Estlink, VSC transmission with black-start capability

Gunnar VIRK, Raine PAJO
AS Nordic Energy Link, Eesti Energia AS
Estonia

SUMMARY

Estlink is designed as a bidirectional ±150 kV, 350 MW HVDC system, which consists of two voltage-source ac-dc converter (VSC) stations and two 105 km HVDC cross-linked polyethylene insulated cables, of which 74 km is submarine cable that is buried in the seabed. The 150 kV cable for the land section, 22 km in Finland and 9 km in Estonia, has aluminium conductors (2000 mm^2), and the submarine cable section uses copper conductors (1000 mm^2).

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 asynchronous networks and long distance under water. There was considerable competition between conventional and VSC HVDC technologies (HVDC Light®) so in the subsequent feasibility studies and tender evaluation, parameters like investment cost, overload capacity, electrical losses, circuit availability, maintenance cost, and construction time were considered.

As the converters can generate a voltage that can be changed very fast in amplitude and phase, there is a possibility to use the connection to energize a network after a blackout. Using this feature, it is possible to restore the Estonian power system in case of total blackout in a matter of minutes.

When a severe disturbance in the grid occurs that could be the start of a blackout, the Frequency Protection or the AC Abnormal Under Voltage Protection will block the converter and trip the circuit breakers. This means the converter will be operating as an idle generator, ready to be connected to the network, when the operator chooses to close a circuit breaker. Tests to energize the Balti TPP auxiliary power system using the black start function have been conducted successfully.

KEYWORDS

VSC HVDC, black-start, cross-border connections

Gunnar.virk@energia.ee

Introduction

The Estlink interconnection is a joint project between five parties: Eesti Energia, Latvenergo and Lietuvos Energija from the Baltics; and Pohjalan Voima and Helsingin Energia from Finland. To this day, it is the only link to connect the main grids of the Baltic states directly with the markets of other EU countries. Since start of operation in early 2007, it has proven to be a commercially successful project, providing new trading opportunities for the energy companies in the Baltics and new sources of energy for Nordic consumers. Its value for the Baltics will increase significantly after the closure of Ignalina NPP in Lithuania from 2010, both as a source of energy imports to the region and as a back-up facility for starting up the system after a blackout.

When deciding upon the preferred technology for the new interconnection, the main criteria was least overall cost of the project. Characteristics like construction price, maintenance costs, guaranteed availability, losses, date of completion, and over-load capability were taken into account when computing the expected costs [1]. Additional features providing the opportunity to use system services were important for the TSO's, who will own the cable after the end of the commercial phase of the project in 2014.

Among other functions, Estlink equips the Estonian TSO with a possibility to initiate the energizing of a dead network by providing the necessary auxiliary power for thermal power plant units, and stabilization after connecting the production units and consumers to the grid. This is made possible due to the fact that with VSC HVDC technology, the transfer of active and reactive power can be regulated very fast, independent of each other.

The Estonian power system, while being strongly linked in synchronous operation to neighboring Latvian and Russian systems, has little possibilities to start the system after a blackout on its own. The biggest hydro power plant is 1,1 MW; two old gas turbines in Iru could provide auxiliary power to the thermal units in Narva, but the starting of these is problematic, also the control system is not suitable for providing stable frequency. Riga HPP in Latvia could also supply the needed energy, but this is complicated due to a long distance to the main generating units in the North-Eastern part of Estonia. Narva HPP with an installed capacity of 120 MW would be ideal for the task, but unfortunately lies on the other side of the border with Russia and is intended for the purposes of Leningradskaja NPP in a case of emergency (Figure 1).

Figure 1. Possible alternatives for black start

Opposed to the Russian and Latvian systems, the Finnish power system works in a different synchronous area. The only links between Finland (Nordic power system) and IPS/UPS are B2B HVDC 1400 MW in Viiburi and 350 MW Estlink DC connections. Thus it is not likely that a blackout in IPS/UPS will cause the Finnish power system to follow. Estlink should be thus the most reliable outside source of emergency power in the case of blackout.

The paper is composed in the following manner: first, the background of the Estlink project in regard to the tender evaluation criteria is briefly introduced; in the subsequent section, information on the trading principles of Estlink is provided; following this, the basic principles of VSC technology are touched; as a final topic, the black-start capability is introduced. The paper ends with a conclusion.

Considerations for the choice of technology

The main objective of the investment into Estlink was to provide trading opportunities for the three incumbent power producers in the Baltic and a source of power to two Finnish investors. In order to achieve the maximization of profits, the NPV of different cost items of the competing tenders had to be evaluated for the lifetime of the connection. The method for including the different cost items were:
Construction price – as a lump sum
Maintenance costs – the present value of maintenance costs for the lifetime of the connection.
Unavailability – opportunity cost of lost trade over the life time of the project
Losses – present value of the purchased loss energy
Date of completion – expected profit in case of shorter construction time
Over-load capacity – present value of additional profits from over-load capacity

Based on the specifications in the offers to the tender, the least-cost solution was picked. It is clear that the higher losses weight heavy on the costs side of the VSC technology. For VSC, the losses according to producer data are around 5% [2]. This is also backed by data from two years of operation. As a counterweight, the aspects speaking for VSC were construction price and fast completion. With significantly lower space requirements and minimum construction on site due to modular design of components, VSC gained an overall advantage compared to classic HVDC.

Trading possibilities from the connection to the Nordic market

The Baltic states have a total peak load of 5000 MW with diversified production capacities (thermal, nuclear, hydro) of 9000 MW. There is no exchange for bulk electricity trades in the Baltic, so a market price cannot be specified. However, for most of the year there is a surplus of production capacities with a lower marginal cost than the price on the Finnish day-ahead power market. This situation is expected to last until the closure of Ignalina NPP in Lithuania in the end of 2009. As at the time of construction of Estlink (nor at the current point in time) there were no connections to other European markets from the Baltics. At the same time, the TSO's had other priorities in cross-border capacity investments. In order to provide a possibility to utilize the excess production capacities, the Baltic power producers were interested in building the link by themselves [3].

The project was implemented in a special purpose company, Nordic Energy Link. The investors to the project, owning a part in the company, each have the right to use a certain share of the cable capacity in either direction. Based on the usage notifications submitted to Nordic Energy Link from the investors one day ahead, the total usage of Estlink is determined for each hour and remaining capacity offered on Free Capacity auction to third users. All costs incurring with operating the link and transmitting energy, are covered by the investors and users of the cable. Thus, the profit from cross-border trades from using Estlink and auction proceedings go directly to the owners and depend on the utilization of the capacity by the particular owner.

The commercial phase of the project will last until 31.12.2013 the latest. After this date, the exemption from the EU regulation on conditions for access to the network for cross-border exchange of electricity, under which the connection currently operates, will expire and the connection will be used for market coupling purposes by the Finnish and Baltic TSO's.

VSC technology overview

Estlink is constructed as an HVDC connection using VSC technology. The converter bridge is set up of six valves, two valves for each phase. Each phase is connected to the positive potential and negative potential through series-connected IGBT units. The output voltage is switched between the positive and negative voltage (Figure 2).

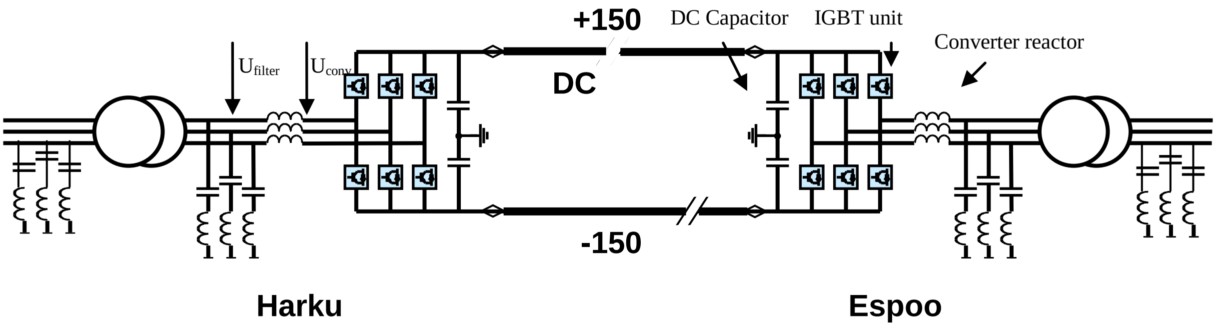

Figure 2. Estlink simplified diagram

The DC voltage is transformed to a sine waveform using optimal pulse width modulation (PWM), where each valve is turned on and off with high frequency. The output voltage is modeled with changing the duration of each switching (Figure 3). To ensure optimal switching, all IGBT units are turned on and off simultaneously by the valve control unit, which gets information about the voltage across the IGBTs.

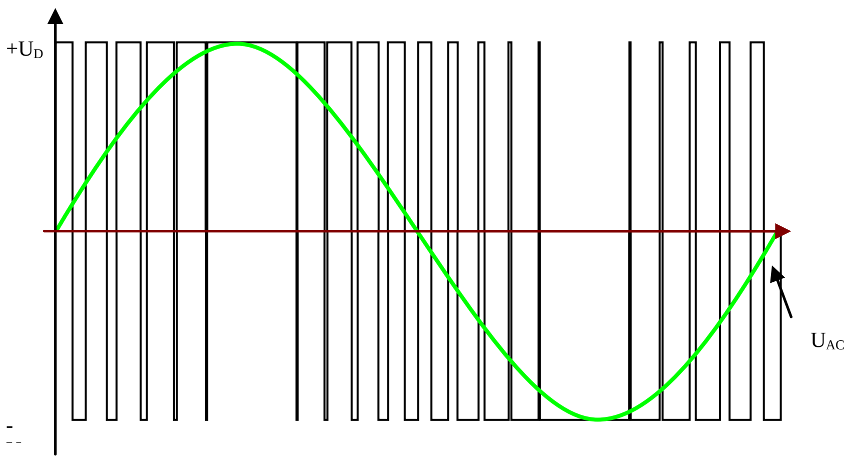

Figure 3. Example of pulse with modulation

The possibility to control active and reactive power flow fast and independently of each other is achieved by changing the PWM pattern. By changing the phase angle between converter voltage and filter voltage, the active power flow can be regulated (Figure 4). Plot a shows the rectifier mode, where the converter voltage is in phase lag and power is transferred to the DC side. Plot b shows active power transfer to the AC side. At the same time, reactive power can be adjusted independently of active power flow and separately at both ends of the connection by changing the amplitude difference between the filter voltage and the converter voltage (Figure 4, plot c and d).

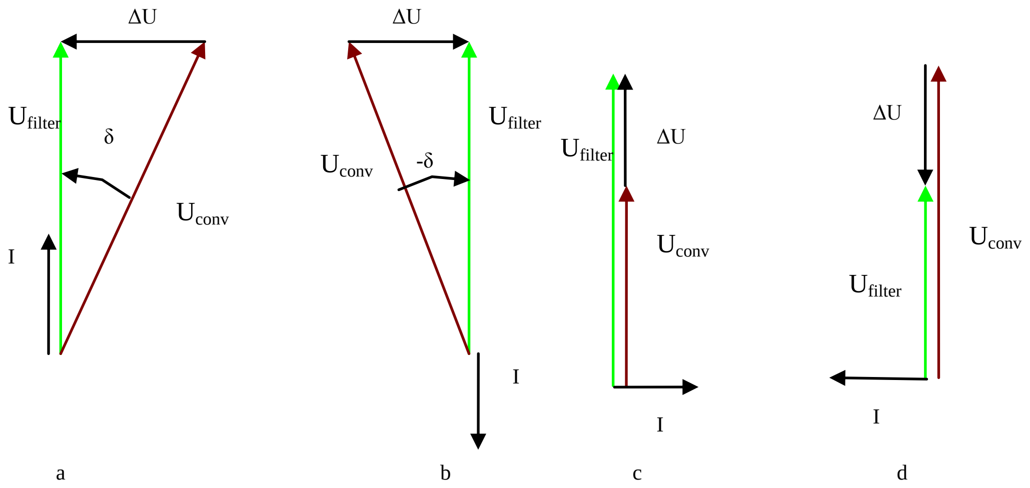

Figure 4. Active and reactive power control: a) Rectifier; b) Inverter; c) Reactive power consumption; d) Reactive power generation

In contrast to the classical HVDC technology, VSC is a self-commutated converter technology which does not need an active network at the receiving end for operation.

Tests of black-start function

Estlink will go to black start mode automatically whenever the frequency in the AC system on the Estonian side goes out of the range 47-53 Hz for more than a second or when the AC voltage goes below 0,7 p.u. for more than 6 seconds. Black-start mode can also be initiated manually if for some reason automatic transfer did not occur.

In order to prove the black-start capability of Estlink, several real tests have been conducted since the commissioning of the connection. The aim of these tests has been to ascertain that automatic transfer to black-start mode is possible and that the HVDC link can maintain the frequency and voltage in island operation with a thermal unit while providing the necessary active power to cover the auxiliary power needs of the unit.

In the tests, a black-out was simulated by opening the circuit-breakers in Harku substation that connect Harku converter station to the Estonian grid. Also, the reserve auxiliary power source for Estlink from the Harku substation 20 kV bus was disconnected. To simulate the dead grid, an island in the network was created, consisting of a 330 kV line connecting Harku converter station with a generation unit at Balti PP and it's auxiliary power transformer.

In the subsequent steps, the necessary switching was performed to connect the lines and auxiliary power transformer of the thermal power unit to be energized.

With an active power capability of 350 MW, the converter can supply enough energy to start a 200 MW thermal unit in Balti PP with its 10 MW auxiliary power needs, and provide power control in the subsequent synchronous operation with the thermal unit. The transmitted active and reactive power will follow the difference between the total load and total generation in the black starting network. There will be an instantaneous change in the transmitted power from the converter, corresponding to the size of the load or generation.

A comprehensive overview of the field test results obtained by ABB is provided in a separate paper [4].

Manual transfer to black-start mode

In case automatic transfer to black-start mode has not taken place, the start up is performed according to the following sequence:

- Check that the Espoo (Finland) converter is deeenergized
- Check that the converter breaker in Harku (Estonia) is open
- Manually, order transfer to black-start mode
- Energize the converter in Espoo
- Manually, deblock the converter in Espoo
- Check that the converter breaker in Harku is open
- Manually, deblock the Harku converter (house load operation).

After deblocking, the control gives a voltage reference so as to increase the converter transformer primary voltage from zero to 315 kV.

The necessary preconditions for manual black-start initiation are:

- Espoo converter must be operating without problems or be ready to be started
- The DC circuit must be closed
- The cooling water for the valves must be above +5 °C
- The station batteries must be charged
- The emergency battery for the cooling pump must be charged

There is no auxiliary power for heating the water in the valve cooling system. Thus with low outside temperatures, the expected time span for a possible re-energizing in case of manual initiation is not more than 1 hour. Also, the batteries for cooling pumps, disconnector motor, and control and protection system will not last much longer.

On the grid side, the restrictions are not as rigid as to the availability of auxiliary power. Most of the switches can be operated as long as 10 hours after the blackout. However, in order to ensure that the thermal and mechanical parameters of the boilers and turbines do not deviate from the requirements for restarting the units, auxiliary power must be provided in not more than 10 minutes after the emergency stop. Otherwise, the whole process would be extended to several hours.

Conclusion

The Estlink project has been a success considering the first two years in operation. The actual amount of power traded on a yearly basis has surpassed expectations. Both the Finnish and Baltic parties have benefited from the trades in Estlink.

Estlink provides invaluable system services for the TSO's on both side of the connection, already in the commercial phase of the project. In addition to the voltage control, frequency control, reactive power control and damping control, which have been proven themselves in operation, tests to confirm that the black-start function of Estlink is a fast and reliable way of starting up a dead grid. Instead of starting with small units to power up bigger ones, the system can be restored in a matter of minutes from a neighboring system that operates in different synchronous area. The converter will be like an idle generator ready to be connected to the network. The link also helps to stabilize the system after the first units have been reconnected into the grid.

In addition to the black-start tests, the Estonian TSO will perform a test for independent operation of the Estonian power system from the IPS/UPS for several hours in spring 2009, following similar tests done since the 1990's. This time, the test will also involve Estlink – its automatic frequency control (AFC) capabilities will be tested for stabilizing the Estonian system.

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