle that also contains the 66kV CB A ‘X’ CB Fail relay. All ‘X’ CB Fail relays in the cubicle, including for 66kV CB A shall be replaced.

The Group-2753 ‘X’ CB Fail relay for each CB shall be retired and replaced with a SEL-351S CB Management and Back-Up for CB Fail relay. The CB control fuses shall also be retired and replaced with new CB control MCB’s. The CB controls and metering for each CB shall also be retired from the mimic. Retire ‘X’ Supplementary Back-Up for CB Fail in Cubicle-3166 for CB’s 66kV CB A, Tr1 22kV CB & Tr2 22kV CB.

- Install 4 CB Management relays (SEL-351S) relays on the following CBs:
  - 66kV CB A
  - Transformer 1, 22kV CB
  - Transformer 2, 22kV CB
  - 1-2 Bus-Tie 22kV CB
- The relays shall provide the following functions:
  - CB management, including local and remote controls
  - Back-Up for CB Fail
  - Supplementary Back-Up for CB Fail (if still required)

Transformer Differential Protection

The existing ‘X’ and ‘Y’ transformer differential relay have a delta connected CT on the 22kV side. The GFN controls require a neutral from a star connected CT. To change one set of CT’s from delta to star connection will require the replacement of the differential relay, where the phase shift configuration across the transformer can be managed inside the relay.

The Group-2819 ‘X’ transformer differential relays shall be retired and replaced with a SEL-787-3 transformer differential relays.

- Install 2 new t Transformer Differential relays (SEL-787) relays for transformers 1 & 2
- The relays shall provide the following functions:
  - Transformer differential protection
  - REF protection

As part of the works, all functionality in the Cubicle-3166 REF Protection Package shall be retired and be replaced in other relays as required. The Cubicle-3166 Package (Cub-20) shall be retired.

Transformer Gas & T/C Protection

The two GFN option will require BGO to operate with an open 22kV Bus-Tie CB when 2 GFN’s are in service. This will require the transformer voltage control to be replaced to allow for independent voltage control when the buses are split. As part of the changes for the new voltage controls, the Gas & T/C Protection Relays will be replaced to integrate isolation processes.

The Group-2598 Transformers Gas & T/C Protection relay and Group-2634 Transformer Alarm & Protection Inhibit Auxiliary relay shall be retired and replaced with two SEL-2414 Transformers Gas & T/C Protection relays. They will utilise remote IO via IEC61850 in the SEL-2440 to be installed for voltage control at the transformer (refer 0.- 22 kV Voltage Control).

- The transformer Gas & T/C protection relays (SEL-2414) shall provide the following functions:
  - Transformer Gas & T/C Protection
  - Alarm & Protection Inhibit

22kV Capacitor Bank No 1 Protection & CB / Step Switch Management

The GFN installation requires the capacitor bank star point to be un-earthed and left floating. The capacitor current balance protection will need to be replaced for this.

The capacitor bank protection relay will also need to be replaced to provide integration into the REFCL scheme.

The M1AM-3238 O/C & E/F relay shall be retired and replaced with a SEL-351S CB Management and Protection relay. The Group-2749 Neutral Balance relay shall be retired and replaced with a GE-F35 Step Switch Management and Neutral Balance Protection relay.

- Capacitor Protection and CB Management (SEL-351S) relay shall provide the following functions:
  - OC & EF protection
  - CB management, including local and remote controls
- Retire CB control and metering for CB on mimic.
- Capacitor Step Protection and Step Switch Management (GE-F35) relay shall provide the following functions:
  - current neutral balance protection for 4 off capacitor steps
  - CB management, including local and remote controls for 2 off step switches
- Retire step switch control on mimic.

22kV Capacitor Control

To allow for possible split bus capacitor bank control, the capacitor bank auto controller will be replaced.

The following relays will be retired:

- DED-1488 Capacitor Control
- Group-2932 Interposing Relays
- DED-0753A Var Sensing

The following relays shall be required:

- SEL-2411 Capacitor Control

22 kV Voltage Control

The station shall now be required to operate in split 22kV bus mode with the 22kV Bus-Tie CB open. This will require the transformer voltage control to be replaced to allow for split bus, independent voltage control.

- Retire 2 2V161-2203 Voltage Regulating Relays
- Retire Group-2654 Transformer Parallel Control Relay
- Retire DED-466 (Modified) Air CB, Fuses & Set Point
- Install SEL-451 Control Relay configured as Voltage Regulating Relay

- Install 2 Transformer Interface Boxes each consisting of:
  - SEL-2440 Remote IO Module
  - REG-SK1 TPI BCD Encoder
  - Transformer control MCB's, including remote control for OLTC AC Supplies
- Voltage Regulating Relay (SEL-451) will execute and manage the following functions:
  - Parallel Voltage Control
  - Independent Voltage Control (for open 22kV Bus-Tie CB)
- Digital IO and Analogue Inputs shall utilise IEC61850 signalling – Refer WND VRR design
- Remote IO Module (SEL-2440) will provide remote IO points for transformer voltage control and Gas & T/C Protection
- TPI BCD Encoder (REG-SK1) will take individual transformer Tap Positions from the radial switch that was previously used for Out Of Step detection and encode as BCD to be used as inputs to the SEL-2440

22 kV UV/OV Supervision

The station shall now be required to operate in split 22kV bus mode with the 22kV Bus-Tie CB open. This will require separate 22kV UV/OV supervision to be installed on each bus.

The Group-2506 Station U/V & O/V relay shall be retired.

22kV Undervoltage & Overvoltage Supervision shall now be performed in the SEL-2440 relays in the Transformer Interface Boxes (refer - 22 kV Voltage Control). This will execute and manage the following functions:

- Undervoltage Alarm Initiation
- Overvoltage Alarm Initiation
- VRR interlocking

RTAC RTU and HMI

- Install RTAC RTU for new HMI.
- Install HMI.

2.3.2 Metering Schemes

Where being installed, CB management relays will replace mimic and remote metering.

22 kV PQM

- Existing ION-7650 PQM to be retained, moved and reconfigured for transformer 1 only.
  - The PQM will be moved to free the cubicle for installation of the new transformer protection relays.
- An additional ION 7400 PQM shall be installed and configured for transformer 2.
  - With split 22kV bus operation, separate PQM monitoring will now be required for each bus.

GFN PQM

- Install Elspec PQM & data recorder

This recorder is capable of recording 16 analogue & 32 digital channels of data at a sampling rate of 1000 samples per cycle. 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 (ie transformer currents). The purpose of this recorder is to aid with GFN commissioning and long term monitoring.

The ELSPEC shall be time stamped by NTP.

2.3.3 Ground Fault Neutraliser

Control Cubicle

The GFN control unit is a single cubicle per GFN 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

The cubicle will contain an interface controller in the form of a SEL-2440 DPAC control unit in the top 2U of this cabinet.

VT Supplies (R,W,B & N) are required from the bus into the GFN controller along with Transformer neutral summation (I_N) circuits.

Inverter

The Residual Current Compensation technique used by the GFN requires an Inverter to inject current into the ASC via an auxiliary winding. The inverter must be sized to displace the full capacitive current drawn by the system and as a result requires significant power.

The inverter shall be installed in the control room or a separate air conditioned hut as per ZD090 in the switchyard. If installed in the control room, venting of heat from the inverter shall be evaluated to ensure the control room does not get too hot under GFN operation. Inverter AC Supplies are to be supplied from the new station service transformer.

2.3.4 VT supplies

Auxiliary transformer for GFN

A VT supply from the new 22kV Bus VT is required to the GFN control unit. For earth fault detection, an open delta (U_N) input is required from the 22kV bus VT at 110V secondary. To achieve this, Swedish Neutral has provided an auxiliary transformer in their GFN control cubicle. R, W, B supplies from the 22kV transformer VT auto voltage changeover shall be made available to the GFN system.

22kV Transformer VTs

The VTs on the 22kV transformer CBs are of an unknown voltage rating and shall be replaced so as to be suitable for GFN operation. They shall be replaced with units capable of 1.9 times nominal voltage for a period of 8 hours.

2.3.5 Protection settings

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

Feeder protection relays will have configuration review to introduce Directional SEF functionality.

2.3.6 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.

2.3.7 Control and monitoring requirements

- Remote Control and Monitoring of new;
  - X MEF, Neutral Voltage & Neutral System CB Management Relay (GE- F35)
  - Station Earth Fault Management Relay (SEL-451)
  - 22kV Feeder Protection Relays (SEL-351S)
  - 66kV CB A Management Relays (SEL-351S)
  - 22kV Transformer & B-T CB Management Relays (SEL-351S)
  - Transformer Differential Relays (SEL-787E).
  - Transformer Gas & T/C Protection Relays (SEL-2414)
  - Voltage Regulating Relay (SEL-451)
  - Transformer Remote IO Module (SEL-2440)
  - Capacitor Protection and CB Management (SEL-351S)
  - Capacitor Step Protection and Step Switch Management (GE-F35)
  - Capacitor Controller (SEL-2411)
  - GFN IO Module (SEL-2440)
  - GFN Controller
  - ELSPEC Power Quality recorder

Remote control and monitoring 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.

2.3.8 Communications Requirements

Ethernet Connectivity

6 zone substation Sub-LAN RSG-2100 Ethernet switches shall be installed. GFN controls shall utilise IEC61850, so redundant Ethernet paths will now be required to all devices utilising IEC61850.

All communications shall be over 100 BASE-FX (optic fibre) Ethernet back to the zone substation Sub-LAN RSG-2100 Ethernet switches.

4 existing RS400 Serial Servers are to be moved from main Ethernet switches to Sub-LAN switches. RJ45 ports on RS400's are to be used for devices requiring RJ45 Ethernet connection.

2 Fortigate 60D Firewall units shall be installed to link the Sub-LAN switches to the main station Ethernet Switches.

Refer to Appendix for Ethernet connectivity.

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

A new Tekron TCG-01 GPS Clock is to be installed for time stamping all equipment. All NTP capable equipment shall synchronise with the BGO GPS NTP server

All non NTP capable equipment is to be connected to the BGO GPS IRIG-b loop.

2.3.9 415/240 AC Supplies

The existing 50 KVA station service supply transformers are located in the switchroom and are supplied from two BGO 22kV feeders (BGO11 & BGO24). The size of these station service transformers will not be adequate for the RCC inverter used to drive faulted phase voltage to zero via the Arc Suppression Coil.

This station service transformers shall be replaced with 2 off 500kVA kiosk type station service transformers supplied from the same 22kV feeders with LV mains upgraded accordingly (subject to space constraints).

- The AC Supplies must ensure capacity and reliability requirements are fulfilled for the ARC Suppression Coils.
- A new AC Changeover Board shall be installed
- Current limiting fuses are to be installed on distribution AC board supplies.
- Upgrade existing station AC board and incoming mains such that they are compliant with existing standards
- Install AC supplies for the GFN inverter to meet its specifications
- 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.

2.3.10 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.

The additional equipment being installed may require an additional parallel battery string to be installed.

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”

2.3.11 Cubicle Works

Refer to Appendix 4.3 for proposed cubicle layouts.

Cubicle 1

- Install 1 off RSG2100 Ethernet Switch
- Install 1 off SEL-3530-4 RTAC
- Install 1 off Tekron GPS Clock
- Install 2 IDG60D Firewall

Cubicle 2

- Retire 1 off Group-2506 U/V & O/V relay

Cubicle 3

- Retire 2 2V161-2203 VRR
- Retire 1 Group-2654 Transformer Parallel Control
- Retire 1 DED-466 Air CB, Fuses & Set Point
- Retire 1 Group-2634 Transformer Alarm & Protection Inhibit Auxiliary

Cubicle 8

- Install 1 TPC-1551WP Station HMI

Cubicle 9

- Install 1 RSG2100 Ethernet Switch
- Install 1 Elspec G5 DFR PQM & Data Recorder
- Install 1 ION-7650 PQM (relocated from cubicle 11)
- Install 1 ION-7400

Cubicle 11

- Retire 1 DED-466 Data Recorder Isolation & Power Supply (if still existing)
- Retire 1 DED-500 Station Voltage Transformer & Capacitor Summation
- Relocate 1 ION-7650 PQM (moves to cubicle 9)
- Install 1 RSG2100 Ethernet Switch
- Install 1 SEL-451 VRR
- Install 2 SEL-787-3 Differential & REF Relay
- Install 2 SEL-2414 Transformer Gas & T/C Protection
- Install 2 Fibre Optic Termination Boxes (Multicore Fibres to Transformers)

Cubicle 12

- Retire 1 Group-2819 Transformer Differential Protection Relays

Cubicle 13

- Retire 1 Group-2598 Transformers Gas & T/C Protection

Cubicle 16

- Retire 1 M1AM-3238 EIT O/C & EF Prot Relay
- Retire 1 Group-2749 Capacitor Neutral Balance Protection Relay
- Retire 1 Group 2630 22kV Master E/F Relay
- Install 1 RSG2100 Ethernet Switch
- Install 1 GE-F35 Capacitor Neutral Balance Protection & Step Switch Management Relay
- Install 1 SEL-351S Capacitor Protection & Management Relay
- Install 1 GE-F35 MEF, Neutral Voltage & Neutral System CB Management Relay

Cubicle 18

- Retire 3 SEL-351S Feeder Management Relays
- Install 3 SEL-351S Feeder Management Relays (with IED Ethernet)

Cubicle 19

- Retire 4 SEL-351S Feeder Management Relays
- Install 4 SEL-351S Feeder Management Relays (with IED Ethernet)

Cubicle 20

- Retire 1 Cubicle-3166 Restricted Earth Fault Package

Cubicle 24

- Retire 1 DED-1488 Capacitor Control Unit
- Retire 1 DED-2932 Capacitor Interposing Relays
- Retire 1 DED-0735A Var Sensing Rack
- Install 1 RSG2100 Ethernet Switch
- Install 1 SEL-2411 Capacitor Var Controller

Cubicle 25

- Install 4 SEL-351S CB Management Relay
- Install 1 SEL-451 Station Earth Fault Management Controller

Cubicle 26

- Retire 4 Group-2753 CB Fail Relays

Cubicle 27

- Retire 2 DED-316 Auto CT's
- Install 1 GE-F35 BUEF

Cubicle 28

- Install 1 RSG2100 Ethernet Switch

Cubicle 29

- Install 1 GFN Control Cubicle

Cubicle 30

- Install 1 off GFN Control Cubicle

2.3.12 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.

2.3.13 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.

2.3.14 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.

2.3.15 Radio

No radio communications are required.

2.3.16 Weather Station

A weather station is to be installed 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.

2.3.17 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 1,832 surge diverters across the 22kV three phase and single phase system.

This covers all feeders ex BGO 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 BGO distribution network contains four 22kV regulating systems:

Table 4 BGO regulating systems

Feeder	Name	Manufacturer	Phasing	Issue
BGO013	STRATHFIELDSAYE P35 REG	COOPER	2 x 200 A	Open delta with independent voltage control.
BGO023	AXEDALE P232 REG	Unknown	5 MVA	No Issue
BGO023	GREYTOWN P110 REG	Wilson Elec	1 MVA	No Issue
BGO023	HEATHCOTE P397 REG	Unknown	5 MVA	No Issue

The following regulator requires modification in order to meet the requirements for installing the GFN.

3.4.1 Strathfieldsaye P35 regulator

Strathfieldsaye P35 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 supplied from BGO zone substation contains a significant amount of single phase lines. Whilst planning philosophies have always attempted to balance the single phase system, inevitably this is difficult to achieve and the objective has been load balancing rather than capacitive balancing. In order to balance the capacitance of the three phase system such that the ASC can be correctly tuned, balancing substations that utilise low voltage capacitors to inject the missing capacitance onto the system are to be placed at selected locations on the 22kV distribution system in addition to courser balancing by altering phase connections of single phase lines.

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	11
3 Phase Balancing Units	27

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

Each RVE or VWVE ACR on the BGO 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
AXE CREEK P18 ACR	22kV	RWB	VWVE27
HEATHCOTE P399 ACR	22kV	RWB	VWVE27
AXEDALE P233 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
COSTERFIELD P1 ACR	CAPM5
STRATHFIELDSAYE P70 ACR	CAPM5

Table 8 ACR and control box requirements summary

Units	Number of sites
ACR replacements	3
Control box replacements	2

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	22
ACRs	0

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	3,524

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)
BAYMONT-EXETER	315
BRAMBLE-MUNDY	500
CONDON-ALLISON	1000
HARPIN-STRICKLAND	500
KING-ARTHUR	500
MC IVOR-MICHAEL	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

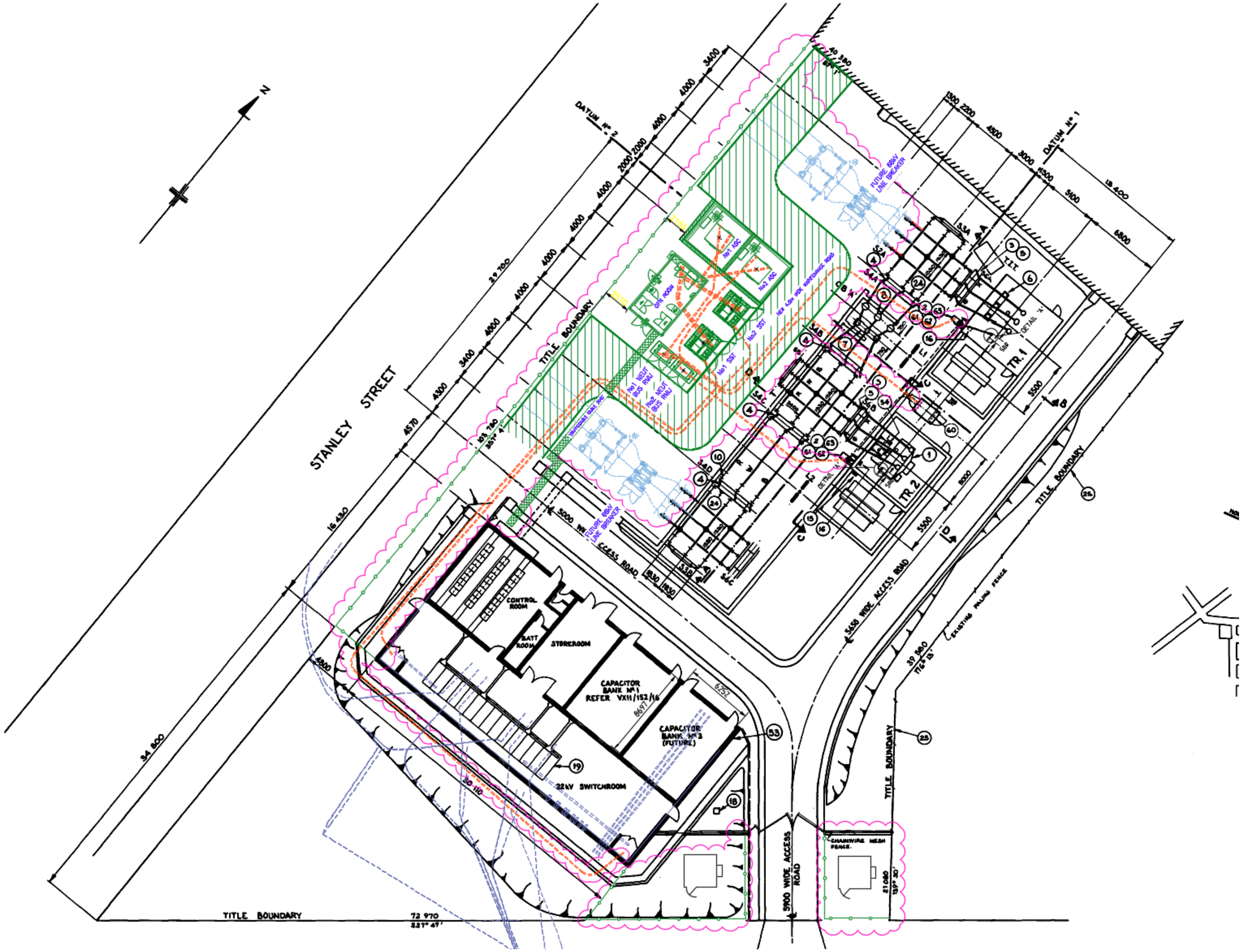
HV customer connection sizes are set out in table 12.

Table 12 Isolation substation requirements

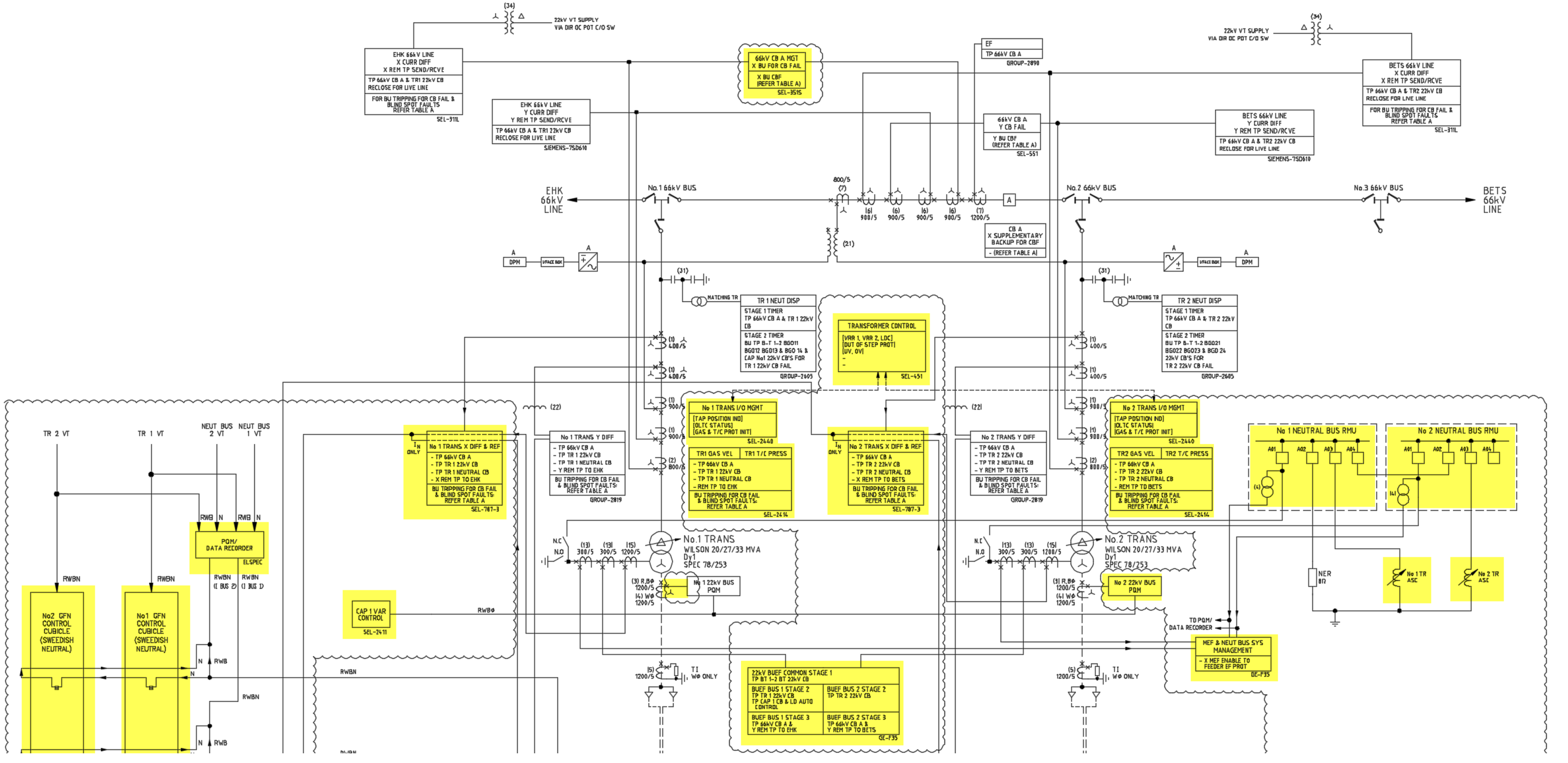
Size	Quantity
6 MVA	2

4 Appendix

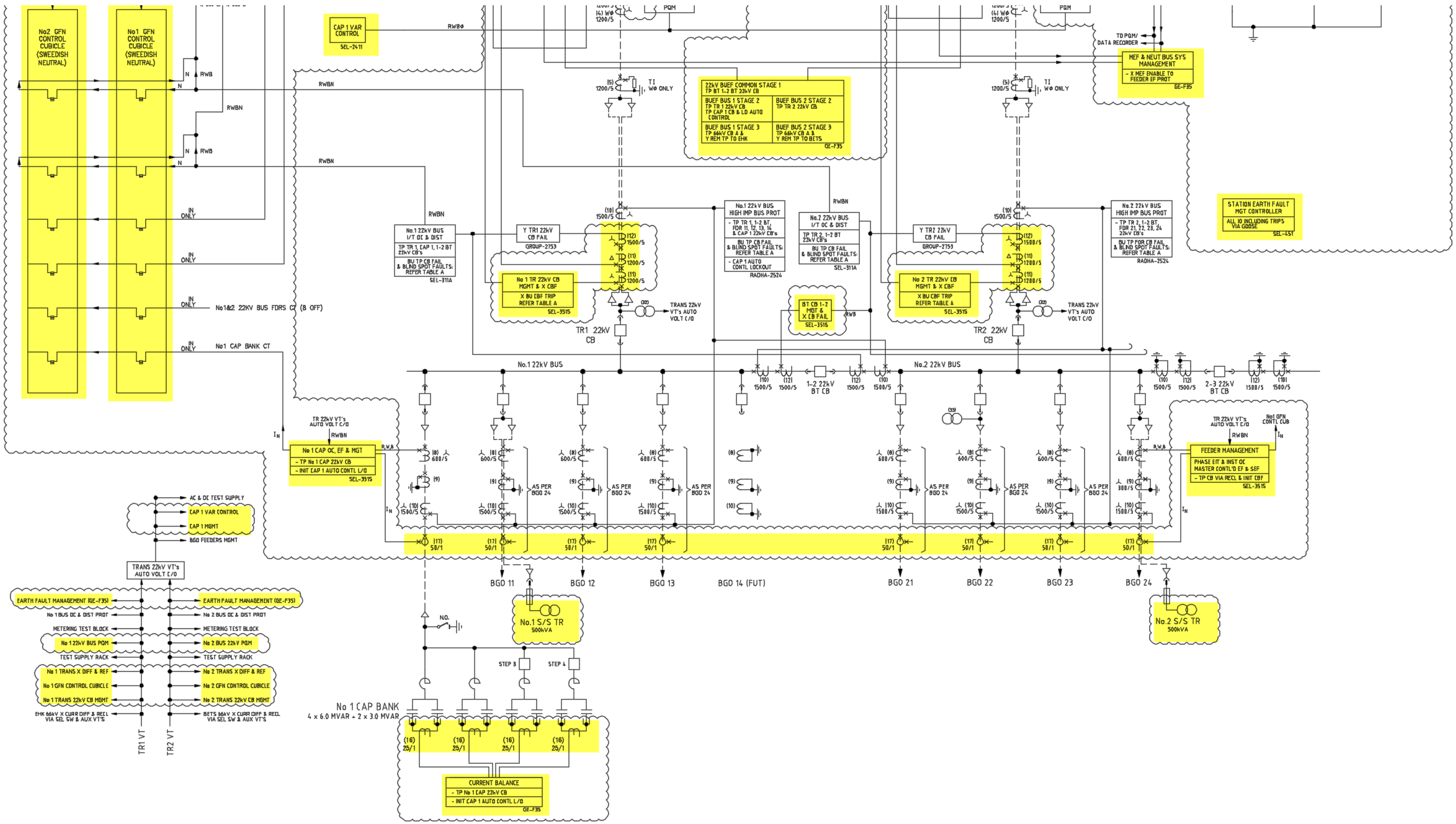
4.1 Proposed Site General Arrangement



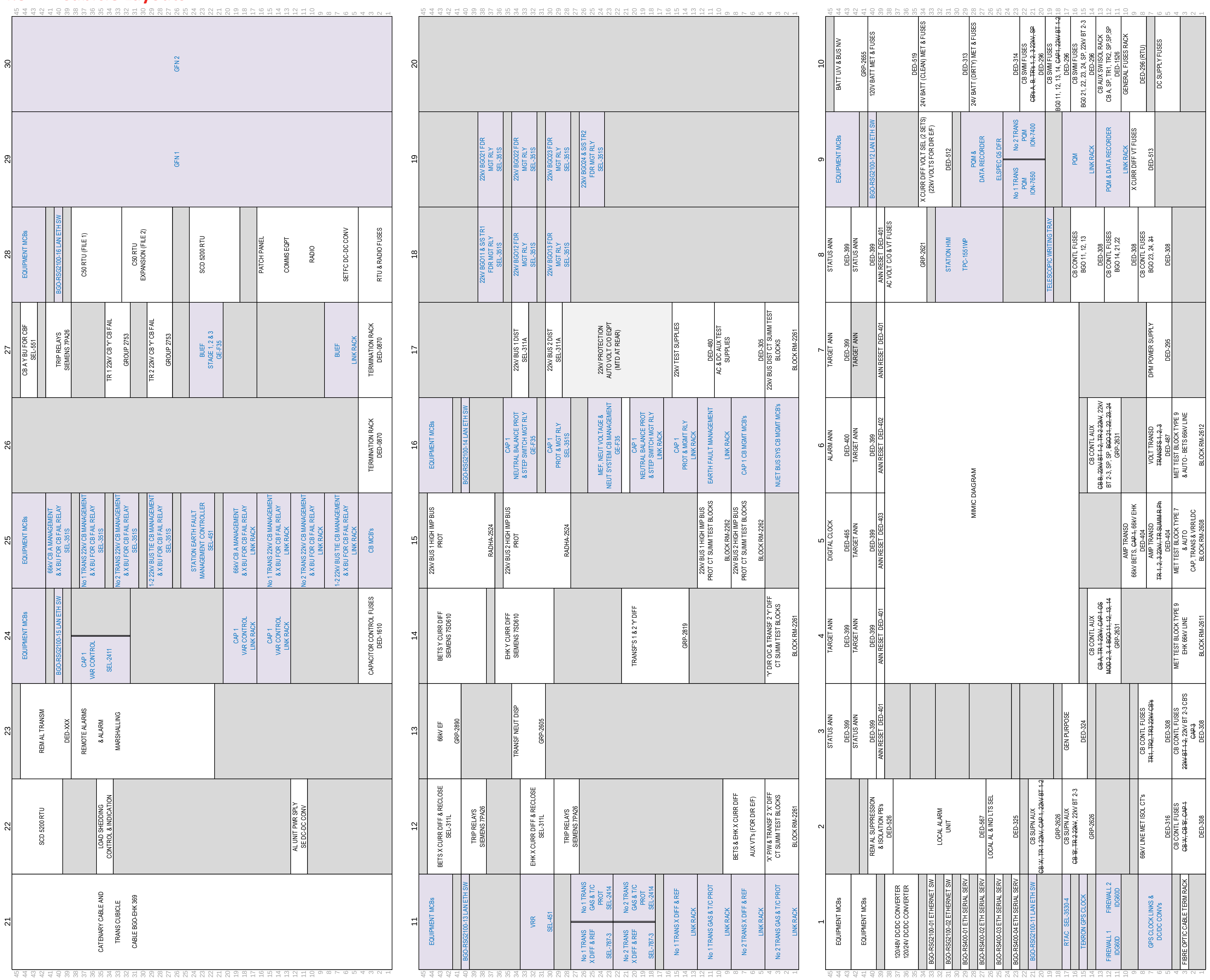
4.2 Protection Schematic (Part)



Protection Schematic (Contd.)



4.3 Cubicle Layouts



4.4 Ethernet Connectivity