Econnect

# Standby Generation Program

# Mixed-Use High Rise
# Preliminary Feasibility Study
# Grid Connection of Diesel Generator

# Econnect Project No: 1532

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# 1 Executive Summary

Econnect Australia has been 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 connecting a new diesel generator set to the low voltage (LV) distribution system in a Sydney high rise building. The customer installation is located in the Sydney CBD area.

The diesel generator is to provide parallel operation with the grid as well as standby capability to three of the six supplies fed from the Energy Australia distribution substation. Information on the maximum demand of these supplies is limited and it is recommended that load monitoring be undertaken to establish the maximum demand. However it is likely that to supply the peak summer load will require a generator at least 1500kVA in size.

Due to the requirement to provide standby capacity to only the participating supplies, connection of the generator will require construction of a new switchboard connected in series with the three participating supplies. Two options for the connection are investigated for overall feasibility:

- **Option 1 – Common Bus Connection.** A single new LV switchboard is constructed with a rating of 3200A, and the generator connected to this board via a circuit breaker matched to the generator size. A new LV feeder rated at 2 x 1600A connects the new board to the Energy Australia LV bus.
- **Option 2 – Split Bus Connection.** Three adjacent new LV switchboards are constructed (one per existing supply), with respective ratings of 1600A, 800A and 1600A corresponding to those of the three participating supplies. The generator breakers are parallel connected on the generator side, connecting to a common metering panel and thence to the generator cubicle.

These options are assessed with respect to thermal capacity, voltage changes, fault level contribution, protection and control requirements, planning issues and budget cost. The cost estimates for each option are as follows:

| | Cost estimate |
|---|---|
| Option 1: Common Bus Connection | $1,066,000 |
| Option 2: Split Bus Connection | $1,111,000 |

The principal conclusions are:

- Significant cost is involved to address the fault level issue at the Energy Australia substation. As a minimum, a fault limiting device is required on the generator at an estimated cost of $350,000. This is a short-term measure until the longer-term issue of fault levels throughout Sydney CBD substations is addressed.
- Shutdown of all customer supplies for a period of several hours will be required in order to carry out the generator connection. This may present planning difficulties.

The report also makes recommendations in regard to load monitoring, inspection of customer switchboards to clarify fault rating, determination of method for remote generator dispatch, and the long-term issue of fault levels in the Sydney CBD.

# 2 Introduction

Econnect Australia has been 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 connecting a new diesel generator set to the low voltage (LV) distribution system in a Sydney high rise building. The customer installation is located in the Sydney CBD area.

The main objective of the study is to understand the technical issues and costs associated with the connection of the standby generator in a manner that permits grid parallel operation for dispatchable demand reduction. The following key issues were considered:

- Existing essential and non-essential electricity demand at the site and the required size of the generator;
- Network technical constraints including thermal limits, network voltages, power quality and fault levels;
- Technical feasibility of parallel operation;
- Protection and control requirements;
- Electricity distribution network augmentation requirements; and
- Planning issues associated with the connection works.

# 3 Scope

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

- Site visit to determine existing plant ratings and evaluate site physical topology and constraints;
- Review of existing switchgear;
- Collation and review of 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; and
- Collection of all findings in a report.

# 4 Technical Overview

## 4.1 Parallel Operation of Standby Generators

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 protection may be 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 1**, 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.

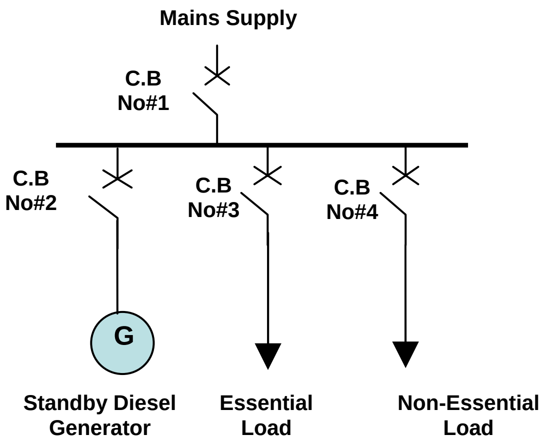


**Figure 1: Single Line Diagram Illustrating Parallel Operation of Diesel Generator**

## 4.2 Customer Installation

The customer is supplied at 415V via Energy Australia indoor substation. Three parallel 11kV feeders from zone substation feed a single LV bus via separate 11000/433V transformers each rated at 1000kVA. The transformers connect to radial 11kV feeders via isolating and earthing switches, and to the LV bus via 1600A air type circuit breakers.

Six supplies are run from the Energy Australia LV bus: four supplies are to separate customer LV switchboards (denoted 'Switchboard #1' through 'Switchboard #4' below), and two are to street supplies operated by Energy Australia. Switchboard #1 supplies low-rise commercial tenants within the building who are non-participants in the standby generation project. Switchboards #2 and #4 (feeder rating 1600A each) supply mid-rise and high-rise residential tenants, while Switchboard #3 (feeder rating 800A) supplies a residential carpark at ground level.

Figure 2 shows the existing Energy Australia substation. Further diagrams are presented in Appendix A, showing details of the customer switchboards.

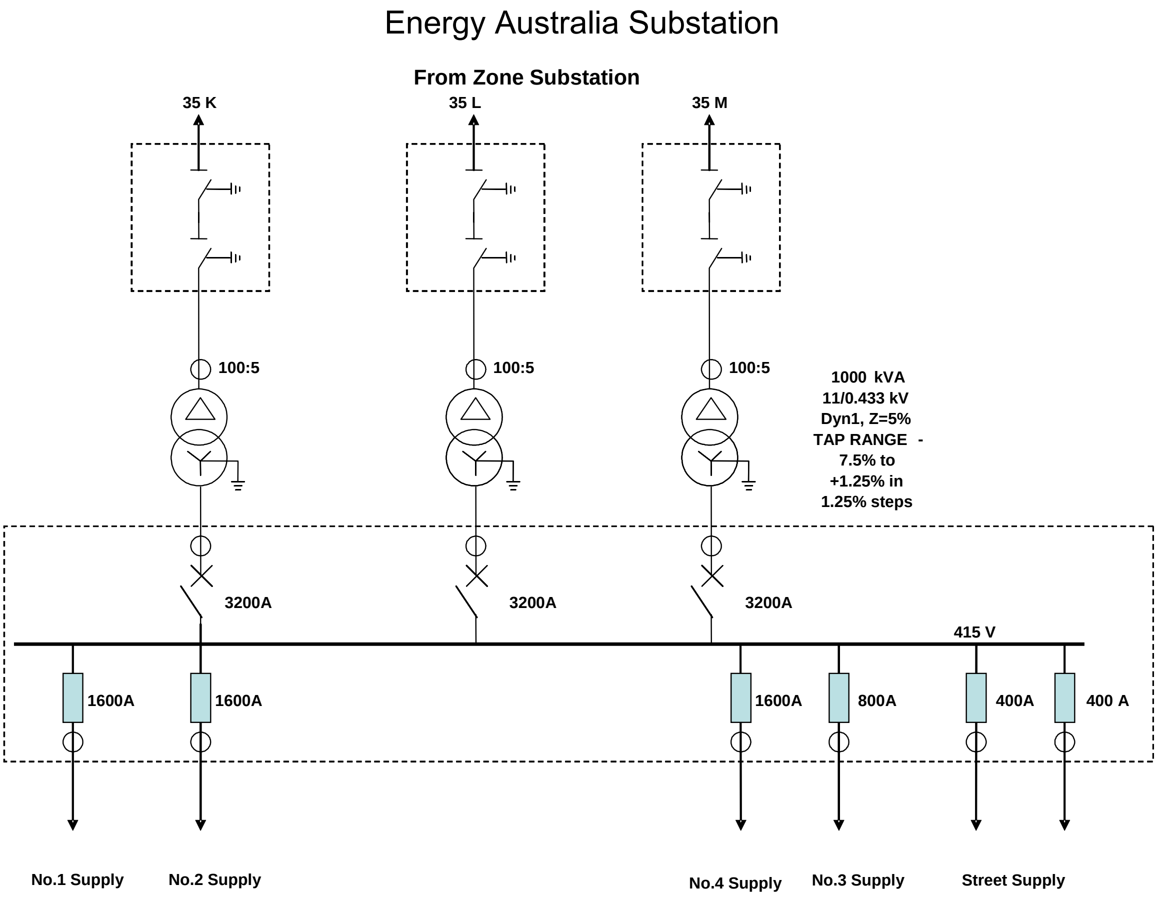


**Figure 2**: Single line diagram: Energy Australia Substation

The absence of emergency generator capacity at the customer site has been a matter of concern for some years. In 2001 a preliminary investigation took place into connecting a 300kVA emergency generator, sufficient to restart the lifts and supply water pumps in the event of a power blackout. The current proposal instead seeks to provide full residential load coverage during grid outages, and to maximise the return on investment by operating to provide demand reduction capability to the grid at other times.

### 4.3 Load Estimates and Generator Requirement

There is uncertainty regarding the maximum demand on the three participating supplies. Figures provided by Energy Australia show aggregate maximum demand (MD) at Energy Australia substation is roughly 2400kVA (summer peaking). However, existing load estimates for individual feeders at the substation are based on small samples and contain some spurious readings. Based on these estimates it appears that the two street feeders may account for up to 500kVA of the 2400kVA aggregate MD, with the non-participating Switchboard #1 responsible for a further 800kVA.

The tentative conclusion to be drawn from these figures is that the 1000kVA generator suggested for this project is probably too small to supply the peak summer residential load, and that partial load shedding would be necessary to avoid overloading the generator when operating in standby mode. In order to satisfy the peak load requirement without load shedding, it is likely that a larger generator will be required, with a rating of at least 1500kVA. Technical feasibility has been assessed based on a maximum generator size of 2000kVA.

To better establish the required generator size, it is recommended that demand on Switchboards #2, #3 and #4 be logged over the forthcoming summer period. This will permit a more reliable estimate of the generator size required to meet peak summer load.

An important consideration in determining the required generator size has been the ability to start the largest motor under standby operation. The largest motors in the customer premises are the drives for 'high rise' lifts 1 and 2, each 60kVA in size. Motor starting currents may be up to 8 times the rated current, so the peak power draw from one of these lift motors is up to 480kVA. As the smallest generator size being considered for this project is 1000kVA, no issue is anticipated with the ability to start any of the lift motors or other plant (such as stormwater pumps) during a power outage.

## 5 Identification of Connection Options

In order to provide standby generator supply to the three LV switchboards (#2, #3 and #4) it will be necessary to interrupt these supplies and tee-connect the generator to all three at some point.

As the remaining supplies (Switchboard #1 and the street feeders) do not participate in this scheme, there is a need to ensure that in standby mode the limited power output of the generator be provided exclusively to Switchboards #2, #3 and #4. Further, this must be done without altering the feeding arrangements to the remaining supplies, to avoid replacement of existing switchgear and planning issues that will escalate the project cost. For this reason a direct connection of the generator to the Energy Australia LV bus is not considered feasible.

An alternative option is to augment the existing Switchboards #2, #3 and #4, with additional feeders and switchgear to accept the parallel generator infeed. However, such an augmentation would require spare capacity in existing switchboards and extended outages to supplies fed from these switchboards, involving significant inconvenience to building tenants and requiring careful planning. These factors contribute large costs to the project, in addition to the capital cost of extending the existing boards and physically accommodating the extensions within the building fabric. Accordingly, the option of augmenting the existing switchboards has also been discounted.

The remaining alternative is to build a new switchboard adjacent to the new generator, containing all new switchgear and LV protection required for the parallel connection. The new board would be inserted in series with each of the three supplies by interrupting the existing LV cables, and running new cables approximately 50 metres from the Energy Australia bus to the new switchboard and thence to the existing Switchboards #2, #3 and #4. This alternative involves minimal disruption to building tenants, as the bulk of construction occurs remote from the existing supplies. Moreover, the proposed generator site within the carpark area is of sufficient size to accommodate switchboards of the appropriate rating, once planned modifications to accommodate the generator are complete.

Accordingly, two connection options have been identified based on construction of new LV switchboards in series with the three existing supplies. These may be summarised as follows:

- **Option 1 – Common Bus Connection.** (Figure 3.) A single new LV switchboard is constructed with a rating of 3200A, and the generator connected to this board via a circuit breaker matched to the generator size. A new LV feeder rated at 2 x 1600A connects the new board to the Energy Australia LV bus. Existing supplies to Switchboards #2, #3 and #4 are interrupted and replaced by feeders from the new switchboard, individually protected by fuses. The generator breaker is synchronised to the main 3200A circuit breaker to enable parallel plus standby mode operation.

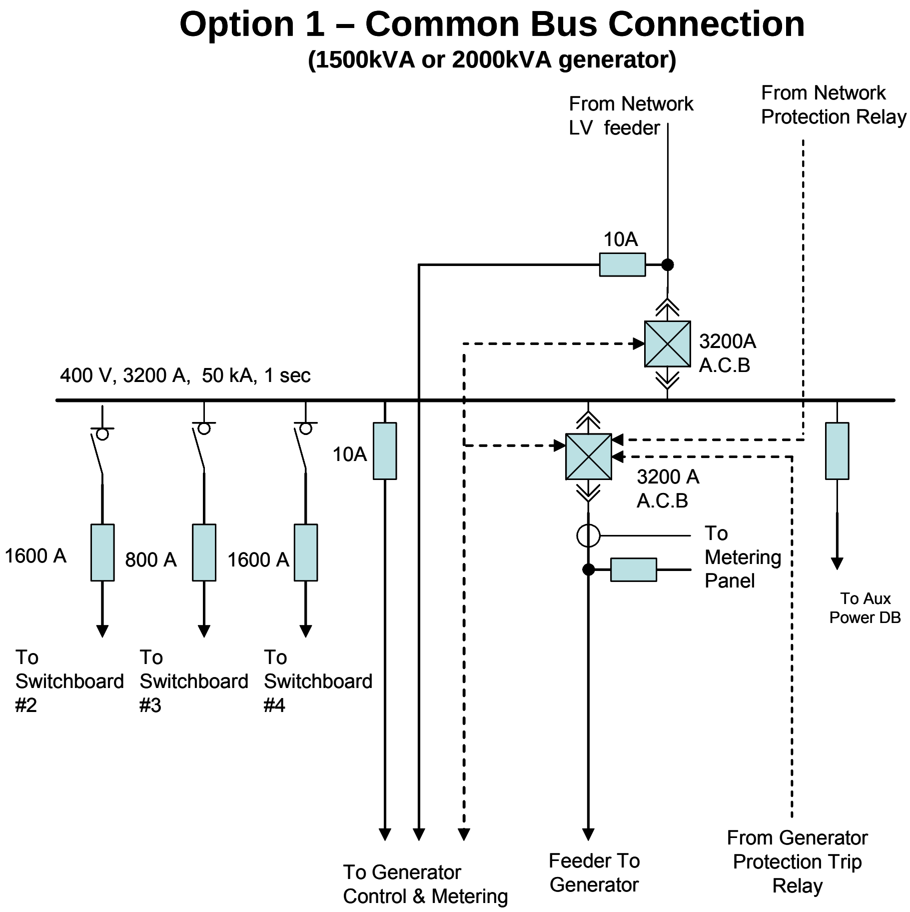


**Figure 3**: Single line diagram for Option 1

- **Option 2 – Split Bus Connection.** (Figure 4.) Three adjacent new LV switchboards are constructed (one per existing supply), with respective ratings of 1600A, 800A and 1600A corresponding to those of the three participating supplies. Each board has two circuit breakers, one for the mains and one for the generator, each sized to match the feeder rating. The generator breakers are parallel connected on the generator side, connecting to a common metering panel and thence to the generator cubicle. The existing feeder cables are interrupted, brought into the mains-side breakers on each board, and new cables brought out from each busbar to the existing Switchboards #2, #3 and #4.

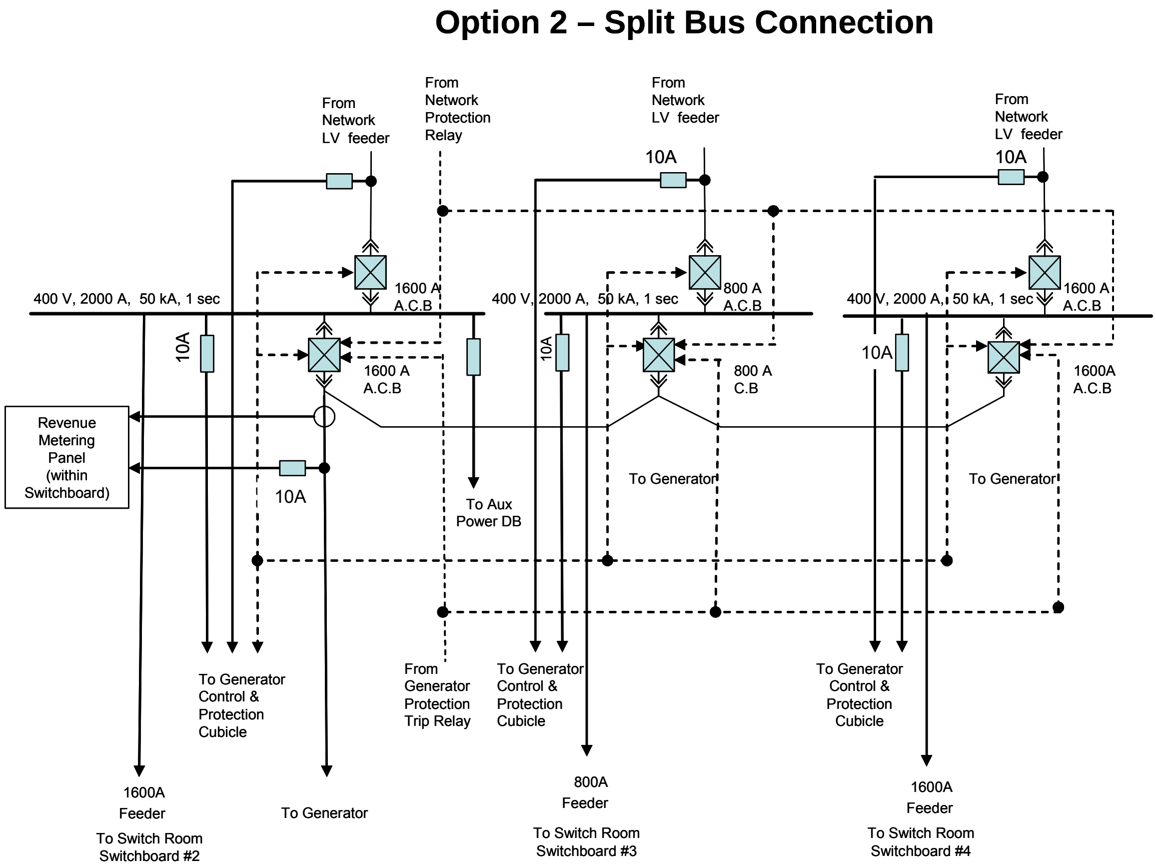


**Figure 4:** Single line diagram for Option 2

Enlarged versions of the single line diagrams for each option can be found in Appendix A.

# 6 Option One (Common Bus Connection) – Technical Discussion

## 6.1 Thermal Constraints

Due to the fact that the maximum generator output is less than the maximum existing load on the Energy Australia substation, there are no anticipated issues with thermal constraints on the Energy Australia network. On the customer side, the proposed rating of 3200A on the new LV mains cable is sufficient to carry both the full output of the generator and the anticipated peak load for Switchboards #2, #3 and #4.

It is anticipated that at times of less than maximum load, some export power from the generator to the 11kV grid will be available to reduce current flow and losses in adjacent parts of the Sydney CBD. To avoid possible uncertainty in metering the net power flow under such conditions, this option provides for revenue metering at the generator itself.

## 6.2 Voltage Constraints

In this section the effect of the generator connection on 415V and 11kV bus voltages is investigated.

Voltage rise may be defined as the difference between the steady-state voltage levels when the generator is connected (maximum generation output) and the voltage levels at zero-generation output. The zero-generation scenario is essentially identical to the existing system with no generator connected. Voltage rise is used as a planning criterion to gauge the effect of new plant on an existing distribution network.

Voltage step is the difference between the voltage level under normal operation and the (steady state) voltage level following a protective trip of the generator. The worst case voltage step occurs at maximum generator output, and is essentially the same as the voltage rise defined above, since a zero-generation scenario also reflects the system conditions after a generator trip.

**Table 1** shows the network impedances relevant to voltage rise calculations. Effective source impedances at the Energy Australia 11kV and 415V busbars were provided by Energy Australia, and take into account the parallel connection of the three 11kV incomers. The impedance of the new 3200A feed to the generator switchboard has been calculated from Australian Standard AS 3008, based on a cable run of 40 metres with the conceptual design outlined in Appendix B.

| | **Resistance (% on 100MVA)** | **Reactance (% on 100MVA)** |
|---|---|---|
| Source impedance at Energy Australia substation 11kV bus | 4.51 | 55.59 |
| Additional effective impedance from 11kV to LV busbar | 28 | 168 |
| Additional impedance of LV cable to generator board | 42 | 21 |
| Total source impedance to generator | **75** | **245** |

**Table 1**: Infeed impedances (Option 1)

The worst case voltage rise occurs under the condition that

1. the generator current and customer load current are in phase; and
2. the voltage difference across the infeed impedance is in phase with the generator voltage.

Under such circumstances, the voltage rise is equal to the product of the maximum per-unit generator current magnitude and the per-unit infeed impedance magnitude. While the worst-case conditions occur only under highly unfavourable conditions of capacitive loading, they nonetheless establish an upper bound for the voltage rise and voltage step under more typical circumstances.

The maximum voltage rise calculated at the Energy Australia 11kV and 415V busbars, under Option 1 with a maximum generator size of 2000kVA, is presented in Table 2 below.

| | Maximum voltage rise and step, % |
|---|---|
| Energy Australia substation 11kV busbar | 1.1 |
| Energy Australia substation 415V busbar | 4.5 |
| Generator 415V busbar | 5.1 |

**Table 2**: Maximum voltage rise / voltage step (Option 1)

The Energy Australia *Electricity Network Operation Standards* (July 2004) stipulate that operating voltages for LV distribution networks ideally remain between an upper limit of 438V (264V single phase) and a lower limit of 391V (226V single phase), although the operating voltage range may be larger under certain circumstances. These voltage limits correspond to a maximum deviation from nominal voltage of +5.5% to -5.8%. The *Standards* specify no firm limit on steady-state voltage changes, other than a 10% limit for voltage dips up to 10 seconds in duration for 'normal CBD supply'.

It is concluded that the maximum 4.5% voltage rise at the network point of common coupling is within acceptable limits, while the voltage rise at 11kV is comparatively insignificant. It should be stressed that these voltage rise values are under worst case conditions that are unlikely to occur in practice. They will also reduce proportionately if a smaller generator is used.

## 6.3 Fault Level Constraints

Energy Australia reports the existing fault level on the 11kV bus as 9.4kA. This is consistent with the equivalent source impedance values given in Table 1.

Based on the effective source impedance values in Table 1, the existing fault level on the Energy Australia LV bus can be calculated in the same manner as 61.5kA at 415V. Allowing for a 6 per cent drop in steady state voltage, the maximum fault level is 65.2kA.

Energy Australia advises that the fault rating of the Energy Australia substation LV switchboard is 65kA. This switchboard is therefore already operating at its maximum fault capability, and any further significant fault contribution will necessitate replacement of the board. We have been unable to verify the fault rating of the existing customer switchboards.

The estimated fault level contribution at the terminals of a 2000kVA generator is 14kA at 415V, based on a transient reactance of 0.2pu on rating. There is no significant reduction due to the cable impedance between the generator and the Energy Australia LV bus, as the magnitude of this impedance is less than 5 per cent of the transient reactance. At 11kV the fault level contribution is approximately 0.52kA. The fault level contribution will scale with the generator size, but even for a 1000kVA generator the contribution is in the order of 7kA at 415V and 0.26kA at 11kV.

It is concluded that the fault level is severely constrained at this site and that parallel connection of the diesel generator will necessitate either replacing the Energy Australia LV switchboard and customer LV switchboards, or limiting the current fed from the generator under network fault conditions.

Replacement of the Energy Australia switchboard is discounted as a short-term option due to the high cost, inconvenience to tenants, planning and timescale issues. However it must be recognised that the fault level issue is likely to worsen in future with or without the connection of additional embedded generation, and that the same issue is likely to arise in other substations similar to Energy Australia substation. In the longer term there will be a need for Energy Australia to address this issue with a programme of substation upgrades across the Sydney CBD.

The preferred alternative in the short term is to install a power electronic fault limiting device at the generator so as to nullify the fault level contribution. Such a device is manufactured by ABB and known as an $I_S$-Limiter. The cost of such a device is high (approximately $350,000) and significant to the feasibility of this project; however, the alternative course of replacing the Energy Australia switchboard as part of the present project is likely to be still more costly.

## 6.4 Power Quality Issues

It is anticipated that the contribution of the diesel generator to harmonic voltage distortion levels would be insignificant, since three-phase synchronous generators are not a significant source of harmonics. The connection to the network is unlikely to excite any resonance. Further study is not considered necessary, unless the background levels of harmonics or flicker are already problematic.

Diesel generators have controllable and stable power ramp rate. Therefore, it is anticipated that the generator will not contribute to voltage fluctuations or flicker when connected in parallel with the grid, except for unplanned trips as discussed in Section 6.2.

Under standby operation of the generator, power quality may be an issue due to low fault levels at the LV network under islanding conditions, particularly if distorting or fluctuating loads are present on the LV network. This is an inherent characteristic of standby operation and is not expected to be a problem at this site.

## 6.5 Electrical Protection and Controls

### 6.5.1 11kV Network Fault Protection

#### 6.5.1.1 Existing Protection Scheme

The 11kV existing protection scheme (see Appendix A, drawing 2) consists of three 11kV supplies 35K, 35L, and 35M:

- Phase overcurrent relays with input from 100:5 class 10P25 current transformers located adjacent to the 11kV terminals of the 11/0.433kV 1000kVA transformer with remote trip output to The Zone substation feeder 35/37K;

- The Zone substation has instantaneous overcurrent, time-delayed overcurrent, and earth fault protection on feeder with back-up overcurrent and earth fault protection;
- Remote trip from the zone substation trips corresponding 415V air circuit breaker at 11kV/415V substation whenever the 11kV feeder protection operates.

The existing protection scheme isolates the 11kV/415V transformers in the event of an 11kV feeder fault. Therefore, it is not necessary to install additional neutral voltage displacement protection as operation of an island including the 11kV system may only occur in the event of a primary protection or circuit breaker failure. This risk is present in the existing system and will not be increased significantly by the parallel operation of the generator.

### 6.5.2 Generator Protection

Generator protection is recommended for the safe parallel or standby operation of the generator. Duplicate or complementary protections with independent d.c. supplies are recommended including the following as a minimum.

- Generator protection relay including:
    - phase instantaneous and time-delayed overcurrent;
    - earth fault instantaneous and time-delayed overcurrent;
    - under / over voltage; and
    - under / over frequency.
- Anti-islanding (G59) relay including:
    - rate of change of frequency (ROCOF df/dt);
    - vector displacement; and
    - under / over frequency.
- Primary and backup auxiliary tripping relays.
- Duplicated D.C. battery-backed power supplies.

Additional generator protections may be installed depending on the relative importance of the generator and manufacturer's recommendations. All of the above equipment may be installed in a single Generator Control and Protection panel. It is recommended that protections are wired as shown in **Figure 5.** (See also Appendix A for an enlarged version of this diagram.)

Generator Control & Protection Panel

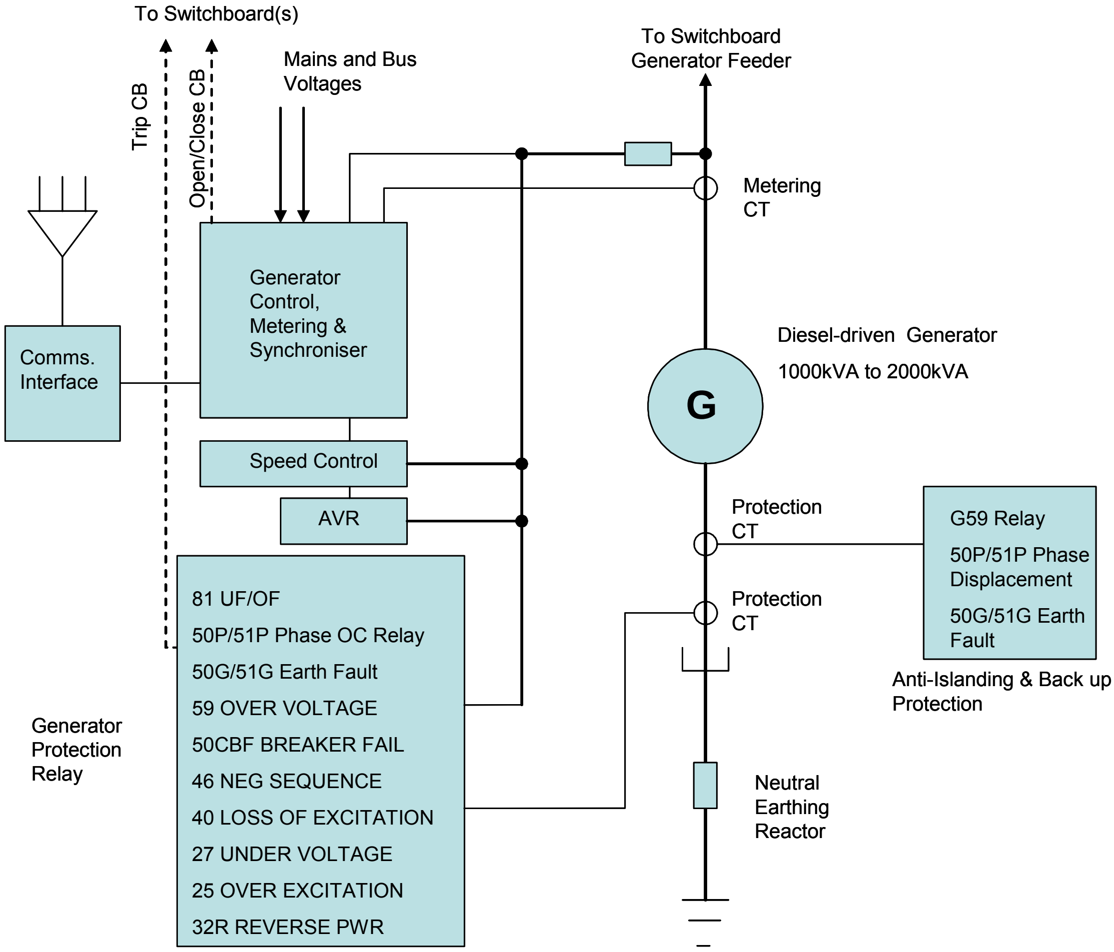


**Figure 5**: Generator protection and control single line diagram

### 6.5.3 Generator Synchronising Controls

To allow parallel operation controls will be required as follows:

- auto synchroniser or PLC;
- engine management relay;
- three-phase metering current transformers;
- generator voltage sensing inputs;
- single-phase bus voltage sensing inputs; and
- communications interface and line connection for remote control/monitoring.

## 6.6 Planning Issues

### 6.6.1 11kV/415V Substation

The substation is fed by 3 x 50% rated 11kV feeders. The design permits the isolation of a single 11kV feeder at a time without interruption of customer low voltage supply. Modification to the 11kV system may be performed by isolation of one feeder at a time and does not present any special planning difficulties.

The design requires the feeder cables for supplies #2, #3 and #4 to be replaced with longer cables (approximately 60 metres) to be installed to connect to the new LV switchboard. The installation and termination of these cables will require a shutdown of the customer supply.

### 6.6.2 Low Voltage Switchboards

In order to provide standby power supply to metered and unmetered portions of Switchboards #2, #3 and #4 but not #1, the generator supply must be connected to the incomer of each of the main switchboards. A planned outage of the customer supplies #2, #3 and #4 only will be required in order to terminate the new cables which will be installed between the new 415V switchboard(s) located adjacent to the generator and the existing main switchboards. It may be possible to schedule this work to coincide with the 11kV/415V substation works to minimise the supply outage period.

## 6.7 Budget Costs

The total cost estimate for this option is $1,066,000 based on a 1500kVA generator, as outlined in Table 3 below. However, the generator size is subject to further investigation and monitoring of customer loads. Should it be found on further investigation that the aggregate peak load for Switchboards #2, #3 and #4 is substantially less than 1500kVA, use of a 1000kVA generator may be sufficient. This will reduce the cost for this option accordingly.

| Item | Unit Plant Cost ($) | Unit Install Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| Building Works | - | 60,000 | 1 | 60,000 |
| Diesel Generator Set (1500kVA) | 230,000 | 3,000 | 1 | 233,000 |
| Engine & Fuel System Control Panel | 93,000 | 3,000 | 1 | 96,000 |
| Day Tank | 20,000 | 5,000 | 1 | 25,000 |
| Fuel Delivery System | 44,000 | Incl. | 1 | 44,000 |
| Exhaust System | 47,000 | Incl. | 1 | 47,000 |
| LV Switchboard | 100,000 | 5,000 | 1 | 105,000 |
| Generator Protection, Synchronising & Control Panel | 60,000 | 3,000 | 1 | 63,000 |
| Fault Limiter | 350,000 | - | 1 | 350,000 |
| Cables, supports and terminations | 10,000 | 3,000 | 1 | 13,000 |
| Testing & Commissioning | | | | 15,000 |
| Overhead | | | | 15,000 |
| **Total** | | | | **1,066,000** |

**Table 3**: Cost estimates for Option 1

# 7 Option Two (Split Bus Connection) – Technical Discussion

## 7.1 Thermal Constraints

From the point of view of thermal constraints, Option 2 and Option 1 are essentially identical, and so the discussion in Section 6.1 applies equally to this option. There are no anticipated issues with network thermal constraints.

## 7.2 Voltage Constraints

The network impedances relevant to voltage rise calculations for Option 2 are shown in Table 4 below. The only difference from Option 1 is the slightly different impedance between the Energy Australia LV switchboard and the generator bus, owing to the different cable and busbar configuration.

For this option there are three parallel circuits to the generator board, two rated at 1600A and one at 800A. The 800A cable is designed with twice the impedance of the 1600A cables in order to obtain a correct division of current. The total impedance is calculated from AS3008 based on a conceptual design as described in Appendix B. The length of each circuit is taken as 40 metres.

| | **Resistance (% on 100MVA)** | **Reactance (% on 100MVA)** |
|---|---|---|
| Source impedance at Energy Australia substation 11kV bus | 4.51 | 55.59 |
| Additional effective impedance from 11kV to LV busbar | 28 | 168 |
| Additional impedance of LV cable to generator board | 33 | 13 |

**Table 4**: Infeed impedances (Option 2)

The maximum voltage rise calculated at the Energy Australia 11kV and 415V busbars, under Option 2 with a maximum generator size of 2000kVA, is presented in Table 5 below.

| | Maximum voltage rise and step, % |
|---|---|
| Energy Australia substation 11kV busbar | 1.1 |
| Energy Australia substation 415V busbar | 4.5 |
| Generator 415V busbar | 4.9 |

**Table 5**: Maximum voltage rise / voltage step (Option 2)

As with Option 1, it is concluded that the voltage rise at the network point of common coupling is within acceptable limits, while the voltage rise at 11kV is comparatively insignificant.

## 7.3 Fault Level Constraints

The issues with fault level are essentially identical to those presented by Option 1 and discussed in Section 7.3. In order to avoid replacement of the Energy Australia LV switchboard, a fault limiting device will need to be fitted at the generator switchboard.

## 7.4 Power Quality Issues

As discussed in Section 6.4, no power quality issues are expected to arise from connection of the generator. Power quality issues may arise under standby operation due to the lower fault level under island conditions, but this condition is not expected to arise frequently.

## 7.5 Electrical Protection and Controls

The design of the electrical protection and controls is substantially the same as for Option 1, as discussed in Section 6.5. The principal difference is the presence of three circuit breakers (instead of one) connecting the generator to the new switchboards, and another three circuit breakers on the mains side of these boards. Each of these groups of three is tripped and closed as a single unit, in response to signals from the generator protection and control panels as described in Section 6.5.

## 7.6 Planning Issues

Please refer to Section 6.6 for discussion on planning issues, which are substantially the same as for Option 1.

## 7.7 Budget Costs

The total cost estimate for Option 2 is $1,111,000 based on a 1500kVA generator, as outlined in Table 6. However, the generator size is subject to further investigation and monitoring of customer loads. Should it be found on further investigation that the aggregate peak load for Switchboards #2, #3 and #4 is substantially less than 1500kVA, use of a 1000kVA generator may be sufficient. This will reduce the cost for this option accordingly.

| Item | Unit Plant Cost ($) | Unit Install Cost ($) | Qty | Amount ($) |
|---|---|---|---|---|
| Building Works | - | 60,000 | 1 | 60,000 |
| Diesel Generator Set (1500kVA) | 230,000 | 3,000 | 1 | 233,000 |
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| Day Tank | 20,000 | 5,000 | 1 | 25,000 |
| Fuel Delivery System | 44,000 | Incl. | 1 | 44,000 |
| Exhaust System | 47,000 | Incl. | 1 | 47,000 |
| LV Switchboards | 45,000 | 5,000 | 3 | 150,000 |
| Generator Protection, Synchronising & Control Cubicle | 60,000 | 3,000 | 1 | 63,000 |
| Fault Limiter | 350,000 | - | 1 | 350,000 |
| Cables, supports and terminations | 10,000 | 3,000 | 1 | 13,000 |
| Testing & Commissioning | | | | 15,000 |
| Overhead | | | | 15,000 |
| **Total (+/- 20%)** | | | | **1,111,000** |

**Table 6**: Cost estimates for Option 2

# 8 Conclusions

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

- Significant cost is involved to address the fault level issue at the Energy Australia substation. As a minimum, a fault limiting device is required on the generator at an estimated cost of $350,000. This is a short-term measure until the longer-term issue of fault levels throughout Sydney CBD substations is addressed.
- There are no anticipated issues with thermal constraints or power quality, other than those that can be anticipated under conventional standby operation in the event of an outage.
- The worst case voltage step is 4.5% at the Energy Australia LV point of common coupling, which is within limits set under the *Electricity Network Operation Standards*.
- The existing protection scheme for the 11kV system will ensure that islanding of the generator with other customers via the 11kV network will not be an issue. Anti-islanding protection will be required to prevent islanding with other customers having 415V supply from Energy Australia substation.
- Shutdown of all customer supplies for a period of several hours will be required in order to carry out the generator connection. This may present planning difficulties.

# 9 Recommendations

This report recommends:

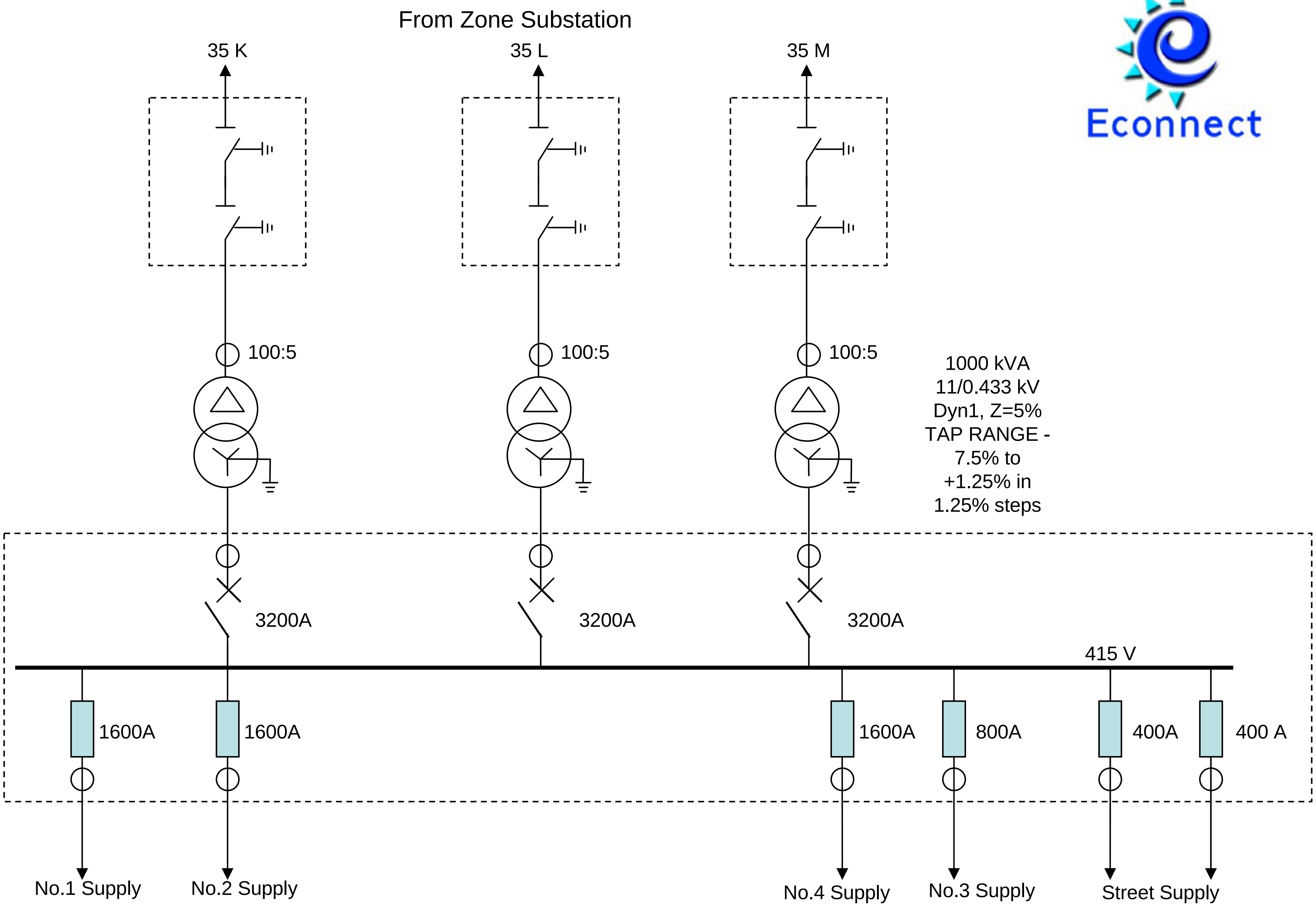
1. That load monitoring on participating customer Switchboards #2, #3 and #4 be undertaken over the forthcoming summer period to assess more precisely the maximum demand, so that an appropriate generator size may be selected.
2. That the fault rating on all customer LV switchboards supplied from Energy Australia substation be confirmed by inspection, to determine whether an upgrade of customer switchboards will be required.
3. That the broader issue of upgrade of substations in the Sydney CBD area be recognised. Fault levels on LV busbars in Energy Australia substation and other CBD substations can be expected to increase in future with or without the connection of additional generation. In the longer term a programme of substation upgrades to accommodate higher LV fault levels will be required.
4. That the preferred method for remote dispatch of generation via a communication link is determined.

## 10 Appendix A: Single Line Diagrams

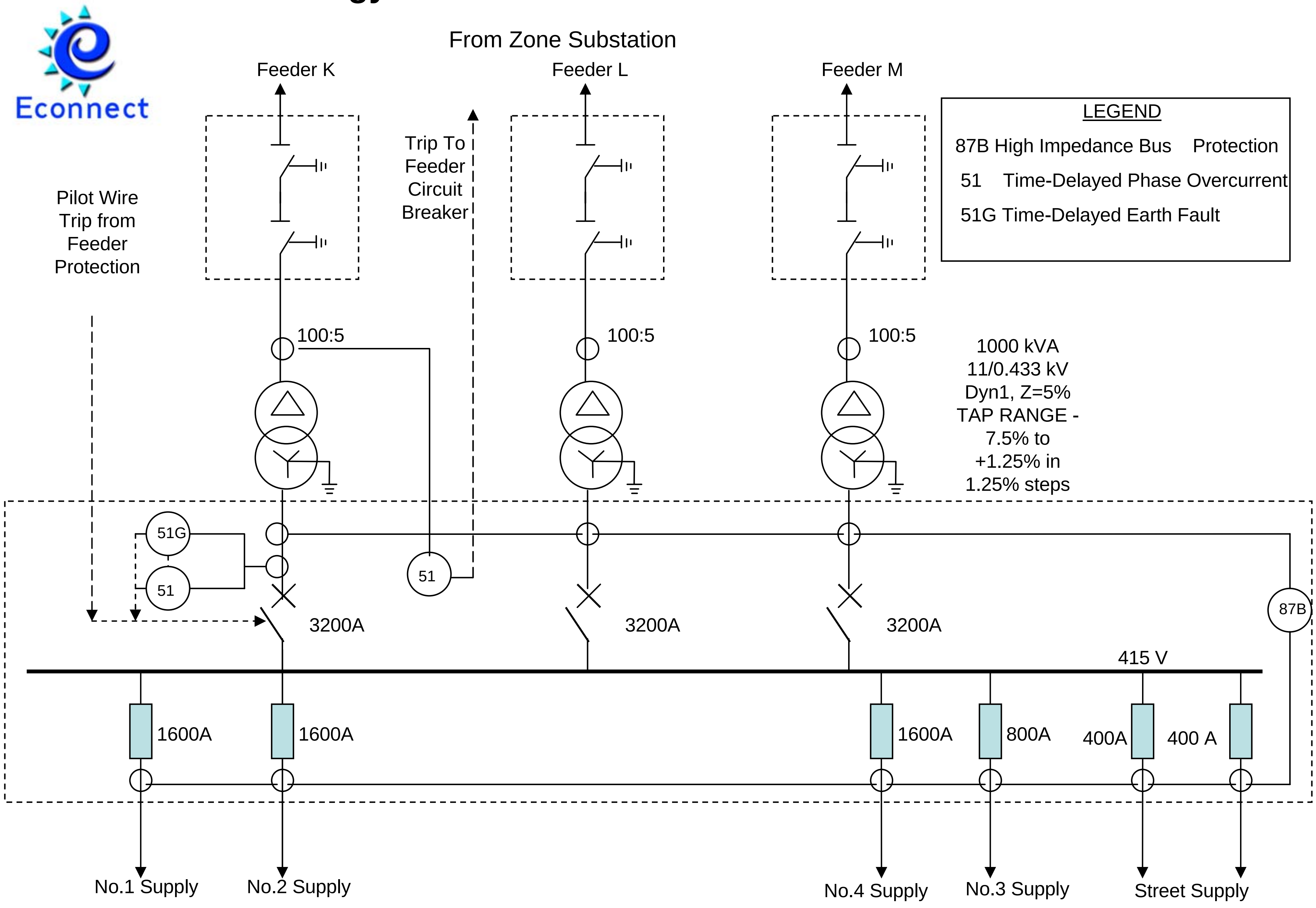
**List of Drawings**

1. Energy Australia Substation (existing configuration)
2. Energy Australia Substation Protection Scheme
3. Customer Main Switch Room Supply No. 2 (existing configuration)
4. Customer Main Switch Room Supply No. 3 (existing configuration)
5. Customer Main Switch Room Supply No. 4 (existing configuration)
6. Option 1 – Common Bus Connection (1000kVA generator)
7. Option 1 – Common Bus Connection (1500kVA or 2000kVA generator)
8. Option 2 – Split Bus Connection
9. Generator Control and Protection Panel

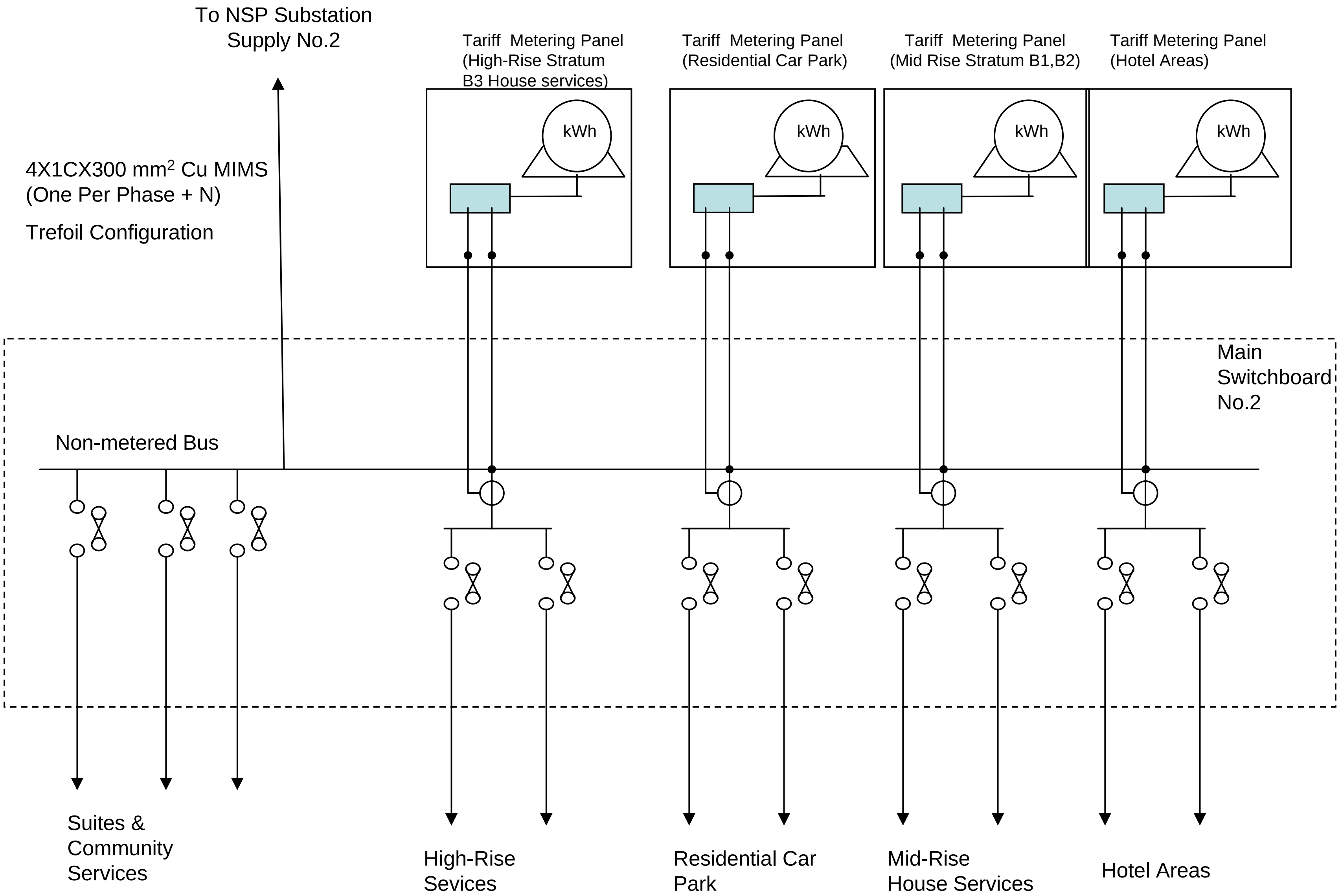
# Energy Australia Substation



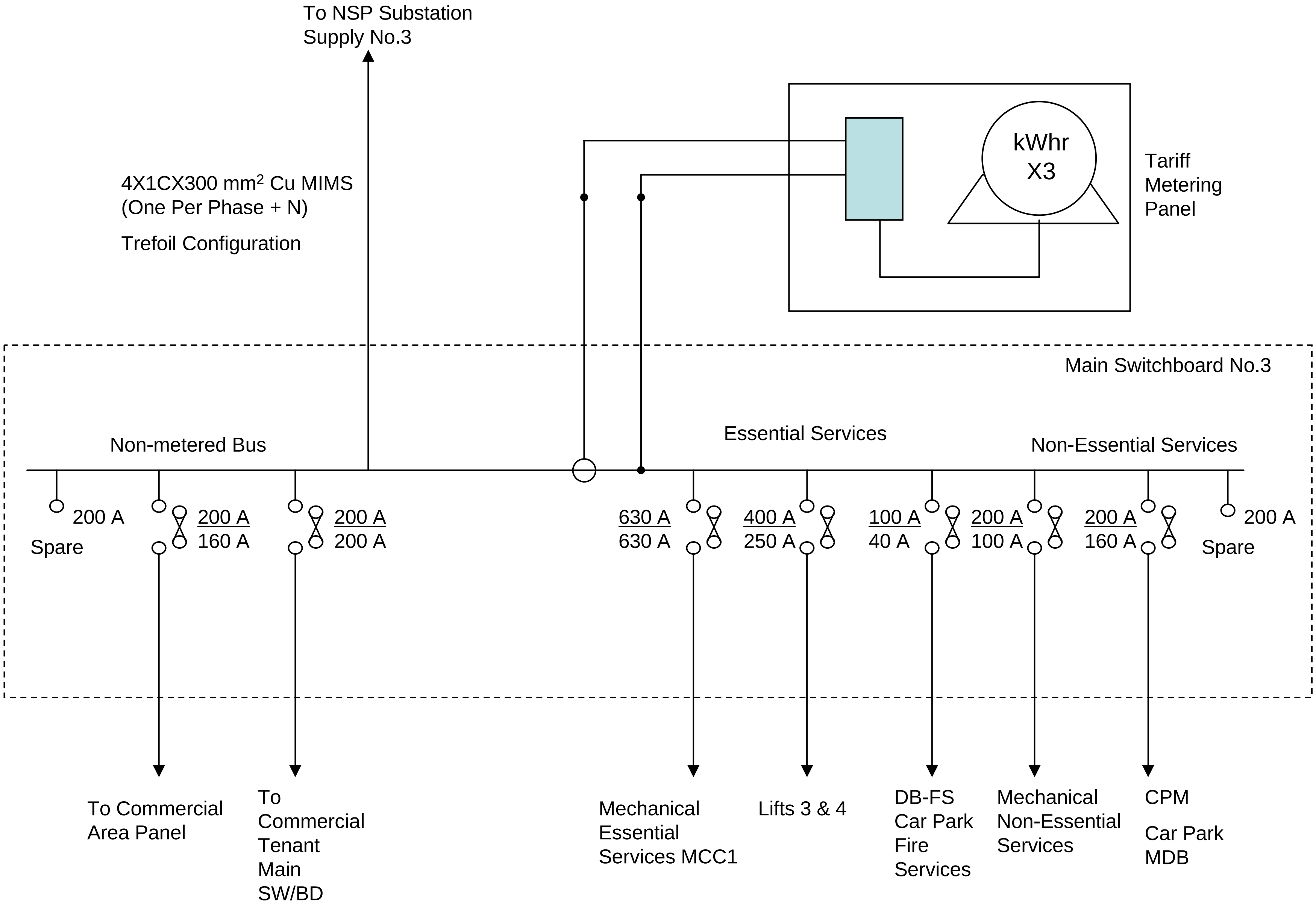
# Energy Australia Substation Protection Scheme



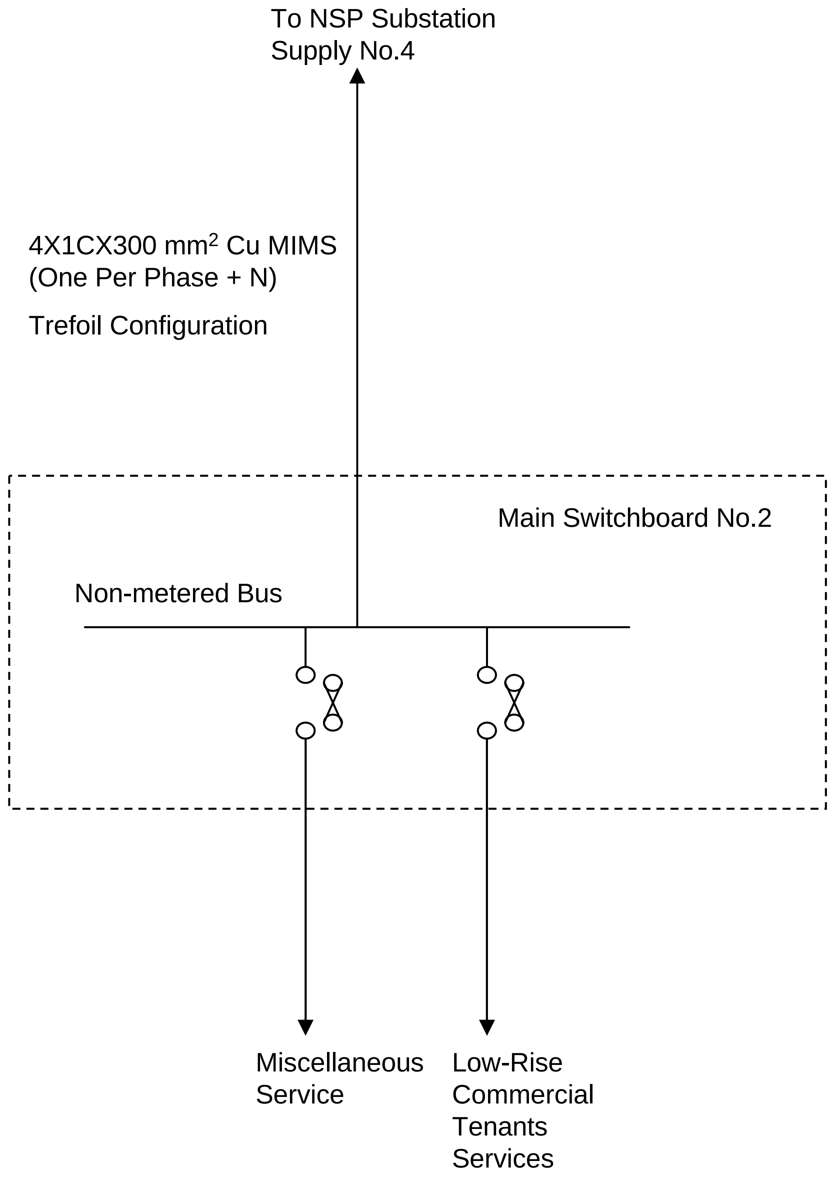
# Existing Customer Main Switch Room (Supply No.2)



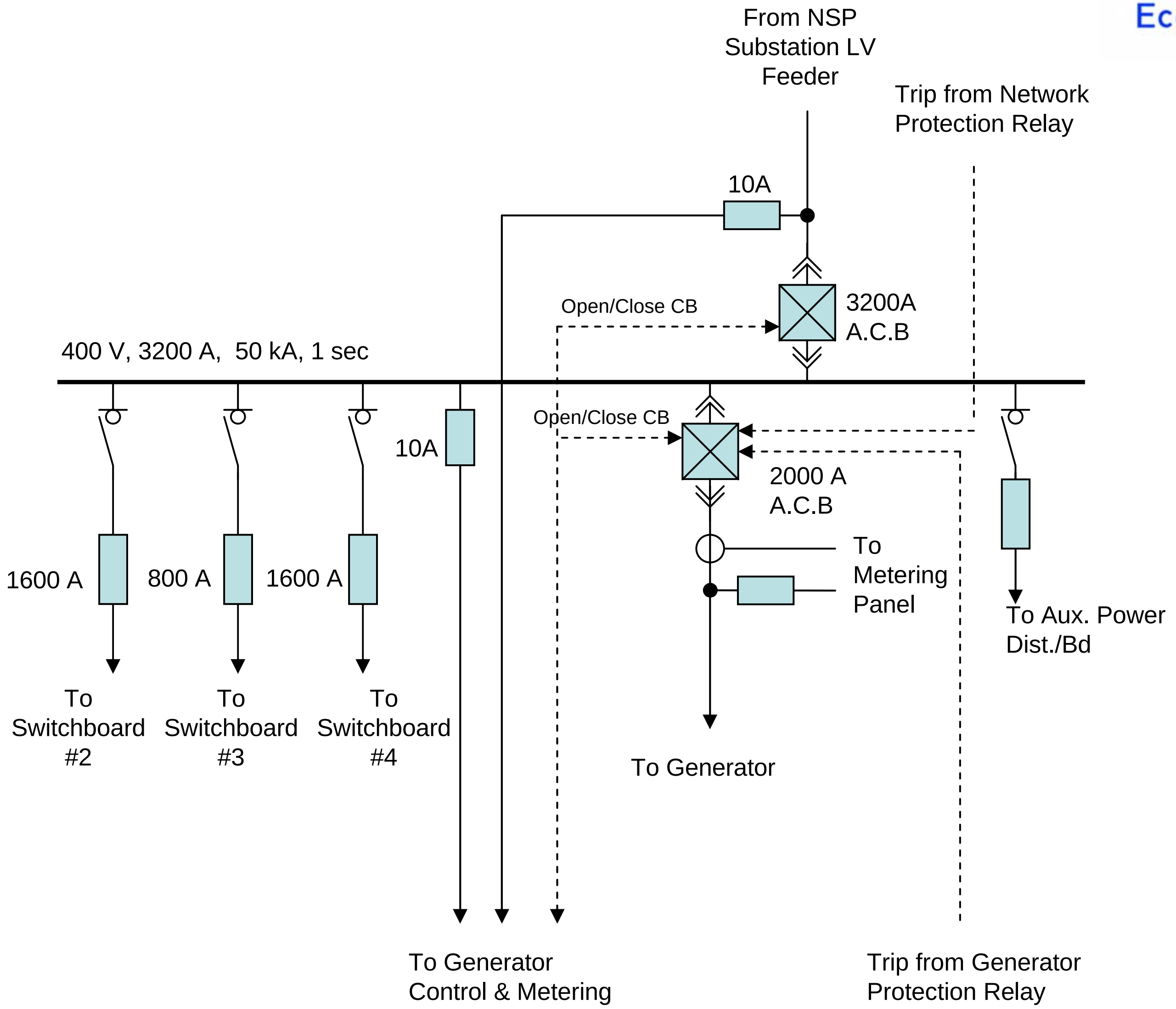
# Existing Customer Main Switch Room
# (Supply No.3)



# Existing Customer Main Switch Room (Supply No.4)

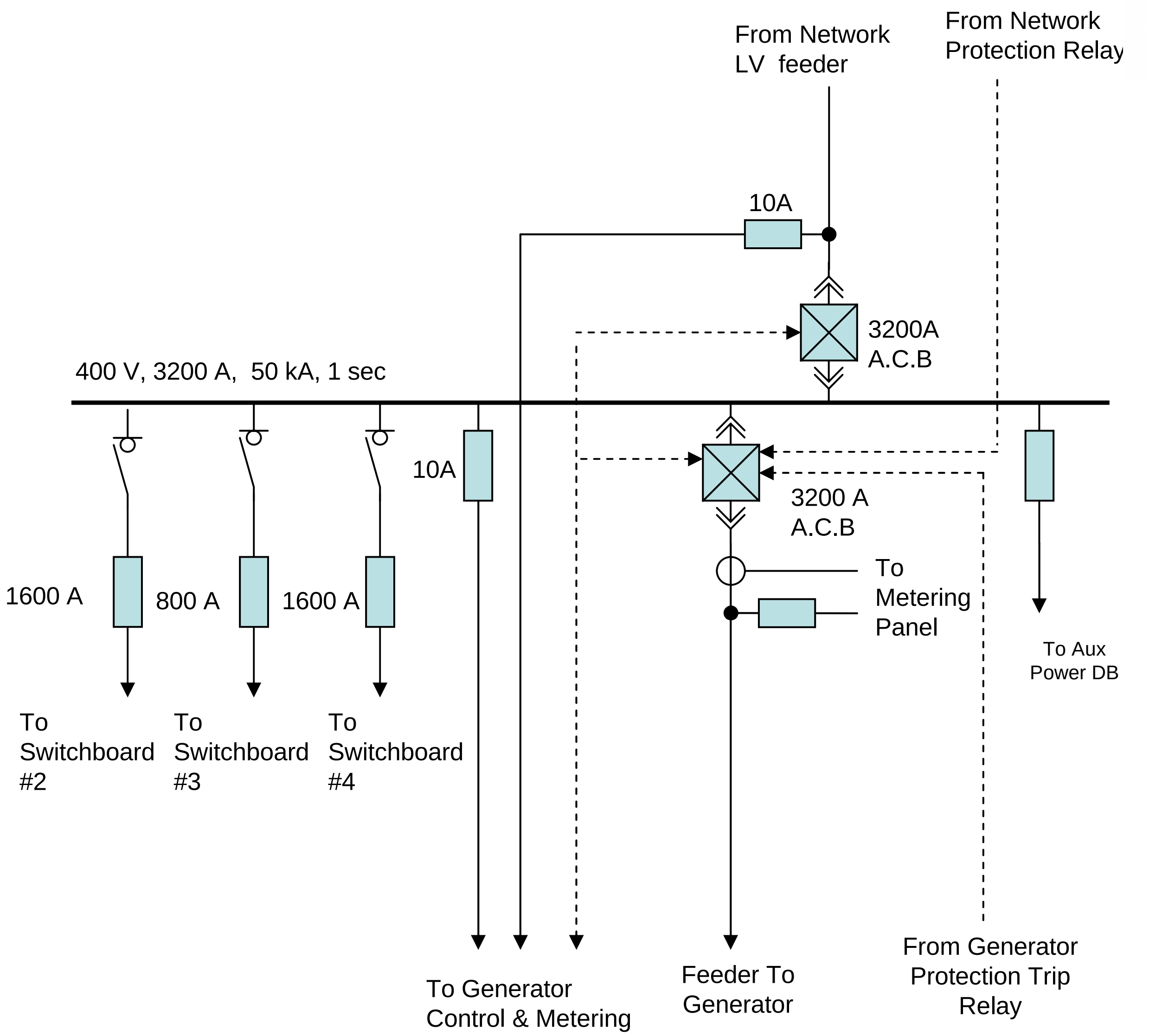


# Option 1 – Common Bus Connection
## (1000kVA generator)

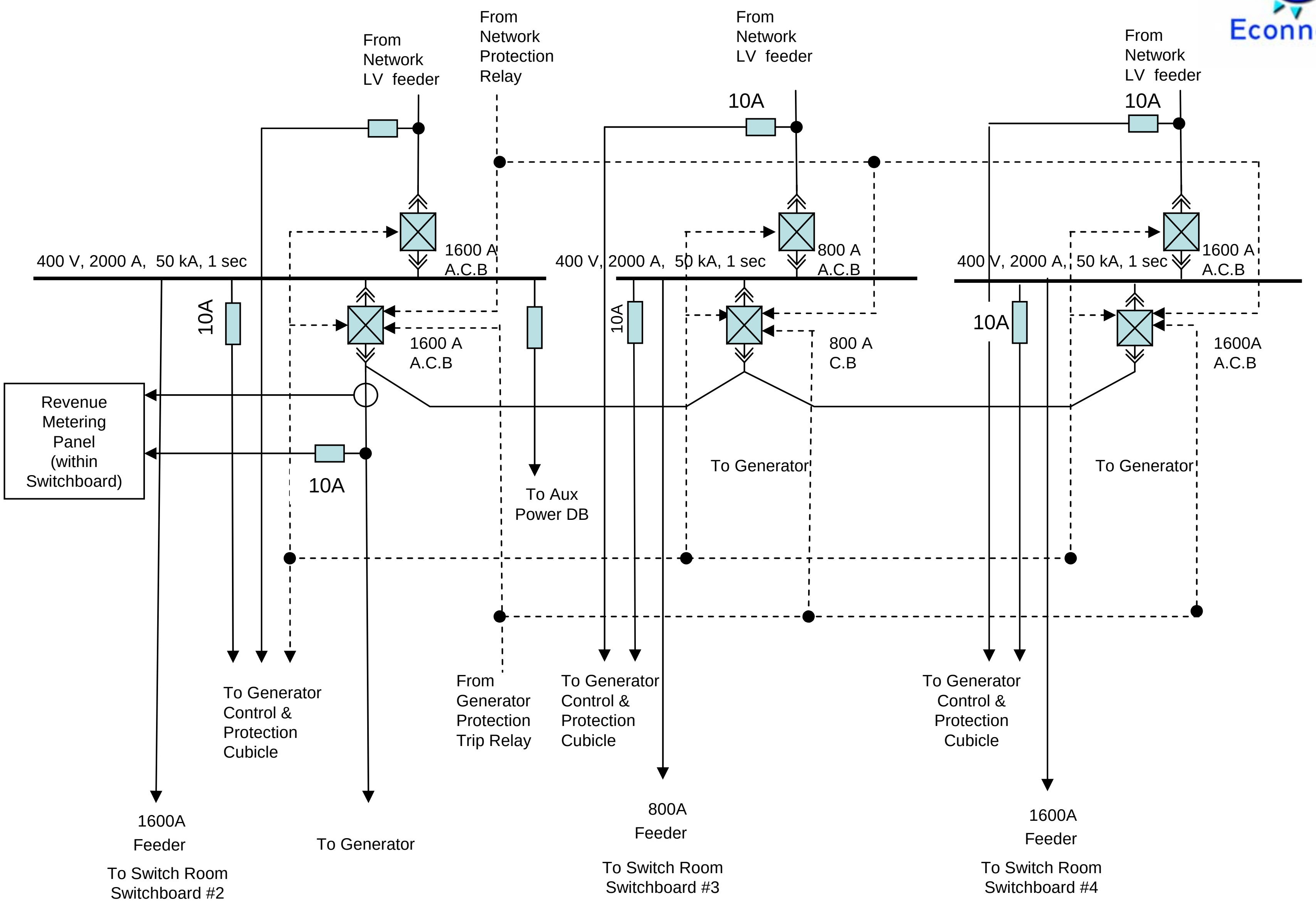


# Option 1 – Common Bus Connection

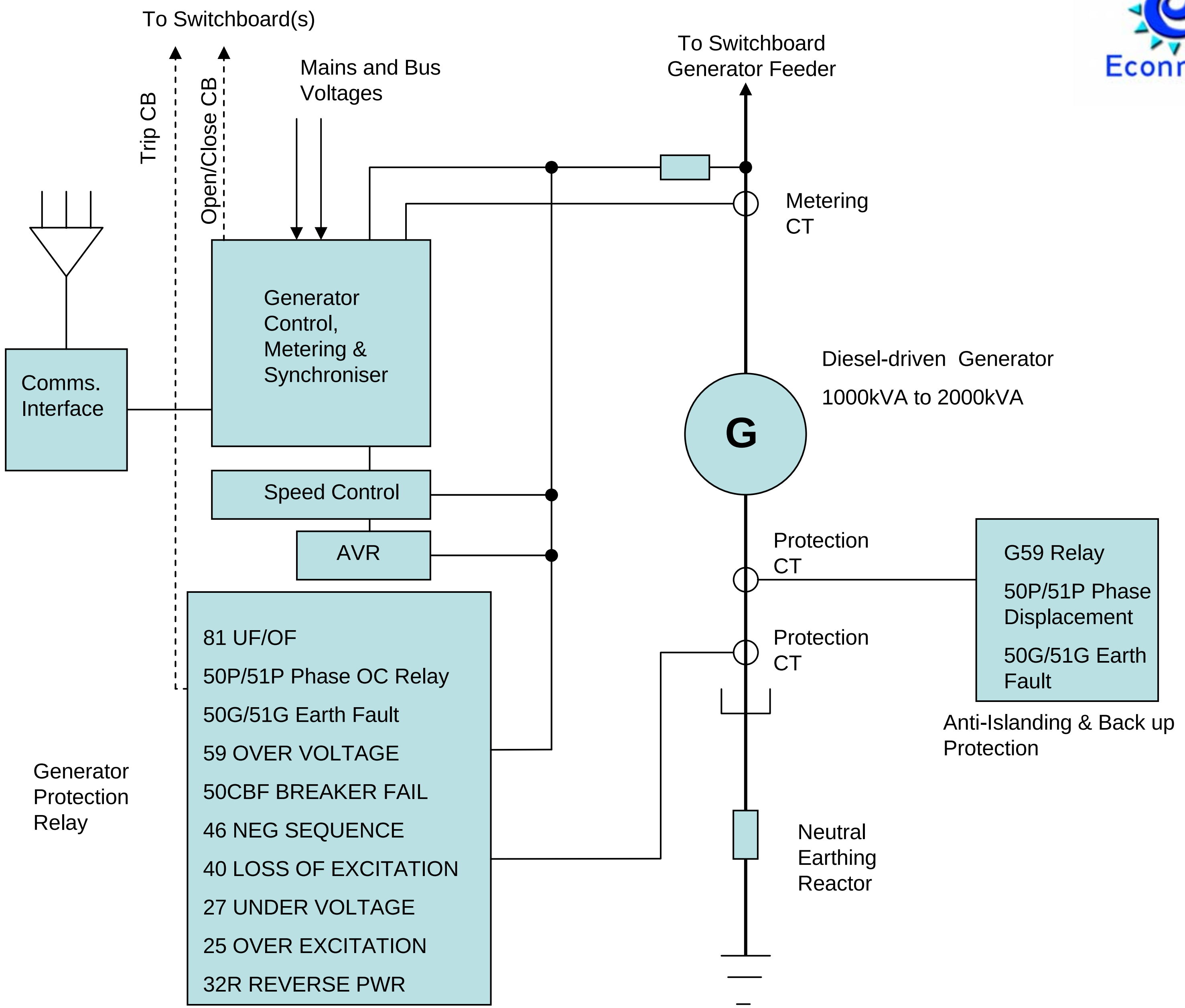
**(1500kVA or 2000kVA generator)**



# Option 2 – Split Bus Connection



# Generator Control & Protection Panel

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# 11 Appendix B: Calculation of Cable Impedances

## 11.1 Common Calculations

Per-unit base impedance on 100MVA base at 415V:

$415^2 / (100 \times 10^6) = 0.00172\ \Omega$

2000kVA generator = 0.02 pu on 100MVA base

Transient reactance of 0.2 pu on generator base = 10 pu on 100MVA base

## 11.2 Option 1 – Single 3200A circuit

*Note: conceptual design only.*

Try 9 x 240mm$^2$ single-core Al (x 3 phases) XLPE cables in non-metallic enclosure in air

Current rating per triplet: 360A per phase (AS 3008 Table 7)

Combined current rating: 3240A per phase

Reactance at 50Hz: 0.0818 Ω/km (AS 3008 Table 30)

Resistance at 50Hz: 0.162 Ω/km (AS 3008 Table 34, at 90°C)

Over a 40m cable run (0.04km):

$Z = (0.04 / 9) \times (0.162 + j0.0818) = 0.000720 + j0.000364\ \Omega$

$Z_{pu}$ = **0.419 + j0.212 pu** on 100MVA base

$|Z_{pu}|$ = 0.470 pu, or 4.7% of 10 pu transient reactance

## 11.3 Option 2 – Three circuits at 1600A / 1600A / 800A

*Note: conceptual design only.*

For one 1600A circuit, try 6 x 185mm$^2$ single-core Al XLPE cables as above

Current rating per triplet: 300A per phase (AS 3008 Table 7)

Combined current rating: 1800A per phase

Reactance at 50Hz: 0.0835 Ω/km (AS 3008 Table 30)

Resistance at 50Hz: 0.212 Ω/km (AS 3008 Table 34, at 90°C)

Over a 40m cable run (0.04km):

$Z = (0.04 / 6) \times (0.212 + j0.0835) = 0.00141 + j0.000557\ \Omega$

$Z_{pu}$ = 0.820 + j0.324 pu on 100MVA base

For the 800A circuit, use 3 x 185mm$^2$ cables, giving impedance 2Z for correct current sharing

Overall impedance is Z || 2Z || Z = 0.4Z = **0.328 + j0.130 pu** on 100MVA base

$|Z_{pu}|$ = 0.353 pu, or 3.5% of 10 pu transient reactance