A National Electricity Market has been operating in south and eastern Australia since 1999. In anticipation of this market commencing, Queensland and New South Wales (NSW) agreed to construct a substantial electricity interconnection between the two states. Commercial service started in 2001. As the NSW transmission system was already connected to the state systems in Victoria and South Australia (SA), this project has completed the interconnection of the four states on Australia’s south and eastern seaboard. It has established one of the world’s longest alternating current systems, stretching over 4500 km from Cairns in far north Queensland to Port Augusta in South Australia, as shown in Fig. 1.

The peak demand in NSW, Victoria and SA together is about 20,000 MW. In Queensland, it is about 6,000 MW. The new interconnector has a planned transfer capacity of up to 1,000 MW into NSW and 500 MW into Queensland.

Fig. 1: 275/330/275 kV power interconnection, east and south Australia.
The Interconnector connects the existing 275 kV grid at Tarong in southern Queensland to the existing 330 kV grid in northern New South Wales at Armidale. It includes 560 km of 275 kV and 330 kV double circuit transmission lines, substations, as well as Static Var Compensators (SVC). The SVCs have the purpose to achieve dynamic voltage control. They are also equipped with power oscillation damping controls to enhance dynamic stability. And furthermore, they control local switched shunt line reactors, as well.

The formation of the new interconnection between previously separated systems has resulted in the modification of existing modes of oscillation, as well as the creation of new modes. One such mode is characterized by Queensland generators oscillating against those in Victoria and SA by 0.3 Hz. If this was not adequately damped it could potentially limit power transfer across the new interconnector.

Control of power system damping
Achievement of adequate power system damping has depended upon coordination of many fast acting controls. These include power system stabilizers in excitation controls of large generators, as well as stabilizing controls fitted to the SVC used to support the high power transfer over long distances. While damping of electro-mechanical oscillations between the systems of Queensland and the other states is inherently poor, investigations have confirmed that with appropriate SVC controls, damping can be maintained at adequate levels.

Objectives of the SVCs
The SVCs are critical to the maintenance of stability between the interconnected power systems of Queensland and New South Wales. The SVCs which are installed at Blackwall and Braemar substations have the main objective of providing dynamic voltage support to the bus, and in a general manner, offer continuous voltage control during the load variations in the transmission lines. In addition, they provide dynamic and fast response reactive power following system contingencies, enhance damping of system electro-mechanical oscillations in the transmission lines and enhance first swing stability by maintaining system voltages during large disturbances.

The SVCs allow continuously variable reactive power throughout the operating range. This provides the feature of flexible control and permits optimum operation performance during all types of network conditions.

Dynamic stability
In the Australian network, groups of power stations and load areas in each state are connected together by long transmission networks. This configuration leads to the presence of modes of oscillation between generator groups that comprise mostly thermal and hydro stations. These oscillations are excited by natural disturbances and switching events on the systems, causing cyclic disturbances to voltage and frequency. Poorly damped or growing oscillations can be potentially harmful to power system security.
The transfer capability of the interconnection will be reduced if any of the SVCs is unavailable to damp electro-mechanical system oscillations. Consequently, SVC availability, reliability and robustness is of paramount importance.

Results from network tests confirmed the good performance of the SVCs controlling the voltage and damping the power swings within the bounds of safe operations limits. The interconnection between New South Wales and Queensland came into operation in 2001.

**SVC design**

A single-line diagram of the Braemar SVC is shown in Fig. 2a. Its overall rating of 80 Mvar inductive to 150 Mvar capacitive is provided by means of a 115 Mvar TCR (Thyristor-controlled reactor), a 115 Mvar TSC (Thyristor-switched capacitor) and four Harmonic filter branches rated together at 35 Mvar.

The harmonic filters are tuned to the 3rd, 5th, 7th, and 11th harmonics and have the dual purpose of providing reactive power at network frequency (50 Hz), and at the same time achieving filtering of harmonics generated inside the SVC. The filtering function sees to it that no unacceptable levels of harmonics generated by the SVC are allowed into the surrounding grid.

The rating of the SVC is defined at 1.0 pu system voltage (275 kV). At maximum continuous primary voltage 1.1 pu (303 kV), the SVC is capable of continuously producing 100 Mvar capacitive power and up to 150 Mvar for a duration of one hour every 24 hours period. In the inductive operating range, the limit for continuous, unrestricted operation is 96.8 Mvar at 1.1 pu voltage. At voltages above 1.1 pu, the SVC reactive power absorption is limited by a TCR current controlling function, maintaining almost constant Mvar up to 1.3 pu voltage. Above 1.3 pu system voltage, the SVC will operate for about 1 second before limiting actions are taken in order to avoid overloading of the SVC.

Blackwall SVC (Fig. 2b), has an overall rating of 50 Mvar inductive to 250 Mvar capacitive. This dynamic range is provided by means of a 150 Mvar TCR, a 150 Mvar TSC, and a 5th Harmonic filter rated at 100 Mvar. At maximum continuous primary voltage, the SVC can produce 150 Mvar capacitive continuously, and 250 Mvar for one hour every 24 hours period.

**Control & Protection**

![Control & Protection Diagram](image)

**Main Circuit**

![Main Circuit Diagram](image)

Fig. 3: SVC control system for Blackwall SVC.
Control of local reactive devices
On top of their dynamic ranges, the Braemar and Blackwall SVCs are equipped each with a control of up to six local shunt reactive devices such as line reactors and shunt capacitors, located in the power grid. The shunt reactive devices have the purpose of accommodating slow variations in the reactive power balance of the systems, minimising the SVC losses and optimizing the operating points of the SVCs for steady-state conditions.

Voltage control
The main objective of the control system (Fig. 3) is to determine the SVC susceptance needed in the point of connection to the 275 kV system, in order to keep the system voltage close to its desired value. This function is realized by measuring the system voltage and comparing it with a set (reference) value. In case of a discrepancy between the two values, the controller orders changes in the susceptance until equilibrium is attained.

The controller operation results in a susceptance order from the voltage regulator, which is converted into firing orders for each thyristor. The overall active SVC susceptance is given by the sum of susceptances of the harmonic filters, the continuously controllable TCR and the TSC if switched into operation.

The control system also includes supervision of currents and voltages in different branches. In case of need, protective actions are taken.

Thyristor valves
The thyristor valves consist of single-phase assemblies (Fig. 4). Each valve comprises two stacks of antiparallel connected thyristors. The thyristors are electrically fired. The energy for firing is taken from snubber circuits, also being part of the valve assembly. The order for firing the thyristors is communicated via optical light guides from the valve control unit located at ground potential.

The TCR and TSC valves each comprise a number of thyristors in series, to obtain the voltage blocking capability needed for the valves. One thyristor is redundant, allowing the SVC to maintain operation with one thyristor level shortened. For one whole SVC, well over a hundred single thyristors are in use, each with a voltage rating of 6.5 kV.

Technical Data SVC

<table>
<thead>
<tr>
<th>Braemar</th>
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<tbody>
<tr>
<td>Controlled voltage</td>
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<tr>
<td>275 kV</td>
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<tr>
<td>SVC rating</td>
<td>SVC rating</td>
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<tr>
<td>80 Mvar inductive to 150 Mvar capacitive (1 h) / 100 Mvar capacitive (continuously).</td>
<td>50 Mvar inductive to 250 Mvar capacitive (1 h) / 150 Mvar (continuously).</td>
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<tr>
<td>Control system</td>
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<td>Three-phase symmetrical voltage control including power oscillation damping.</td>
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<td>Thyristor valves</td>
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