SVCs for improved power transmission capacity in the central Norwegian grid
As a result of large power demanding industry development in central Norway, the demand in the region has increased dramatically and is expected to grow further. The power import capacity to the region has previously been limited by the risk of voltage collapse. As a remedy, two SVCs (Static Var Compensators) were commissioned in 2008, as well as nine MSCs (Mechanically Switched Shunt Capacitors). With the installation of the two SVCs, the power import capacity to the region has increased by 200-400 MW, depending on the operating conditions.

The SVCs, each rated at \( \pm 250 \text{ Mvar} \), were installed at Viklandet and Tunnsjödal substations in the 420/300 kV power transmission network, Fig. 2. At Viklandet, the system voltage is 420 kV. At Tunnsjödal, the voltage is 300 kV, but earmarked to be upgraded to 420 kV at a later stage. Also at Tunnsjödal, a 100 Mvar MSC is part of the scheme, for increased short term capacitive capability, utilizing the inherent short term overload capability of the SVC transformer.

**Main SVC design**

The two SVCs are identical in their design and optimized for 420 kV grid connection, Fig. 3. The main design is a 6-pulse configuration with three TCR branches (Thyristor Controlled Reactor), each rated at 111 Mvar, two TSC branches (Thyristor Switched Capacitor), each rated at 116 Mvar, and an array of harmonic filters tuned to the 5th, 7th, and 12th harmonic frequency. The overall filter rating is 58 Mvar.

At Tunnsjödal substation, the system voltage is 300 kV, but there are plans for a 420 kV upgrade of the substation. Consequently, the Tunnsjödal SVC is designed and prepared for future 420 kV grid connection, but commissioned with a 300 kV connection. As a result, the SVC has reduced rating in the intermediate 300 kV time period. The continuous rating is reduced from \( \pm 250 \text{ Mvar} \) to 140 Mvar inductive (absorption) to 147 Mvar capacitive (generation). Additionally, the 100 Mvar MSC branch can be utilized continuously, thereby increasing the capacitive range to 207 Mvar.

**SVC control**

The SVCs are controlled by a micro-processor based control system based on the ABB MACH 2 concept. This system is built around an industrial PC with add-in circuit boards and I/O racks connected via standard type field buses. Due to extensive use of computers and micro-controllers, powerful internal supervision is enabled.

**Power system control**

The purpose of the SVCs is to perform system control tasks as follows:

- Steady state voltage control at Viklandet 420 kV bus as well as Tunnsjödal 420 (300) kV bus.
- Enhance damping of system electro-mechanical oscillations by means of POD (Power Oscillation Damping) based on active power measurements.
- Control of an external MSC in the substations. This will reserve a dynamic SVC range to be utilized for system contingencies.
**Power Oscillation Damper**

There are several well-known local-area as well as inter-area power oscillation modes in the Norwegian power system. These modes include an inter-area 0.45 Hz oscillation between Norway and Finland, a 0.65 Hz oscillation between Norway and southern Sweden, and a local 0.85 Hz oscillation within the Norwegian grid. The Power Oscillation Dampers of the Viklandet and Tunnsjödal SVCs are equipped to damp particularly the local 0.85 Hz oscillation mode.

**Control of external shunt capacitor banks**

The SVCs are equipped with a Q Optimizer, which ensures coordinated control between SVCs and shunt capacitors in the same substation. The shunt capacitors (MSCs) perform the steady-state main voltage control, such that the SVC operates close to balance between inductive and capacitive mode. This ensures that the SVC has maximum dynamic capability available to provide fast response to counteract grid disturbances.

The Q Optimizer at Viklandet SVC controls one out of two 100 Mvar MSC connected to 132 kV in the substation. Tunnsjödal SVC controls an external 100 Mvar MSC connected to 300 kV. Both SVCs connect the external MSC when the SVC has generated more than 80 Mvar for more than 15 minutes. Similarly, the SVC disconnects the MSC when it has consumed more than 80 Mvar for more than 15 minutes.

**Earth fault locator**

The SVC protection system does not have selective indication to identify a faulty branch for earth faults. Instead, both SVCs are equipped with an Earth Fault Locator, which automatically identifies the earth fault and commences operation at reduced capacity with the faulty branch disconnected. The method consists of an automatic re-close sequence to connect and energize each branch until the earth fault is located. The faulty branch is disconnected, and the SVC continues running at reduced capacity.

**Thyristor valves**

Each 3-phase thyristor valve consists of three single-phase assemblies consisting of a vertical stack of BCTs (Bi-Directional Control Thyristor) (Fig. 4). A BCT is two anti-parallel high power thyristors integrated into one single silicon wafer and assembled into one housing. Snubber circuits (series connected resistors and capacitors) are mounted in parallel with each thyristor. The thyristors are electrically fired, with energy for firing taken from the snubber circuits.

The BCTs offer a compact and high reliability design. The thyristors are liquid cooled, using a 50/50 mixture of glycol and de-ionized, low conductivity water as coolant.

**Environmental precautions**

By recommendation of the Norwegian Pollution Control Authority, a containment system is in place, preventing all possible leakage of glycol based cooling water to ground. This ensures containment of cooling water in case of leakage in the valve hall in the control building or around the outdoor heat exchangers.

The transformer oil containment system consists of the transformer pit, connected to an oil separation tank. The oil separation tank is connected to the drainage system. In case a transformer oil leakage is detected, a valve closes between the transformer pit and the oil separation tank, which ensures containment of transformer oil in the pit.

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**Main technical data**

<table>
<thead>
<tr>
<th>System voltage</th>
<th>Viklandet: 420 kV</th>
<th>Tunnsjödal: 300 kV, to be upgraded to 420 kV at a later stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVC rating</td>
<td>250 Mvar inductive to 250 Mvar capacitive at 420 kV</td>
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<tr>
<td>MSC rating</td>
<td>100 Mvar short-time capacitive (Tunnsjödal only) at 420 kV</td>
<td></td>
</tr>
<tr>
<td>SVC connection</td>
<td>6-pulse</td>
<td></td>
</tr>
<tr>
<td>Control scheme</td>
<td>Voltage control by means of a closed loop system with control of the positive-phase sequence voltage; Q Optimizer for coordination of SVC and MSC; Power Oscillation Damper for damping of local power oscillations in the grid.</td>
<td></td>
</tr>
<tr>
<td>Thyristor valves</td>
<td>BCT type thyristors, water cooled, indirect light firing</td>
<td></td>
</tr>
</tbody>
</table>

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*Fig. 4: Thyristor valves for three TCR and two TSC branches.*

*Fig. 5: Tunnsjödal SVC.*