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The Estlink HVDC Light® Transmission System

L Ronström	M L Hoffstein	R Pajo	M Lahtinen
ABB	ABB	Eesti Energia	Fingrid
Sweden	Sweden	Estonia	Finland

SUMMARY

The Estlink transmission system operates at ±150 kV DC and is rated at 350 MW of active power in either direction. The system was ready for operation in Dec 2006, only 19 months after the award of the contract. The link interconnects the national grids of Estonia and Finland, enabling the exchange of electric power between the Baltic states and the Nordel electric system for the first time.

The main reasons for launching the Estlink project were to have an additional trading possibility and to increase the security of supply in the Baltic region. HVDC was an obvious choice for the transmission, due to the asynchronous networks and the long distance under water. There was considerable competition between conventional and VSC HVDC technologies (HVDC Light® by ABB), and the parameters of investment cost, overload capacity, electrical losses, circuit availability, maintenance cost and construction time were considered in the subsequent feasibility studies and tender evaluation.

The HVDC Light® converter is based on a six-valve converter bridge, equipped with semiconductor valves consisting of a number of series-connected IGBT (Insulated Gate Bipolar Transistor) units.

The converters are connected by two cables, each 105 km in length, of which 74 km are submarine cables. The 150 kV cable for the land section, 22 km in Finland and 9 km in Estonia, has an aluminium conductor (2000 mm^2 – 3.10 in^2), and a copper conductor (1000 mm^2 – 1.55 in^2) is used for the submarine cable section.

The +/- 150 kV HVDC cables have polymeric insulation that was developed for the HVDC Light® system.

The control system is ABB's fully computerized and fully integrated MACH2 control, protection and monitoring system. It is a redundant system, in which all functions are duplicated.

The control functions include Active power control, Reactive power control, AC voltage control, Emergency power control, Frequency control, and Damping control, for the Finnish grid. The black-start feature will make it possible to start up parts of the Estonian network in only minutes after a total black-out.

Estlink has been in operation since early January 2007, with few disturbances.

KEYWORDS

Estlink, HVDC Light, VSC, IGBT, transmission, cable, underground, submarine

e-mail: leif.ronstrom@se.abb.com

Introduction

The Estlink transmission system is owned by a special-purpose company, Nordic Energy Link AS. This company is owned by five Baltic and Finnish utilities: Eesti Energia, Latvenergo, Lietuvos Energija, Helsingin Energia and Pohjolan Voima. The link is one of the priority projects in the European Union's (EU's) plan to ensure continuity of supply in the power system, improve the cross-border power infrastructure and help create more efficient power markets in Europe. The link interconnects the national grids of Estonia and Finland, enabling the exchange of electric power between the Baltic countries and the Nordel electric system for the first time.

Fig. 1 Map of the Estlink transmission system

The system was ready for operation in Dec 2006, only 19 months after the award of the contract.

The project was the subject of a public open tender in 2004. HVDC was an obvious choice for the transmission system, due to the asynchronous networks and the long distance under water. There was considerable competition between conventional and VSC HVDC technologies, and the parameters of investment cost, overload capacity, electrical losses, circuit availability, maintenance cost, and construction time were considered in the subsequent feasibility studies and tender evaluation.

As a result of the evaluation, VSC (Voltage Source Converter) technology was judged to be the preferred technology. Similar projects operating successfully in the USA and Australia have shown VSC technology to be reliable and advantageous.

General system description

Estlink uses ABB's HVDC Light® technology, i.e. a Voltage Source Converter at each end and a pair of polymeric insulated HVDC cables in between. The transmission system operates at ±150 kV DC and is rated at 350 MW of active power in either direction, with a low ambient temperature overload capacity of 365 MW.

The Estonian converter is located in the Harku substation outside Tallinn, and the Finnish converter in the Espoo substation, west of Helsinki. Estlink is connected to Eesti Energia's 330 kV system at Harku, and to Fingrid's 400 kV system at Espoo. The two converter stations are capable of generating or consuming up to 125 Mvars of reactive power independently of each other, and independently of the active power transfer.

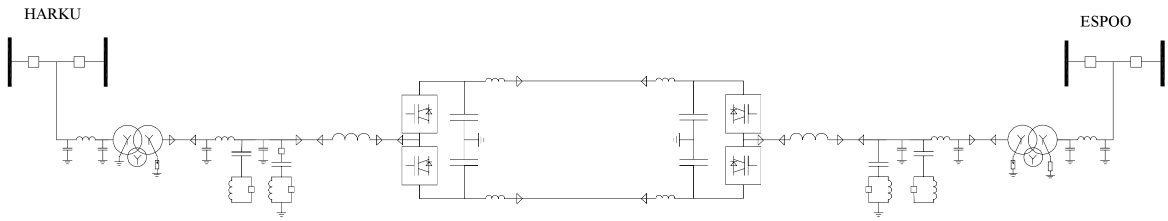

Fig. 2 Single-line diagram

HVDC converter stations
The two identical converter stations are connected to the networks via 380 MVA three-phase power transformers. At each station, the converter equipment, consisting of AC filters, DC capacitors and smoothing reactors, HVDC converter valves and control and auxiliary systems, is housed inside a building, which protects the equipment from the weather and serves as an electro-magnetic and audible noise shield.

Fig.3 Harku HVDC Light® converter building

Voltage Source Converters
The HVDC Light® converter is based on a six-valve converter bridge, equipped with semiconductor valves, consisting of a number of series-connected IGBT (Insulated Gate Bipolar Transistor) units. Each IGBT unit has 24 IGBT and 12 diode chips connected in parallel.

A capacitor bank on the DC side of the converter bridge provides energy storage and a low-inductance path for the turn-off current. The capacitor bank is connected between the positive and negative DC pole, and it is mid-point grounded to provide a ground reference for the converter. The DC voltage is ±150 kV.

The converter's two-level topology means that, by turning the valve transistors on and off, the AC connection point of the converter bridge is switched between +150 kV and -150 kV. The valve switching method for Estlink uses Pulse Width Modulation (PWM) with special functions for harmonic cancellation: Optimized PWM (OPWM). Each valve is switched 23 times per 50 Hz cycle.

The AC side of the converter bridge is connected to a series reactor, the Converter Reactor, providing low-pass filtering of the PWM-switched converter voltage, to give the desired fundamental-frequency voltage, and providing an impedance between the converter voltage and the 195 kV AC filter bus voltage.

The power flow between the AC and DC side is defined by the fundamental-frequency voltage across the reactor. The amplitude and phase of the voltage on the AC side of the converter reactor is determined by the grid. The active and reactive power can be controlled independently by using the PWM pattern to vary the phase shift and amplitude of the converter voltage.

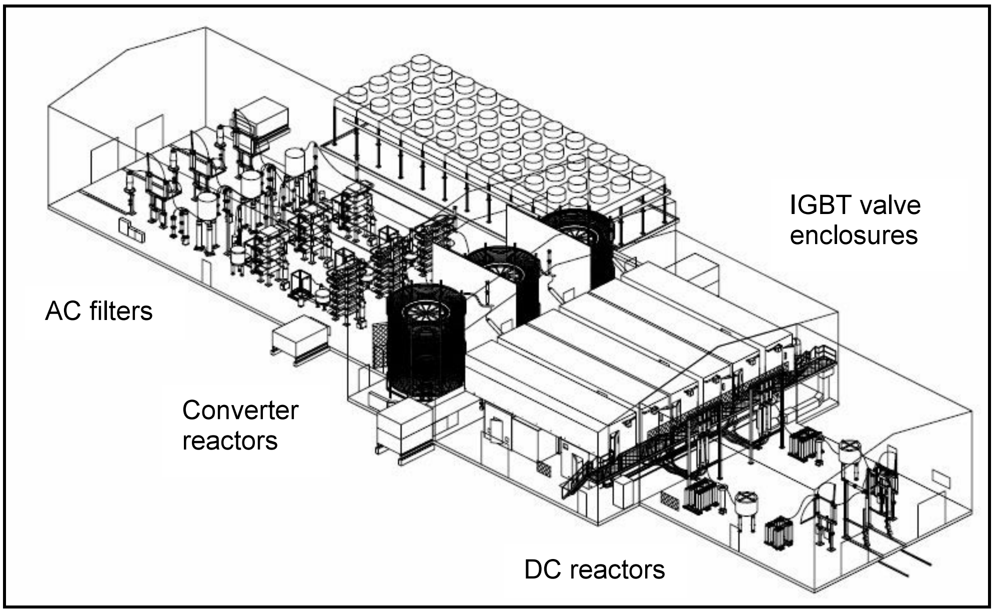

Fig. 4 CAD drawing of Espoo building

The converter reactor (one for each phase) is a large, air-cooled, air-core reactor, with a magnetic shield around it to eliminate magnetic fields outside the reactor. The magnetic shields permit the three reactors to be placed close together, enabling a compact design of the converter building.

AC and DC filters

Two AC filter banks take care of the harmonics generated by the switching of the converter. They are tuned to the 32^{nd} and 60^{th} harmonics. One filter bank in Harku is connected only when starting the converter, due to network restrictions concerning maximum connectible reactive power. Six-pulse characteristic harmonics are cancelled by the OPWM switching method.

On the DC side, the DC capacitors, located in the valve enclosures, and a smoothing reactor on each pole reduce the ripple on the direct current. The symmetry of the bipolar design, and the fact that the DC cables are laid close together, keep disturbing psophometric current on a low level.

HVDC cables

The converters are connected by two cables, each 105 km in length, of which 74 km are submarine cables. The 150 kV cable for the land section, 22 km in Finland and 9 km in Estonia, has an aluminium conductor (2000 mm^2 – 3.10 in^2), and a copper conductor (1000 mm^2 – 1.55 in^2) is used for the submarine cable section.

The +/- 150 kV HVDC cables have polymeric insulation that was developed for the HVDC Light® system.

Submarine cable

The submarine cable is specified for a water depth of up to 100 metres. With the two cables bundled and buried 1 metre into the seabed, the cable pair is thermally designed for the continuous transfer of 350 MW.

The cable design is a standard design for HVDC Light® cables for moderate water depths, shown in Fig 5.

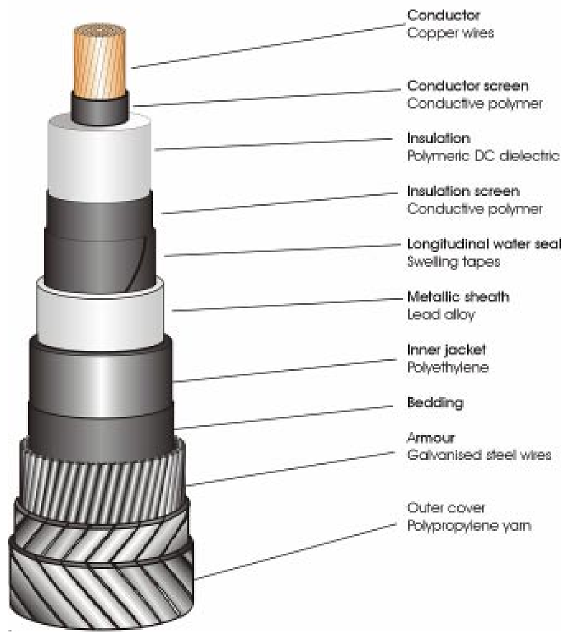

Fig 5 Submarine cable design

The cables are single-layer armoured, which makes it possible to have the cables coiled on the cable laying ship. Coiling the cables provides a high degree of flexibility when selecting a cable-laying ship, since no turntable is needed on the ship. The flexibility in the selection of the ship also gives an advantage to the owner of the cable in the event of cable repair being necessary.

Land cable

The main differences between the land cable and the submarine cable are that the land cable has an aluminium conductor, and that the outer layers on the land cables are composed of a copper wire screen, aluminium laminate and an HDPE outer jacket.

Fig. 6 Land cable laying from a cable wagon.

The land cables were laid in lengths of approx. 750 metres which were joined together with pre-fabricated joints of a special design for HVDC Light®. The two cables were laid in the trenches with a 0.1 metre separation distance between them.

At crossings of larger roads, ducts were pre-installed by directional drilling or hammer jacking, depending on the soil conditions. In total there were 15 drilled crossings in Finland, and the longest drilling was 60 metres. One duct for each cable was used, and the ducts were filled with Bentonite clay after the cable pulling, for thermal reasons.

In Finland, approx. 60% of the cables were installed from a drum wagon. The method was found to be fast and safe and was selected, where feasible, due to accessibility along the cable trench. The method, shown in Fig. 6, was used in combination with normal cable pulling for different sections.

Control equipment

The control and protection system is the fully computerized and fully integrated MACH 2 control, protection and monitoring system, which has been used in more than 400 installations in AC and HVDC substations since the late 1990s. The control system is duplicated, for full redundancy, and each control system consists of pole, converter and valve control units and some controls for auxiliary systems. The converter protection systems are also fully redundant and integrated in the MACH 2 system, but operate independently from the control systems.

The station control and monitoring system, SCM, contains the local operator workstations (OWS), transient-fault recorders (TFR), a sequence-of-events recorder (SER) and a gateway for the remote control of the converter from the grid companies' SCADA systems. All SCM functions are fully integrated in the MACH 2 system.

Each converter station can be fully controlled from either of the national control centres in Estonia and Finland. Redundant telecommunication channels for this are in operation. The link is normally controlled from one control centre, but in case of telecommunication outages, it can be operated from the other control centre, or from the OWS at either converter station control room.

A Web server is also included, which enables the owner to access the link’s operating status, the TFR files and the SER lists from any computer in the owner companies’ intranets.

Transmission control system

The link will permit the exchange of power between the Baltic countries and Nordel, but will also be used to support the Baltic Sea region during network emergencies and to provide damping control to Finland for inter-area power oscillations.

The “Black Start” function can be used to aid restoration of the Estonian grid in the unlikely event of a complete network collapse.

The basic control functions are:

- Active power control, which controls the active power flow at the connection point to the Finnish 400 kV grid at the reference value, set by the operator.
- Reactive power control, which will keep a fixed reactive power exchange with the network, independently of the active power exchange, however within the converter's ratings.
- AC voltage control, a mode in which the converter supplies reactive power automatically up to its limits to attempt to keep the grid voltage stable during disturbances and load changes.

The network-related special controls for Estlink are:

- Emergency power control, which rapidly changes the active power level to preset values, depending on the network contingencies. Automatic change to AC voltage control or Frequency control mode is also a feature offered by this control.
- Frequency control, which can be activated in either station, but not simultaneously. This feature is able to adjust the active power for frequency control purposes in the frequency range from 47.0 to 53.0 Hz. The control adds or subtracts a contribution to the power order, proportional to the frequency deviation. Estlink and other HVDC links outside the Nordel area can provide Fingrid with a competitive option for the purchase or reservation of certain amounts of production capacity, since Fingrid does not have its own frequency control capacity.
- Damping control (Finland only), the purpose of which is to increase the damping of inter-area power oscillations which may arise after severe faults and during high transmission levels, thus increasing the operational security of the grid. It is not practical to allow the damping control to counteract all minor fluctuations in the grid, the additional damping is used only if they increase beyond the selected dead band. Thus, the damping control is in stand-by mode for most of the time and has no effect on the power transmission of the link. The controller's implemented transfer function has several parameter sets, which are selectable by the operator.

Black start

The ability of the HVDC Light® converters to generate a voltage that can be changed very quickly in amplitude and phase, offers the possibility of energizing a black network after a blackout. This is implemented in Estlink for the Estonian side. The transformer is equipped with a special auxiliary power winding for self-supply of the converter station, and the control system has schemes for detecting a network blackout. If such a blackout occurs, the converter will automatically trip the connection to the grid, and continue to operate in "house-load" operation, supplied through the DC from the Finnish station. The converter can also be started manually in Black-start mode, if needed.

The network restoration sequence starts with the Harku station running without load. The voltage and frequency are decided by the converter, which in this case operates in frequency control mode as a generator. The AC network is then connected, first with a small load, then with more loads, up to the rating of the link.

The black-start feature will make it possible to start up parts of the Estonian network in only minutes after a total black-out. In the network restoration scenarios, worked out by the grid operator, Estlink would provide auxiliary power to selected power units. After restarting such a unit and connecting it to the network island, more generation can be connected. Estlink and the connected generation will share the load through the use of droop. When sufficient generation is feeding the network, the mode of operation of the converter can be changed from frequency/voltage control to power/voltage control, as is the normal case.

Commissioning

Estlink was commissioned during the autumn of 2006. The equipment and subsystem tests were fairly short activities due to the valves being delivered in factory-built and tested enclosures, and the control system being extensively tested in the factory together with a network and main-circuit simulator.

The VSC technology allows part of the system tests to be done with single converters, not inter-connected, only connected to its AC grid. This minimizes the need for coordination between the converter stations. Most of the Estlink systems could be tested this way, only requiring reactive power from the network. The final part before commercial operation, power transmission tests, requiring the use of active test power, was done in only two weeks.

Nearly all tests were performed using remote control. This method had the advantage of checking the communication paths and the functionality of the SCADA software and control screens in the remote control centres, at the same time as testing the performance of the converter. Early operator training was an additional advantage.

Operation

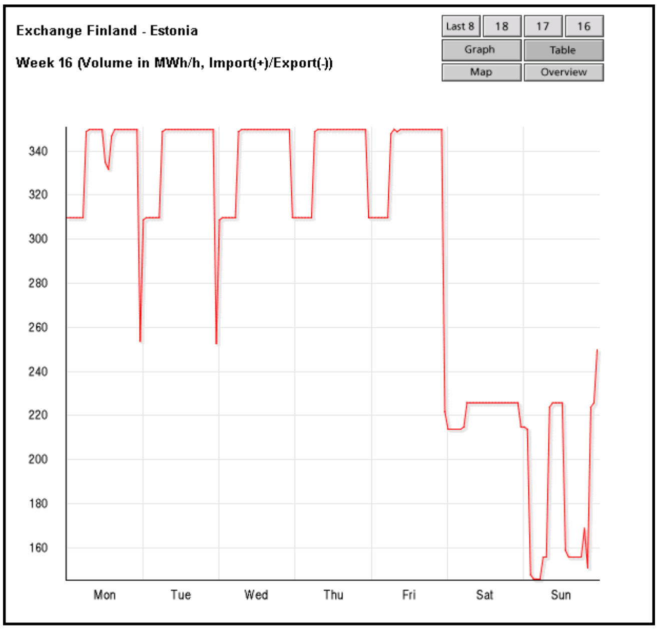

Fig. 7. NordPool diagram of Estlink operation in Week 16, 2007

Estlink began commercial operation in January 2007. The utilization can be viewed live at http://www.nordpool.com/. Fig 7 is the graph for week 16, indicating the daily flow of power between Finland and Estonia. The positive scale indicates that Finland is importing power from Estonia this week.

The reliability and availability of the link can not be fully evaluated after only a few months of operation, but the events so far have been very few. They can mostly be attributed to flaws discovered during testing, but not yet corrected.

Conclusion

The Estlink project is the largest in the world to employ VSC HVDC technology and is a unique project, not only in the area of the Baltic Sea. It is also a further development stage in the field of electrical power transmission. It was the first step in connecting the Baltic power system with the rest of the European power system and currently the Baltic states are planning additional connections to Scandinavia (Finland and Sweden) and UCTE (through Poland). The vision of the Baltic states is to have one common electricity market around the Baltic Sea, and this vision will become true only by constructing additional interconnectors. The Baltic Sea Electricity Market will ensure the security of supply in the future and will guarantee optimal electricity prices.

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