A Compact, High Capacity 330kV Substation for the Sydney Central Business District

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Summary

Sydney has a population of over 4 million people with approximately 1 million living in the inner suburbs and Central Business District (CBD). The strong population growth and changing demographics of the city of Sydney has lead to a growth in demand for electricity. A major infrastructure project is being constructed to meet this demand. A critical component of this project is the new Haymarket Substation located close to the CBD.

Bringing a high capacity connection at transmission voltage close to the CBD distribution network and its load has presented challenges in the design of the substation and its component parts so as to address the issues of environmental impacts and public safety in the inner city environs.

This paper describes the particular innovative building design solutions and extensive systems monitoring adopted for the Haymarket Substation to address these challenges and how these innovations have been effectively coupled with proven high voltage plant designs.

Key Words


1. Introduction

The 330kV/132kV Haymarket Substation is a major component of the MetroGrid Project, the most significant upgrade of Sydney’s electricity supply since the 1970’s. Having commenced in 1998, the project is targeted for commissioning from early 2004.

The MetroGrid Project comprises a 28 kilometre, 330kV underground cable from a major transmission substation located in the southern suburbs of Sydney, to the new Haymarket Substation on the edge of the Sydney CBD. In this location, this compact, high capacity substation will provide a major switching and transmission supply point to the local distribution network supporting the city of Sydney and its inner suburbs.

2. The Need for Network Augmentation

The need for the MetroGrid Project has been driven by a strong increase in inner Sydney’s demand for electric power. Approximately one million people live in and around Sydney’s CBD and inner suburbs and their demand for power has increased significantly in recent years. The Government initiative to increase the residential population of the CBD has also changed the load profile for the
city. This strong growth in residential properties and the increase in air-conditioning load has “pushed” the peak summer loads.

Over recent summers, peak demand for electricity in inner metropolitan Sydney has increased by three to four percent per annum. Forecasts predict similar rates of growth on average over the next 10 years. While the Sydney load has been winter peaking, strong growth in the summer peak load is predicted to change this to summer peaking within the next few years.

A simplified representation of the existing EHV transmission network supplying Sydney and the inner suburbs with the new MetroGrid Project is shown in Figure 1.

![Figure 1: Sydney Electricity Supply Network showing MetroGrid](image)

3. **Haymarket Substation and Connections**

In its initial configuration, the Haymarket Substation will be connected to the extra high voltage network via a single 330kV cable to the Sydney South Substation. This cable will be installed in a buried trench in roadways and public areas for 24 kilometres and in a deep tunnel for the final four kilometres into the Haymarket Substation.

The new 330kV cable will have a continuous, cyclic rating of 750 MVA and a three day emergency rating of 900MVA. To match this capacity and provide necessary redundancy, the Haymarket Substation will have three 400 MVA transformers with a mesh 330kV bus of four bays of gas insulated switchgear. There will be a 132kV double bus with 24 bays of gas-insulated switchgear. The initial system configuration will have nine 132kV feeder connections to Haymarket Substation.

A shunt reactor will also be located at Haymarket connected to the 132kV bus for reactive power support and voltage control for the Sydney load. Future augmentations have been considered with the 330kV bus capable of connecting a future second 330kV cable.

4. **Constraints of the Substation Site and Criteria for Specification**

This decision to locate the end of the MetroGrid cable close to the CBD strongly shaped the specification for the Haymarket Substation. In determining the specification for the new substation,
designers visited a number of similar projects internationally and discussed the design of inner city substations with suppliers and other high voltage authorities around the world.

From these studies the following important parameters were identified for the proposed substation:

- The proposed location close to the CBD would limit the potential size of the substation area due to limited site availability and high cost of land thus requiring a very compact substation design over a number of levels.
- The proximity of neighbours in the CBD would require a substation with a very low environmental impact in terms of visibility, noise and electric and magnetic fields.
- For the same proximity reasons the public safety requirements of the substation would also need to be very high and the assessment of the consequences of plant failure would be a major “shaper” of the substation and substation plant design.
- For such a critical supply point for the Sydney CBD the critical EHV plant to be installed in the substation must be of the highest quality with proven designs and strong operational experience

Based on these parameters and the system requirements of the MetroGrid Project, a compact site in the Haymarket area of the southern CBD was chosen. While the site was appropriately zone for utility use, it was adjacent to a proposed pedestrian network with high public exposure and high profile neighbouring properties including inner city University buildings and a major Sydney Hotel.

5. Substation Specification and Design

The main substation features of the Haymarket Substation are:

- Predominantly underground substation of a high energy density design
- Single level, below ground, EHV plant floor with 28 bays of 330kV and 132kV GIS
- Gas insulated transformers (GIT) and gas insulated reactor (GIR)
- Dry Cooling System for the GITs and GIR
- Unique integrated substation SF6 containment system
- Highly monitored substation plant and substation auxiliaries

Taking account of the location and the adjacent land uses it was also proposed that the substation be designed to accommodate a commercial building above the required substation. While this will avoid “sterilisation” of the site, it places additional requirements on the design of the substation and the
specification of the EHV plant. The development approval granted by the Sydney City Council stipulated an architectural competition to achieve an external façade suitable for the CBD environs. A view of the substation as proposed is shown in Figure 2.

The Haymarket Substation building is divided into three underground floors and two, above ground, mezzanine floors as shown in Figure 3. This arrangement provides the opportunity for “as small as possible” footprint for the substation and a functional locating of the equipment throughout the substation building.

The basement of the building will contain the main 415V switchboards, the auxiliary transformers and the main emergency containment chamber for the SF₆ gas containment system as the main substation components. It will also serve as the cable floor for the substation with the two cable tunnels interfaces and the cable entries for the various 132kV cables and the 330kV cable.

![Figure 3: Haymarket Substation Floor Arrangement](image)

Directly above the cable floor is the main EHV plant floor. This is a single room containing, on one level, the 28 bays of 330kV and 132kV gas-insulated switchgear, the three gas insulated transformers and the gas insulated reactor and thus achieving a very high energy density for the site.

Above the plant floor, the “first” underground floor contains the substation control room, and other auxiliary plant rooms including the substation ventilation system as well as the substation vehicular entrances, parking and unloading facilities including a 10/100 tonne gantry crane and removable hatches for access to the lower floors.

The two above ground mezzanine floors will principally contain the plant for the gas insulated transformers and reactor dry cooling system.

### 6. Major Electrical Components

While the focus of the substation specification and design has been to provide innovative solutions to the safety and environmental challenges, the focus on the specifications for the major EHV plant has been to select well-established designs with strong operational experience. This combination was seen as providing the best balance of innovation and proven designs and performance to meet the critical criteria for this very important substation.
The gas-insulated switchgear is a highly reliable make supplied to the market for many years. Similarly the gas insulated power transformers and the reactor being supplied are based on the technology supplied the market for many years.

6.1. Gas Insulated Switchgear

A fundamental feature of the gas-insulated switchgear is the high degree of versatility provided by a modular design. The switchgear used for the 330kV bus and switchbays has a single-phase encapsulated design which keeps dielectric and dynamic stresses to a minimum. The cast-aluminium housings used for the enclosure make the system lightweight and corrosion-resistant while the low bay weight ensures minimal floor loading and eliminates the need for complex foundations. There are flanges with O-ring seals at all Inter-module joints.

The design and service criteria of the 330kV switchgear apply generally also to the 132kV switchgear. The main design difference between both concepts is the three phase enclosure used for the switchgear for the 132kV use in order to achieve extremely low component dimensions. This concept allows a very compact design with reduced space requirements. The 132kV switchgear at Haymarket Substation is equipped with a double busbar system of 3150 Amp rating. Extensive R&D activities in the very recent past and the resulting progress in materials allowed the implementation of such a high performance busbar rating in the existing feeder designs without changing the space requirements for the GIS installation.

Monitoring the actual status of a breaker or a bay provides a high level of reliability. All elements required for controlling and monitoring of the circuit-breaker are integrated in the control unit. The gas-monitoring unit for the bay is located above the control unit. It contains elements for centralized monitoring of the gas compartments throughout the entire bay. Each bay is divided into functionally separated gas compartments (busbar, disconnector, circuit-breaker etc.) by gas-tight partition insulators.

All gas compartments can be read by the central gas-monitoring unit via testing and maintenance connections. As a rule, several sections of the passive busbar form one gas compartment. The control unit and the gas-monitoring unit are mounted on the front operator-control section of the bay. The local control cubicle contains all equipment required for controlling and monitoring the bay.

Figure 4 View of 330kV GIS at Haymarket Substation
6.2. Gas Insulated Transformers and Reactor

The assessment of environmental and public safety consequences of plant failure was seen as a major consideration in the selection of transformer technologies. To this end expressions of interest were called for the supply of extra high voltage, high power transformers for the Haymarket Substation with the technology to limit the consequences of transformer failure on the compact site.

The result of that expression of interest was that only one technology was put forward which was judged to provide a proven satisfactory level of public safety and environmental impact as a consequence of transformer failure in the Haymarket location. This technology was the gas insulated transformer technology.

The gas insulated transformer and gas insulated shunt reactor being supplied are based on this established technology. The first gas-insulated transformer was developed in 1956 and today more than 10,000 units have been manufactured at voltages up to 275kV and 300MVA capacity with eleven units of gas insulated transformers of this voltage/capacity in operation today.

The gas-insulated transformers to be installed at the Haymarket Substation have a rated voltage of 330kV and rated capacity of 400MVA. This will make these units the highest voltage and the largest capacity gas insulated transformers so far installed in the world.

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Table I. Principal Ratings of Gas Insulated Transformers

An evaluation of the risks of such high rating GITs resulted in the design requirement to retain existing designs for the heat exchangers, tapchangers and main gas seal. Importantly, the tank diameter was selected to be equivalent to the one previously used in order to use the same O-ring seal so as to ensure the gas tightness achieved in existing proven transformer designs.

The equivalent heat exchanger design was achieved by selecting an auto transformer design with an equivalent cooling load compared with the existing lower rating, double wound designs already in operation. The gas blowers and gas coolers are also based on proven designs. The selection of this auto transformer design created a rating problem for the tapchangers. Therefore an excitation winding in a separate core to isolate the tap windings was introduced to prevent the unwanted need for developing a new tap changer design. Each tank contains a main and series transformer.

Figure 5 shows one of the three 400MVA GITs for Haymarket in factory test.
A gaped core design with radial blocks is used for the core construction of the 132kv, 121MVAr shunt reactor. The cooling and insulation technology is similar to that of GITs. The maximum capacity and voltage of existing units in service are 150MVAr and 275kV respectively so that this reactor is designed and built within the previous experience.

6.3 Transformers and Reactor Dry Cooling System

A maximum 4540kW heat load generated from the three gas insulated transformers and one gas insulated shunt reactor will need to be radiated from the cooling system to the air. While various heat exchange methods used in previous installations were studied for the Haymarket Substation, a “closed water system with dry air coolers” was selected because of reduced maintenance requirements and cost and elimination of any Legionella bacteria risk.

The water-air heat exchangers are located in the aboveground mezzanine floors and the heat is transferred to the air using the air blowers. The gas/water heat exchangers are located in the transformer floor and the heat from the transformer is transferred to the water. The cooling water flows in the closed loop and transports the heat. There is no water spraying system. Because the cooling efficiency is low compared with water spraying system, this system needs large size radiators and large volume of airflow. The key environmental factor for this system is to control the large volume of airflow and to reduce the noise from the air flow and fans. To this end, silencers are provided at the inlet and outlet to reduce the noise from the cooling system.

7. Gas Management System

This gas insulated transformer technology provides particular challenges for the substation in its use of Sulphur Hexafluoride gas (SF₆). The large amount of the gas required for the gas insulated transformers leads to specific specification requirements for the substation design. In particular, the need for an integrated gas management system to prevent a major loss of SF₆ gas following a failure in one of the transformers was included in the substation specification by the TransGrid in consideration of the high potential greenhouse impact of SF₆.

It is normal practice in indoor gas insulated substations to vent any SF₆ gas leaks to the atmosphere to ensure occupational safety. Haymarket substation has large gas volumes in the transformers and reactors and venting to atmosphere following a large gas leak (no matter how extremely unlikely such a leak would be) was regarded as not acceptable. A strategy was put in place to contain the SF₆ gas.
following such a leak to ensure a high level of environmental performance as well as occupational safety in the Haymarket Substation.

Each transformer and reactor is enclosed within a sealed area. In the event of a significant gas leak, the air circulation to the affected area is isolated so the gas can accumulate in the enclosure space. Dampers also operate to guide larger volumes of gas to a chamber in the cable basement, which is designed to laminate the gas flow. This allows nearly all the SF$_6$ to concentrate in the lower part of the chamber where it can be reclaimed. The ventilation system and enclosure spaces are monitored for low oxygen or excessive SF$_6$ as well as the monitoring of gas pressures and density in the HV equipment.

Gas management procedures are an integral part of the system to ensure effective gas capture and management of confined spaces.

8. Control and Monitoring Systems at Haymarket

The Haymarket control system integrates a range of systems critical to the operation of the substation. These systems include:

- GIS monitoring and control
- Protective relays, metering and substation control
- Tunnel monitoring
- SF$_6$ management
- Cable monitoring
- Building management

The systems implemented at the Haymarket Substation form an integral component of the innovative strategies to achieve the goals for this project. To achieve the required level of reliability, a dual redundant 100Mb fibre optic Ethernet ring was chosen to form the substation Local Area Network (LAN). The system has no single point of failure above the Remote Terminal Unit (RTU) of each bay or subsystem.

All protection, control and metering equipment provide condition indication over the network as well as records and waveforms. Extensive monitoring is also provided on the HV equipment and building systems. This information is brought together into a condition-monitoring database, which forms the central focus of all substation data. It provides real-time information and the condition history of the substation plant through a corporate condition monitoring network.

9. Conclusions

The location and capacity requirements of the Haymarket Substation have presented many critical challenges to the substation designers and equipment suppliers. The cost effective management of the environmental and community impacts of the substation in a close to CBD location has set the criteria for the substation’s design and future operation.

Now in the construction phase, the Haymarket substation being built will set new standards in safety and the management of environmental impacts for an inner city substation. The performance specification has required innovative designs and groundbreaking engineering solutions to meet the multiple and varied expectations of stakeholders and the community.

10. References