THE NORNED HVDC CABLE LINK
A POWER TRANSMISSION HIGHWAY BETWEEN
NORWAY AND THE NETHERLANDS

Jan-Erik Skog[1] Kees Koreman[2] Bo Pääjärvi[3] Thomas Worzyk[4] Thomas Andersröd[5]
[1]jan.skog@statnett.no, Statnett, N-0302 Oslo Norway
[2]k.koreman@tennet.org, TenneT, NL-6800 AS Arnhem, The Netherlands
[3]bo.paajarvi@se.abb.com, ABB Power Technologies, SE-77180 Ludvika, Sweden
[4]thomas.worzyk@se.abb.com, ABB Power Technologies, SE-37123 Karlskrona, Sweden
[5]thomas.andersrod@nexans.com, Nexans, N-0509 Oslo, Norway

ABSTRACT

The NorNed HVDC Cable Link is under construction. The transmission connects the hydro-power based Norwegian grid with fossil fuelled ac system in The Netherlands. The 700 MW, 580 km long link will be the longest cable transmission in the world and will be in commercial operation towards the end of 2007.

1. INTRODUCTION

This paper describes the novel technology used in both converter stations and in the submarine cable system especially suitable for an extremely long cable HVDC connection.
The flexibility and speed in controlling the level and direction of the power flow gives a number of benefits like increased security of electricity supply, improved utilization of the power plants, reduced CO_2 emissions and assistance in further development of renewable wind power.
Further the functionality in power exchange and the trading mechanism is outlined.

2. TECHNOLOGY

2.1 Transmission configuration

The main circuit configuration consists of a 12-pulse converter ± 450 kV with the mid point earthed and two cables. The arrangement is a very attractive solution for a single converter block scheme for extremely long cable transmissions. The transmission voltage is effectively 900 kV giving fairly low cable current and low losses. The total losses are 3.7 % at 600 MW load. The DC link is designed to operate continuously at 700 MW when all converter cooling equipment is in operation.
The converter midpoint earth in Eemshaven constitutes the zero DC Voltage potential reference for the DC side. This is accomplished by a midpoint reactor which also blocks 6-pulse harmonic currents Otherwise is injected into the DC cables. The midpoint in Feda is isolated from earth with an arrester to protect the midpoint from over-voltages. To optimize the rating of the over-voltage protection in the midpoints a RC damping circuit is installed in both midpoints.
The configuration is shown in Figure 1.

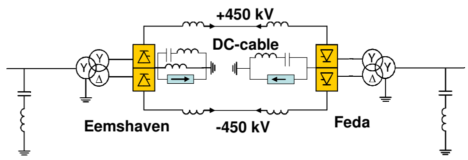


Figure 1. NorNed main circuit configuration

2.2 Converter stations

The converter stations are located at the Feda substation in Norway and at the Eemshaven substation in The Netherlands.
In Feda the AC side equipment is connected to the 300 kV AIS substation and placed outdoors. In Eemshaven the AC side equipment is connected to the 380 kV GIS station by cables and the AC filters are located indoors. Further the DC side equipment in Eemshaven is installed in a DC hall to avoid problems with flashover due to salt contamination from the sea.
The converter transformers are of single phase, three winding type. Six double-valves in the valve hall are arranged to provide the +- 450 kV twelve-pulse converter. The twelve-pulse converter has a voltage rating of 900 kV while the DC voltage to ground is 450 kV. Each single valve has 120 thyristors including three redundant devices. The smoothing reactors are 700 mH, oil-insulated type with the bushings protruding into the valve hall and DC hall(NL). As the DC cables are entering straight

into the converter stations there are no DC filters required.
The AC filters and shunt capacitor banks provides totally 485 Mvar of reactive power in Feda and 432 Mvar in Eemshaven.

The configurations are as follows:

Feda

- Two 100 Mvar filter banks each consisting of one double-tuned 11th/13th filter branch of 48 Mvar and one HP24 branch of 52 Mvar
- One HP3 filter bank of 95 Mvar
- Two shunt capacitor banks each of 95 Mvar.

Eemshaven

- Two 110 Mvar filter banks each consisting of one double-tuned 11th/13th filter branch of 50 Mvar and one HP24 branch of 60 Mvar
- Two shunt capacitor banks each of 106 Mvar.

2.3 Cable system

General

The cable system consists of a mass impregnated paper insulated cable type. This cable technology is more than 100 years old and it was employed in the first submarine HVDC cable in 1954. Although other insulation materials have been used time and again the MI type of insulation is the one over 90 % of all HVDC submarine transmission projects employ.

This cable system is split in two, a shallow part delivered by ABB and a deep part delivered by Nexans Norway AS. The system is built as a bipolar system consisting of two HVDC cables of 580km each. The maximum transmission capacity is 700 MW.

Deep part system

The deep part system consists of:

- 2x1.5km Tunnel Cable NODE-L 450kV 1x760mm2.
- 2x156km Submarine Cable NOVA-L 450kV 1x700mm2.
- 2xOil filled Sealing End EOPU 450kV
- 2xTransition Joint Submarine to Tunnel cable.

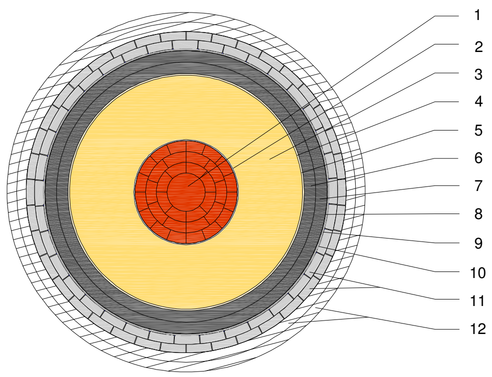
Both the submarine and the Tunnel cable is a MI type of cable.

The cable starts at Feda in Norway and runs through a 1.4km long tunnel down to a jointing chamber. Here the cable is jointed to the submarine cable. From there the cable runs through a 150m long micro tunnel down to the seabed approx. 45m under sea level. Further on the cable goes 156km out the Fedafjord and is jointed to the ABB single-core cable.

The deep part MI type cable has been developed extensively over the last 15 years and it is certified for transmission of 800 MW at 500 kV, according to Electra No 72. The mechanical test on this cable was conducted for 500 m depth according to Electra No. 68.

The design parameters of the MI cable are:

- Power to be transmitted
- The given voltage level
- The transient voltage level
- The maximum allowable electrical stresses in no-load and full-load conditions



No.	Constituents	Nominal thickness (mm)	Nominal diameter (mm)
1	Conductor, copper		
2	Conductor screen		
3	Insulation		
4	Insulation screen		
5	Fabrick tape		
6	Lead sheath, F3		
7	Polyethylene sheath, MDPE		
8	Bedding tape		
9	Reinforcement		
10	Bedding tape		
11	Armour, galvanized steel wires, two layers		
12	Outer serving/PP yarn		107

Nominal Cable weight: 35.2 kg/m

Figure 2 Drawing of Submarine MI cable

Shallow part system

The Shallow cable covers the largest part of the 580 km transmission distance. Beside the electric data, the design of submarine HVDC cables must take other parameters into consideration, such as:

- Water depth

- Burial depth
- Thermal resistivity of the sea bottom
- Annual variation of the sea bottom temperature and sea water

Data related to the sea bottom conditions can only be achieved by a comprehensive route survey. Based on these data, and operational and test requirements, the dimensions of the constructive layers of the cable can be designed. As conditions change along the route, the optimum cable design would also be different for different route sectors. However, it is prudent to keep the number of variations small in a given project. For the NorNed submarine cable, three different designs from two suppliers were chosen.

The shallow part is covered by two different ABB cable designs:
a) the single core HVDC cable. A pair of this cable will run through approx 154 km of North Sea in up to 70 m of water. The cable is very similar to the Deep part cable depicted in Figure 2.

b) the double-core FMI (=”Flat Mass-impregnated”) cable shown in Figure 3. This cable

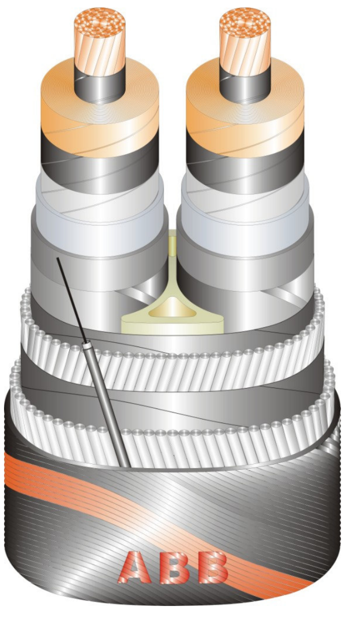


Figure 3. Submarine FMI cable

design is a novelty. It comprises two independent cable cores each representing a complete electric system. The FMI cable comprises two independent cable cores each rated 450 kV dc put side by side into a common steel wire armouring. Each cable core has its own insulation, metallic sheath and plastic sheath. An extruded plastic profile between the cores supports the cable cores. A common counter-helical steel wire armouring protects the flat cable. It offers an extremely low outside magnetic field as the conductors with counter-acting currents are only 100 mm apart. Also, both cores can be laid in a single operation. Due to the small distance between the heat generating conductors, the ohmic losses in the FMI cable are reduced by using a slightly larger cross section (790 mm^2) compared to the single-core cables (700 mm^2).
The FMI cable will run along approx. 270 km of water.

Although the tensional forces during cable laying are very moderate in the shallow waters, both ABB submarine cable types are provided with a strong double-helical steel wire armouring. The wire armouring is a part of a cable protection system which, together with burying of the cable into the sea bottom, protects the cable from external impacts from e.g. anchors and fishing gear. Statistics show that the overwhelming majority of submarine cable faults are caused by external impact. A convincing protection system is important to keep availability high.

A 28 km portion of the FMI cable is equipped with a fibre-optical temperature sensor embedded into the armouring. See Figure 3. It enables a distributed temperature measurement along the cable route closest to the Dutch coast. This route portion is particularly interesting for temperature monitoring as the sea bottom morphology is prone to considerable changes. Temperature measurements can potentially also reveal changes in the cable environment.

Land cables

Beside the submarine cable the shallow part also comprises a pair of 790 mm^2 single-core land cables. As the requirements for tensional strength and impact protection are considerably lower than for the submarine cables the land cables have only one layer of steel wire armouring. The length of the land cables is approx. 1500 m. They are laid in an open trench between the FMI landfall and the converter station in Eemshaven.

3. AC SYSTEM CHARACTERISTICS

3.1 Norway

The Norwegian AC system is characterised by its extreme amount of hydropower. The highest density of plants is found in the west. The system therefore is characterised by strong transmission lines west – east to the most densely populated areas around Oslofjord.

When considering linking of the Dutch and the Norwegian systems it is important to note that the coupling in fact is to the Nordic system (Nordel), ref. Figure 4.

Figure 4 Scandinavian grid

It is easy to see that the Norwegian grid is not particularly strong in the south. This is a challenge in the import situation and is now carefully being studied as part of the detailed engineering of NorNed.
An already planned upgrade of the grid between Evje and Holen north of Kristiansand will when in place, improve the situation drastically.

The Norwegian AC system is also characterised by the large variance in power production caused by the greatly varying precipitation, ref. Figure 5.

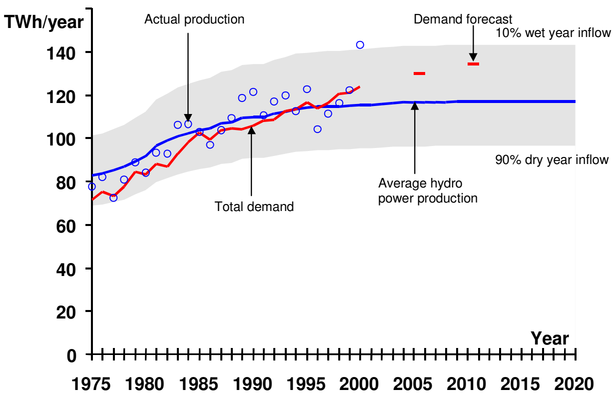


Figure 5 Actual production since 1975

This great difference as compared to the continental power generation system is one of the main drivers motivating NorNed.

3.2 The Netherlands

The converter station will be connected to the Dutch AC-network in Eemshaven. This substation is an indoor GIS substation based on a breaker-and-a-half scheme.

Two generators are connected to the 380 kV substation in Eemshaven in addition to the HVDC converter. Next to the two transformers, 220 kV/380 kV with a rated power of 750 MVA each, connect the 380 kV substation to the adjacent 220 kV substation.
A single line diagram is given in Figure 6.

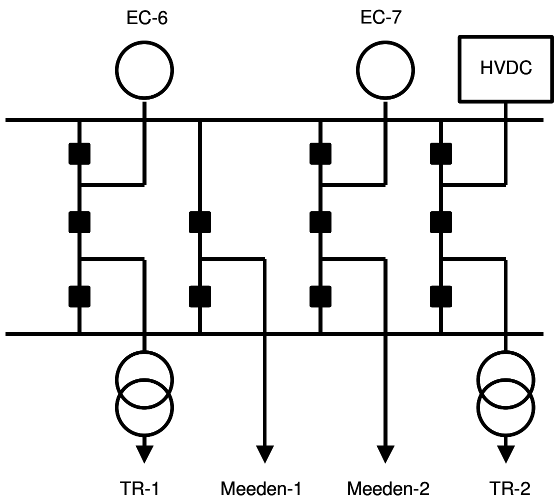


Figure 6 Schematic diagram substation Eemshaven

A four circuit 380 kV line, two of which are currently operated at 220 kV, connects the substation with the main 380 kV network in The Netherlands. All circuits have a rated capacity of 2500 MVA (4000 A). The circuits terminate in substation Meeden where a coupling with the UCTE network exists.

The connection of the NorNed converter station to the 380 kV network can be considered a strong connection. The impedance of the system is low leading to a high short circuit level of 18.5 GVA.

The strong 380 kV system also means that the reactive power requirements for the HVDC system are moderate. The reactive power exchange with the AC system may vary between 100 Mvar to the grid and 50 Mvar from the grid depending on the transmitted power with a zero Mvar exchange at 700 MW transmitted power.

The existence of power generators at the connection point has lead to the requirement that during the design of the HVDC system particular attention needed to be paid to the interaction between the converter system and the generators. This sub synchronous resonance study showed that the effects are minimal so no special measures need to be taken into the HVDC control system.

The Dutch grid code imposes strong requirements with respect to harmonics in the connection point. The European requirements for 35 kV networks and lower as given in EN 50160 are also mandatory for 380 kV networks in The Netherlands. The grid code also prescribes that a continuous measurement of the harmonic distortion shall be present in the connection point.

4. UTILIZATION OF THE LINK

The development of the HVDC connection between Norway and The Netherlands is strongly motivated by differences in the power markets in both countries. This difference imposes that the actual power transmission in the NorNed link may change several times a day.

At present the maximum ramping speed of the connection is fixed at 20 MW/min leading to a full power reversal in 1 hour. It is however expected that the power market will require a higher ramping speed leading to a full power reversal in less than half an hour. It has be taken into the design of NorNed that the ramping speed can be set manually or automatically between 1 MW/minute and 100 MW/minute to obtain maximum flexibility in the operation of the link.

It is also expected that the inherent overload capacity of NorNed shall be utilized extensively. A continuous load prediction system is currently being developed together with the suppliers to facilitate this. This system will inform the operators about the allowable transmission capacity dependent on the environmental conditions and historical transmitted power values. The HVDC cable will be equipped with a temperature monitoring system in the thermal bottlenecks (landfalls and Waddenzee crossing) to increase the accuracy of the load prediction system. It is foreseen that this system will largely increase the flexibility in power transmission thereby leading to optimal power market facilitation.

5. TRADING MECHANISM

NorNed will be the first power link between Nordel and the continent planned to be open to the power market. The principles for this arrangement have been agreed; the details are still being worked on.

The main trading over the link is presumed to be one day ahead spot market trading based on the price difference between the markets. A typical price difference curve is shown in fig. 7.

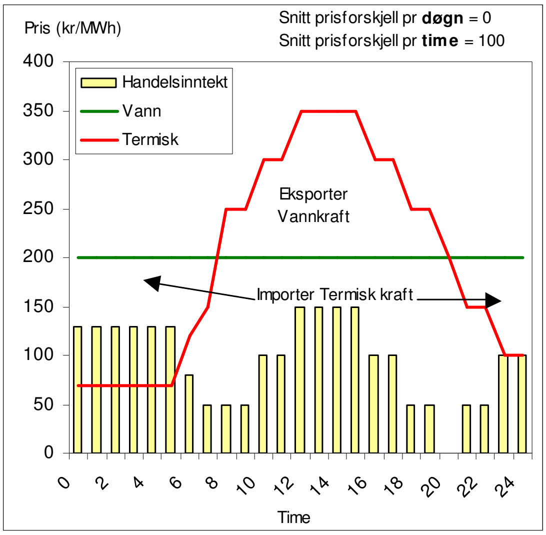


Figure 7 Typical price difference curve

In spite of quite equal average spot market prices the hour-by-hour differences are quite significant most of the time.

The practical arrangement for the market coupling is still being studied and developed. The parties have agreed that APX (Amsterdam Power Exchange) and Nordpool (the Nordic Power Exchange) shall administer the presumed implicit auction system for power trade. The way the power exchanges will be compensated will be agreed and the direct net income from the trade will be shared 50/50 between TenneT and Statnett.

The linking into Nordpool, physically through Norway, has already commercially been organised by the fact that the Scandinavian countries are part of the Nordpool power market.

The development towards more European integration with respect to power trade is, however, not finalised. Presently the parties therefore are looking into possibilities for multi market coupling systems to possibly find an even more sustainable trading system for NorNed.

The parties also have a principle agreement regarding trade with system services, e.g. reserve power. Within the existing ETSO regime these possibilities are not readily available. It is, however, believed that these formal hindrances will disappear in the future.

6. CONCLUSIONS

The NorNed HVDC Cable link will be the first power link directly between Norway and continent. The main power trading over the link is planned to be one day ahead spot market trading based on the price differences between the markets. The practical arrangement for the market coupling is still being studied and developed. The direct income from the trade will be shared 50/50 between TenneT and Statnett.
The link will further provide increased security of supply, improved utilization of the power plants, reduced CO_2 emissions and assist in further development of renewable wind power.
The components in the transmission are proven and have been used in many HVDC cable schemes. However the configuration used is new with one 12-pulse converter for +- 450 kV DC transmission voltage connected to two cables. This arrangement is very suitable for extremely long transmissions. The NorNed cable will be by far the longest cable link, 580 km route distance. Despite this long distance the electrical losses are quite low, 3.7 % at 600 MW transmitted power.

References

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