Abstract – The existing HVDC scheme connecting the North Island and the South Island of New Zealand is presently being upgraded to 1400 MW. As part of the HVDC upgrade, a time domain simulation model of the interconnector is developed and presented in this paper. The model will be used to study transient stability and the dynamic performance of the HVDC link and both interconnected power systems. Special features of the model are several power modulation controllers designed for frequency and voltage support and the utilization of a round power operation mode.

Index Terms – HVDC Modeling, Interconnected Power Systems, Power Modulation Control, Power System Stability, Round Power Operation

I. INTRODUCTION

The existing HVDC scheme connecting the North Island and the South Island of New Zealand is presently being upgraded. During this upgrade also known as the New Zealand Inter Island HVDC Pole 3 Project, the existing HVDC Pole 1 based on mercury arc valves is replaced by a new HVDC Pole 3 based on light triggered thyristor valves. The existing thyristor based Pole 2 remains but its control system is replaced to match the new Pole 3 control system. Pole 2 and the new Pole 3 are then operated as a non-balanced bipolar HVDC scheme. The process of upgrading the link is divided into 3 stages. Commissioning of Stage 1 with a rated bipolar power of 1000 MW is in the beginning of 2013 and Stage 2 with a rated bipolar power of 1200 MW will be completed end of 2013. Stage 3 (1400 MW) is presently a planned future upgrade. The project is funded by Transpower, the Transmission Asset Owner and System Operator in New Zealand. Transpower awarded the HVDC design, engineering, and commissioning contract to Siemens in 2009.

The HVDC link is expected to give greater flexibility for siting new generators in the New Zealand power system. This increase in site opportunities is expected to result in cheaper to build and cheaper to run generators, which should result in lower electricity costs to consumers. In addition to the economic advantages for construction of new generators, the HVDC link is expected to enable the development of renewable generation in the South Island by ensuring a reliable connection between the South and North Island.

One very distinctive feature of the upgraded HVDC link is the newly introduced so-called round power mode. Hereby, one pole operates in North flow and the other pole operates at the same time in South flow. If the poles operate at different power levels, the resulting total power flow will be non-zero North or South flow. Therefore, this mode of operation allows the HVDC bipole to operate below the minimum pole power level and even to reverse the power flow smooth and without power interruption, which is normally the case for thyristor based HVDC systems due to the minimum pole power restriction. As a consequence, the power flow on the interconnector can be ramped up instantaneously to either direction without power reversal. This round power mode will not initially be made available to the New Zealand electricity market, but is included in the design for potential operation as the electricity market progresses.

Of special interest to the New Zealand HVDC project is also the dynamic performance of the HVDC link, as it provides the only power link between the islands. By using the fast controllability of the HVDC link, it is possible to enhance the performance of both interconnected AC systems using individually designed modulation functions. The beneficial impact of modulation functions on the power system stability is well-known and has to be studied thoroughly, [1] and [2]. Thus, modulation functions were also studied in 1991 for the New Zealand Pole 2 HVDC project [3]. For the upgrade, the Pole 2 modulation functions were re-studied to take account of the increased capacity that will be provided at completion of the project, and of the changes that have occurred in the New Zealand power system since 1991, [4] and [5].

II. THE NEW ZEALAND POWER SYSTEM

The high voltage transmission system in New Zealand is owned, maintained, and operated by Transpower. The North Island power system can be characterized as an extremely widespread and long-distance 220 kV network with large generation facilities in the centre and north of the North Island. The HVDC converter station is located at Haywards...
near Wellington, which is in the south of the North Island far away from these major generation facilities. The short-circuit level that is required to operate the HVDC system is mainly provided by synchronous condensers at the Haywards Substation. Since no other generation units are nearby, these condensers tend to oscillate as one local group against the rest of the North Island power system. Special modulation functions of the HVDC scheme are required to damp these condenser oscillations, especially the first swing after severe system disturbances. The South Island power system can be characterized as a strong and well meshed 220 kV network with many large generation facilities. The HVDC converter station is located at Benmore in the center of the South Island and surrounded by large hydro-electric power plants. A full map of the power system is shown in Fig. 1.

III. THE HVDC LINK

The HVDC link is connected at both converter stations to the 220 kV AC system. At the North Island, the HVDC terminal is connected to the Haywards Substation and at the South Island, the HVDC terminal is connected to the Benmore Substation. The HVDC link is built for bipolar power transmission and operated at +/- 350 kV DC. The converter stations are connected by three parallel submarine DC cables of about 40 km length and two overhead transmission lines of 35 km in the North Island and 535 km in the South Island. The nominal bipolar power transmission depends on the construction stage and the direction of the power flow. For north flow, the DC link is rated at 1000 MW in Stage 1, 1200 MW in Stage 2, and at 1400 MW in Stage 3. For south flow, the DC link cannot be operated at these power levels due to AC system constraints in the North Island caused by the lack of sufficient reactive power support and generation reserve constraints in the South Island. Depending on the Wellington load demand, the maximum transfer capability is between 420 MW and 950 MW. The transmission limits for south flow are variable and the HVDC control system monitors the AC system status and applies the power limits automatically to ensure system security and prevent a voltage collapse in the North Island.

IV. ROUND POWER MODE AND OPERATION

Generally, the HVDC system (and thus the developed simulation model) can be operated in either bipolar operation, as two independent monopoles, or in the round power mode. When the round power mode is enabled, the actual operation of the individual poles depends on the bipole power order. At high power order, the HVDC system is operated bipolar. At medium power order, the HVDC system is operated monopolar with one pole blocked. At low power levels, the HVDC system is in round power operation with one pole in North flow and the other pole in South flow. The steady-state operation characteristic in the round power mode is given in Fig. 2.

V. POWER MODULATION CONTROLS

The following subsections describe briefly the non-standard power modulation control functions considered in the model development. These functions are mainly responsible to maintain power system stability after severe disturbances in the power system. The standard HVDC control functions such as the converter control and the transformer tap changer control are generally known and described in [1], [2] and [4].
A. Frequency Stabilization Control (FSC)

The Frequency Stabilization Control FSC is a frequency controller based on frequency signals from both networks. This controller is mainly used to provide rapid frequency support from the other islands AC system in the event of a sudden frequency deviation on either island. The control also provides effective damping of post fault power oscillations. This controller was already implemented in the existing HVDC Pole 2 controls [3]. The FSC transfer function is shown in Fig. 3.

![Figure 3](image1.png)  
**Figure 3. Transfer Function: Frequency Stabilization Control (FSC)**

B. Spinning Reserve Sharing (SRS)

The Spinning Reserve Sharing SRS controller is a frequency controller designed as a proportional controller with the objective to share any frequency deviation which is outside the normal operating frequency bands between the North and the South island. This controller enables the generators in both power systems to provide power reserves to support the network frequency after a severe disturbance in either power system. This controller was already implemented for the existing HVDC Pole 2 controls [3]. The SRS transfer function is shown in Fig. 4.

![Figure 4](image2.png)  
**Figure 4. Transfer Function: Spinning Reserve Sharing (SRS)**

C. Frequency Keeping Control (FKC)

The FKC is a newly implemented frequency controller which uses the frequency signals from both networks. Initially, the HVDC link will operate with the FSC and SRS; the FKC mode will not initially be made available to the New Zealand electricity market, but is included in the design for potential operation as the electricity market progresses. The controller is designed to minimize the absolute frequency difference between North and South. This controller is an alternative to the existing FSC and SRS controllers. If the control system ensures that both AC frequencies are the same then system reserves can be sourced on either AC island system as if the HVDC link was an AC link. The FKC control is not enabled if the FSC and SRS controllers are in service (and vice versa). The FKC transfer function is shown in Fig. 5.

![Figure 5](image3.png)  
**Figure 5. Transfer Function: Frequency Keeping Control (FKC)**

D. Constant Frequency Control (CFC)

Constant Frequency Control CFC for Haywards islanded is implemented for the North Island only. This controller is needed if the AC system in Wellington is suddenly separated from the rest of the North Island power system due to a severe disturbance in the power system. The controller is designed as a PI controller with the frequency at the Haywards Substation as input signal. Therefore, the HVDC system can control the frequency and maintain stable operation of the Haywards / Wellington area island. This controller was already implemented for the existing HVDC Pole 2 controls [3]. The CFC transfer function is shown in Fig. 6.

![Figure 6](image4.png)  
**Figure 6. Transfer Function: Constant Frequency Control (CFC)**

E. Wellington Over-Frequency Brake (WFB)

In addition to the frequency controller listed above, a fast DC power reduction function is implemented, which is used to limit the frequency rise in the Haywards / Wellington area after islanding. The Wellington Over-Frequency Brake WFB is enabled for North Flow only, i.e. when Haywards is in inverter operation. This controller was already implemented for the existing HVDC Pole 2 controls. The WFB transfer function is shown in Fig. 7.

![Figure 7](image5.png)  
**Figure 7. Transfer Function: Wellington Over-Frequency Brake (WFB)**

VI. TIME DOMAIN SIMULATION EXAMPLES

This section will provide some simulation results for the power modulation controllers introduced above to demonstrate their beneficial impact on the power system performance and stability. Moreover, simulation results with enabled round power mode will be presented.

A. Demonstration of the Round Power Mode

In order to demonstrate the round power mode, the HVDC system is ramped across the power range of interest. In the beginning, the HVDC system operates bipolar at 200 MW South flow. Then, the bipolar power order is changed to 200 MW North flow at a ramp rate of 100 MW/min. The transition level between bipolar and monopolar operation is 120 MW.
and the transition level between monopolar operation and round power operation is 75 MW. The minimum pole power level is 35 MW. A negative bipole power order indicates South flow and a positive bipole power order indicates North flow. The pole power order is always positive and the power flow direction is indicated by a flag not shown in the plots. The measured power at Haywards is positive for rectifier operation, i.e. South flow. The results are shown in Fig. 8.

Figure 8. Simulation Results: Demonstration of the Round Power Mode

In Section (1), both poles are operated bipolar in South flow. In Section (2), Pole 3 is blocked and Pole 2 is operated monopolar in South flow. In Sections (3) and (4), the HVDC system is in round power operation with Pole 2 in South flow and Pole 3 in North flow. In Section (5), Pole 2 is blocked and Pole 3 is operated monopolar in North flow. In Section (6), both poles are operated bipolar in North flow.

B. Demonstration of Frequency Stabilization Control FSC and Spinning Reserve Sharing SRS Control

The Frequency Stabilization Control FSC and the Spinning Reserve Sharing SRS control are normally enabled at the same time. For demonstration, the frequency at Haywards is rapidly increased during 1200 MW North flow on the HVDC link and thus the FSC acts mainly on the change of frequency. The SRS acts slowly and distributes the frequency deviation at the North island to both interconnected power systems and thus reducing the absolute frequency deviation at the North island. The simulation results are shown in Fig. 9.

Figure 9. Simulation Results: Demonstration of the Frequency Stabilization Control FSC and the Spinning Reserve Sharing SRS Control

C. Demonstration of Frequency Keeping Control FKC

In the future, the FSC and the SRS controller will be replaced by a new controller covering both control tasks, the newly developed Frequency Keeping Control FKC. For demonstration and comparison to the previous example, the frequency at Haywards is rapidly increased again by the same amount as in the FSC+SRS demonstration in the previous subsection and the controller minimizes the frequency deviation between the North island and the South island in
order to share the frequency deficiency. The final steady-state difference between the North island and the South island frequency deviation can be explained by the dead band in the transfer function. The simulation results are shown in Fig. 10.

![Simulation Results: Demonstration of the Frequency Keeping Control FKC](image1)

**D. Demonstration of Wellington Over-Frequency Brake and the Constant Frequency Control for Haywards islanded**

The functionality of the Wellington Over-Frequency Brake WFB is demonstrated at high frequency conditions at Haywards during inverter operation.

![Simulation Results: Demonstration of the Wellington Overfrequency Brake WFB and the Constant Frequency Control CFC](image2)

Therefore, the HVDC is operated bipolar at 1200 MW North flow and the network frequency in North Island is raised. If the network frequency exceeds the setpoint of 51 Hz, the HVDC power order is reduced accordingly. In the following, the Constant Frequency Control CFC for Haywards islanded is manually enabled by the operator once an island is detected. Thus, the controller reduces the HVDC power further to about 200 MW while controlling the frequency deviation at Haywards to zero. However, as a consequence of the control action, the frequency deviation at Benmore is increased. The simulation results are shown in Fig. 11.

**VII. CONCLUSION**

The New Zealand HVDC Interconnector is an upgraded bipolar power transmission project establishing the only interconnection between the North Island and the South Island. Of special interest is therefore the development of a transient stability simulation model to study the implemented modulation control functions. Another feature covered by the developed simulation model is the newly introduced round power operation mode, which allows smooth transition near zero power and fast ramp-up to either direction if required by any of the modulation controls.

**REFERENCES**


