Econnect

# Demand Management & Planning Project

# Standby Generation Program

# Preliminary Feasibility Study

# Econnect Project No: 1449

| | |
|---|---|
| **Prepared For** | Demand Management & Planning Project, Department of Infrastructure, Planning & Natural Resources Suite 201, Level 2 52 Atchison Street St Leonard's NSW 2065 |

| | Name | Date | Signature |
|---|---|---|---|
| **Prepared By** | Nadia Yousif | 17 June 2005 | |
| **Checked By** | Stephen Loft | 17 June 2005 | |
| **Approved By** | Damian Stevens | 17 June 2005 | |

| Document History | | |
|---|---|---|
| **Issue No** | **Description** | **Date** |
| 000 | Original Document Issue | 17 June 2005 |
| | | |
| | | |

| Copy No. | Copy Issued To | Company |
|---|---|---|
| 1 | Chris Tully | Demand Management & Planning Project<br>Department of Infrastructure,<br>Planning & Natural Resources |
| 2 | Econnect (Project File) | Econnect |

# Table of Contents

# 1 Executive Summary

## 1.1 Outline

A preliminary investigation into the feasibility of utilising existing standby diesel generator sets as despatchable demand reduction. The scope of this investigation included six sites located in the south-eastern Sydney area of New South Wales.

The key objectives of the study were to understand the technical constraints and capital costs associated with the conversion of the standby generator sets for either mains parallel or Synchronise-Close-Transfer-Trip (SCTT) modes of operation.

## 1.2 Environmental Issues

Distributed generation has an advantage of line losses avoidance compared with remote centralised generation plants. However, when compared with other sources of energy, diesel generators are a high NOx emitter, and an average CO2 emitter. Technology with higher overall efficiency and low emission profile is preferred, such as Combined Heat and Power (also known as co-generation or CHP) and combined-cycle gas turbines.

Appropriate management of CO2 and NOx emissions is recommended if widespread use of diesel generators for peak generation is proposed. This can be achieved by installation of air pollution control equipment such as Selective Catalyst Reduction device also known as SCR.

## 1.3 Risk Management Issues

A higher rate of utilisation of the generator may increase the probability of generator failure, which may not be available for emergency supply (until manually reset) should interruption of mains supply occur.

SCTT operation has a lower risk of supply outage when compared with parallel operation as the generator is operated in an island mode decoupled from the power network. However, SCTT operation will result in a reduction in power quality when compared with the mains supply.

## 1.4 Budget Costs

Available despatchable demand reduction ranged from 90 kVA to 1454 kVA over the six sites investigated. The costs per kVA of available demand reduction varied from 150 to 1,432 $/kVA. The spread is due to variation in existing generator set capabilities and capacity.

The cost for upgrade to generator set controls and protection for SCTT or parallel operation is largely independent of generator rating. Parallel operation has a greater cost than SCTT operation due to the need for additional protection that requires upgrade of 11kV switchgear.

A detailed summary of budget costs and overall ranking for each site and connection option is presented in **Section 13**.

## 1.5 Recommendations

It is recommended that Hospital No.2 site is the selected as the subject of a more detailed feasibility study. Hospital No.2 has two each 750 kVA diesel generator sets with existing synchronising capability installed in 2002 making it the most attractive site. A detailed list of recommendations is provided in **Section 14**.

# 2 Introduction

Econnect Australia was engaged by the “Demand Management Project,” a joint venture between the Department of Infrastructure, Planning and Natural Resources (DIPNR), Transgrid and Energy Australia to perform a preliminary investigation into the feasibility of utilising existing standby diesel generator sets for despatchable demand reduction. The scope of this investigation included six sites located in the south-eastern Sydney area of New South Wales.

**Figure 1** shows the geographical location of the six sites:

- **Hospital No.1**, with one 310kVA generator set,
- **Hospital No.2**, with two 750 kVA generator sets,
- **Hospital No.3**, with one 220kVA, one 1270kVA and one 550kVA generator set,
- **Hospital No.4**, with one 1475kVA generator set,
- **Government Organisation No.1**, with one 350kVA generator set,
- **Government Organisation No.2**, with one 350kVA generator set.

The main objective of the study was to understand the technical issues and costs associated with the conversion of the standby generators for use in either parallel or Synchronise-Close-Transfer-Trip (SCTT) operation. The following key issues were considered:

- Existing essential and non-essential electricity demand at the sites and the possible level of peak load reduction;
- Network technical constraints at each site including thermal limits, network voltages, power quality and fault levels;
- Technical feasibility of SCTT and/or parallel operation;
- Protection and control requirements;
- Power distribution network augmentation required, if any; and
- Planning issues associated with the conversion works.

Confidential

**Figure 1: Geographical Location of the Six Nominated Sites**

# 3 Scope

The scope of the preliminary feasibility study included the following activities:

- Site visit to examine each site to determine existing plant ratings and evaluate site physical topology and constraints;
- Review of existing generators and switchgear;
- Obtain and review distribution network data from Network Service Provider(s);
- Identification of potential connection options, considering technical constraints and economic implications of such constraints, illustrated with diagrams;
- Identification of the available peak load demand reduction taking into account circuit thermal limits, connected load and generator ratings;
- Identification of obvious limitations, in terms of thermal capacity, steady-state voltage rise, voltage step and network fault level for each of the proposed options.
- Production of a report assessing each generation site in isolation, containing six sections, one for each generation site proposed, as well as an overall summary outlining and ranking the relative attractiveness of the six sites.

# 4 Overview of Generator Operating Modes

## 4.1 Standby Operation

Standby diesel generator sets provide emergency supply to essential loads in the event of mains supply failure. Essential loads may include fire services, lifts, critical electronic equipment, instrumentation, and emergency lighting.

An auto-transfer switch and automatic generator controls are generally provided to automatically start the standby generator set, disconnect the mains supply and connect the site electrical load to the standby generator set.

With reference to **Figure 2**, normally the total site electrical load is supplied from the mains supply as shown in **Figure 2** System A. Upon detection of loss of mains supply;

- Mains circuit breaker (C.B No #1) is tripped;
- Non-essential loads are disconnected by opening circuit breaker CB No #4;
- The generator set is started and brought up to speed;
- Load is transferred to the standby generator set by closing the generator circuit-breaker (C.B No #2).

**Figure 2** System B shows an electrical system where essential and non-essential loads are segregated into separate busbars or switchboards. Standby operation for System B is identical with the exception that the bus-tie circuit breaker CB No #5 is tripped instead of mains circuit breaker CB No #1.

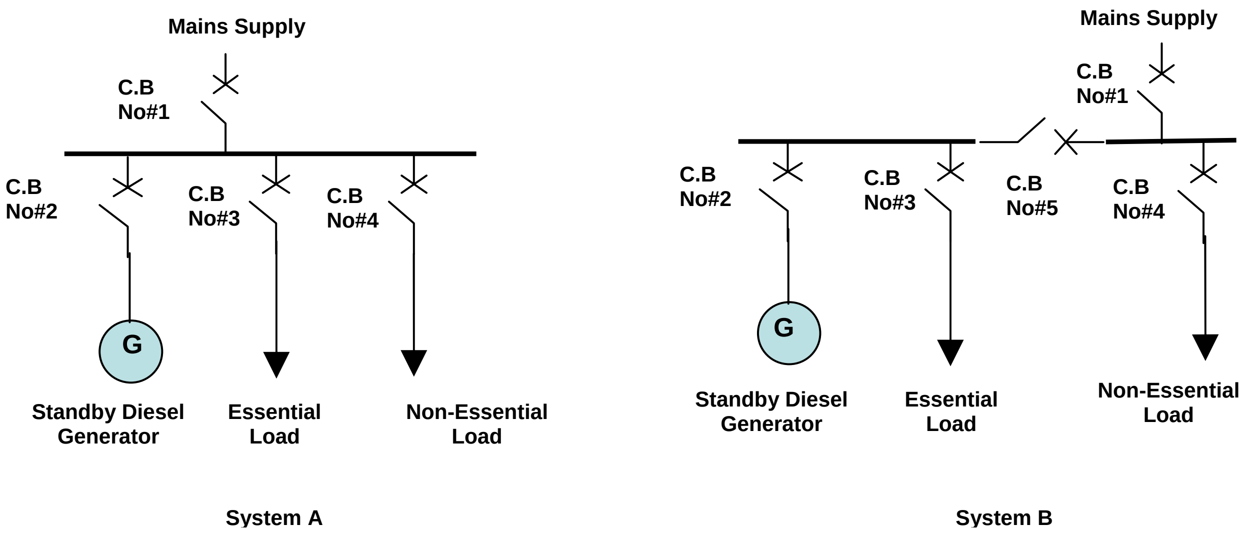



**Figure 2: Single Line Diagrams Illustrating Standby Mode for a Diesel Generator**

During this process, power supply to the site is interrupted for up to ten minutes, the time it takes to start-up and connect the standby generator. Unless mains synchronising capability is provided, it is necessary to interrupt the load a second time in order to switch the load back to mains supply when power to the site has been restored. This is the main disadvantage of the auto-transfer switch standby configuration. For reliable starting of the generator in an emergency, six-monthly maintenance and exercising of the generator set is required. This requires connection of a load bank unless momentary interruption of supply to essential loads is permitted.

## 4.2 Synchronise-Close-Transfer-Trip Operation (SCTT)

When configured for SCTT operating mode, a generator set is capable of despatchable demand reduction without interruption of the power supply to the site. The generator will operate in parallel with the mains supply for a short time only (several seconds).

With reference to **Figure 2** System A, a typical generator operating sequence is as follows:

- Initiate remote start of generator set (manual or automatic);
- Start generator set;
- Synchronise generator to mains supply;
- Close generator circuit breaker (CB No#2);
- Transfer load from mains to generator; and
- Trip mains circuit breaker (CB No#1) to island generator.

To shutdown the generator set, a typical operating sequence is:

- Initiate remote shutdown of generator set (manual or automatic);
- Synchronise generator to mains supply;
- Close mains circuit breaker (CB No#1);
- Transfer load from generator back to mains;
- Trip generator circuit breaker (CB No#2) to island generator; and
- Initiate generator cool down sequence; and
- Shutdown diesel engine.

Standby operation for **Figure 2** System B is identical with the exception that the bus-tie circuit breaker CB No#4 is opened instead of mains circuit breaker CB No#1.

## 4.3 Parallel Operation

Parallel operation involves the synchronisation and connection of the generator to the mains supply for the time period required for network demand reduction. Depending on the rating of the generator set and the local site load, export of power into the electricity distribution network may be possible. Regardless of whether grid export is possible, additional protections are required to prevent unsafe conditions in the electricity distribution network which may affect nearby customer and distribution network assets and personnel.

With reference to **Figure 2** System A or System B:-

A typical start sequence for parallel operation is as follows:

- Initiate remote despatch of generator set (manual or automatic);
- Start generator set;
- Synchronise generator to mains supply;
- Close generator circuit breaker (CB No#2);
- Ramp up generator load to rated output; and
- Continue to operate generator in parallel with mains.

A typical shutdown sequence for parallel operation is as follows:

- Initiate remote shutdown of generator set (manual or automatic);
- Ramp down the generator load to zero;
- Open generator circuit breaker (CB No#2);
- Initiate generator cool-down sequence; and
- Shutdown generator engine.

# 5 Hospital No.1

## 5.1 Local Network Technical Overview

Hospital No.1 is supplied at 415 V from one LV switchboard connected to an Energy Australia kiosk substation by one incoming cable (4 X 1C X 400 $mm^2$, approximately 50 m in length) through a 1000 A circuit breaker (located at the 415 V switchboard). The cable is fed by a 750 kVA, 11/0.433 kV transformer which are connected to the 11 kV network by Ring Main Units (RMU). The RMUs are normally connected to the 132/11 kV Zone substation by an 11 kV radial feeder. **Figure 3** illustrates the distribution system of Hospital No.1.

The existing standby diesel generator set (310 kVA) provides emergency supply to the hospital essential load as the non-essential load (non-essential lighting and air-conditioning) will be load shed at emergency interruption of the main supply. The generator is connected to the main switchboard via an incoming cable (approximately 50 m in length) via 250 A circuit breaker (located at the 415 V switchboard). Automatic Transfer Switch (ATS) automatically switches between the normal supply and emergency supply.

In the event of loss of mains mechanical interlocks prevent the generator from being connected in parallel with the mains.

The total load range of the hospital according to Demand Management and Planning Projects report by Energetics [1] is 622 kVA – 180 kVA.

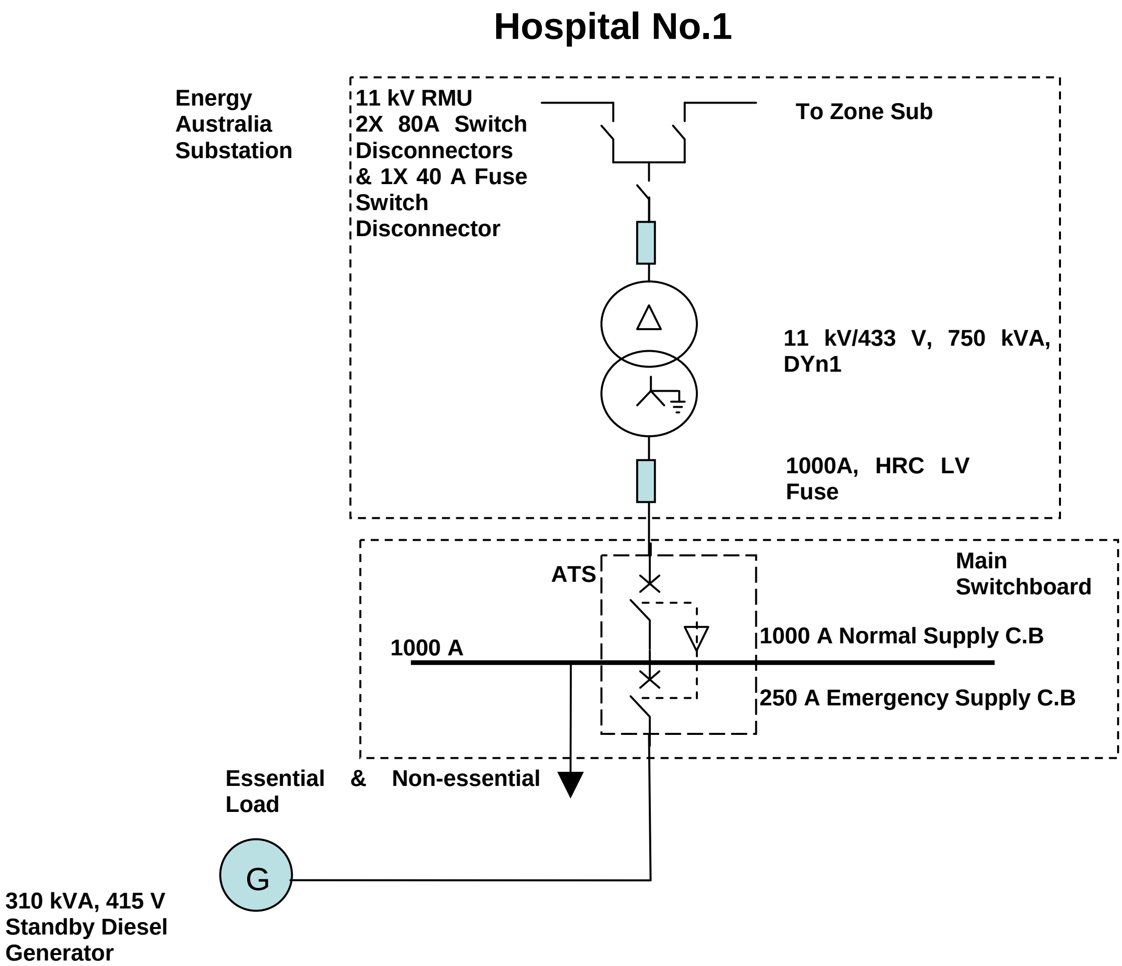



**Figure 3: Single Line Diagram Illustrating Distribution System Configuration for Hospital No.1**

## 5.2 Summary of Connection Options

Two options for the utilisation of the of diesel generator set for despatchable demand reduction were investigated as follows:

**Option 1 –Parallel Operation**

The hospital total load (622 kVA) is greater than the prime rating of the generator. Therefore, grid export is not expected to be possible at peak load conditions. There may be small grid export of 68 kVA at light load times (180 kVA, [1]). Maximum peak load demand reduction expected for parallel operation is approximately 248 kVA (equivalent to prime rating of the generator set).

**Option 2 - SCTT Operation for the Standby Diesel Generating Unit**

This option includes Synchronise-Close-Transfer-Trip (SCTT) operation of the generator set. Since the normal load is greater than the rating of the generator, this option would require separating the total load into essential load and non-essential load bus sections. This is not considered feasible as a new switchboard would be required. The existing switch room is congested and there is insignificant space for a new switchboard. This option was not investigated further.

## 5.3 Option 1 - Parallel Operation

This option proposes parallel operation for the existing standby generator. This would require additional protection schemes to allow parallel operation. This can be obtained by replacing the existing RMU with a new RMU (c/w 2 each switch disconnector and 1 each circuit breaker) with new cubicle to accommodate the additional protection scheme.

The existing generator circuit breaker (with continuous current rating of 250 A) cannot accommodate the new generation rated current (345 A). It is therefore recommended to replace the existing circuit breaker with a new circuit breaker that can accommodate the generation rated output.

Grid export to the 11 kV network is not expected at peak load times as the load is greater than the prime rating of the generator. The maximum peak load reduction expected in this option is 248 kVA.

### 5.3.1 Thermal Limits

For Option 1, small grid export of 68 kVA is expected at minimum load times. Therefore no thermal constraints exist on the 11 kV network, RMU, 11 kV / 433 V transformer and 415 V main supply switchgear.

The existing generator circuit breaker with continuous current rating of 250 A, cannot accommodate 248 kVA generation. Replacement of the existing circuit breaker with new 630 A is therefore recommended.

### 5.3.2 Voltage Issues

In this section, the affect of the generator connection on 415V and 11 kV bus voltages was investigated.

Voltage rise has been defined as the difference between the voltage levels when the generator is connected (maximum generation output) and the voltage levels at zero-generation output. Zero-generation scenario represents the system before connection of the generator.

Voltage step is the difference between the voltage level at normal conditions and the voltage level at contingency conditions (generator trip). The worst case voltage step could be equivalent to voltage rise defined above, since a zero-generation scenario reflects the system conditions after generator trip.

Based on the assumptions listed in Appendix B1, 11 kV bus voltage percentage steady state voltage rise and the 415 V buses were calculated using preliminary modelling (PSS/Viper). The results are presented below in **Table 1**.

| Bus | Base (kV) | Voltage Rise/Step % |
|---|---|---|
| 11 kV Zone Substation | 11 | 0.31 |
| 11 kV Site | 11 | 0.57 |
| 415V Site | 0.4 | 2.12 |

**Table 1: Percentage Steady State Voltage Rise from the Nominal Voltage (1 p.u.) and Voltage Swing**

The percentage voltage rise/step for 415 V level is lower than the Energy Australia allowable upper limit (upper limit of 438 V, approximately 6% voltage rise from 415V) - Please refer to Energy Australia Electricity Network Operation Standards [3]. At the 11 kV buses, the percentage voltage rise is insignificant.

It is therefore anticipated that steady state voltage rise/step will not be an issue for this option.

For evaluation of maximum voltage level at 415 V and 11 kV buses (with connection of the generators), accurate 11 kV feeder loads and existing voltage levels at 11 kV and 415 V buses are required. It is expected that all bus voltages can be maintained less than 1.06 p.u. and therefore over voltage is not likely to be an issue.

### 5.3.3 Fault Levels

Based on the assumption in Appendix B1, the symmetrical fault contribution of the generator at 0.415 kV bus is 3.1 MVA at 415 V. The existing fault level of the network at 415 V & 11 kV side of an Energy Australia substation is 15 MVA and 83 MVA respectively. Therefore the expected fault levels at the Hospital No.1 network and the existing headroom for the existing switchgear is illustrated in **Table 2**.

| Bus | Existing fault level (MVA) | Switch Gear Design Rating MVA(kA)* | Available Head Room MVA(kA) (for switch gear) | Contribution Of the Generator (MVA) @415 V |
|---|---|---|---|---|
| 11 kV Switchgear | 83 | 381(20 kA) | 298 MVA | > 1.5 MVA |
| 415 V Switchboard | 15 | 25 MVA(34 kA) | 10 MVA | 1.5 MVA |
| 415 V Switchgear | 15 | 36 MVA( 50 kA) | 21 MVA | 1.5 MVA |

*** The design ratings for the switchgear are the instantaneous withstand ratings**

**Table 2: Fault Level Contribution of the Generator and the Network Plus the Existing Headroom for the Existing Switchgear**

It is evident from the available headroom in **Table 2** that the existing switchgear and the LV switchboard are capable of accommodating the additional fault levels from the generator.

### 5.3.4 Power Quality

It is anticipated that the contribution of the diesel generators to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. Their connection to the network is unlikely to excite any resonance. Harmonic voltage distortion is likely to be marginally reduced due to the small increase to network fault level. Further study is not considered necessary unless power quality issues exist at present taking in consideration availability of sensitive equipment.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generators will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips.

Under islanding operation of the generators, power quality could be an issue due to low fault levels at the LV network under islanding conditions and if there is any distorting or fluctuating loads at the LV network.

### 5.3.5 Protection & Control Schemes

#### 5.3.5.1 11kV Protections

Additional protection schemes (primary protection scheme) are recommended at the 11 kV RMU to permit safe parallel operation of the generator and mitigate risk of unsafe island operation of the generator set. The recommended protection scheme includes the following:

- Protection class CT & 11kV /110 V 3-phase voltage transformer with 5 Limb Core or 3 each single phase.
- Multifunction protection relay including:
  - 3 Phase directional instantaneous and time-delayed overcurrent for earth & phase faults,
  - Neutral voltage displacement.
- Back-up overcurrent relay including:
  - 3 phase instantaneous and time-delayed phase overcurrent,
  - 3 phase instantaneous and time-delayed phase neutral over currents.
- Primary and backup auxiliary tripping relays.
- Duplicated d.c. battery backed power supplies.

The existing RMU can not accommodate the additional protection schemes due to space restrictions. Also, the RMU 11 kV switch fuse is not suitable for coordinating the planned protection schemes for this option. It is therefore recommended to replace the existing RMU with new RMU that consists of two disconnectors and vacuum or SF6 circuit breaker. The RMU should be suitable to accommodate the additional protection schemes.

#### 5.3.5.2 Generator Protections

Additional generator protections are recommended for the safe parallel operation of the generator. Duplicate protections with independent d.c. supplies are recommended. Recommended generator protections are as follows:

- Three-phase set of protection class current transformers (CTs),
- Generator protection relay including:
  - 3 phase instantaneous and time-delayed phase and neutral overcurrent for earth & phase faults,
  - Under/over voltage,
  - Under/over frequency,
  - Low forward or reverse power,
  - Negative current sequence,
  - Loss of excitation,
  - Over excitation,
  - Circuit breaker fail,

- Back-up overcurrent relay including:
    - 3 phase instantaneous and time-delayed phase overcurrent,
    - 3 phase instantaneous and time-delayed earth fault,
    - Rate of Change of Frequency (ROCOF or df/dt),
    - Vector shift,
    - Circuit breaker fail,
- Primary and backup auxiliary tripping relays,
- Duplicated d.c. battery backed power supplies.

#### 5.3.5.3 Generator Synchronising Controls

To allow parallel operation additional controls will be required:

- Synchronising and control panel as shown in **Figure A1** complete with auto synchroniser;
- 3 phase metering current transformers;
- 3 phase generator voltage sensing inputs;
- Single phase bus voltage sensing inputs;
- Communications interface for remote control/monitoring; and
- Digital AVR compatible with new controls.

The synchroniser may be accommodated along with the generator protections and d.c. supplies in a single Generator Synchroniser and Protection panel per generator.

### 5.3.6 Planning Issues

This option will require replacement of the existing kiosk substation with new kiosk that includes two disconnectors and vacuum or SF6 circuit breaker and 3-phase voltage transformer with 5-limb core. Commissioning this replacement will require installation of new kiosk adjacent to the old one and reconnection of cables to the new kiosk. Supply interruption will be required for a period of several hours to enable transfer of cables to the new kiosk substation. It is recommended that temporary generators are used to maintain supply to the hospital during the works. Alternative switching arrangements will be required in the 11 kV network to continue supply to other nearby customers during the works.

Physical space available at the LV switchboard may be an issue in terms of replacement of generator circuit breaker and inclusion of protection CTs and Auto Transfer Switch panel modifications. In addition, physical space available at the generator enclosure is not adequate to accommodate the generator synchronised control and protection panel. Therefore, it is recommended to install the generator synchronised control and protection panel in a separate enclosure installed beside the generator.

### 5.3.7 Budget Costs

Please refer to Appendix C.

### 5.3.8 Conclusions

After investigating the technical feasibility, the following conclusions were reached:

- SCTT operation option is not technically feasible as the load connected at the main switchboard (where the generator is connected – 710 kVA) is greater than the generator prime rating (248 kVA).
- 248 kVA demand reduction is expected for Option 1- parallel operation.
- Small grid export of 68 kVA is possible.
- Replacement of the existing generator switchgear (250 A) is required with greater continuous current rating switchgear (recommended 630 A).
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.
- Physical space indoors is an issue when considering installation of a new synchronising control and protection panel at the generator or the switch room.

# 6 Hospital No.2

## 6.1 Local Network Technical Overview

Hospital No.2 is supplied at 415 V from four 415 V essential and non-essential switchboards as shown in **Figure 4**. The switchboards are supplied by two Energy Australia indoor substations. Each substation consists of 2 each 1500 kVA, 11/0.433 kV transformers connected to the 11 kV network by Ring Main Units (RMU). The RMUs are normally connected to the 33/11 kV Zone substation by an 11 kV radial feeder.

There are two existing standby diesel generator sets (2 each 750 kVA) which provides emergency supply to the hospital essential load. The generators are connected to the 415 V Essential Switchboards No.1 & No.2 via three incoming cables (approximately 50 m in length). One cable feed Essential Switchboard No.1 and the other two cables feed Essential Switchboard No.2.

SCTT operation is available for exercising the generator sets. A programmable logic controller (PLC) manages the connected load and determines whether one or two generator sets are started as the load is shared between the two sets.

The existing SCTT operation is available across a single ATS at the Essential Switchboard No. 2.

The maximum load at Essential Switchboard No. 1 load is less than 205 kVA (equal to the continuous current rating of the incoming generator supply cable 285 A, 185 $mm^2$). The maximum load at the Essential Switchboard No. 2 is less than 410 kVA (equal to the continuous current rating of the two incoming generator supply cable each 285 A – based on underground duct installation 0.8 ducting factor).

The maximum total load of the hospital according to Demand Management and Planning projects by Energetics [1] is 2000 kVA. Minimum total load is less than the total maximum essential load of the hospital (615 kVA).

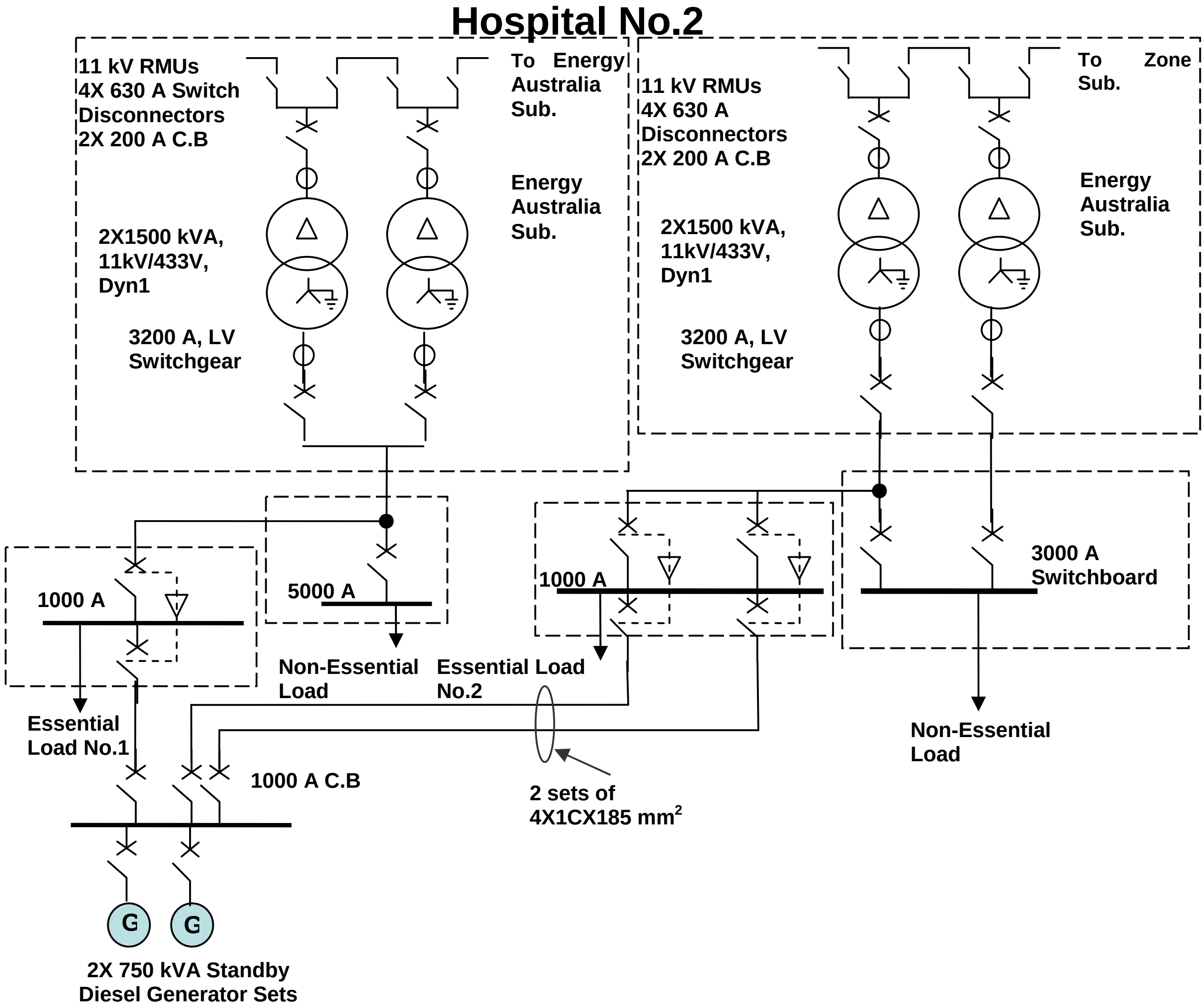



**Figure 4: Single Line Diagram Illustrating Hospital No.2 Distribution System Configuration**

## 6.2 Summary of Connection Options

Two options for the utilisation of the two diesel generator sets (2X750 kVA) for despatchable demand reduction were investigated as follows:

**Option 1 – Parallel Operation**

The hospital total load (2000 kVA) is greater than the prime rating of the two generators sets (1200 kVA). Therefore, grid export is not expected to be possible at peak load conditions. Grid export may be possible at minimum load times.

The expected demand reduction in this option is 1200 kVA (equivalent to the prime rating of the generator sets).

**Option 2 – Synchronise Close Transfer Trip Operation (SCTT)**

This option is to retain the existing Synchronise-Close-Transfer-Trip (SCTT) operation at Essential Switchboard No.2 and add an automatic remote start/stop capacity to facilitate despatchable demand reduction. The maximum demand reduction for this option is 410 kVA.

## 6.3 Option 1 - Parallel Operation

This option proposes parallel operation for the two existing standby generator sets (2X750 kVA). This would require islanding protection schemes to allow safe parallel operation of the generator sets. Upgrade work is required for the generating unit to allow for parallel operation.

The expected demand reduction in this option is 1200 kVA, based on the prime ratings of the generator sets.

### 6.3.1 Thermal limits

The 11 kV switchgear, 11 kV / 433 V transformers and 415V switchgear can accommodate the possible grid export.

1200 kVA is expected to be the load on the generator sets to supply the hospital load. This indicates a possible thermal constraint at the cables that connects the generator to the switchboards (3 sets of 4X1CX185 $mm^2$, 285 A, with 50 m length each).

The 415 switchgear and switchboards can accommodate the 1200 kVA generation output.

### 6.3.2 Voltage Issues

In this section the impact of the generator connection on percentage voltage rise at 415 V and 11 kV buses was investigated.

Based on the assumptions listed in Appendix B1, percentage steady state voltage rise for 11 kV and the 415 V buses were calculated using preliminary modelling (PSS/Viper). The results are presented below in **Table 3**.

| Bus | Base (kV) | Voltage Rise/ step (%) |
|---|---|---|
| 11 kV Zone Substation | 11 | 1.84 |
| Site 11 kV | 11 | 2.69 |
| Site 415V Essential Load No1 | 0.4 | 3.12 |
| Site 415 V Essential Load No2 | 0.4 | 3.15 |

**Table 3: Percentage Steady State Voltage Rise**

The percentage voltage rise/step for 415 V level is lower than the Energy Australia allowable limit (upper limit of 438 V, approximately 6% voltage rise) - Please refer to Energy Australia Electricity Network Operation Standards [3]. At the 11 kV buses, the percentage voltage rise is insignificant.

It is therefore, anticipated that steady state voltage rise/step will not be an issue for this option.

For evaluation of maximum voltage level at 415 V and 11 kV buses (when connection of the generators), accurate 11 kV feeder loads and existing voltage levels at 11 kV and 415 V buses are required. It is expected that all bus voltages may be maintained less than 1.06 p.u. and therefore over voltage is not likely to be an issue.

### 6.3.3 Fault Levels

Based on the assumption in Appendix B1, the symmetrical fault contribution of the generators at 0.415 kV bus is 15 MVA at 415 V. The existing fault levels of the network at 415 V & 11 kV buses of the Energy Australia substations are 15 MVA and 88 MVA respectively. The expected fault levels at the Hospital No.2 network and the existing headroom for the existing switchgear are illustrated in **Table 4**.

| Bus | Existing fault level (MVA) | Switch Gear Design Rating MVA(kA)* | Available Head Room MVA(kA) (for switchgear) | Contribution Of the Two Generators @415 V |
|---|---|---|---|---|
| 11 kV Switchgear | 88 | 400 MVA(21 kA) | 298 MVA | > 7.5 MVA |
| 415 V Switchboard | 15 | 47 MVA( 65kA) | 32 MVA | 7.5 MVA |
| 415 V Switchgear | 15 | 47 MVA( 65 kA) | 32 MVA | 7.5 MVA |

*** The design ratings for the switchgear are the instantaneous withstand ratings**

**Table 4: Fault Level Contribution of the Generator and the Network Plus the Existing Headroom for the Existing Switchgear**

It is evident from the available headroom in **Table 4** that the existing switchgear and the LV switchboard are capable of accommodating the additional fault levels from the generator.

### 6.3.4 Power Quality

It is anticipated that the contribution of the diesel generators to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. Their connection to the network is unlikely to excite any resonance. Harmonic voltage distortion is likely to be marginally reduced due to the small increase to network fault level. Further study is not considered necessary unless power quality issues exist at present taking in consideration availability of sensitive equipment.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generators will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips.

Under islanding operation of the generators, power quality could be an issue due to low fault levels at the LV network under islanding conditions and if there is any distorting or fluctuating loads at the LV network.

#### 6.3.5 Protection & Control Schemes

##### 6.3.5.1 11kV Protections

Additional protection schemes (primary protection scheme) are recommended at the 11 kV RMU to permit safe parallel operation of the generator and mitigate risk of unsafe island operation of the generator set. The recommended protection scheme includes the following:

- Protection class CT & 11kV /110 V 3-phase voltage transformer with 5 Limb Core or 3 each single phase.
- Multifunction protection relay including:
    - 3 Phase directional instantaneous and time-delayed overcurrent for earth & phase faults,
    - Neutral voltage displacement.
- Back-up overcurrent relay including:
    - 3 phase instantaneous and time-delayed phase overcurrent,
    - 3 phase instantaneous and time-delayed phase neutral over currents.
- Primary and backup auxiliary tripping relays.
- Duplicated d.c. battery backed power supplies.

The existing RMU can not accommodate the additional protection schemes due to space restrictions. It is to replace or extend the existing RMU to accommodate the required voltage transformer.

##### 6.3.5.2 Generator Protections

Additional generator protections are recommended for the safe parallel operation of the generator. Duplicate protections with independent d.c. supplies are recommended. Recommended generator protections are as follows:

- Three-phase set of protection class current transformers (CTs) for each generator.
- Generator protection relay for each including:
    - 3 phase instantaneous and time-delayed phase and neutral overcurrent for earth & phase faults,
    - Under/over voltage,
    - Under/over frequency,
    - Low forward or reverse power,
    - Negative current sequence,
    - Loss of excitation,
    - Over excitation,
    - Circuit breaker fail.

- Anti-Islanding relay for each generator including:
  - 3 phase instantaneous and time-delayed phase overcurrent,
  - 3 phase instantaneous and time-delayed earth fault,
  - Circuit breaker fail,
- Primary and backup auxiliary tripping relays,
- Duplicated d.c. battery backed power supplies.

#### 6.3.5.3 Generator Synchronising Controls

To allow parallel operation and load control the following upgrade work will be required for each generator:

- Upgrade the existing synchroniser control and protection operation for parallel operation
- Remote control and monitoring communications interface for existing PLCs and controls.

The upgraded synchroniser may be accommodated along with the generator protections and d.c. supplies in a single Generator Synchroniser and Protection panel per generator.

### 6.3.6 Planning Issues

Generally, no issues were identified in terms of space.

The available physical space at the substation is adequate to accommodate the additional protections at 11 kV sides of the transformers.

The available space at the generators is adequate for upgrade to synchronise control and protection panel.

### 6.3.7 Budget Costs

Please refer to Appendix C.

## 6.4 Option 2 – Synchronise Close Transfer Trip Operation (SCTT)

This option proposes to retain the existing SCTT operation and add an automatic remote start/stop capacity to facilitate peak load lopping.

Upgrade work is required for the generating unit to allow for SCTT mode of operation. No major network augmentation and protection schemes are required at 11 kV level as the generator will only be connected to the network for a short time of during load transfer.

The expected peak demand reduction for this option is 410 kVA.

### 6.4.1 Thermal Limits

The SCTT operation of the generator would not increase the 11 kV loading. The maximum demand reduction is equal to the total essential load connected to essential switchboard No.2 (410 kVA).

There is thermal constraint at one of the cable sets that connects the generators to essential switchboard No.2 (4X1CX185 $mm^2$, 285 A) through SCTT operated switchgear. It is recommended to replace one cable set by higher rating cable that can accommodate the generation output of 410 kVA.

The 415 V switchgear and switchboards can accommodate the maximum generator export of 410 kVA.

### 6.4.2 Steady State Voltage Swing and Rise

The SCTT operation of the generating units is similar to the current standby operation in terms of network voltage issues. Therefore, it is anticipated that SCTT operation of this generator will not contribute to steady-state voltage rise problems.

### 6.4.3 Fault Levels

The generators will not contribute to existing fault levels in this option as the generators will be connected to the network for a short duration during load transfer.

### 6.4.4 Power Quality

The generator units will be connected to the network for short time during load transfer. Therefore, it is anticipated that the contribution of SCTT operated generator to harmonic levels in the network is insignificant.

The generator unit will be connected to the network for short time during load transfer. Therefore, it is anticipated that flicker emission of the SCTT operated generator is insignificant.

The fault level of the LV system is small when the generator is SCTT operated. This could result in power quality issues if there are any distorting loads.

### 6.4.5 Planning Issues

The available space at the generators is adequate for upgrade works of synchronise control and protection panel.

Standby generator will be out of service during controls upgrade. Portable standby generators are recommended as a contingency.

### 6.4.6 Protection & Control Schemes

To allow SCTT operation of the two Generators, additional protections are not recommended, as paralleling with the mains is only for a short time during load transfer. The HLI for remote operation and interface for existing PLCs and controls is required.

### 6.4.7 Budget Costs

Please refer to Appendix C.

## 6.5 Conclusions for Option 1 & 2

After investigating the technical feasibility of Option 1 & 2, the following conclusions were reached:

<u>Option 1 – Parallel Operation</u>

- 1200 kVA demand reduction is expected.
- Grid export of 337 kVA is possible.
- Replacement of the three cable sets that connects the generators to the Essential Load Switchboard No.1 and 2.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.

<u>Option 2 – SCTT Operation</u>

- 410 kVA demand reduction is expected.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.
- Replacement of one cable set that connects the generators to the Essential Load Switchboard No. 2.

# 7 Hospital No.3

## 7.1 Local Network Technical Overview

Hospital No.3- is fed from Carlton 33/11kV Zone Substation. Carlton 33/11kV substation provides Hospital No.3 with three different points of supply referred as Hospital No 3A, No 3B and No 3C.

Hospital No 3A: This point of supply serves both essential and non essential loads of the Hospital No.3 Main Campus. In addition two standby generators are presently installed: one 220kVA Olympian Caterpillar engine located outdoors adjacent to the Clinical Service Building (CSB), this generator was commissioned in 2003 and one A second 1270kVA Cummins engine, located in a plant room in the tower Ward Block installed in 2004.

Hospital No 3B: This point of supply serves both essential and non essential loads of the Hospital No.3 Main Campus. Furthermore a 550kVA Caterpillar engine, located in a plant room in the basement of the CSB, installed in 1991.

Hospital No 3C: This point of supply serves both essential and non essential loads of the Hospital No.3 and therefore has not been investigated further in this section.

Each of these three generators is connected via Auto Transfer Switch arrangements (ATS). **Figure 5a and 5b** illustrate further the Standby Generation arrangement of the Hospital No.3 Main Campus.

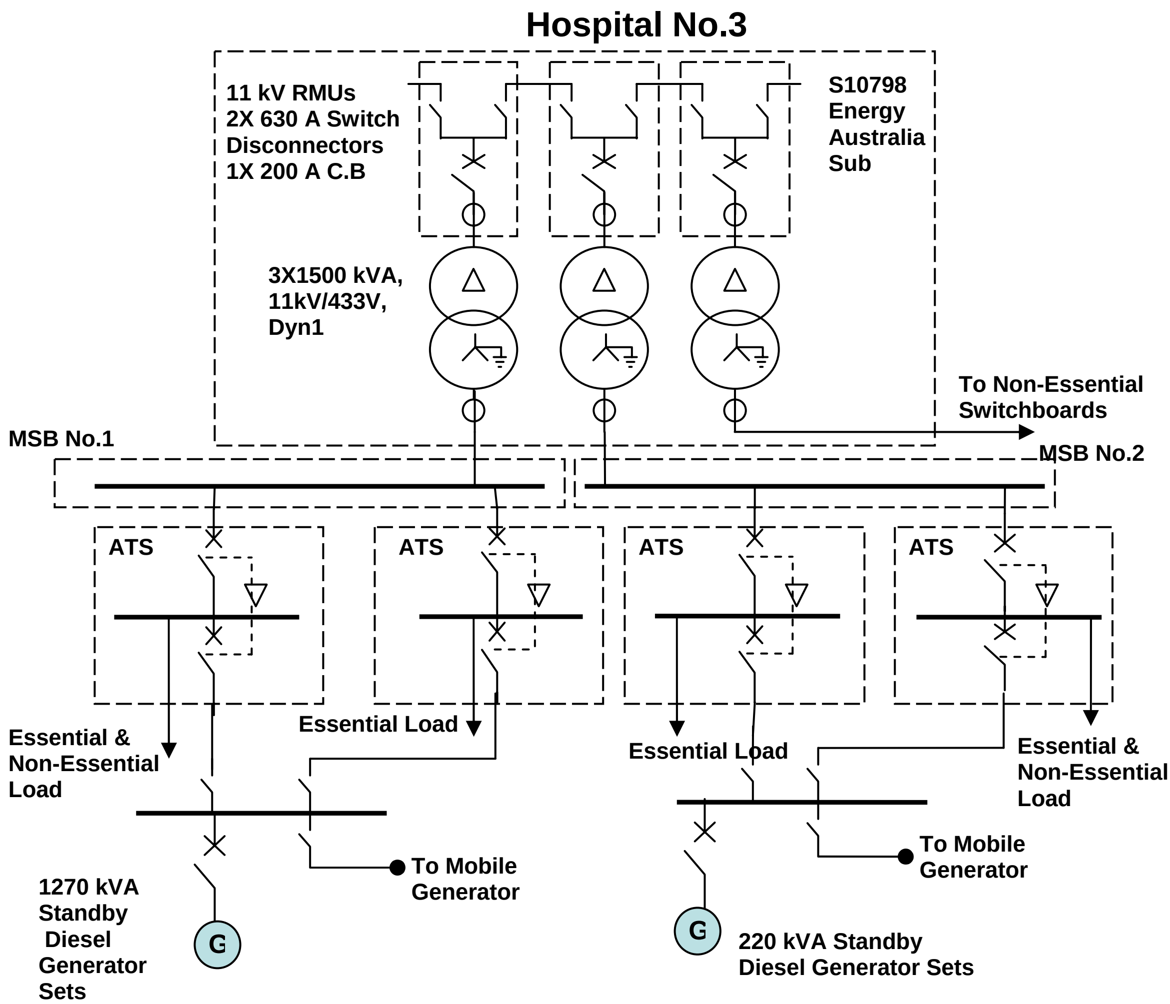



**Figure 5a: Single Line Diagram Illustrates Hospital No.3 Distribution System (Part 1)**

Hospital No.3 (Continued)

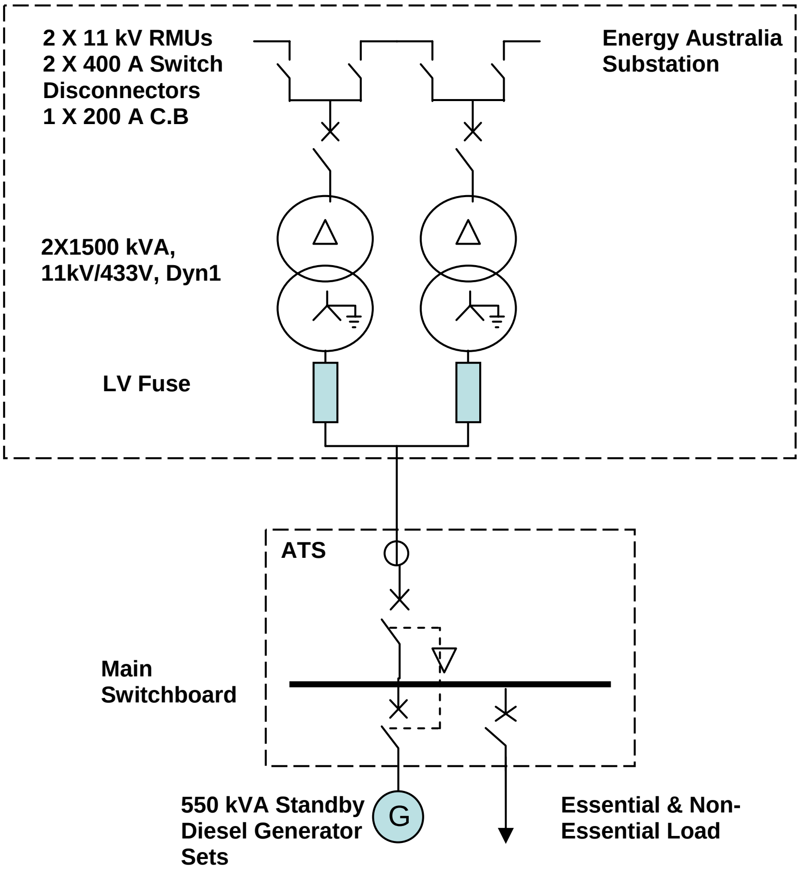



**Figure 5b: Single Line Diagram Illustrate Hospital No.3 Distribution System (Part 2)**

## 7.2 Summary of Connection Options

The following sections investigate two different connection options for the potential use of the existing 220 kVA, 1270 kVA and 550 kVA diesel generator sets to assist with network demand management (i.e. despatchable demand reduction operations).

**Option 1 –Parallel Operation**

Based on Energetics Demand Management and Planning Project Report [1] issued in June 2004, the Hospital No.3 Main Campus 2003 minimum demand in was approximately 1500kVA and the 2003 maximum demand is 3900kVA. The three diesel Generators connected to the main campus 11kV network have a combined prime capacity of approximately 80% of their standby rating or 1630kVA. Therefore it is possible for the Hospital No.3 Main campus to be a net power export when all three generators are operated in parallel. It is to be noted however that 1500kVA minimum demand condition occurs only on Sunday, while for any other day the minimum load is approximately 1900kVA which is above total generation prime capacity.

The maximum load connected onto Hospital No.3A and Hospital No.3B is approximately 2454kVA and 618kVA which correspond to a minimum load of 933kVA and 235kVA respectively. Therefore we expect Hospital No.3A and 3B to be a net importer most of the year, noting that they may become net exporters during winter minimum load conditions.

A parallel operation of all three generators connected at Hospital No.3 main Campus will lead to a maximum peak demand reduction of 1630 kVA.

**Option 2 - Synchronise Close Transfer Trip Operation (SCTT)**

Synchronise Close Transfer Trip (SCTT) operation requires the generator to supply all load connected to the islanded network. Based on the data available it is not yet possible to determine whether the existing generation connected onto Hospital No.3A will provide enough capacity for such mode of operation. However rating of the equipment installed at Hospital No.3A substation indicates that the electrical installation was designed to accommodate a load greater that the actual generation capacity installed.

On the other hand based on equipment rating of the Hospital No.3B substation indicate that the electrical installation is designed to accommodate up to 630A (i.e. ATC switchboard rating) which is slightly greater than the 550kVA generator with a prime capacity of 440kVA or 612A. Therefore it can be concluded that the actual load may enable SCTT operation of the 550kVA generator located at the Hospital No.3B substation however further load growth can make this mode operation unstable. A maximum peak demand reduction of 440 kVA is expected for this option.

For both 1270 kVA and 220 kVA we do not recommend SCTT operation.

## 7.3 Option 1 - Parallel Operation

### 7.3.1 Thermal Limits

Based on the existing minimum demand for both Hospital No.3A and 3B a net export of generation for each of these is expected to be marginal as most of the time demand exceeds generation. Therefore thermal constraint for reverse power flow through the existing 11/LV transformer is not expected to be a potential issue.

The low voltage ATS switchboard connected to the existing 1270kVA, 550kVA and 220KVA Generators are rated at 2000A, 630A and 300A respectively. Furthermore we expect all LV cablings between the generator set and the load to be adequately rated to accommodate the generator full output. On that basis we do not expect the thermal rating of LV or HV existing equipment to be a limiting factor the parallel operation of the generators installed at Hospital No.3A & 3B.

### 7.3.2 Voltage Issues

Based on the Demand Management and Planning Project Report issued by Energetics [1] the Hospital No.3 Campus load is mainly composed of 85% of small motors and therefore inductive. However Hospital No.3 Campus is also equipped with power factor correction equipment which maintains at all time a power factor close to unity. As a result it is derived that most of the voltage rise on the 11kV circuit between Carlton and Hospital No.3A will be caused by active power flow.

As demonstrated in the previous sections, parallel operation of the generator will mean a net import of power for most of the year. Under minimum load conditions the net export of generation is not expected to be greater than 260kVA for Hospital No.3A and 200kVA for Hospital No.3B.

Based on Energy Australia impedance data this would result to a voltage rise of less than 0.1% for Hospital No.3A and would have barely any effect on Hospital No.3B voltage profile as Hospital No.3 only represent 20% of the load connected on Carlton Feeder 1.

On the other hand the sudden disconnection of the combined 1500kVA of generation at Hospital No.3A or disconnection of the 550kVA of generation at Hospital No.3B will lead to a step in voltage magnitude of 0.5% which is acceptable to meet Energy Australia statutory limits.

It is to be noted that based on the data available, Generation impact on low voltage could not be assessed and therefore further study will be required should Hospital No.3 decide to proceed with the parallel operation of its generators.

### 7.3.3 Fault Level Consideration

Hospital No 1: The combined rating of the two generators connected at Hospital No.3A is roughly 1500kVA with an expected fault contribution of 5 p.u. The equivalent impedance of the 3x1500kVA is estimated to be in the order of 2.6% on a 1500kVA base. The impedance between Hospital No.3A and Carlton 11kV busbar is in the magnitude of 0.066 Ohm or 0.03% on 1500kVA base. This gives us an approximate additional fault contribution at Hospital No.3A 415V busbar of 5 p.u. which will be reduced to 4.4 p.u. on 1500kVA base or 6.6MVA at Carlton 11kV zone substation busbar.

Hospital No 2: The impedance between Hospital No.3B and Carlton 11kV busbar is in the magnitude of 0.12 Ohm or 0.06% on a 550kVA base. The impedance of Hospital No.3A 11/415kV transformer is approximately 0.036 p.u. on a 1500kVA base or 0.013 p.u. on a 550kVA base. The generator transient reactance is estimated to be in the order of 0.2 p.u. on 550kVA base. The 11kV circuit impedance will reduce the initial generator fault contribution from an estimated 5 p.u. to a 4.7 p.u. on a 550kVA base or 2.6MVA at Carlton 11kV busbar.

Therefore it is established that parallel operation of the three diesel generators will contribute to an increase in the Carlton 11kV fault level of approximately 17MVA. Carlton 11kV fault level is presently estimated to be in the order of 145MVA and circuit breakers installed at Carlton 11kV busbar are expected to withstand an absolute fault level of at least 250MVA.

The other substations connected to the same 11kV circuit as Hospital No.3A & 3B are assumed to be designed to withstand Carlton 11kV ultimate fault level.

It is therefore concluded that the parallel operation of the three generators connected to Hospital No.3will not increase the existing fault to such an extent that the switchgear limits at Carlton 11kV busbar are exceeded.

### 7.3.4 Power Quality

It is anticipated that the contribution of the diesel generators to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. Their connection to the network is unlikely to excite any resonance. Harmonic voltage distortion is likely to be marginally reduced due to the small increase to network fault level. Further study is not considered necessary unless power quality issues exist at present taking in consideration availability of sensitive equipment.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generators will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips.

Under islanding operation of the generators, power quality could be an issue due to low fault levels at the LV network under islanding conditions if there are any distorting or fluctuating loads on the LV network.

### 7.3.5 Conclusions

Our preliminary Investigations have demonstrated that:

The load presently connected to the Hospital No.3does not allow for Synchronise Close Transfer Trip (SCTT) Operation of the generators without a major replacement of switchboards.

Parallel operation of the generators at Hospital No.3A & 3B is technically feasible and will not adversely impact upon the Carlton 11kV network. However a thorough risk assessment is recommended to establish that such mode of operation will not introduce excessive risk with respect to security and reliability of supply.

# 8 Hospital No.4

## 8.1 Local Network Technical Overview

Hospital No.4 is supplied by 2500 A, 415 V switchboard as shown in **Figure 6**. The switchboard is fed by 11 kV / 415 V, 3X 1500 KVA transformers that are connected to the 11 kV network via an Energy Australia HV substation.

There is a standby diesel generator at 1470 kVA rating. The generator provides emergency supply to the hospital essential load that is normally supplied by the main supply. The non-essential load is connected to the same switchboard.

There is auto transfer switch (ATS) between the normal supply and the generator supply.

The total essential and non-essential load range according to reference [1] is 800 kVA -2170 kVA.

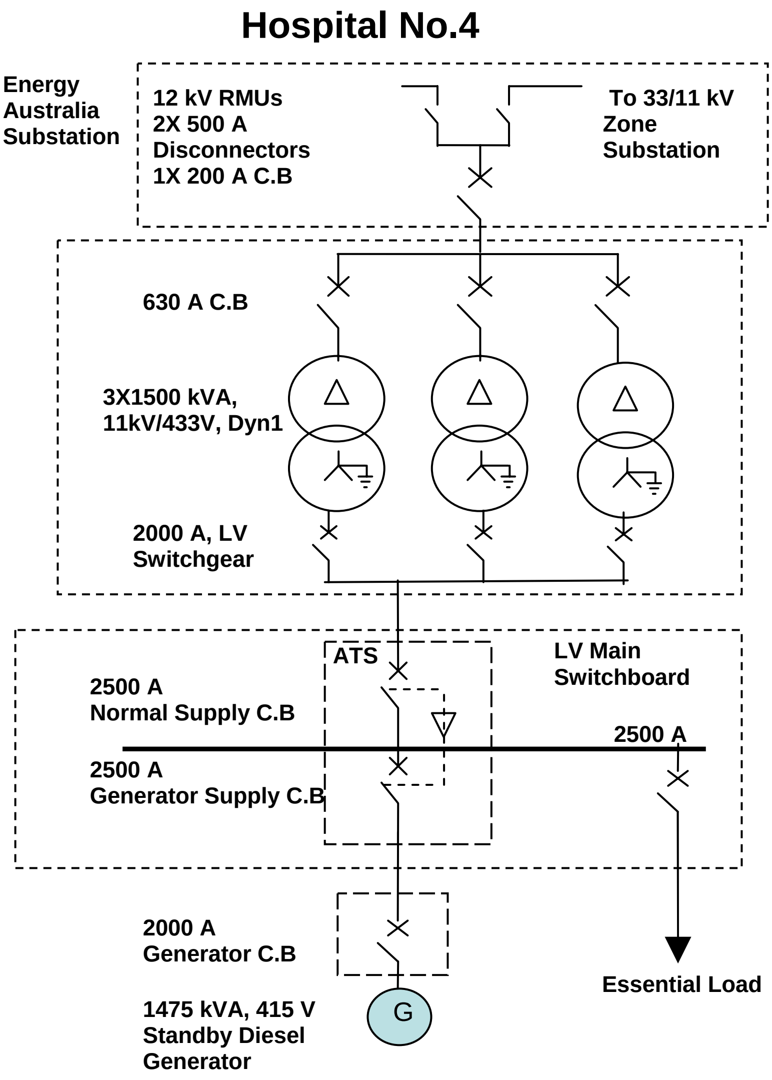



**Figure 6: Single Line Diagram Illustrating Hospital No.4 Distribution System**

## 8.2 Summary of Connection Options

The preliminary feasibility study for Hospital No.4 investigated two possible options for the connection of a single 1470 kVA diesel generator set to the 11 kV network.

**Option 1 –Parallel Operation**

The hospital total load is greater than the generation capacity of the generator. Therefore, grid export is not expected to be possible at peak load time. There may be possible grid export at minimum load times. Peak load demand reduction expected for parallel operation is 1176 kVA (equivalent to the prime rating of the generator).

**Option 2 - Synchronised Close Transfer Trip (SCTT)**

This option considers SCTT operation for the generating unit. Since the switchboard load is greater than the generator rating, this option is not feasible as it would require separating the total load in to essential load and non-essential load buses. This is considered not feasible due to cost and space restrictions. Therefore, this option was not investigated further for this site.

## 8.3 Option 1 - Parallel Operation

This option proposes parallel operation for the existing standby generator set (1470 kVA). This would require islanding protection schemes to allow safe parallel operation of the generator sets. Upgrade work is required for the generating unit to allow for parallel operation.

The expected demand reduction in this option is 1176 kVA. Based on the essential load and the prime ratings of the generator set, grid export to the 11 kV network is not expected to be possible at any time.

### 8.3.1 Thermal Limits

As there is no grid export expected, no thermal limits issue is present in terms of 11 kV network, RMU, 11 kV / 433 V transformers and 415 V main supply switchgear.

The existing generator circuit breaker with continuous current rating of 2500A can accommodate the 1176 kVA generation capacity transfer to the load.

### 8.3.2 Voltage Issues

In this section the impact of the generator connection on percentage voltage rise at 415 V and 11 kV buses was investigated.

Based on the assumptions listed in Appendix B1, percentage steady state voltage rise for 11 kV and the 415 V buses were calculated using preliminary modelling (PSS/Viper). The results are presented below in **Table 5**.

| Bus | Base (kV) | Voltage Rise (%) |
|---|---|---|
| 11 kV Carlton | 11 | 0.72 |
| 11 kV Hospital No.4 | 11 | 1 |
| 415V Hospital No.4 | 0.4 | 2.24 |

**Table 5: Percentage Steady State Voltage Rise**

The percentage voltage rise for 415 V level is lower than the Energy Australia allowable limit (upper limit of 438 V, approximately 6% voltage rise) - Please refer to Energy Australia Electricity Network Operation Standards [3]. At the 11 kV buses, the percentage voltage rise is insignificant.

It is therefore, anticipated that steady state voltage rise will not be an issue for this option.

For maximum voltage level at 415 V and 11 kV buses evaluation (with connection of the generators), accurate 11 kV feeder loads and existing voltage levels at 11 kV and 415 V buses are required.

### 8.3.3 Fault Levels

Based on the assumption in Appendix B1, the symmetrical fault contribution of the generators at is 15 MVA at 415 V. The existing fault level of the network at 415 V & 11 kV buses is 38 MVA and 120 MVA respectively. Therefore the expected fault levels at the Hospital No.4 network and the existing headroom for the existing switchgear is illustrated in **Table 6**.

| Bus | Existing fault level (MVA) | Switch Gear Design Rating MVA(kA)* | Available Head Room MVA(kA) (for switch gear) | Contribution Of the Generator @415 V |
|---|---|---|---|---|
| 11 kV Switchgear | 120 | 381 MVA(20 kA) | 261 MVA | > 7 MVA |
| 415 V Switchboard | 38 | 54 MVA (75 kA) | 16 | 7 MVA |
| 415 V Normal Supply Switchgear | 38 | 47 MVA( 65kA) | 9 MVA | 7 MVA |
| 415 V Generator Switchgear | 38 | 61 MVA( 85 kA) | 23 MVA | 7 MVA |

*** The design ratings for the switchgear are the instantaneous withstand ratings**

**Table 6: Fault Level Contribution of the Generator and the Network Plus the Existing Headroom for the Existing Switchgear**

It is evident from the available headroom in **Table 6** that the existing switchgear and the LV switchboard are capable of accommodating the additional fault levels from the generator.

The maximum fault levels at the 415 V buses are relatively high resulting in small headroom for connection of additional generation. It is therefore recommended in later stages to confirm the configuration of the Hospital No.4 substation in terms of transformer parallel operations that results in high fault levels at 415 V buses.

### 8.3.4 Power Quality

It is anticipated that the contribution of the diesel generators to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. Their connection to the network is unlikely to excite any resonance. Harmonic voltage distortion is likely to be marginally reduced due to the small increase to network fault level. Further study is not considered necessary unless power quality issues exist at present taking in consideration availability of sensitive equipment.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generators will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips.

Under islanding operation of the generators, power quality could be an issue due to low fault levels at the LV network under islanding conditions if there are any distorting or fluctuating loads at the LV network.

#### 8.3.5 Protection & Control Schemes

##### 8.3.5.1 11kV Protections

This option will require anti-islanding protection on the 11 kV system to permit safe parallel operation of the generator and prevent unwanted islanding. The recommended protection scheme includes the following:

- Protection class CT & 11kV /110 V voltage transformer 3 phase with 5 Limb Core or 3 each single phase.
- Replace the existing overcurrent protection with multifunction protection relay including:
  - 3 Phase directional instantaneous and time-delayed overcurrent for earth & phase faults,
  - neutral voltage displacement.
- Back-up overcurrent relay including:
  - 3 phase instantaneous and time-delayed phase overcurrent,
  - 3 phase instantaneous and time-delayed phase neutral over currents.
- Primary and backup auxiliary tripping relays.
- Duplicated d.c. battery backed power supplies.

The RMU is suitable to accommodate the additional protection schemes.

##### 8.3.5.2 Generator Protections

Additional generator protections are recommended for the safe parallel operation of the generator. Duplicate protections with independent d.c. supplies are recommended. Recommended generator protections are as follows:

- Three-phase set of protection class current transformers (CTs),
- Generator protection relay including:
  - 3 phase instantaneous and time-delayed phase and neutral overcurrent for earth & phase faults,
  - Under/over voltage,
  - Under/over frequency,
  - Low forward or reverse power,
  - Negative current sequence,
  - Loss of excitation,
  - Over excitation,
  - Circuit breaker fail.

- Anti-islanding relay including:
    - 3 phase instantaneous and time-delayed phase overcurrent,
    - 3 phase instantaneous and time-delayed earth fault,
    - Rate of Change of Frequency (ROCOF df/dt),
    - vector shift,
    - Circuit breaker fail,
- Primary and backup auxiliary tripping relays,
- Duplicated d.c. battery backed power supplies.

#### 8.3.5.3 Generator Synchronising Controls

To allow parallel operation additional controls will be required:

- Synchronising and control panel as shown in **Figure A1** complete with auto synchroniser;
- 3 phase metering current transformers;
- 3 phase generator voltage sensing inputs;
- Single phase bus voltage sensing inputs;
- Remote control/monitoring communications interface; and
- Digital AVR compatible with new controls.

The synchroniser may be accommodated along with the generator protections and d.c. supplies in a single Generator Synchroniser and Protection panel per generator.

### 8.3.6 Planning Issues

Generally, no issues were detected in terms of available space.

The available physical space at the Energy Australia substation is adequate to accommodate a replacement 11 kV RMU.

The available space at the generator is adequate for installation of new synchronise control and protection panel.

### 8.3.7 Budget Costs

Please refer to Appendix C.

### 8.3.8 Conclusions

After investigating the technical feasibility, the following conclusions were reached:

- SCTT operation option is not technically feasible as the load connected at the main switchboard is greater than the generator prime rating.
- 1176 kVA demand reduction is expected for Option 1- parallel operation.
- Grid export is possible.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.
- Physical space indoors is not an issue when considering installation of a new synchronising control and protection panel at the generator or the switch room.

# 9 Government Organisation No.1

## 9.1 Local Network Technical Overview

The Government Organisation No.1 is supplied by an Energy Australia Substation as shown in **Figure 7**. The substation consists of 11 kV /433 V, 500 kVA transformer that is connected to the 11 kV network through tee connection.

The existing standby diesel generator has a standby rating of 350 kVA. The generator provides emergency supply to the site essential load. The essential load is connected to two LV switchboards: one supplies essential load and the other supplies combination of essential and non-essential load.

There are two automatic transfer switches at the two switchboards which automatically switch between the normal supply and the generator supply up on loss of main supply.

The total load range according to reference [1] is 150 kVA - 231 kVA. The maximum essential load at ATS No.2 switchboard is less than 90 kVA (equivalent to continuous current rating of the ATS No.2 switchgear 125 A).

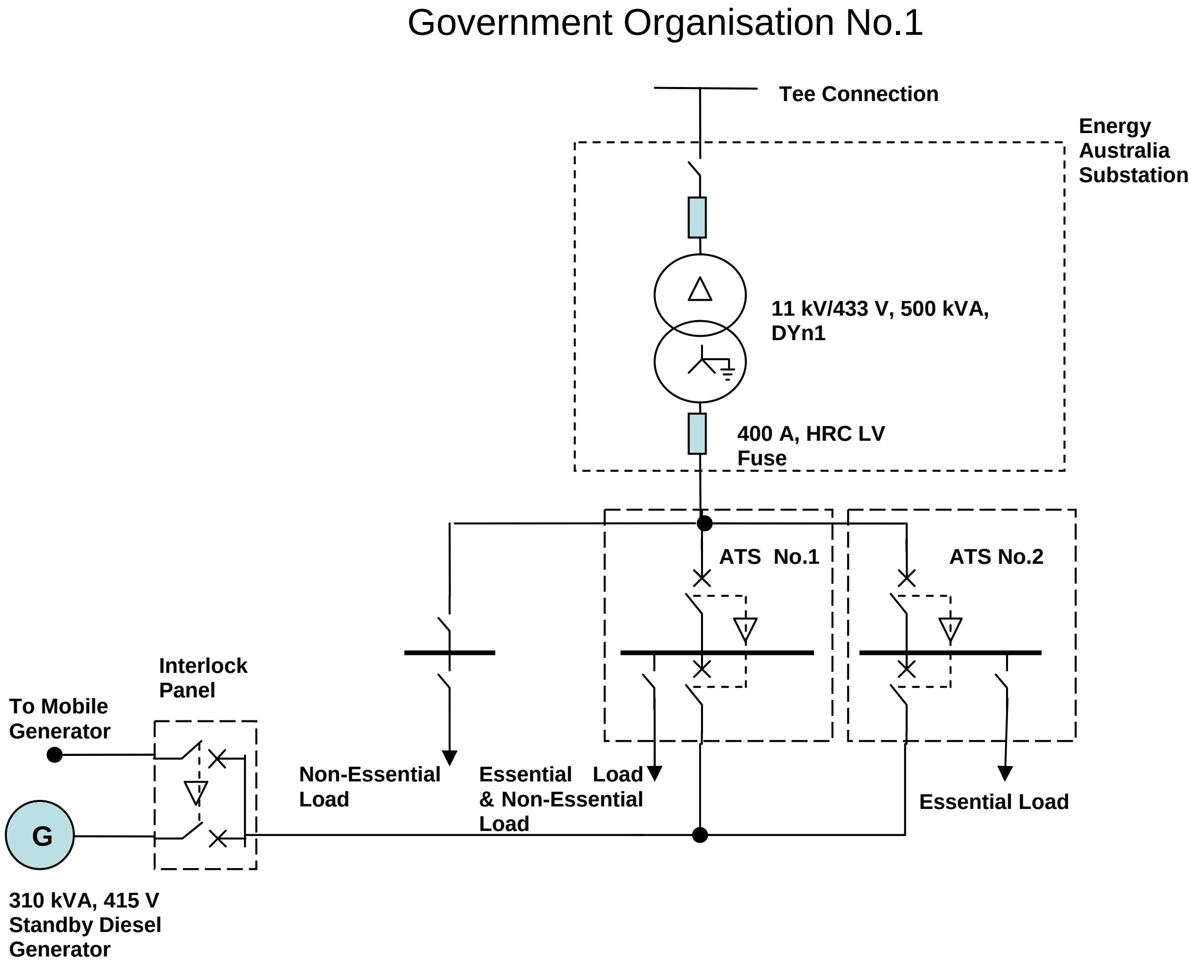



**Figure 7: Single Line Diagram Illustrating Government Organisation No.1 Distribution System**

## 9.2 Summary of Connection Options

Two possible options for the connection of up to 350 kVA of diesel generating units to the 11 kV network are considered:

**Option 1 –Parallel Operation**

This option proposes parallel operation of the generator by modifying ATS No.1 and retains ATS No.2. Small grid export is expected for this option.

**Option 2 - Synchronised Close Transfer Trip (SCTT)**

This option considers SCTT operation at ATS No.2. The essential load (90 kVA) is less than the generator prime rating (280 kVA). SCTT operation at ATS No.1 is not recommended as the essential and non-essential load could be greater than the prime rating of the generator (280 kVA).

Peak load demand reduction of 90 kVA (equivalent to essential load connected to ATS No.2).

## 9.3 Option 1 - Parallel Operation

This option proposes parallel operation for the existing standby generator set (350 kVA). This would require modification of ATS No.1 and retaining ATS No. 2. Islanding protection schemes to allow safe parallel operation of the generator sets. Upgrade work is required for the generating unit to allow for parallel operation.

The expected demand reduction in this option is 280 kVA. Based on the essential load and the prime ratings of the generator set, grid export to the 11 kV network is not expected to be possible at any time.

### 9.3.1 Thermal Limits

As no grid export is expected, no thermal limits issue is present in terms of 11 kV network, tee connection, 11 kV / 433 V transformers and 415 V main supply switchgear.

The existing generator circuit breaker with continuous current rating of 800 A, can accommodate the 280 kVA generation capacity transfer to the load.

### 9.3.2 Voltage Issues

In this section the impact of the generator connection on percentage voltage rise at 415 V and 11 kV buses was investigated.

The change in voltage (voltage rise) due to the connection of the generator is evaluated by the difference between the maximum generation output with minimum local load and zero generation output with maximum local load. Percentage steady state voltage rise for 11 kV and the 415 V buses were calculated using preliminary modelling (PSS/Viper). The results are presented below in **Table 7**.

| Bus | Base (kV) | Voltage Rise/Step % |
|---|---|---|
| 11 kV Zone Sub | 11 | 0.18 |
| 11 kV Site | 11 | 0.34 |
| 415V Site | 0.4 | 2.12 |

**Table 7: Percentage Steady State Voltage Rise**

The percentage voltage rise for 415 V level is lower than the Energy Australia allowable limit (upper limit of 438 V, approximately 6% voltage rise) - Please refer to Energy Australia Electricity Network Operation Standards [3]. At the 11 kV buses, the percentage voltage rise is insignificant.

### 9.3.3 Fault Levels

Based on the assumption in Appendix B1, the symmetrical fault contribution of the generator at is 2 MVA at 415 V. The existing fault level of the network at 415 V & 11 kV buses is 10 MVA and 96 MVA respectively. Therefore the expected fault levels at the Government Organisation No.1 network and the existing headroom for the existing switchgear is illustrated in **Table 8**.

| Bus | Existing fault level (MVA) | Switch Gear Design Rating MVA(kA)* | Available Head Room MVA(kA) (for switch gear) | Fault Contribution Of the Generator |
|---|---|---|---|---|
| 11 kV Switchgear | 96 | 381 MVA(20 kA) | 261 MVA | < 2 MVA |
| 415 V Switchgear | 10 | 36 MVA( 50 kA) | 26 MVA | 2 MVA |

*** The design ratings for the LV switchgear are the instantaneous withstand ratings**

**Table 8: Fault Level Contribution of the Generator and the Network Plus the Existing Headroom for the Existing Switchgear**

It is evident from the available headroom in **Table 8** that the existing switchgear and the LV switchboard are capable of accommodating the additional fault levels from the generator.

### 9.3.4 Power Quality

It is anticipated that the contribution of the diesel generators to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. Their connection to the network is unlikely to excite any resonance. Harmonic voltage distortion is likely to be marginally reduced due to the small increase to network fault level. Further study is not considered necessary unless power quality issues exist at present taking in consideration availability of sensitive equipment.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generators will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips.

Under islanding operation of the generators, power quality could be an issue due to low fault levels at the LV network under islanding conditions and if there is any distorting or fluctuating loads at the LV network.

### 9.3.5 Protection & Control Schemes

#### 9.3.5.1 11kV Protections

This option will require anti-islanding protection schemes (primary protection scheme) at 11 kV RMU to permit safe parallel operation of the generator. The recommended protection scheme includes the following:

- Protection class CT & 11kV /110 V voltage transformer 3 phase with 5 Limb Core or 3 each single phase.
- Multifunction protection relay including:
    - 3 Phase directional instantaneous and time-delayed overcurrent for earth & phase faults,
    - Neutral voltage displacement.
- Back-up overcurrent relay including:
    - 3 phase instantaneous and time-delayed phase overcurrent,
    - 3 phase instantaneous and time-delayed phase neutral over currents.
- Primary and backup auxiliary tripping relays.
- Duplicated d.c. battery backed power supplies.

The existing RMU can not accommodate the additional protection schemes due to space restrictions. Also, the RMU 11 kV switch fuse is not suitable for coordinating the planned protection schemes for this option. It is therefore recommended to replace the existing RMU with a new RMU that consists of two disconnectors and air vacuum circuit breaker. The RMU should be suitable to accommodate the additional protection schemes.

#### 9.3.5.2 Generator Protections

Additional generator protections are recommended for the safe parallel operation of the generator. Duplicate protections with independent d.c. supplies are recommended. Recommended generator protections are as follows:

- Three-phase set of protection class current transformers (CTs),
- Generator protection relay including:
    - 3 phase instantaneous and time-delayed phase and neutral overcurrent for earth & phase faults,
    - Under/over voltage,
    - Under/over frequency,
    - Low forward or reverse power,
    - Negative current sequence,
    - Loss of excitation,
    - Over excitation,
    - Circuit breaker fail.

- Anti-islanding relay including:
    - 3 phase instantaneous and time-delayed phase overcurrent,
    - 3 phase instantaneous and time-delayed earth fault,
    - Rate of Change of Frequency (ROCOF df/dt),
    - Vector shift,
    - Circuit breaker fail,
- Primary and backup auxiliary tripping relays,
- Duplicated d.c. battery backed power supplies.

#### 9.3.5.3 Generator Synchronising Controls

To allow parallel operation additional controls will be required:

- Synchronising and control panel as shown in **Figure A1** complete with auto synchroniser;
- 3 phase metering current transformers;
- 3 phase generator voltage sensing inputs;
- Single phase bus voltage sensing inputs;
- Remote control/monitoring communications interface; and
- Digital AVR compatible with new controls.

The synchroniser may be accommodated along with the generator protections and d.c. supplies in a single Generator Synchroniser and Protection panel per generator.

### 9.3.6 Planning Issues

This option will require replacement of the existing Energy Australia Substation with new kiosk that includes two disconnectors and air vacuum circuit breaker RMU. Commissioning this replacement will require installation of new kiosk beside the old one and transfer of existing cables to the new kiosk to minimise mains supply outage time.

Physical space available at the LV switchboard may be an issue in terms of required replacement of the generator circuit breaker and inclusion of protection CTs and Auto Transfer Switch panel modifications. Physical space available at the generator enclosure adequate to accommodate the generator synchronised control and protection panel.

### 9.3.7 Budget Costs

Please refer to Appendix C.

## 9.4 Option 2 – Synchronise Close Transfer Trip Operation (SCTT)

This option proposes SCTT operation at ATS No.2 and adds an automatic remote start/stop capacity for the generator to facilitate peak load lopping.

SCTT operation at ATS No.1 is not recommended as the essential and non-essential load may be greater than the prime rating of the generator.

Upgrade work is required for the generating unit to allow for SCTT mode of operation. No major network augmentation and protection schemes are required at 11 kV level as the generator will only be connected to the network for a short time of during load transfer.

Peak load demand reduction expected for parallel operation is 90 kVA (equivalent to essential load connected to ATS No.2).

### 9.4.1 Thermal Limits

The SCTT operation of the generator would not increase the 11 kV loading. The maximum generation output expected is equal to the essential load 90 kVA. The 415 V switchgear and switchboards can accommodate the expected maximum generation output.

### 9.4.2 Steady State Voltage Rise

The SCTT operation of the generating units is similar to the current standby operation in terms of network voltage issues. Therefore, it is anticipated that SCTT operation of this generator will not contribute to steady-state voltage rise problems.

### 9.4.3 Fault Levels

The generators will not contribute to existing fault levels in this option as the generators will be connected to the network for a short duration during load transfer.

### 9.4.4 Power Quality

The generator units will be connected to the network for short time during load transfer. Therefore, it is anticipated that the contribution of SCTT operated generator to harmonic levels in the network is insignificant.

The generator unit will be connected to the network for short time during load transfer. Therefore, it is anticipated that flicker emission of the SCTT operated generator is insignificant.

The fault level of the LV system is small when the generator is SCTT operated. This could result in power quality issues if there are any distorting loads.

### 9.4.5 Planning Issues

Physical space available at the LV switchboard may be an issue in terms of replacement of generator circuit breaker and inclusion of protection CTs and Auto Transfer Switch panel modifications. In addition, physical space available at the generator enclosure is adequate to accommodate the generator synchronised control and protection panel.

### 9.4.6 Protection & Control Schemes

To allow SCTT operation of the generator, additional protections are not recommended, as paralleling with the mains is only for a short time during load transfer. The following additional controls will be required for both SCTT operating modes:

- Synchronising and control panel as shown in **Figure A1** complete with auto synchroniser;
- 3 phase metering current transformers;
- 3 phase generator voltage sensing inputs;
- Single phase mains and bus voltage sensing inputs;
- Digital AVR compatible with new controls;
- Communications interface for remote control/monitoring.

DC power supply for the controller may be taken from the generator start battery via a d.c. converter to provide isolation and hold-up voltage during generator starts.

### 9.4.7 Budget Costs

Please refer to Appendix C.

## 9.5 Conclusions for Option 1 and 2

After investigating the technical feasibility of Options 1 and 2, the following conclusions were reached:

<u>Option 1 – Parallel Operation</u>

- 280 kVA demand reduction is expected.
- Small grid export is possible.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.

<u>Option 2 – SCTT Operation</u>

- 90 kVA demand reduction is expected.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.

# 10 Government Organisation No.2

## 10.1 Local Network Technical Overview

The Government Organisation No.2 is supplied by an Energy Australia Substation as shown in **Figure 8**. The substation consists of 11 kV /433 V, 500 kVA transformer that is connected to the 11 kV network through a Ring Main Unit (RMU).

The existing diesel generator at 350 kVA standby rating provides emergency supply to essential loads. The essential load is connected to 415 V main switchboard. There are two separate switchboards that supply non-essential load.

There is auto transfer switch at the main switchboard automatically switches between the normal supply and the generator supply up on mains failure.

The maximum load at the essential switchboard must be less than the ATS switchgear continuous current rating 575 kVA, 800 A and is likely to be less than the standby generator rating (350 kVA).

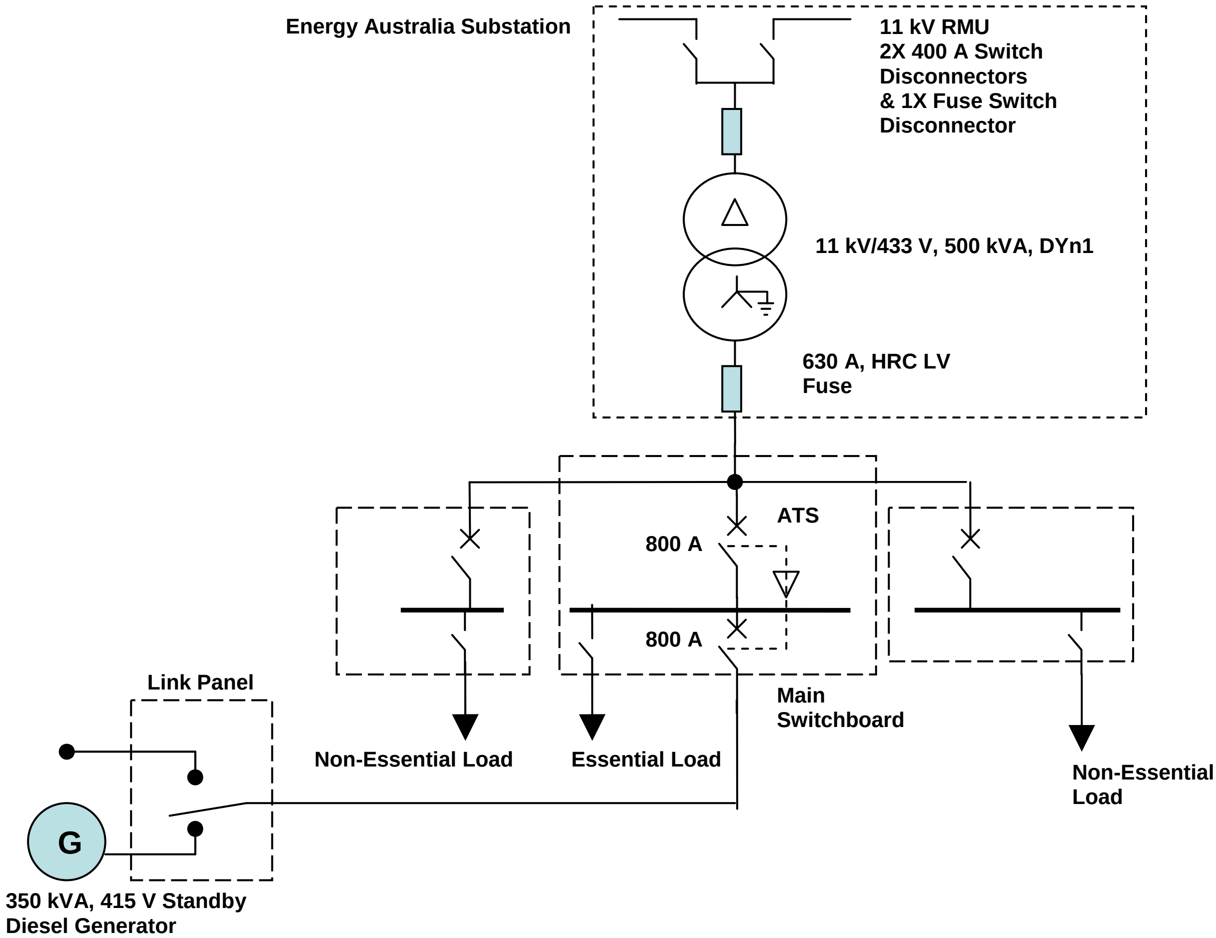



**Figure 8: Single Line Diagram Illustrating Government Organisation No.2 Distribution System**

## 10.2 Summary of Connection Options

The preliminary feasibility study for Government Organisation No.2 investigated the following two options for the connection of the 350 kVA diesel generator set to the 11 kV network.

**Option 1 –Parallel Operation**

The essential load is greater than the prime capacity (280 kVA) of the generator by approximately 2 times. Therefore, grid export is not expected to be possible at any time. There may be small grid export at minimum load times. At the time of writing this report, the minimum load data was not available. Peak load demand reduction expected for parallel operation is 280 kVA.

**Option 2 - Synchronised Close Transfer Trip (SCTT)**

The SCTT operation may be feasible as long as the essential load is less than the prime rating of the generator. The peak load demand reduction expected for this option is equivalent to the essential load (up to the prime rating of the generator set).

## 10.3 Option 1 - Parallel Operation

This option proposes parallel operation for the existing standby generator set (350 kVA). This would require islanding protection schemes to allow safe parallel operation of the generator sets. Upgrade work is required for the generating unit to allow for parallel operation.

The expected demand reduction in this option is 280 kVA. Based on the essential load and the prime ratings of the generator set, grid export to the 11 kV network is not expected to be possible at any time.

### 10.3.1 Thermal Limits

As no grid export is expected, no thermal limits issue is present in terms of 11 kV network, RMU, 11 kV / 433 V transformers and 415 V main supply switchgear.

The existing generator circuit breaker with continuous current rating of 800 A, can accommodate the 280 kVA generation capacity transfer to the load.

### 10.3.2 Voltage Issues

In this section the impact of the generator connection on percentage voltage rise at 415 V and 11 kV buses was investigated.

Based on the assumptions listed in Appendix B1, percentage steady state voltage rise for 11 kV and the 415 V buses were calculated using preliminary modelling (PSS/Viper). The results are presented below in **Table 9**.

| Bus | Base (kV) | Voltage Rise % |
|---|---|---|
| 11 kV Zone Sub | 11 | 0.16 |
| 11 kV Site | 11 | 0.28 |
| 415V Site | 0.4 | 2.14 |

**Table 9: Percentage Steady State Voltage Rise**

The percentage voltage rise for 415 V level is lower than the Energy Australia allowable limit (upper limit of 438 V, approximately 6% voltage rise) - Please refer to Energy Australia Electricity Network Operation Standards [3]. At the 11 kV buses, the percentage voltage rise is insignificant.

It is therefore anticipated that steady state voltage rise will not be an issue for this option.

For maximum voltage level at 415 V and 11 kV buses evaluation (with connection of the generators), accurate 11 kV feeder loads and existing voltage levels at 11 kV and 415 V buses are required.

### 10.3.3 Fault Levels

Based on the assumption in Appendix B1, the symmetrical fault contribution of the generator is 2 MVA at 415 V. The existing fault level of the network at 415 V & 11 kV buses is 10 MVA and 118 MVA respectively. Therefore the expected fault levels at Government Organisation No.2 network and the existing headroom for the existing switchgear is illustrated in **Table 10**.

| Bus | Existing fault level (MVA) | Switchgear Design Rating MVA(kA) * | Available Head Room MVA(kA) (for switch gear) | Contribution Of the Generator @415 V |
|---|---|---|---|---|
| 11 kV Switchgear | 118 | 248 MVA(13 kA) | 130 MVA | > 2 MVA |
| 415 V Normal Supply Switchgear | 10 | 47 MVA( 65kA) | 37 MVA | 2 MVA |
| 415 V Generator Switchgear | 10 | 36 MVA(50 kA) | 26 MVA | 2 MVA |

*** The design ratings for the switchgear are the instantaneous withstand ratings**

**Table 10: Fault level contribution of the generator and the Network plus the existing headroom for the existing switchgear**

It is evident from the available headroom in **Table 10** that the existing switchgear and the LV switchboard are capable of accommodating the additional fault levels from the generator.

### 10.3.4 Power Quality

It is anticipated that the contribution of the diesel generators to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. Their connection to the network is unlikely to excite any resonance. Harmonic voltage distortion is likely to be marginally reduced due to the small increase to network fault level. Further study is not considered necessary unless power quality issues exist at present taking in consideration availability of sensitive equipment.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generators will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips.

Under islanding operation of the generators, power quality could be an issue due to low fault levels at the LV network under islanding conditions and if there is any distorting or fluctuating loads at the LV network.

### 10.3.5 Protection and Control Schemes

#### 10.3.5.1 11kV Protections

This option will require anti-islanding protection schemes (primary protection scheme) at 11 kV RMU to permit safe parallel operation of the generator. The recommended protection scheme includes the following:

- Protection class CT & 11kV /110 V voltage transformer 3 phase with 5 Limb Core or 3 each single phase.
- Multifunction protection relay including:
  - 3 Phase directional instantaneous and time-delayed overcurrent for earth & phase faults,
  - Neutral voltage displacement;
- Back-up overcurrent relay including:
  - 3 phase instantaneous and time-delayed phase overcurrent,
  - 3 phase instantaneous and time-delayed phase neutral over currents;
- Primary and backup auxiliary tripping relays; and
- Duplicated d.c. battery backed power supplies.

The existing RMU can not accommodate the additional protection schemes due to space restrictions. Also, the RMU 11 kV switch fuse is not suitable for coordinating the planned protection schemes for this option. It is therefore recommended to replace the existing RMU with a new RMU that consists of two disconnectors and air vacuum circuit breaker. The RMU should be suitable to accommodate the additional protection schemes.

#### 10.3.5.2 Generator Protections

Additional generator protections are recommended for the safe parallel operation of the generator. Duplicate protections with independent d.c. supplies are recommended. Recommended generator protections are as follows:

- Three-phase set of protection class current transformers (CTs),
- Generator protection relay including:
  - 3 phase instantaneous and time-delayed phase and neutral overcurrent for earth & phase faults,
  - Under/over voltage,
  - Under/over frequency,
  - Low forward or reverse power,
  - Negative current sequence,
  - Loss of excitation,
  - Over excitation,
  - Circuit breaker fail.

- Anti-islanding relay including:
    - 3 phase instantaneous and time-delayed phase overcurrent,
    - 3 phase instantaneous and time-delayed earth fault,
    - Rate of Change of Frequency (ROCOF df/dt),
    - Vector shift,
    - Circuit breaker fail;
- Primary and backup auxiliary tripping relays; and
- Duplicated d.c. battery backed power supplies.

#### 10.3.5.3 Generator Synchronising Controls

To allow parallel operation additional controls will be required:

- Synchronising and control panel as shown in **Figure A1** complete with auto synchroniser,
- 3 phase metering current transformers,
- 3 phase generator voltage sensing inputs,
- Single phase bus voltage sensing inputs.
- HLI remote operation
- Digital AVR compatible with new controls.

The synchroniser may be accommodated along with the generator protections and d.c. supplies in a single Generator Synchroniser and Protection panel per generator.

### 10.3.6 Planning Issues

This option will require replacement of the existing RMU (two disconnectors and one fuse switch) with a new RMU that includes two disconnectors and a vacuum or SF6 circuit breaker. Commissioning this replacement may require installation of new RMU beside the existing one and connection of the existing cables to the termination of the new RMU. The physical space available for accommodating the new RMUs and the protection panel proposed for this option is insufficient without expansion of the substation. As the substation encroaches into a public alley, planning permission for an expansion may be difficult to obtain.

Physical space available at the LV switchboard may be an issue in terms of replacement of generator circuit breaker and inclusion of protection CTs and Auto Transfer Switch panel modifications. In addition, physical space available at the generator enclosure is adequate to accommodate the generator synchronised control and protection panel.

### 10.3.7 Budget Costs

Please refer to Appendix C.

## 10.4 Option 2 – Synchronise Close Transfer Trip Operation (SCTT)

This option proposes to operate the standby generator under SCTT mode and add an automatic remote start/stop capacity to facilitate peak load lopping.

Upgrade work is required for the generating unit to allow for SCTT mode of operation. No major network augmentation and protection schemes are required at 11 kV level as the generator will only be connected to the network for a short time of during load transfer.

Based on prime rating of the generator, the expected peak demand reduction for this option is 280 kVA.

### 10.4.1 Thermal Limits

The SCTT operation of the generator would not increase the 11 kV loading. The maximum generation output expected is equal to the prime rating of the generator 280 kVA. The 415 V switchgear and switchboards can accommodate the maximum generation output 280 kVA.

### 10.4.2 Steady State Voltage Swing and Rise

The SCTT operation of the generating units is similar to the current standby operation in terms of network voltage issues. Therefore, it is anticipated that SCTT operation of this generator will not contribute to steady-state voltage rise problems.

### 10.4.3 Fault Levels

The generators will not contribute to existing fault levels in this option as the generators will be connected to the network for a short duration during load transfer.

### 10.4.4 Power Quality

The generator units will be connected to the network for short time during load transfer. Therefore, it is anticipated that the contribution of SCTT operated generator to harmonic levels in the network is insignificant.

The generator unit will be connected to the network for short time during load transfer. Therefore, it is anticipated that flicker emission of the SCTT operated generator is insignificant.

The fault level of the LV system is small when the generator is SCTT operated. This could result in power quality issues if there are any distorting loads.

### 10.4.5 Planning Issues

Physical space available at the LV switchboard may be an issue in terms of replacement of generator circuit breaker and inclusion of protection CTs and Auto Transfer Switch panel modifications. In addition, physical space available at the generator enclosure is adequate to accommodate the generator synchronised control and protection panel.

### 10.4.6 Protection & Control Schemes

To allow SCTT operation of the generator, additional protections are not recommended, as paralleling with the mains is only for a short time during load transfer. The following additional controls will be required for both SCTT operating modes:

- Synchronising and control panel as shown in **Figure A1**,
- 3 phase metering current transformers,
- 3 phase generator voltage sensing inputs,
- Single phase mains and bus voltage sensing inputs.
- Digital AVR compatible with new controls
- HLI for remote operation and interface for existing PLCs and controls.

DC power supply for the controller may be taken from the generator start battery via a d.c. converter to provide isolation and hold-up voltage during generator starts.

### 10.4.7 Budget Costs

Please refer to Appendix C.

## 10.5 Conclusions

After investigating the technical feasibility of both Option 1 and Option 2, the following conclusions were reached:

<u>Option 1 – Parallel Operation</u>

- 280 kVA demand reduction is expected.
- Small grid export is possible.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.

<u>Option 2 – SCTT Operation</u>

- A demand reduction less than the generator's prime rating is expected.
- No issues are expected in terms of voltages and increased fault level. Although detailed feasibility studies are recommended to confirm this conclusion.

# 11 Environmental Issues

All distributed generators have the advantage of reduction in network load and hence line loss avoidance when compared with remotely located centralised generation plants.

Diesel-driven distributed generators are generally used as standby generators with the aim to ensure continuity of supply to facilities with an extremely low tolerance for interruption of supply such as medical and electronic equipment. The main driver behind this choice of technology was that diesel distributed generators are the only generators that can provide immediate start-up. Furthermore, diesel-driven distributed generators used fuel stored on-site which reduces the risk of a potential interruption of fuel supply that may exist with other type of technology such as natural gas fuelled generators.

Diesel-driven generators are high NOx emitters and have an efficiency of approximately 35%. Both disadvantages were not of much concern for standby generation as this was combined with a very low utilization, typically less than 500 hours per year.

This study investigates the feasibility of using these generators for a completely different function (peak generation). Therefore the original assumptions and environmental conclusions no longer prevail.

**Figure 9** shows a comparison between the CO2 emissions for various fuels generation.

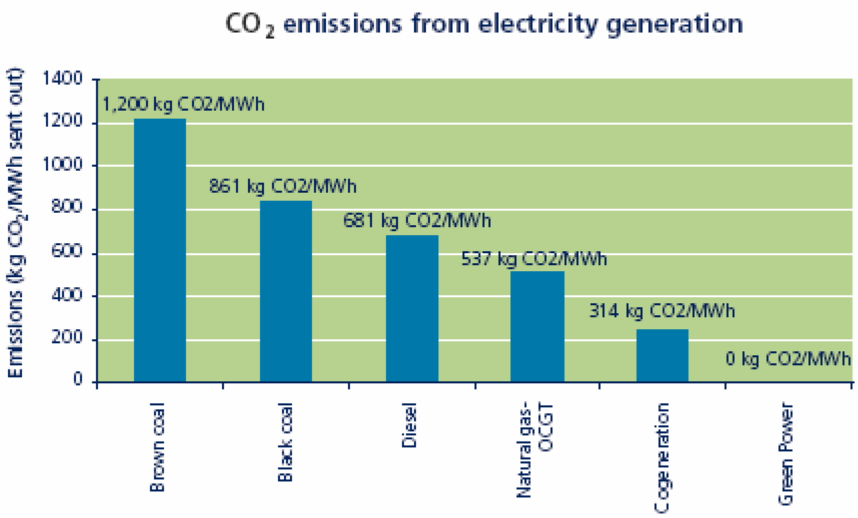



**Figure 9: Comparison $CO_2$ Emission for Various Fuels Electric Generation [3]**

When compared with other sources of energy, Diesel-driven generators are high NOx emitters (4 times greater than the average emission of all type of generation combined), average $CO_2$ emitters and a very low $SO_2$ emitters (15 times less than the average emission of all type of generation combined).

Therefore appropriate management of $CO_2$ and NOx emissions will be required. This can be achieved by installation of air pollution control equipment such as Selective Catalyst Reduction device also known as SCR.

Although peak operation of diesel generation can be economically justified in some cases, it should be noted that Diesel generators are usually not the preferred options for peak generation. This can be explained when considering the cost/efficiency profile and environmental impact of such a scheme. Technology with higher overall efficiency and low emission profile is preferred such as Combined Heat and Power (also known as co-generation or CHP) or combined-cycle gas turbines.

## 12 Risk Management

This topic is too extensive to be thoroughly covered by the scope of this report and we strongly recommend that an individual risk assessment is carried out for each feasible site. However a brief list of potential risk management issues arising from the utilisation of standby generators for peak load generation is highlighted.

A higher rate of utilisation of the generator will increase the probability of generator failure, which may not be available for potential emergency supply should interruption of mains supply occur.

Parallel operation of the generator means that should a fault or other disturbance occur on the distribution network both mains supply and emergency supply can be affected and disconnected. The system should be designed to maintain the generator operating as an island in the event of a credible contingency event. However, abnormal events may occur which will not permit the generator to continue running. Reconnection of the standby generator may require a manual start-up procedure which can delay the restoration of supply to essential loads when compared with the existing standby mode of operation. Power system stability studies are recommended to determine the risk of supply interruption for various events.

# 13 Overall Conclusions

**Table 11** provides a summary of each site and operating configuration.

| Site | Operation Mode | Peak Demand Reduction(kVA) | Budget Cost (AU$) | Budget Cost (AU$/kVA) | Overall Rank[1] |
|---|---|---|---|---|---|
| Hospital No.1 | Parallel | 248 | 355,000 | 1,432 | 10 |
| | SCTT | Not Feasible | Not Feasible | Not Feasible | Not Feasible |
| Hospital No.2 | Parallel | 1200 | 277,000 | 231 | 8 |
| | SCTT | 410 | 62,000 | 151 | 1 |
| Hospital No.3 | Parallel | 1454 / 440[2] | 265,000/212,000[2] | 182 / 482[2] | 6 / 9 |
| | SCTT | Not Feasible | Not Feasible | Not Feasible | Not Feasible |
| Hospital No.4 | Parallel | 1176 | 233,000 | 198 | 7 |
| | SCTT | Not Feasible | Not Feasible | Not Feasible | Not Feasible |
| Government Organisation No.1 | Parallel | 280 | 284,000 | 1,014 | 2 |
| | SCTT | 90 | 85,000 | 944 | 4 |
| Government Organisation No.2 | Parallel | 280 | 309,000 | 1,104 | 5 |
| | SCTT | 250 | 96,000 | 384 | 3 |

**Notes :**

1. The overall ranking is an assessment based on commercial, risk and technical constraints.
2. Hospital No 3A 1270kVA & 220kVA / Hospital No 3B 550kVA.

**Table 11: Overall Site Ranking**

The overall site ranking has been determined based on the following issues in order of priority:

- Risk of supply interruption;
- Maximum demand reduction (kVA); and
- Budget cost per kVA of demand reduction.

The $ cost per kVA of available demand reduction varies from $150/kVA to $1,432/kVA. The large spread is due to the variation in existing equipment capability and capacity. The cost for upgrade to generator set controls and protection for SCTT or parallel operation is largely independent of generator rating. The additional cost for the parallel operation over SCTT operation is due to the need for additional protection that requires upgrade of 11kV switchgear.

Although attractive from a cost and demand reduction point of view, parallel operation of diesel generator sets represents a higher risk of extended supply outage than SCTT operation. Parallel options have been ranked below SCTT options for this reason.

# 14 Recommendations

It is recommended that Hospital No.2 site is the first selected as the subject of a more detailed feasibility study. Hospital No.2 has two each 750 kVA diesel generator sets with existing synchronising capability installed in 2002 making it an attractive option.

We recommend the following issues are the subject of a more detailed feasibility study:

1. Demand Reduction – It is recommended that load connected to the main switchboard (with existing synchronising capability) is recorded to confirm available demand reduction;
2. Risk Management – a formal risk assessment is recommended to evaluate the risk of supply interruption to critical loads. For parallel operation, this will include power systems analysis and transient stability studies.
3. Network Service Provider (NSP) controls – Remote NSP automatic controls and monitoring required to be located in the NSP Control Room or NSP Zone Substation;
4. Telecommunications – the preferred type of communications link;
5. Thermal Limits – Confirmation of thermal ratings of cables and switchgear;
6. Protection – Confirmation of NSP requirements for anti-islanding protection;
7. Power Quality – Investigation of power quality requirements for critical and sensitive loads to confirm feasibility of island operation;
8. Maintenance – Estimation of additional ongoing maintenance costs, if any;
9. Reliability – Run tests to confirm generator will function reliably for required duty and expected load variations.

## 15 References

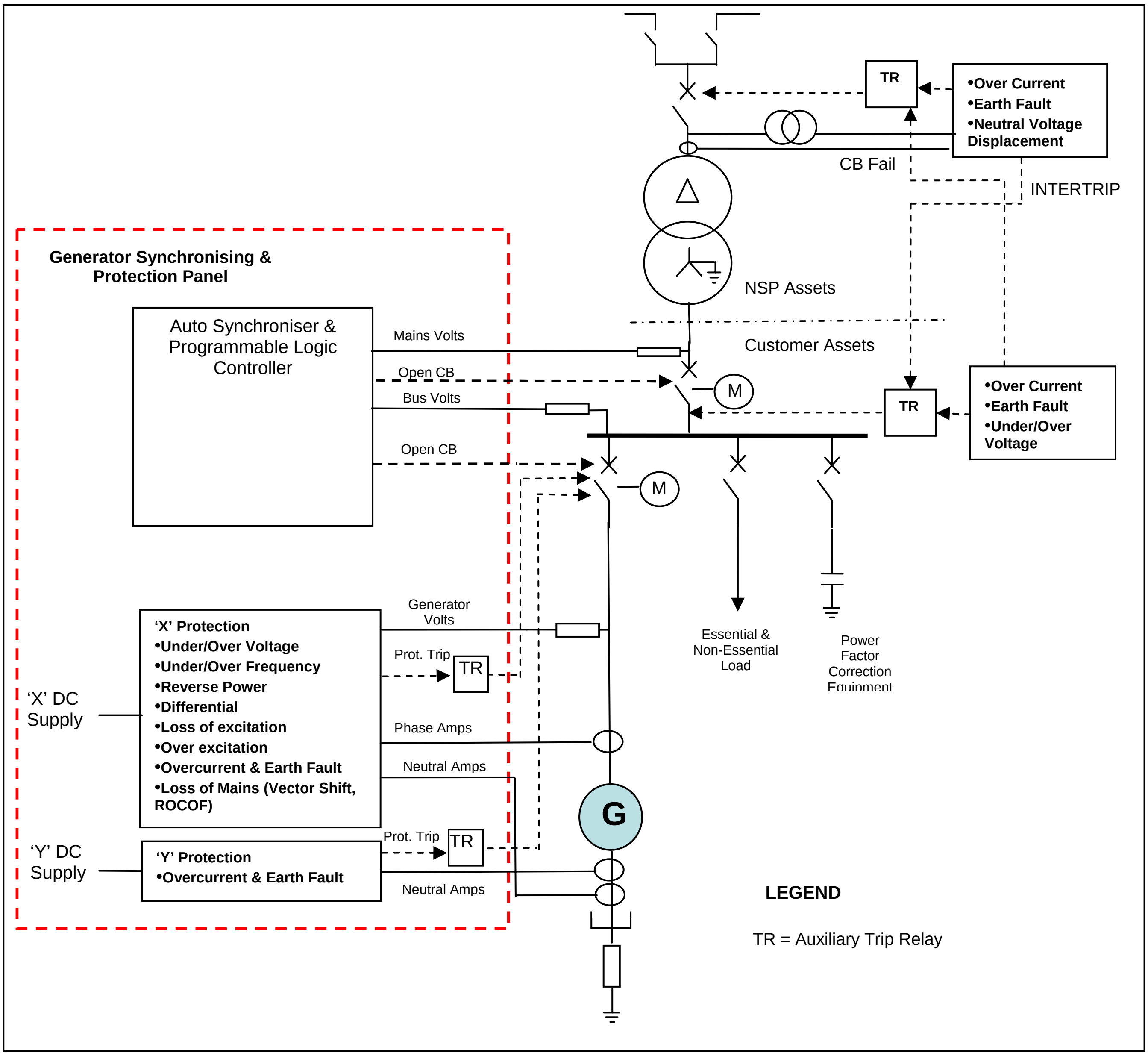

[1] Energetics, 'Demand Management and Planning Projects – Basic Investigations', 2004

[2] Energy Australia, 'Electricity Network Operation Standards amended by CIA'

[3] Green Power, 'Green Power Business Guide', 2005.

# 16 Appendices

## 16.1 Appendix A – Typical Protection and Control Arrangement for Parallel Operation



## 16.2 Appendix B – General Study Assumptions

The following are a list of assumptions that were considered for voltage rise / step and fault level studies:

- In the study model for each site, the 11 kV systems beyond the 11 kV bus of the 33/11 kV Zone Substation were represented by the equivalent fault impedance at 11 kV [5].
- No Load change is considered at the 11 kV feeder load for voltage study. Only customer load change was taken in consideration for the study.
- As the load data were not available at the time of writing this report, the peak load was assumed equivalent to the supply equipment ratings (switchgear, cables etc). The minimum load was assumed equivalent to 20 % of the peak load.
- According to the information provided by Energy Australia about 11 kV voltage range at Zone substation, the tap changer setting of the 132 / 11 kV transformer is set between (11.3 kV and 10.8 kV) with setting voltage equal to 1 p.u.
- The impedance parameters for the 11 kV feeder from 11 kV bus of the Zone substation to 11 kV RMU that connects the customer to the 11 kV network are listed in feeders' data provided by Energy Australia.
- The impedance of the cable which connects the close RMUs at the same substation is negligible.
- The transient and sub-transient parameters for the Caterpillar Standby generator are assumed 20 % and 10 % respectively of the generator rating.

## 16.3 Appendix C – Budget Estimates

### 16.3.1 General Notes, Assumptions and Exclusions

The budget cost for all sites has been based on the following assumptions and exclusions:

1) There is spare space for required additional indoor electrical panels housing the auto-synchronising and load management controls, protection and communications interface;
2) There is sufficient space in the Auto Transfer Switch panels to accommodate the required current transformers, voltage sensing points, watt transducer and control wiring;
3) Where grid export is possible, grid metering installation is capable of metering bi-directional power flows according to NEMMCO requirements;
4) There is sufficient spare capacity in existing cable trenches to accommodate additional control cables;
5) Power cables have been correctly selected to supply existing and forecast load levels at the site;
6) Remote-end monitoring, automatic control and communications equipment required by the Network Service Provider to initiate the remote start/stop of the generators has not been included. Communications lines or radio equipment are excluded. Communications interface at the local end only is included;
7) Operating and maintenance costs are excluded.

### 16.3.2 Budget Cost for Hospital No.1

#### 16.3.2.1 Option 1 – Parallel Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| Replace existing 750kVA kiosk substation with new 750kVA kiosk substation c/w 2 each switch disconnectors, 1 each circuit breaker, CTs, 3 ph. VT., housed in weatherproof enclosure. | 100,000 | 5,000 | 1 | 105,000 |
| Cable and terminations | 1,000 | 5,000 | 1 | 6,000 |
| **Sub-total (Network Augmentation)** | | | | **106,000** |
| | | | | |
| **Generator & LV Switchgear** | | | | |
| Replace Generator circuit breaker (250 A) with greater thermal rating circuit breaker | 13,000 | 5,000 | 1 | 18,000 |
| Diesel generator set modifications for parallel operation including neutral CTs, digital AVR & Protection. | 6,000 | 2,500 | 1 | 8,500 |
| Auto Synchroniser c/w, duplicated battery charger, remote control operation, and batteries, generator protection relay and over-current relay. | 60,000 | 5,000 | 1 | 65,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 1 | 10,000 |
| Control and LV Cables, supports and terminations | 5,000 | 2,500 | 1 | 7,500 |
| **Sub-total (Generator & LV Switchgear)** | | | | **109,000** |
| | | | | |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 30,000 |
| **Total** | | | | **335,000** |

**Table C1: Budget Cost (@ +/- 20%) for Option 1 – Parallel Option, Hospital No.1**

### 16.3.3 Hospital No.2

#### 16.3.3.1 Option 1 – Parallel Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| New Ring Main Unit. | 30000 | 5,000 | 2 | 70,000 |
| Protection c/w Panel and duplicated battery/battery charger | 15,000 | 5,000 | 2 | 40,000 |
| Cable and terminations | 1,000 | 5,000 | 2 | 12,000 |
| **Sub-total (Network Augmentation)** | | | | **122,000** |
| | | | | |
| **Generator & LV Switchgear** | | | | |
| Auto Synchroniser Panel & Protection Panel c/w, batteries, generator protection relay and anti islanding protection relay, remote control communications interface. | 20,000 | 5,000 | 2 | 50,000 |
| Control and LV Cables, supports and terminations | 5,000 | 2,500 | 2 | 15,000 |
| **Sub-total (Generator & LV Switchgear)** | | | | **65,000** |
| | | | | |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 40,000 |
| **Total** | | | | **277,000** |

**Table C2: Budget Cost (@ +/- 20%) for Option 1 – Parallel Option, Hospital No.2**

### 16.3.3.2 Option 2 – SCTT Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Generator & LV Switchgear** | | | | |
| Auto Synchroniser Panel upgrade, remote control communication interface and batteries. | 11,000 | 5,000 | 2 | 32,000 |
| **Sub-total (Generator & LV Switchgear)** | | | | **32,000** |
| | | | | |
| Engineering | | | | 10,000 |
| Testing & Commissioning | | | | 10,000 |
| Contractor Overhead | | | | 10,000 |
| **Total** | | | | **62,000** |

**Table C3: Budget Cost (@ +/- 20%) for Option 2 – SCTT Operation, Hospital No.2**

## 16.3.4 Hospital No.3

### 16.3.4.1 Option 1 – Parallel Operation

**Hospital No 3A - 1250kVA and 220kVA Generators**

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| Three-phase set CT, 3 ph. VT. housed in a weatherproof enclosure. | 20,000 | 5,000 | 3 | 75,000 |
| Cable and terminations | 1,000 | 5,000 | 3 | 18,000 |
| **Sub-total (Network Augmentation)** | | | | **93,000** |
| **Generator & LV Switchgear** | | | | |
| Diesel generator set modifications for parallel operation including neutral CT sans AVR | 10,000 | 5,000 | 2 | 30,000 |
| Generator Synchronizing Protection Panel | 45,000 | 5,000 | 2 | 100,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 2 | 20,000 |
| Control and LV Cables, supports and terminations | 5,000 | 2,500 | 2 | 15,000 |
| **Sub-total (Generator & LV Switchgear)** | | | | **165,000** |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 5,000 |
| **Total** | | | | **265,000** |

**Table C4: Budget Cost (@ +/- 20%) for Option 1 – Parallel Operation, Hospital No.3A- 1270kVA and 220kVA Sites**

**Hospital No 3B - 550kVA Generator**

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| Three-phase set CT, 3 ph. VT. housed in a weatherproof enclosure. | 20,000 | 5,000 | 2 | 50,000 |
| Cable and terminations | 1,000 | 5,000 | 1 | 6,000 |
| **Sub-total (Network Augmentation)** | | | | **56,000** |
| **Generator & LV Switchgear** | | | | |
| Diesel generator set modifications for synchronising, AVR upgrade. | 6,000 | 2,500 | 1 | 8,500 |
| Generator Synchronizing Protection Unit | 55,000 | 5,000 | 1 | 50,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 1 | 10,000 |
| Control and LV Cables, supports and terminations | 5,000 | 2,500 | 1 | 7,500 |
| **Sub-total (Generator & LV Switchgear)** | | | | **76,000** |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 30,000 |
| **Total** | | | | **212,000** |

**Table C5: Budget Cost (@ +/- 20%) for Option 1 – Parallel Operation, Hospital No.3B–550kVA Site**

### 16.3.5 Hospital No.4

### 16.3.5.1 Option 1 – Parallel Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| New Ring Main Unit, c/w circuit breaker, VT | 20,000 | 5,000 | 1 | 25,000 |
| Duplicated Battery Charger/ Battery and Protection Relays Panel | 30,000 | 5,000 | 1 | 35,000 |
| Cable and terminations | 1,000 | 5,000 | 1 | 6,000 |
| **Sub-total (Network Augmentation)** | | | | **66,000** |
| | | | | |
| **Generator & LV Switchgear** | | | | |
| Diesel generator set modifications for parallel operation including neutral CTs, digital AVR. | 6,000 | 2,500 | 1 | 8,500 |
| Auto Synchroniser & protection panel c/w, remote control communication interface, duplicated battery charger, remote and batteries, generator protection relay and anti- islanding relay. | 60,000 | 5,000 | 1 | 65,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 1,000 | 5,000 | 1 | 6,000 |
| Control and LV Cables, supports and terminations | 5,000 | 2,500 | 1 | 7,500 |
| **Sub-total (Generator & LV Switchgear)** | | | | **87,000** |
| | | | | |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 30,000 |
| **Total** | | | | **233,000** |

**Table C6: Budget Cost (@ +/- 20%) for Option 1 – Parallel Operation, Hospital No.4**

### 16.3.6 Government Organisation No.1

#### 16.3.6.1 Option 1 – Parallel Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| Replace existing kiosk with new kiosk c/w 2 each switch disconnectors, 1 each circuit breaker, CTs, 3 ph. VT housed in weatherproof enclosure. | 100,000 | 5,000 | 1 | 105,000 |
| Cable and terminations | 1,000 | 5,000 | 1 | 6,000 |
| **Sub-total (Network Augmentation)** | | | | **111,000** |
| | | | | |
| **Generator & LV Switchgear** | | | | |
| Diesel generator set modifications for parallel operation including neutral CTs & protection and AVR. | 10,000 | 5,000 | 1 | 15,000 |
| Auto Synchroniser & Protection Panel c/w, duplicated battery charger, remote control communication interface and batteries, generator protection relay and anti-islanding relay. | 45,000 | 5,000 | 1 | 50,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 1 | 10,000 |
| Control and LV Cables, supports and terminations | 5,000 | 3,000 | 1 | 8,000 |
| **Sub-total (Generator & LV Switchgear)** | | | | **83,000** |
| | | | | |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 40,000 |
| **Total** | | | | **284,000** |

**Table C7: Budget Cost (@ +/- 20%) for Option 1 – Parallel Operation, Government Organisation No.1**

#### 16.3.6.2 Option 2 – SCTT Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Generator & LV Switchgear (SCTT Unit)** | | | | |
| Diesel generator set modifications for SCTT operation including neutral CTs, Digital AVR. | 4,000 | 2,000 | 1 | 6,000 |
| Auto Synchroniser Panel c/w remote control communications interface, | 15,000 | 5,000 | 1 | 20,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 1 | 10,000 |
| Control and LV Cables, supports and terminations | 4,000 | 2,000 | 1 | 6,000 |
| **Sub-total - Generator & LV Switchgear (SCTT Unit)** | | | | **42,000** |
| Engineering | | | | 20,000 |
| Testing & Commissioning | | | | 15,000 |
| Contractor Overhead | | | | 8,000 |
| **Total** | | | | **85,000** |

**Table C8: Budget Cost (@ +/- 20%) for Option 2 – SCTT Operation, Government Organisation No.1**

### 16.3.7 Government Organisation No.2

### 16.3.8 Option 1 – Parallel Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Network Augmentation** | | | | |
| Substation expansion including civil/earth works, earthing, fence. | 10,000 | 90,000 | 1 | 100,000 |
| Replace existing RMU with new RMU c/w 2 each switch disconnectors, 1 each circuit breaker, CTs, 5 limb, 3 ph. VT. housed in a weatherproof enclosure. | 20,000 | 5,000 | 1 | 25,000 |
| Duplicated Battery Charger/ Battery and Protection Relays Panel | 30,000 | 5,000 | 1 | 35,000 |
| Cable and terminations | 1,000 | 5,000 | 1 | 6,000 |
| **Sub-total (Network Augmentation)** | | | | **166,000** |
| | | | | |
| **Generator & LV Switchgear** | | | | |
| Diesel generator set modifications for parallel operation including neutral CTs, digital AVR. | 10,000 | 5,000 | 1 | 15,000 |
| Auto Synchroniser & protection panel c/w, duplicated battery charger and batteries, generator protection relay and anti-islanding relay. | 25,000 | 5,000 | 1 | 30,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 1 | 10,000 |
| Control and LV Cables, supports and terminations | 5,000 | 3,000 | 1 | 8,000 |
| **Sub-total (Generator & LV Switchgear)** | | | | **63,000** |
| | | | | |
| Engineering | | | | 30,000 |
| Testing & Commissioning | | | | 20,000 |
| Contractor Overhead | | | | 30,000 |
| **Total** | | | | **309,000** |

**Table C9: Budget Cost (@ +/- 20%) for Option 1 – Parallel Operation, Government Organisation No.2**

### 16.3.8.1 Option 2 – SCTT Operation

| Item | Unit Plant Cost ($) | Unit Labour Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| **Generator & LV Switchgear (SCTT Unit)** | | | | |
| Diesel generator set modifications for SCTT operation c/w digital AVR. | 10,000 | 5,000 | 1 | 15,000 |
| Auto Synchroniser Panel, remote control communication interface. | 15,000 | 5,000 | 1 | 20,000 |
| Auto Transfer Switch panel modifications including watt transducer, CTs, and fused voltage sensing connections. | 5,000 | 5,000 | 1 | 10,000 |
| Control and LV Cables, supports and terminations | 4,000 | 2,000 | 1 | 6,000 |
| **Sub-total - Generator & LV Switchgear (SCTT Unit)** | | | | **51,000** |
| Engineering | | | | 20,000 |
| Testing & Commissioning | | | | 15,000 |
| Contractor Overhead | | | | 10,000 |
| **Total** | | | | **96,000** |

**Table C10: Budget Cost (@ +/- 20%) for Option 2 – SCTT Operation, Government Organisation No.2**