CitiPower	ELECTRICITY NETWORKS Asset Strategy and Performance Functional Scope	Powercor Australia

ELECTRICITY NETWORKS

Asset Strategy and Performance

Functional Scope

Functional Scope Created	**6 June 2017**	**By**	Frank Argus		
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1.0	6/06/2017	Original	F. Argus
1.1	8/06/2017	Added Protection and Control Requirements	V Stojakovic
1.2	28/07/2017	Reviewed balancing unit requirements	V.Hadya

1 Project overview

This project scope covers the migration of the Charlton zone substation (**CTN**) 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 Charlton zone substation

CTN zone substation is located in western Victoria and consists of three transformers and six 22kV feeders.

The three transformers are in a banked arrangement and a fault on any one transformer will cause the loss of all three.

Table 1 CTN: existing characteristics (zone substation)

Zone substation	Volume
Feeders	6
Zone substation transformers	3
22kV buses	3
Capacitor banks	2
Station service transformers	1
22kV circuit breakers (switching configuration)	0 (Banked)

Table 2 CTN: existing characteristics (network)

Network	Volume
Total route length (km)	1184
Underground cable length (km)	5
Overhead line length (km)	1179
Underground network (%)	0.40
Overhead single phase	319
Estimated network capacitance (A)	93
Distribution transformers	884
HV regulator sites	24
Fuses	1106

Network	Volume
ACRs	15
Surge arrestor sites	694
HV customers	4

2 ZSS requirements

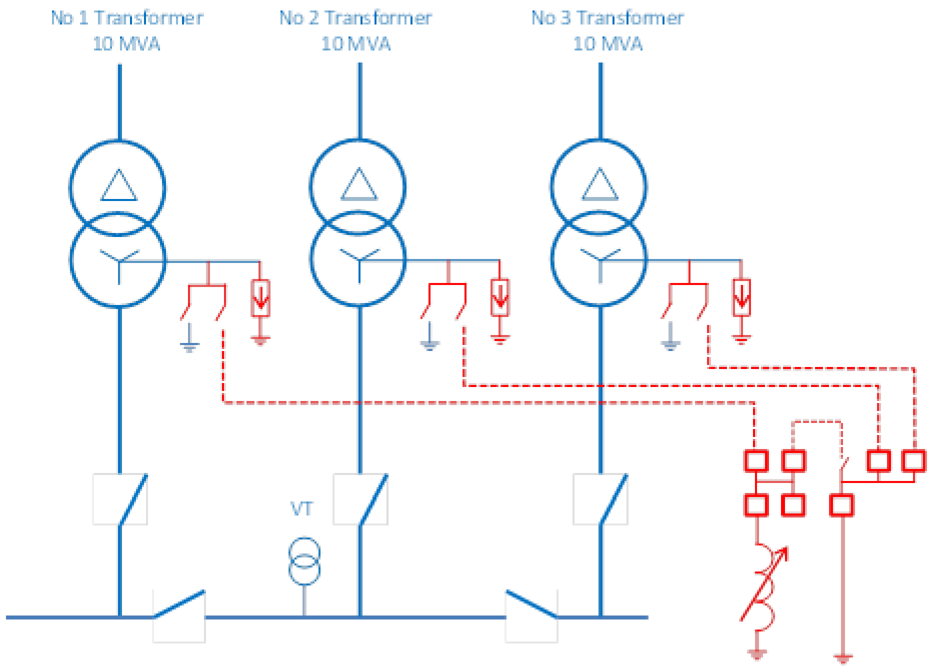
This functional scope sets out the CTN zone substation requirements, including the following:

- establish ASC bund
- install single Swedish Neutral GFN arc suppression coil
- modification of the 22/66kV transformer earthing arrangement
  - installation of two (2) Neutral Bus System
    - bus CBs
    - ASC termination
    - neutral VT installation
  - installation of neutral ground bypass isolators
  - installation of 19kV surge arresters across transformer neutrals
- replace station service supply transformer with a new 500kVA kiosk transformer
- upgrade of the station service supply cabling and installation of new AC distribution board.
- replace one (1) 22kV VT
- replace ALL substation surge arrestors with new 22kV continuous voltage units for resonant network compatibility and 10hr 24kV TOV capability
- development and Installation of Station Earth Fault Management control relay
  - adoption of existing MEF function
  - neutral voltage supervision
  - neutral bus CB management functions
- upgrade six (6) SEL-351S 22kV feeder protection relays to IEC compatible units
- install and commission GFN control and RCC inverter cubicles
- modification of existing capacitor bank
  - remove HV earth from star point
  - install new CB management relay incorporating overcurrent & earth fault functions
- install new Elspec power quality meter
- modification of existing substations communications network configuration
  - install new RSG 2100 Ethernet switches
- install weather station.

2.1 Primary plant requirements

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

Figure 1 CTN single line 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 to the north of the 66kV bus as shown in the proposed general arrangement.

- install 1 off Ground Fault Neutraliser comprising of 1x 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

CTN has two 22kV capacitor banks. The current configurations of these units are as follows:

- the existing No.1 22kV Capacitor Bank comprises of four (4) 2.0MVAR externally fused banks with earthed neutrals. There is existing neutral balance protection. CTs on the neutral feed into the MEF and BUEF relays
- the existing No. 3 22kV Capacitor Bank comprises one (1) 2.0 MVAR bank. This is an enclosed type with an unearthed star point. This bank has current balance protection.

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:

- 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 a station class 19kV surge arrestor between the neutral and earth
- remove the earth connection CTs and disconnect from the earth fault protection schemes.

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 at one module and three (3) at the other for:

- transformer neutral connection (3 transformers)
- 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.

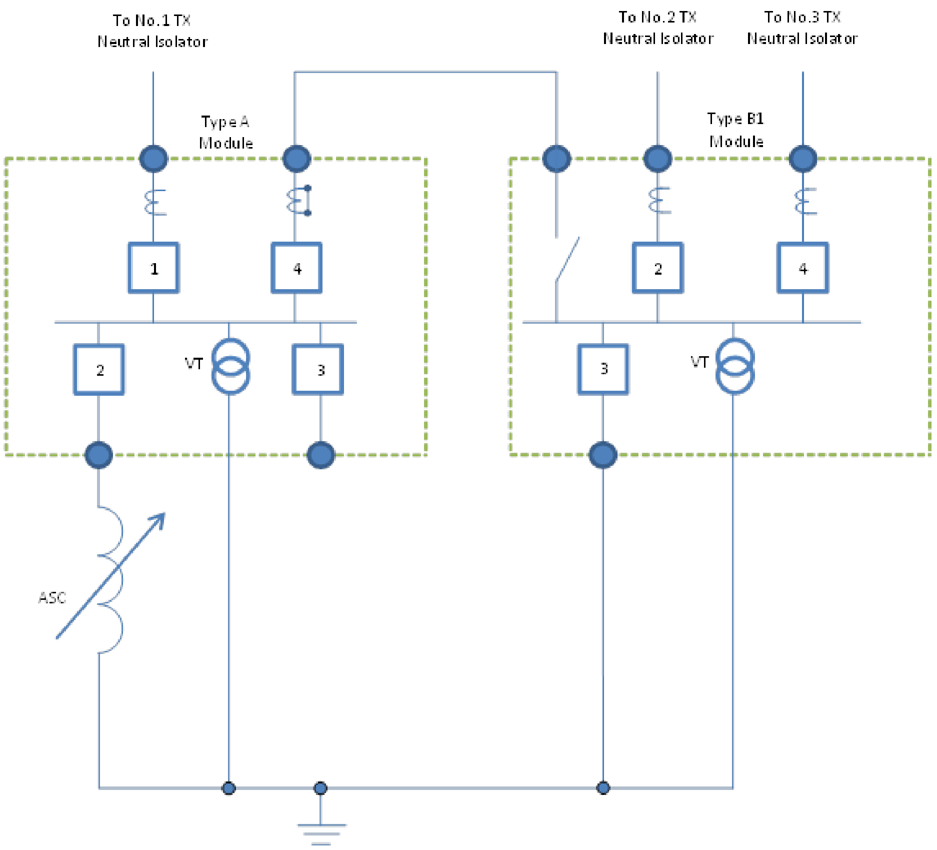


Figure 2 Proposed CTN neutral system single line diagram

2.1.5 Transformer earthing

The three (3) 66/22kV transformers in service at CTN are delta/star connected with the neutral of the star windings solidly earthed.

The neutral earthing arrangement shall be modified to incorporate the new earthing arrangement (refer SLD) with connection to the ASC. The transformer neutral shall have a new HV insulated single phase cable installed underground from the existing transformer neutral earthing point to the HV CB via the 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 VT

Replace the existing No. 2 22kV bus VT 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.

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
CTN001	0.2PL100 300/5	Suitable for sensitivity requirements
CTN002	5P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
CTN003	5P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
CTN004	5P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
CTN005	5P100 300/5	Not suitable for sensitivity requirements, require new CT installation.
CTN006	0.2PL100 300/5	Suitable for sensitivity requirements

At CTN 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 CTs
  - note: factory acceptance of CTs requires non-standard testing to confirm accuracy of zero sequence measurement through full range of load
- Minor relocation of existing bus structure to facilitate the installation of a new 22kV structure in each feeder bay that requires new CTs.
- Installation of new 22kV CT mounting structure in each feeder bay that requires new CTs
- Install CTs and modify secondary relay settings for new CT ratio's and test CT polarity.

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 conduits for secondary circuits

For 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.

For station service supplies:

- Install concrete foundation pad for a 500kVA kiosk transformer.

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 1 – Station RTU

- install one (1) RTAC SEL-3530 for HMI
- install one (1) Advantech TPC-1551WP HMI Screen

Cubicle 2 – Station Differential

Firmware Upgrade of SEL-387E Transformer Differential protection to allow for received GOOSE Trips from the SEL-451 Station Earth Fault Management.

Cubicle 101 & 102 – 66kV Line protection

- install 2 x RSG2100 Sub LAN Ethernet switch

Incorporate new RSG2100 switches into existing Ethernet loop and connect IEDs as per Ethernet connectivity diagram provided in appendices.

Cubicle 103 – STATCOM & Capacitor Banks Voltage Control & No.3 Cap Bank Neutral Balance Protection

- Install one (1) SEL-451 Station Earth Fault Management relay and associated MCBs

Station Earth Fault Management relay is require to perform the automated control of the GFN installed at the substation. This 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

Cubicle 104 – X Master Earth Fault

- Remove existing 1 x 2C138 X Master Earth Fault protection relay & associated wiring
- Install one (1) GE F35 X MEF and Neutral Bus Management relay & associated MCBs

GE F35 X MEF and Neutral Bus Management relay shall provide the following functions:

- Master Earth Fault relay for NER/direct earth in service applications
- neutral voltage supervision
- neutral CB management

Cubicle 4 – Transformer Metering

- Install one (1) ELSPEC Power Quality Meter and Data recorder & associated link rack and MCBs

Panels 11 & 12 – Feeder Management (22kV No.1 & 3 Bus Feeders)

- The existing SEL-351S relays firmware version to be upgraded to accept software version Z106. Existing setting file version Z102 to be converted to Z106 with IEC61850 logic
- Feeder relay configuration shall provide external protection trip initiations via IEC61850 GOOSE
  - these GOOSE initiations shall drive auto reclose functionality direct to lockout through the internal 79DTL function
- The CB fail functionality of the feeder CBs will be provided by the GFN controller. In this case the 66kV CB management relays will be tripped by GOOSE trip initiations from the GFN controller
- The 22kV feeders contain two sets of protection CTs, one for feeder and one for transformer/bus differential protection. The transformer/bus differential protection CTs summation will incorporate CTs installed on new station service transformer.
- 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
- RTU RS485 loops for 22kV feeder protection to be removed after DNP3 SCADA communication is established via Ethernet.

Panel 13– Cap Bank 1 Protection & Control

- Remove the cap bank No.1 neutral current contribution wiring from the MEF and BUEF protection circuit as part of the removal of the No.1 Cap bank earth connection from the neutral star point
- Existing 7SR11 relays will provide current balance protection
- In the CB management SEL-351S relay, existing configuration file (Z106) will be updated to include 61850 logic.

2.3.2 Ground Fault Neutraliser

Cubicle 5 – New GFN Controls

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

CTN Zone substation will only require one (1) GFN controller as it won't require a 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.

VT supplies (R,W,B & V_N) are required from bus into the GFN controller along with feeder and transformer neutral summation (I_N) circuits.

2.3.3 VT supplies

VT supplies 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.

2.3.4 Protection settings

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

- SEL-351S relays will have configuration changes to introduce:
  - GOOSE (via GFN) tripping capability
  - Auto Reclose integration of GFN initiated trips
  - GOOSE message isolation function
- The station MEF and BUEF schemes shall be reviewed for GFN integration (there is no REF protection at CTN)
- Transformer protection settings to be reviewed with the new larger size station transformer in service which is in the transformer protection zone.

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 Metering requirements

A Power Quality Meter (ELSPEC) meter shall be installed as part of this project.

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.

2.3.7 Control and monitoring requirements

- Remote Control and Monitoring of new:
  - SEL-351S Feeder Management Relays
  - SEL-351S Cap Bank 1 CB Management Relay
  - SEL-451 Cap Band 3 CB Management Relay (Part of STATCOM)
  - UR F35 X MEF & Neutral System CB Management Relay
  - GFN Controller
  - ELSPEC Power Quality recorder
  - SEL-351S 66kV CB A and CB C CB Management Relays

Relay communication 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

All communications shall be over 100 BASE-FX (optic fibre) Ethernet back to the zone substation Sub-LAN RSG-2100 Ethernet switches. All devices, that will utilise 61850, will maintain duplicated Ethernet connectivity through a failover arrangement.

Tripping from the GFN to the feeder CBs 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.

Given the proximity of the devices to be connected, two (2) new RuggedCom RSG-2100 switches (location specified in the panel layout drawing attached in appendices) are required at CTN.

- Install Gigabit backbone connection between the Ethernet switches
- Install fibre Ethernet links from the feeder protection relays, cap bank CB management relays, 66kV CBs management relays, X MEF & neutral system CB management relay, station EF relay, ELSPEC PQM, GFN DPAC & RTAC & HMI to each Ethernet switch
- Install fibre connections from GFN Interface controller (SEL-2440)
- Install fibre Ethernet links from BETS Line X Distance protection to each Ethernet switch (connections changed from switched to failover).
- Ensure relay configurations modified to Port Failover configuration
- Ensure Sub-LAN switch architecture configured to support fail over scenarios

A suggested Ethernet connection diagram is included in appendices.

Engineering Access

Powercor SCADA shall ensure remote engineering access is available to 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

The existing Tekron TCG-01 GPS Clock is to be used for time stamping all equipment. All NTP capable equipment shall synchronise with the CTN GPS NTP server. All non NTP capable equipment is to be connected to the CTN GPS IRIG-b loop.

2.3.9 415/240 AC supplies

The existing 63 KVA station service supply transformer is located in the switchyard and is supplied of the 22kV bus. The size of this station service transformer will not be adequate for the RCC inverter used to drive faulted phase voltage to zero via the Arc Suppression Coil.

This station service transformer shall be replaced with a 500kVA kiosk type station service transformer with LV mains upgraded to account for the upgraded capacity.

Since the station service transformer is supplied off the 22kV bus, there is no need for a second station service transformer or an AC changeover scheme.

The AC supplies must ensure capacity and reliability requirements are fulfilled for a single arc suppression coil.

- Install current limiting fuses to be installed on distribution AC board supplies.
- Install AC supplies for the existing AC board and make sure that is compliant with the existing standards.
- Install AC supplies for the GFN inverter to meet its specifications.

Ensure that the Station Service Transformer 22kV CTs (when installed) are connected into the transformer differential protection CT summation circuit along with feeders CTs.

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.

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".

The existing 24V and 120V chargers, batteries and DC distribution boards are located in the battery room and control room. New supplies will be taken from the existing boards as required.

2.3.11 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.

2.3.12 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.

2.3.13 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.

2.3.14 Radio

The existing radio communication link is used to provide DNP communication and remote engineering access with Master Station. The alternative remote access to equipment at CTN will be provided via 3G Modem and Telstra services.

2.3.15 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.

2.3.16 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 1,834 surge diverters across the 22kV three phase and single phase system.

This covers all feeders ex CTN 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 CTN distribution network contains fifteen (15) 22kV regulating systems outlined below:

Table 4 CTN regulating systems

Feeder	Name	Manufacturer	Phasing	Issue
CTN001	BIRCHIP P163 REG	COOPER- 2 x 200 A	RB	Open delta with independent voltage control.
CTN001	BIRCHIP P463 REG	Unknown- 3.75 MVA	RWB	No Issue
CTN001	BORUNG P214 REG	COOPER- 2 x 100 A	RW	Open delta with independent voltage control.
CTN001	BORUNG P79 REG	COOPER- 2 X 100 A	WB	Open delta with independent voltage control.
CTN002	BOORT P398 REG	Wilson Elec- 1 MVA	RWB	No Issue
CTN002	BOORT P399 REG	Wilson Elec- 1 MVA	RWB	No Issue
CTN002	BOORT P51 REG	Wilson Elec- 1 MVA	RWB	No Issue
CTN003	DUMOSA REG	Wilson Elec- 1 MVA	RWB	No Issue
CTN003	WYCHEPROOF P121 REG	COOPER- 2 x 100 A	WB	Open delta with independent voltage control.
CTN004	ST ARNAUD P216 REG	COOPER- 2 x 100 A	RW	Open delta with independent voltage control.
CTN006	DONALD P215 REG	Unknown- 5 MVA	RWB	No Issue
CTN006	DONALD P303 REG	COOPER - 2 x 200 A	RB	Open delta with independent voltage control.
CTN006	LITCHFIELD P43 REG	COOPER- 2 x 50 A	WB	Open delta with independent voltage control.
CTN006	ST ARNAUD P158 REG	Unknown- 3.75 MVA	RWB	No Issue
CTN006	SWANWATER GRE NTH REG	COOPER- 2 x 100 A	RB	Open delta with independent voltage control.

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

3.4.1 Birchip P163 Regulator

Birchip P163 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 Borung P214 Regulator

Borung P214 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.

3.4.3 Borung P79 Regulator

Borung P79 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 Wycheproof P121 Regulator

Wycheproof P121 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.

3.4.5 St Arnaud P216 Regulator

St Arnaud P216 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.

3.4.6 Donald P303 Regulator

Donald P303 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.

3.4.7 Litchfield P43 Regulator

Litchfield P43 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.

3.4.8 Swanwater Gre Nth Regulator

Swanwater Gre Nth 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 CTN zone substation contains approximately 1,179km of overhead conductor length (excluding SWER). Of this, 319km (27 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	21
Single Phase Balancing Units	13
3 Phase Balancing Units	44

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

Each RVE or VWVE ACR on the CTN 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
BIRCHIP P19 ACR	22kV	RWB	VWVE27
BORUNG P1 ACR	22kV	RWB	RVE
DONALD P19 ACR	22kV	RWB	VWVE27
WYCHEPROOF 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
BIRCHIP P209 ACR	CAPM5
BIRCHIP P501 ACR	CAPM5
LITCHFIELD P37 ACR	CAPM5
ST ARNAUD P12 ACR	CAPM5
ST ARNAUD P228 ACR	CAPM5
WATCHEM P29 ACR	CAPM5
WYCHEPROOF P353 ACR	CAPM5

Table 8 ACR and control box requirements summary

Units	Number of sites
ACR replacements	4
Control box replacements	7

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	4

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	241

3.9 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

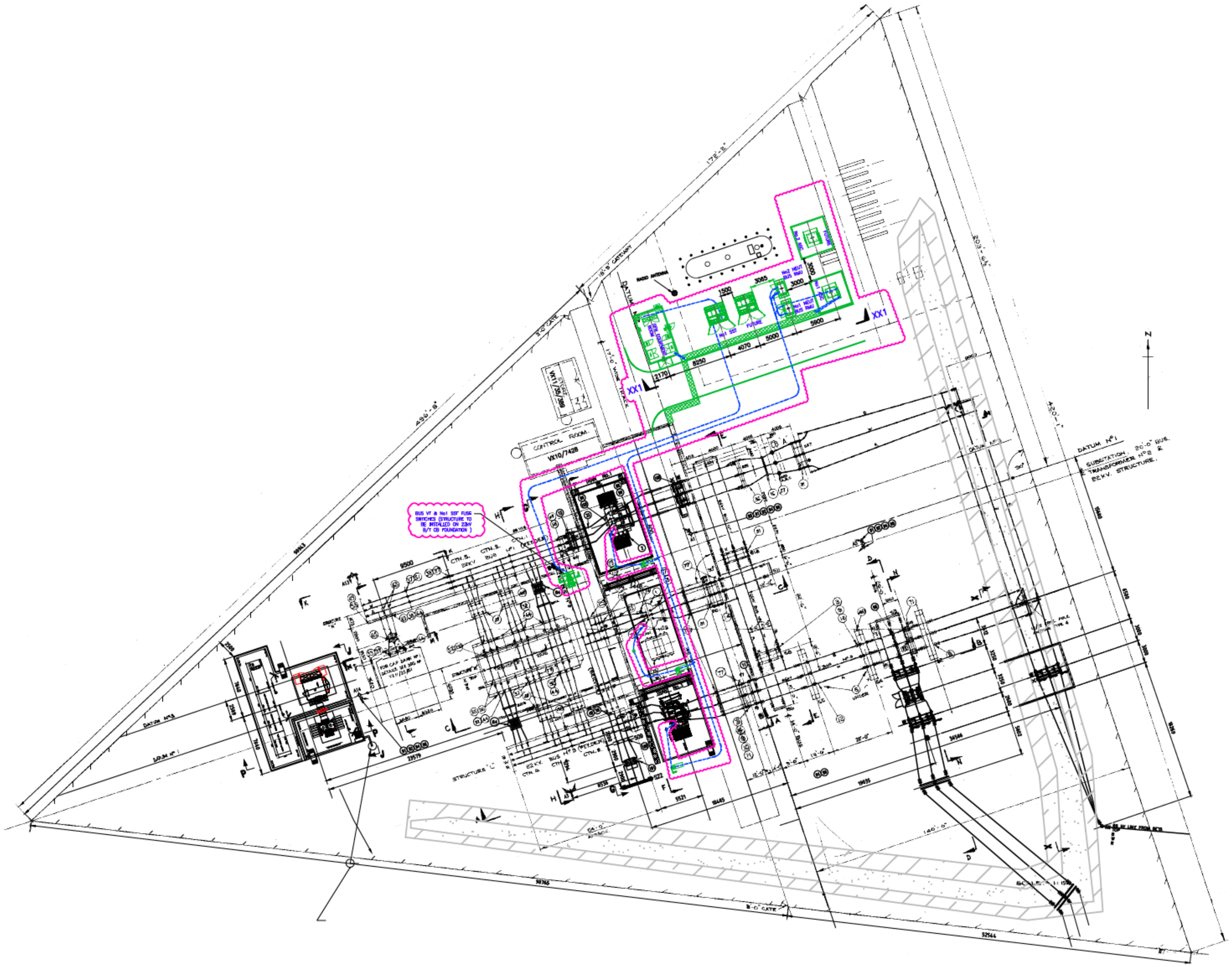
HV customer connection sizes are set out in table 12.

Table 11 Isolation substation requirements

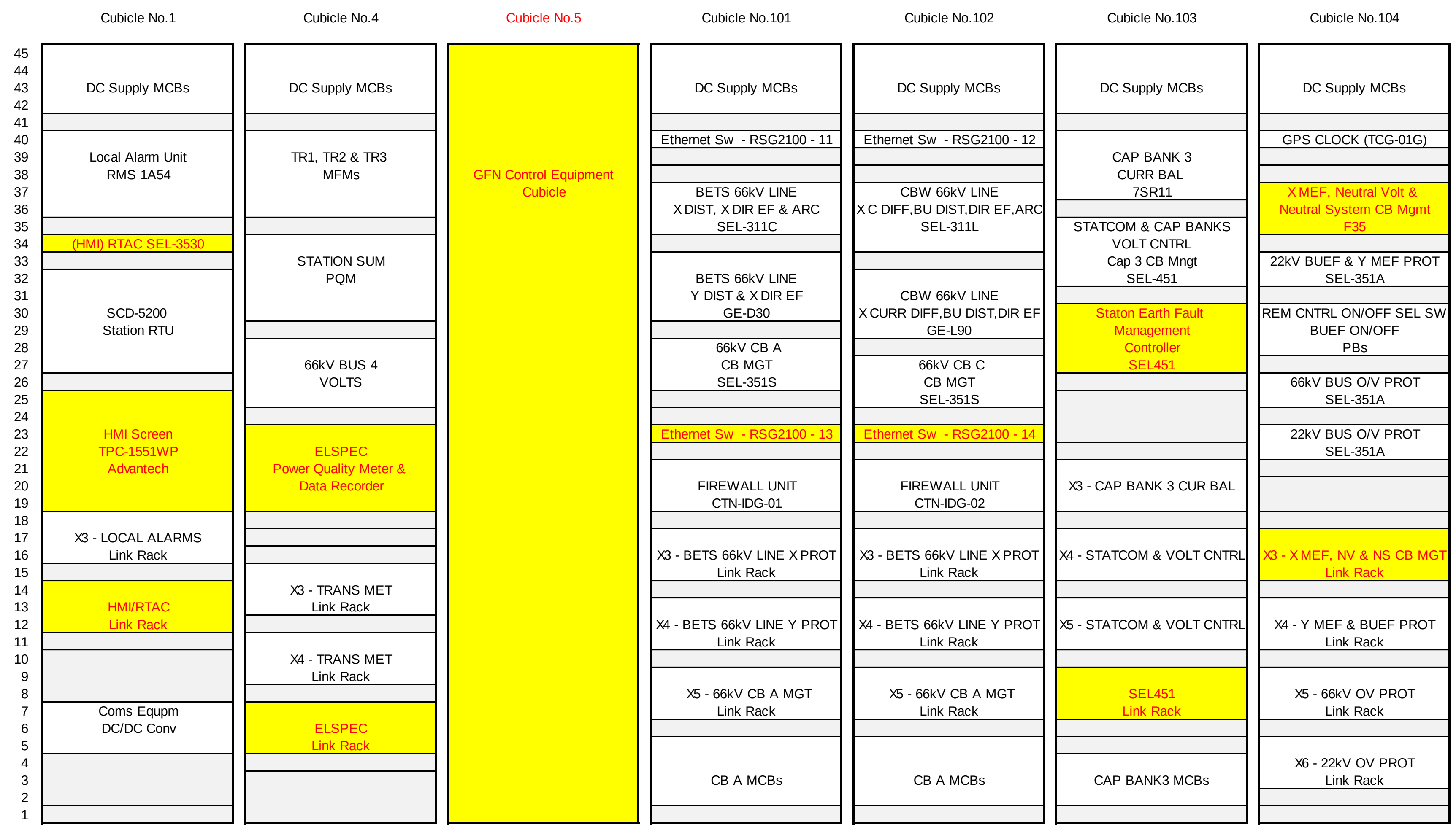
Size	Quantity
3 MVA	4

Appendix

APPENDIX A: Proposed Site General Arrangement

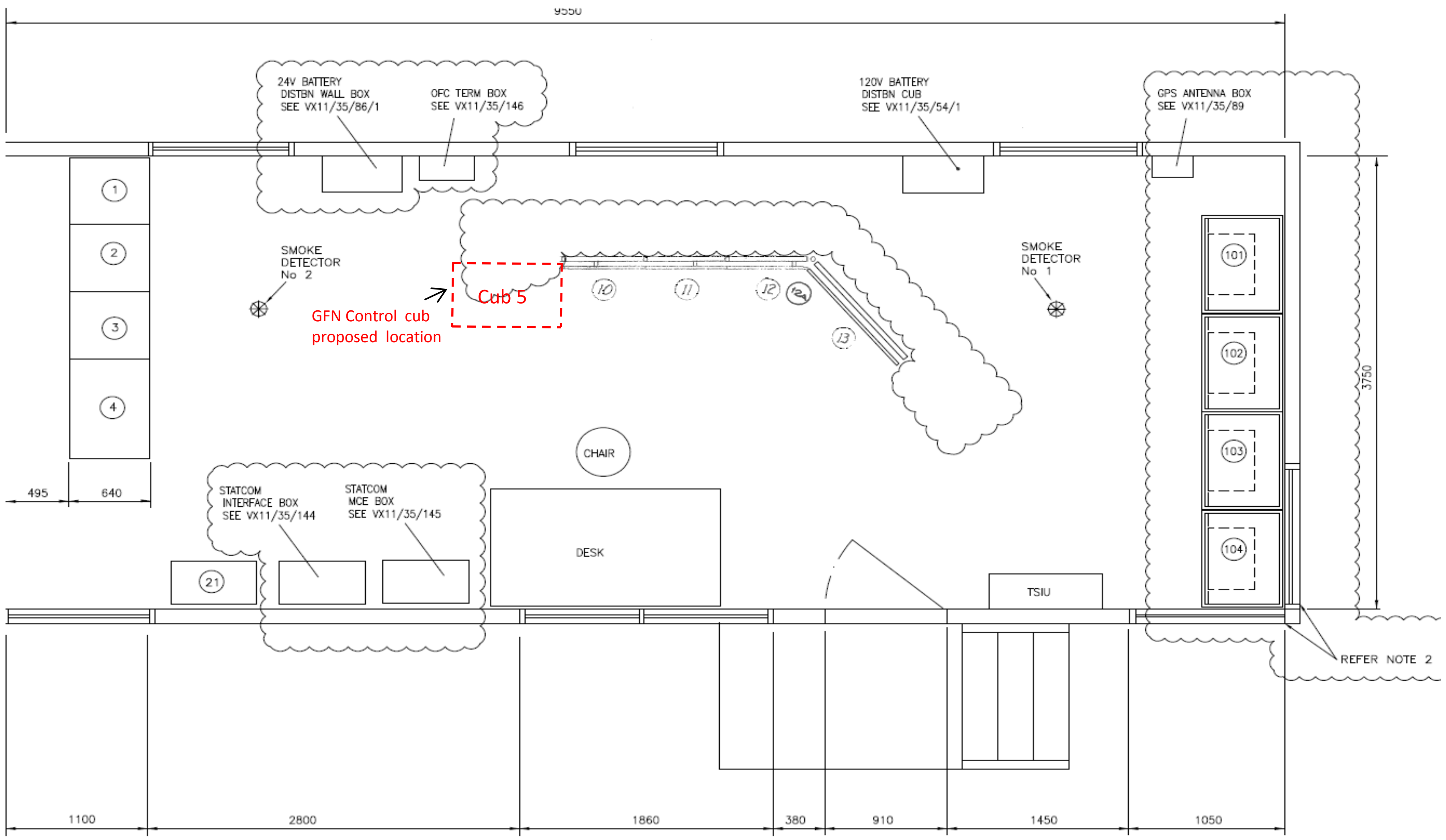


APPENDIX B: Cubicle Layout

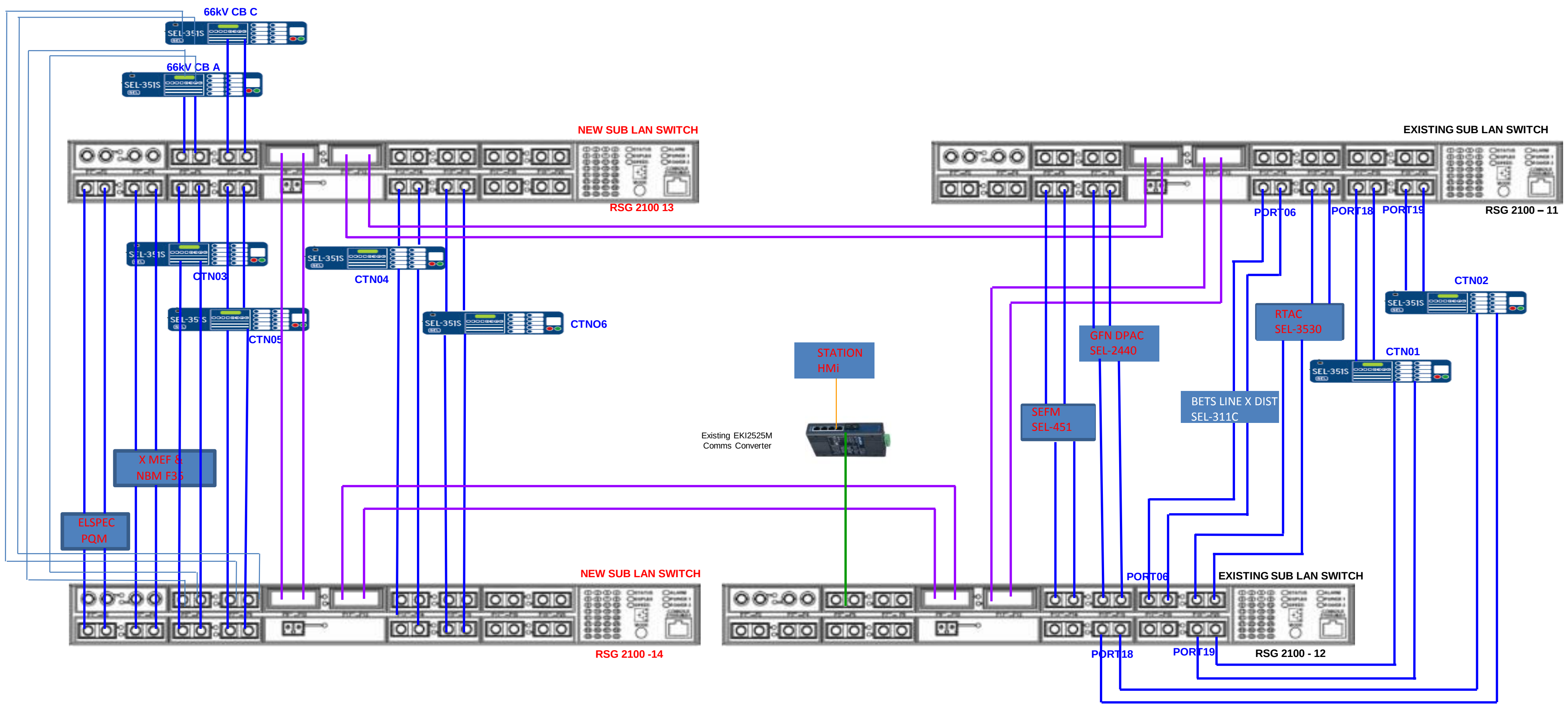


Black | Black | Existing equipment
Red | Red | New equipment

APPENDIX C: Suggested Control Room Layout



APPENDIX D: Ethernet Connectivity



Other relays on site connected to Ethernet

- GE-D30 BETS 66kV Line Y Distance
- SEL-311L CBW 66kV Line X Current Diff
- GE-L90 CBW 66kV Line Y Current Diff
- SEL-351A 66kV Bus OV
- SEL-351A 22kV Bus OV
- SEL-351A BUEF & Y MEF
- SEL-351S No.1 Cap Bank CB Mgt
- SEL-2411 No.1 Cap Bank VAR Controller
- SEL-451 STATCOM & No.3 Cap Bank CB Mgt
- SEL-2411 STATCOM Interface Controller
- SEL-2414 No.2 Trans Monitoring
- TEKRON GPS Clock
- ION-7650 GPS Clock

Other relays on site not connected to Ethernet

- SEL387E transformer diff
- SEL 311B 66kV bus dist

Other existing connections not shown
(refer dwg VX11/35/907/2)

- Firewall units
- 3G Modem
- Radio equipment
- Other comms equipment

APPENDIX E – Proposed Protection Schematic