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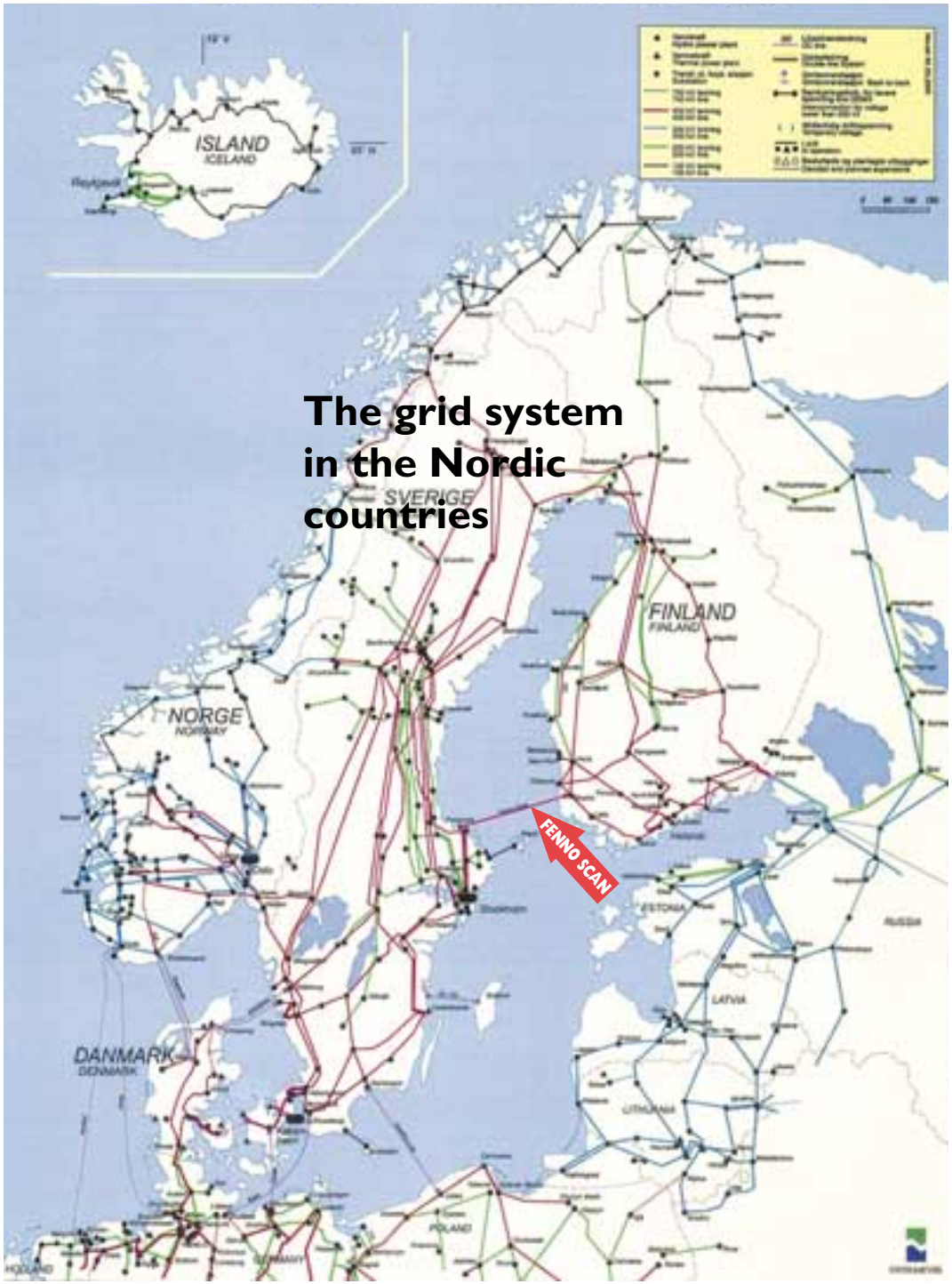
FENNO-SKAN
HVDC LINK

FINGRID OYJ



The grid system in the Nordic countries

The Fenno-Skan HVDC Link System Planning

The Finnish and Swedish power transmission networks are part of the Nordic Nordel joint operation grid.
The generation and consumption of electricity is concentrated in the southern parts of Finland and Sweden. However, the hydro power resources are in the north.

The AC interconnections between Sweden and Finland are located in the north and thus transmission distances in power exchange between the two countries are long. By interconnecting the grids with an HVDC link in the south, the capacity for power trans-mission between the two countries can be greatly increased. Load flows in the Swedish and Finnish networks can also be redistributed through the HVDC link, thus reducing losses in the Nordel grid.

Fenno-Skan - the world´s first 400 kV 500 MW HVDC submarine link

Fenno-Skan, a monopolar 500 MW HVDC interconnection, was built across the Gulf of Bothnia, connecting southern Finland and Sweden. Taken into commercial operation in November 1989, the Fenno-Skan HVDC link was the longest submarine cable interconnection in the world. It was also the first HVDC cable with 400 kV voltage and a rated power of 500 MW.

The link is designed for future extension with a second cable and pole, thus forming a bipolar arrangement. Design of the Fenno-Skan HVDC link was coordinated by the Swedish State Power Board and Imatran Voima Oy, which were also responsible for the civil works. Each company stood for the costs of its own HVDC equipment and half of the HVDC cable.

The Fenno-Skan link is equipped with several control modes in addition to the normal synchronous power control and asynchronous current control. Some of the control modes are activated manually, but there are automatic modes as well.

Special control modes provide the following advantages:

- greater power transmission capacity from Finland to Sweden on the AC interconnections in the north due to increased damping of electromechanical oscillations.
- a higher transient stability limit for power transmission from Sweden to Finland on the northern interconnections and improved network reliability.
- increased power transmission capacity for network sections in the Swedish grid, where voltage collapse is a limiting factor.
- positive damping contribution for subsynchronous oscillations at selected frequencies.
- emergency power control (EPC) to improve transient stability by fast power regulation and to increase transmission capacity by slower regulation. The EPC will be activated automatically with a maximum ramp of 990 MW/s.

Upgrading

After thorough tests on the cable the link was upgraded in 1998 from 500 MW to a maximum continuous capacity of 572 MW depending on the ambient temperature. There is an additional short time (1 hour) overload capability of 600 MW. On-line temperature measurements on the cable surface and in the ground are fed into the Cable Load Prediction System (CLPS) which calculates the current transmission capability.

Fenno-Skan HVDC link, converter station

The converter station on the Finnish side is located next to a conventional 400/110 kV substation. It comprises the following:

- 400 kV AC filters
- converter transformers
- thyristor valves and the related control system
- DC switchyard

A double-breaker bay feeds the HVDC link at the 400 kV substation in Rauma. AC filters are mounted in a 35 x 165 m outdoor switchyard. The DC filters are located in the DC switchyard.

The thyristor valves are erected in a 17 metre-high valve hall. The converter transformers are located along the wall of the valve hall so that the bushings protrude into the hall.

AC filters and shunt capacitor

The two filters (80 Mvar each) and an 80 Mvar shunt capacitor are provided with breakers. A PLC filter (power line carrier) is located between the converter transformers and the AC filters, thus preventing carrier frequency disturbance to the AC network.

The AC filters are identical. Each have two double-tuned branches, tuned to the 11./13. and 24./36 harmonic. The latter branch is of high pass type. The reactive power consumed by the HVDC link is compensated by the filters and the shunt bank. At full active power there is no reactive power unbalance between the link and the 400 kV network.

Converter transformers

The converter transformers are of the single-phase, threewinding type. Three 194.6 MVA units are required. The weight of one unit is 311 tonnes, including oil.

The tap changers of the converter transformers are controlled by the DC voltage, the power transmission in ther HVDC link and the voltage level in the 400 kV network.

A buswork in the valve hall provides the electrical connection for the 12-pulse converter bridge.

792 thyristors in 12 valves

The thyristor valves are airinsulated and water-cooled. The water-cooling system transfers the heat from the valves to the coolers, which are outside the valve hall. All of the three quadruple valves are suspensed from the ceiling of the valve hall.

A single valve consists of eleven thyristor modules. The thyristor modules include six thyristors, a grading circuit, control electronics and equipment needed for water cooling.

There are 792 thyristors altogether; one valve consists of 66 series-connected thyristors. The thyristors are triggered with an electric pulse, but firing information is trans-mitted to the thyristor valve with a light guide in order to avoid electromagnetic disturbances.

The outdoor DC switchyard consists of two smoothing reactors (225 mH And 112.5 mH) and a DC filter.

Overhead line 33 kilometers

The overhead line is built with selfsupporting steel towers. The narrowest possible right-of-way was sought in the design. The width ultimately chosen was only 30 m. The length of the overhead line is 33 km, plus an additional 9 km of separate electrode line. The electrode line is built on wood poles, and the width of right-of-way is 5 m.

Six 565/72 ACSR conductors are used as pole conductors and four 565/72 ACSR as electrode conductors. Earth wires are not used in the link at all. Electrode conductors insulated from the tower and equipped with spark gaps serve as earth wires. The minimum height of the pole conductor from the ground is 10 m and of the electrode conductor 17 m. Potential expansion into a bipolar link was the basis in designing the overhead line. In monopolar use the pole conductors are connected in parallel to minimize loss.

HVDC submarine cable 200 kilometers

The Fenno-Skan cable was at its completion the longest in the world. The total length of the cable connection is 200 km, 198 km of sea cable and 2 km of land cable. The cable construction is the same at sea as on land. The macimum depth of the route is 117 m, with the average depth 80 m. The route was chosen on the basis of a sea bed survey. The cable is laid directly on the sea bed except at the shores, where it is buried in the sea bed when the water depth is less than 10 m. This protects it from pack ice.

The cable is a solid-type with oil-impregnated paper insulation. The rated voltage is 400 kV and the rated output 500...572 MW.

The cross section of the copper conductor is 1200 mm^2. The overall diameter of the cable is 128 mm and the weight 54 kg/m. The total weight of the cable in air is 11000 t. The cable comprises several insulating and protective layers. Oilimpregnated paper is used for insulation and there are layers of lead and plastic on the paper. The plastic sheath protects the cable from corrosion and lends mechanical support to the lead sheath.

Double cross armouring provides the actual mechanical protection.

The cable was made by ABB Cables AB of Sweden and Alcatel STK of Norway. It comprises seven sections. Both factories completed approximately 100 km of cable.

The cable was laid in two parts, which were jointed at sea. Since the cable has a cross-armoured structure, it cannot be coiled. A special cablelaying ship fitted with a turntable was used.

Cathode in Finland, anode in Sweden

The cathode is located on the Finnish side and the anode on the Swedish side. This allows the magnetic field caused by the monopolar link to reinforce the natural magnetic field of the earth, thereby minimizing the magnetic disturbances caused by the link.

A loop 300 mm^2 copper conductor serves as cathode. The size of the loop is 1500 m x 700 m. The loop is connected to the electrode line with two 630 mm^2 plastic-insulated copper cables. Wire netting of titanium serves as sea cathode.

Operation and maintenance

Operation

The converter stations are unmanned. The link is operated either from the power system control centre in Helsinki or Stockholm.

Maintenance

The link is taken out of service for four days once a year for an overhaul. During this period maintenance is performed on the tapchangers and the cooling system.

Inspections are made on the filters, control and protection system, valves and hall equipment. A total of 650 manhours per station are required for the yearly overhaul.

During operation a visual inspection is carried out every fourteen days on the converter station.

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Availability and reliability performance

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Energy Utilization %	44,9	22,5	35,6	33,8	23,1	24,0	29,0	31,5	25,0	32,0	45,0	45,0
Energy Availability %	97,3	84,6*	98,4	98,3	98,4	98,1	98,3	97,9	98,1	98,4	97,9	97,8
Forced Outages %	0,42	13,45*	0,17	0,34	0,15	0,41	0,30	0,62	0,39	0,04	0,65	0,60
Forced Outage Hours	34,3	1179*	14,8	29,6	13,6	32,1	20,1	54,1	34,5	3,3	56,8	52,7
No. of Forced Outages	15	11	3	10	9	4	2	1	8	4	3	6
Scheduled Outages %	2,30	1,95	1,43	1,34	1,46	1,52	1,38	1,44	1,50	1,59	1,49	1,61
Schedule Outage Hours	201	171	126	117	128	133	168	126	131	140	131	141

* A cable fault caused by a ship´s anchor. Repair time 47 days.

Main data of the Fenno-Skan link

Submarine cable	
Rated voltage	400 kV
Rated capacity	500...572 MW
Short time overload capability	600 MW
Rated current	1462 A
Length	200 km
Insulation	oil-impregnated paper
Core	1200 mm^2 copper
Contractors	ABB Cables AB and Alcatel STK
Converter station	
Converter	12-pulse brigde
	12 valves
	792 thyristors
	water-cooling
Transformers	single phase 3-winding
	405: 3/161:3 161 kV
	195/97/97 MVA
AC filters	2 x 80 Mvar
Shunt capacitor	80 Mvar
Contractor	ABB Power Systems Ab
Commissioning	Nov 20, 1989

Owners: Fingrid Oyj and Svenska Kraftnät

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