

A powerful combination

Overview

This paper describes the obtained benefits for the connected AC networks if a VSC converter scheme is added to an existing LCC-HVDC converter scheme. This mixed configuration will be in operation for the DC transmission system between Norway and Denmark and the system and the obtained benefits are further described.

The Norway-to-Denmark HVDC Interconnection

The Skagerrak high-voltage direct current (HVDC) transmission system comprises several HVDC links which together provide a total of 1,700 megawatt (MW) transmission capacity between Kristiansand in southern Norway and Tjele on the Jutland peninsula of northern Denmark. The link is jointly owned by Statnett in Norway, and Energinet.dk in Denmark.

Skagerrak 1&2, rated 500 MW/ \pm 250 kilovolts (kV), was commissioned in 1976-77 and Skagerrak 3, rated 500 MW/ \pm 350 kV, became operational in 1993. Skagerrak 1&2 went into service as a bipole HVDC transmission system, ie, in balanced operation with no ground DC current. When Skagerrak 3 was commissioned, the current direction of Pole 2 in the old link was changed to have the same as Pole 1, thus forming a bipole with links 1 and 2 as one Pole and Skagerrak 3 as the other Pole. This was done in order to minimize the ground current. Now when the fourth link is introduced, Pole 2 has been changed back to the original current direction.

Reactive power properties of a HVDC Classic converter

An HVDC Classic converter always consumes reactive power, normally around 50 percent of the actual active power. To compensate for this, filter/shunt banks are connected/disconnected to keep the balance of reactive power in the alternating current (AC) network within specified limits. Filter/shunt bank switching always produces a step in reactive power, ie, a step in the AC voltage. If the active power is frequently changing, a number of voltage steps will also be observed in the AC voltage. In some installations, a static var compensator (SVC) or synchronous compensator are installed to take care of the total reactive balance in the network, which includes reducing voltage steps at filter/shunt bank connections/disconnections.

Multiple DC power infeeds

The old converters in Norway are located at the converter station in Kristiansand, and are connected to the same 300 kV AC bus. In Denmark, the converters are located at the converter station in Tjele, but are connected to different AC voltages - 150 kV and 400 kV - respectively.

A risk of interference between the converters may occur if HVDC Classic converters are electrically connected close to each other, and especially if the short circuit capacity of the connected AC network is low compared to the total power transfer of all connected converters. If a switching or a small disturbance in the AC network occurs while one converter is operating in inverter mode a temporary commutation failure may occur. This single commutation failure may result in commutation failures in other converters connected to the same AC bus. A commutation failure will reduce both the active and reactive power of the converter considerably, but normally for only a short interval, 100 to 200 ms.

Combining HVDC Classic and HVDC Light

The latest Skagerrak project, Skagerrak 4, was awarded to ABB in 2011, and comprises a fourth link using HVDC Light technology rated at 700 MW/±500 kV which will operate in bipole mode together with the Skagerrak 3 HVDC Classic link. This is the first time an HVDC Classic and an HVDC Light link will be tied together in a bipole configuration. This combined bipole will in most cases be operated with no ground DC current, even if the electrodes are designed for full current. In Figure 1 below, the total interconnection system is shown.

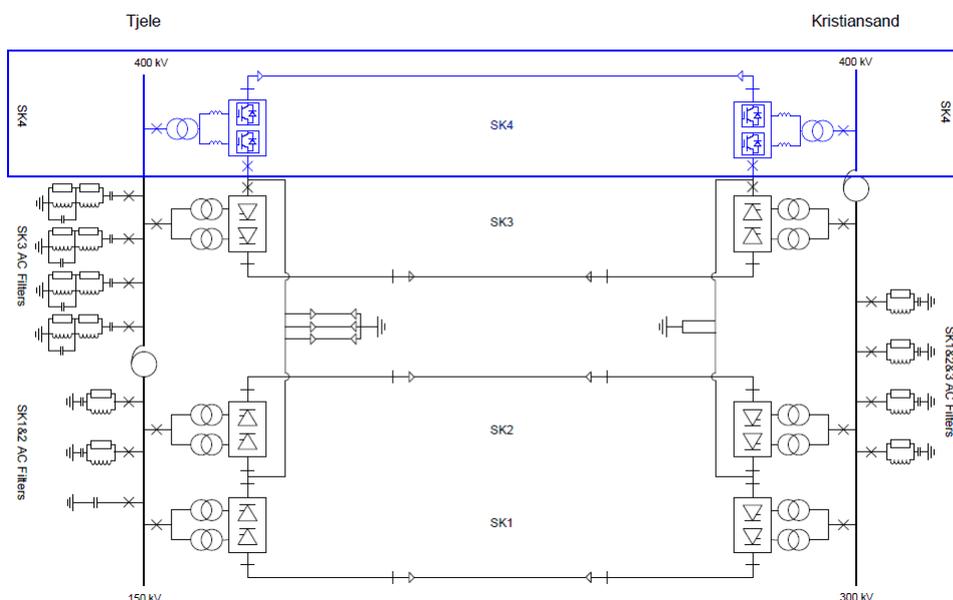


Figure 1. Skagerrak HVDC Interconnection (HVDC Light pole in blue color)

The new link will boost transmission capacity between the mainly hydropower-based Norwegian system and the wind and thermal power-based Danish system by an additional 700 MW, with a DC voltage rating of 500 kV. It will also provide reactive properties and other features for use in the total transmission system that are not possible to achieve with a Classic converter.

Benefits of HVDC Light in Skagerrak 4

The HVDC Light system provides full independent control of both active and reactive power flow within the operating range of the HVDC Light system. Active power can be continuously controlled from zero to full power in both directions, which includes the continuous and smooth passage through zero, and continuous operation at zero transmitted power.

The control of reactive power is completely independent for both stations. The desired reactive power order can be generated by the AC voltage control, or by reactive power order settings. In the rare event of a trip in one HVDC Light converter, the other converter will continue to operate in AC voltage/reactive power control. In the event of a trip in a Classic converter, the HVDC Light converter will keep the AC voltage/reactive power at the desired level.

In an HVDC Light system, a commutation failure cannot occur; only switching between the DC terminals takes place. For the Norway-to-Denmark Interconnection, Skagerrak 4 will continue transmitting power even during network disturbances, even if the Classic converters are affected by commutation failures. Individually in both stations the HVDC Light converter will continue to control AC voltage/reactive power during AC disturbances, meaning AC voltage will be stabilized by the HVDC Light converter, in both Norway and Denmark.

The AC voltage/reactive power control of the HVDC Light converter will also reduce the voltage disturbances of the AC voltage steps introduced by filter/shunt bank switching of the HVDC Classic converters.

During power reversal of the bipole consisting of Pole 3 and 4, the polarity of Pole 3 is reversed by swapping the station's rectifier and inverter operation, changing the polarity of the DC voltage since the DC current only can flow in one direction in an HVDC Classic converter. For Skagerrak 4, the polarity has to be reversed by physical reconnection of the converter through a switching operation. In a pure HVDC Light configuration, power reversal is performed by reversing the DC current flow and keeping the DC voltage at the same polarity. The reason for reversing the polarity of Skagerrak 4 is to minimize the DC current in the earth electrode when operating as a bipole together with Skagerrak 3.

In addition to the above-described benefits of combining HVDC Classic and HVDC Light technology, the HVDC Light converter has 'black-start' capability in the rare event of a total power system outage, enabling fast network restoration using power from the other end of the link.

System benefits from the combined system

- Existing Classic HVDC links can be fully integrated in a total system, especially if the control system of the classic converter is upgraded
- Introducing a continuous AC voltage control in both stations
- Stabilization of the AC voltage in each of the stations
- Black start of the AC network after a total black out
- Operation normally with no DC ground current

Future

There are a number of monopole HVDC Classic installations around the world, mainly using undersea cable. To increase power in these installations, installing an HVDC Light converter as the second pole in order to form a complete bipole instead of adding another HVDC Classic pole can provide a number of system advantages. HVDC Light losses today are nearly equivalent to the losses in an HVDC Classic converter. The DC voltage rating of an HVDC Light system is also compatible with the maximum voltage ratings for DC cables.