SwePol Link sets new environmental standard for HVDC transmission

Leif Söderberg, Bernt Abrahamsson

Six cable links – all of them HVDC (high-voltage direct current) – are currently in service between the power grids of continental Europe and the Nordic region, with another five planned. The latest to be brought on line is the SwePol Link, which connects the electricity networks of Poland and Sweden. It is unique in that, unlike previous installations that depend on electrode stations to transmit the return current under ground or under water, it uses 20-kV XLPE cable to carry this current. The high-voltage HVDC submarine cable used for the SwePol Link is designed for 600 MW at 450 kV.

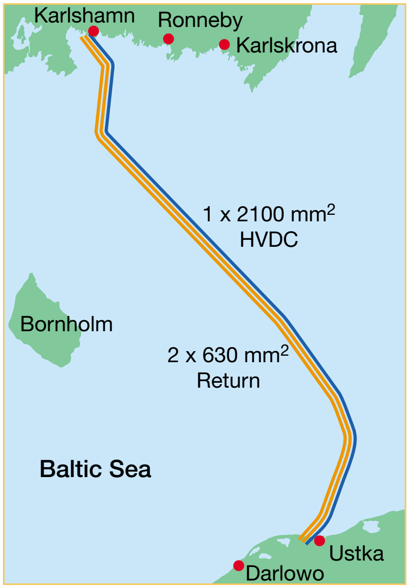
The reason for all these links is the vital need to secure power system reliability in each of the participating countries. They make it easier to optimize power generation in an area in which different countries use different means of power generation and have different power demand profiles over a 24-hour period. Wet summers in the Nordic region result in a considerable power surplus, which can be sold to countries that rely on more expensive fossil fuel-fired power plants. Conversely, any surplus power can be sold back during periods of low load.

Power system reliability in the region is increased by the addition of new HVDC cable links. In the event of grid disruptions, the rapid power balancing ability of these links can be used to compensate for fluctuations in frequency and voltage. For example, it is technically feasible to reverse the entire 600 MW power throughput of the SwePol Link in just 1.3 seconds, although this is not a feature that will be used in practice. Nevertheless, a typical emergency power measure could call for a ΔP ramp-up of 300 MW within a few seconds to prevent grid failure if the voltage in southern Sweden drops below 380 kV.

With all previous links of this kind, electrode stations off the coast transmit the return current under the sea, and this has worked perfectly well (*Table 1*). The first such cable link was laid in 1954

Table 1: Existing HVDC links across the Baltic Sea

Name	*Capacity*	*Year*
Gotland	2 × 130 MW	1954, 1983, 1987 (converted to bipolar)
Konti-Skan	250 + 300 MW	1965, 1988
Skagerrak	2 × 250 + 440 MW	1977,1993
Fenno-Skan	500 MW	1989
Baltic Cable	600 MW	1994
Kontek	600 MW	1995
SwePol Link	600 MW	2000 (first to use return cables)



1 SwePol Link between Sweden and Poland. The power cable (blue) and the return cables (red) run on the same route, being spaced 5 to 10 meters apart in shallow water and 20 to 40 meters apart in deep water.

between Västervik, on the Swedish mainland, and the Baltic island of Gotland. Since then, the power rating has been increased and the original mercury arc valves in the converter stations have been replaced with thyristor valves. The Gotland link has shown excellent reliability and has operated without interruption for eight years since the switch to thyristor valves. This link has also been converted from monopolar to bipolar.

In the case of the SwePol Link, return cables were chosen as an alternative to electrodes in order to pacify local resistance to the project, particularly around Karlshamn. The environmental issues that were raised during planning of this link may also apply to future installations.

Lower emissions benefit the environment

The power link between Sweden and Poland is the latest example of the growing economic cooperation between the countries bordering the Baltic Sea. The cable, which was taken into commercial service in June 2000, is a step towards the large-scale power distribution partnership that is known as the Baltic Ring [1].

The new link allows power generation to be stabilized in both countries, where the seasonal and daily variations in demand can differ considerably. The surplus that builds up in the Nordic region during wet years has already been mentioned. In a really cold year it makes financial sense for this region to import Polish electricity generated from coal rather than start up a condensing oil-fired power plant or a gas turbine.

Polish imports of electricity via the link will in turn reduce environmental impact in that country. The predicted annual net import of 1.7 TWh is expected to reduce emissions from Polish power plants by 170,000 tonnes of sulfur dioxide and 1.7 million tonnes of carbon dioxide, according to calculations by the Swedish power company Vattenfall.

Polish exports of electricity over the link will also reduce environmental impact in the area in the long term.

The country's forthcoming admission to the EU will reinforce this, since it will have to introduce power plants that use modern flue-gas emission control technology.

Poland is currently undertaking an extensive program of privatization. This requires that all power generation and electricity distribution be privatized within three years. Following acquisition, investors must guarantee an investment program that involves upgrading generating equipment to meet EU environmental standards. One example of this is acquisition by Vattenfall of combined heat and power (CHP) plants in Warsaw, where the company has committed itself to invest at least USD 340 million in environmental improvements over the next ten years.

Cable company is set up

SwePol Link AB was formed in 1997 to install, own and operate the cable link between Sweden and Poland. It is a power transmission company that will sell electricity transmission services across the link.

A Polish subsidiary was formed in 1998 to handle the local business. On the Swedish side the link will be used primarily by state-owned Vattenfall, although other companies will be able to sign transmission agreements with SwePol Link.

The new link is approximately 250 km long. It runs from Stärnö, just outside Karlshamn in Sweden, past the Danish island of Bornholm, and returns to land at the seaside resort of Ustka on the Baltic coast of Poland 1, 2.

The Swedish converter station was sited at Stärnö because a 400-kV station and the Swedish main grid are nearby. This avoided having to build new overhead lines that would have marred the Swedish countryside. The Polish converter station 3 is connected to the Polish 400-kV grid at Slupsk, about 12 km from the coast.

The total cost of the link is estimated at about US$ 250 million and has

Crossing the seas with HVDC

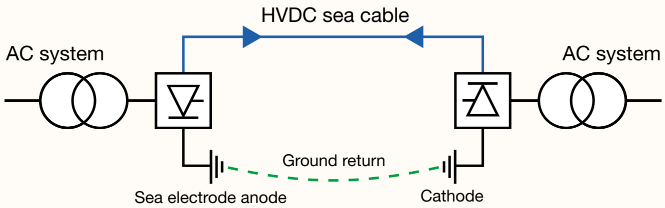
In any long AC power cable link, the reactive power flow due to the high cable capacitance will limit the maximum possible transmission distance. As a result, over a 40-km or so stretch of AC submarine cable, the charging current supplied from shore fully loads the cable and leaves no room for transmitting real power. With DC there is no such limitation, which is why, for long cable links, HVDC is the only viable technical alternative. Another good reason for using DC cable is that it is much cheaper than AC cable.

In an HVDC system, electric power is taken from one point in a three-phase AC network, converted to DC in a converter station, transmitted to the receiving point by submarine cable and then converted back to AC in another converter station and injected into the receiving AC network. HVDC power transmission cable schemes can be variously configured.

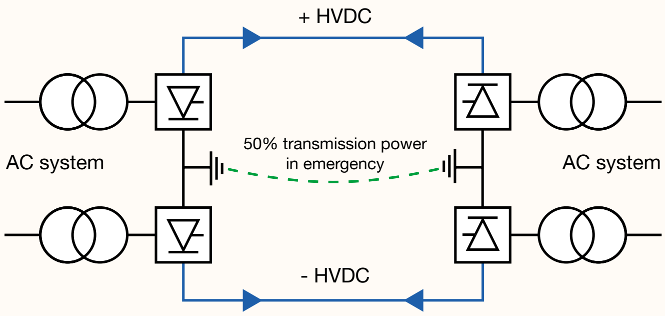
The basic HVDC cable transmission scheme is a monopolar installation that uses the earth and sea to return the current. The sea return reduces the cost of the interconnection since only one cable is necessary between the two converter stations. Losses are also kept to a minimum as the return path has a huge cross section, which makes the resistance negligible. The only losses are due to the voltage drops at the anode and the cathode. The electrodes have to be located well away from the converter stations and the main HVDC cable to avoid corrosion of pipelines or other metallic structures in the vicinity as well as direct current pick-up in transformer neutrals. The good conductivity of the earth and seawater makes it easy to design the electrodes, and it can be said that field experience with monopolar transmissions has been excellent.

A further development of the monopolar transmission scheme is the bipolar configuration. It is actually two monopolar systems combined, one at positive and one at negative polarity with respect to ground. Each monopolar side can operate on its own with ground return; however, if the current at the two poles is equal, each pole's ground current is cancelled to zero. In such cases, the ground path is used for short-term emergency operation when one pole is out of service.

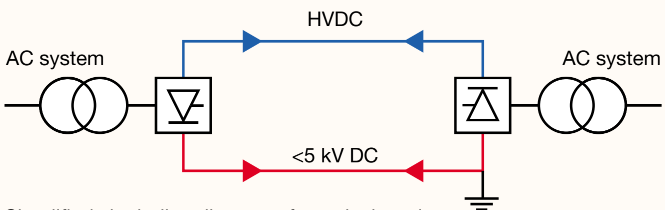
In a monopolar metallic return system, return current flows through a conductor in the form of a medium-voltage cable, thus avoiding potential problems associated with ground return current.



Simplified single-line diagram of a typical modern monopolar HVDC cable link with ground return



Simplified single-line diagram of a bipolar HVDC cable transmission link



Simplified single-line diagram of a typical modern monopolar HVDC cable link with metallic return cable

2 The 250 kilometers long SwePol Link exchanges electrical power between the 400-kV AC grids in Sweden and Poland. The converter stations are located near Karlshamn in southern Sweden and at Slupsk, 12 kilometers from the Polish coast.

involved around 2500 man-years of work for ABB, primarily at its plants in Ludvika and Karlskrona. Both stations will be unmanned, although on-call personnel will be able to provide coverage at short notice.

DC circuit

The land-based power grid is, of course, an AC system. However, for long underwater links DC is the only viable solution on account of the high capacitance of submarine cables. The SwePol Link basically builds on ABB's proven HVDC rectifier technology, which was first used in 1954. In the meantime, performance has been further improved, losses have been reduced and control methods have been continuously upgraded.

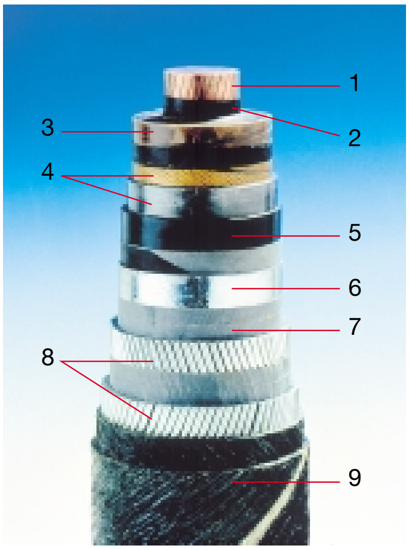
Most cable links are monopolar systems, in which the return current is carried through the ground and the sea. Power is transmitted over a high-voltage cable. It is a common misconception that sea-water carries the return current because of its high conductivity. However, this is not the case; most of the current travels at a considerable depth through the earth.

In the case of the SwePol Link the return current is carried by two insulated copper conductors rated at 20 kV. The use of these conductors eliminates the need for environmentally controversial electrodes.

Another way to reduce any negative side effects of electrodes is to use bipolar technology, which becomes financially viable when the capacity exceeds 1000 MW. In this case the current carried by the electrodes and earth is due entirely to the small imbalance that can never be entirely eliminated by the converters.

3 Valve building in the Slupsk (Poland) converter station

5 Only the cooling assemblies of the fully enclosed and soundproofed transformers are visible in the Slupsk station.



4 SwePol Link power cable. The HVDC submarine cable is rated 600 MW and 450 kV DC. Its overload capacity is 720 MW at temperatures below 20°C.

1 *Conductor*
2 *Conductor screen*
3 *Insulation*
4 *Insulation screen*
5 *Metal sheath*
6 *Protection/bedding*
7 *Reinforcement*
8 *Armor*
9 *Serving*

The high-voltage cable 4 is around 140 mm in diameter, of which the central conductor takes up 53 mm. Instead of being solid, this consists of copper segments to make it more flexible. The segments are shaped individually, then rolled as a unit to achieve an effective copper cross-section in excess of 99%. The rest of the cable consists of various layers of insulation, sealant and armor. The 250-km long cable is made up of four sections which are laid individually and joined by the laying barge.

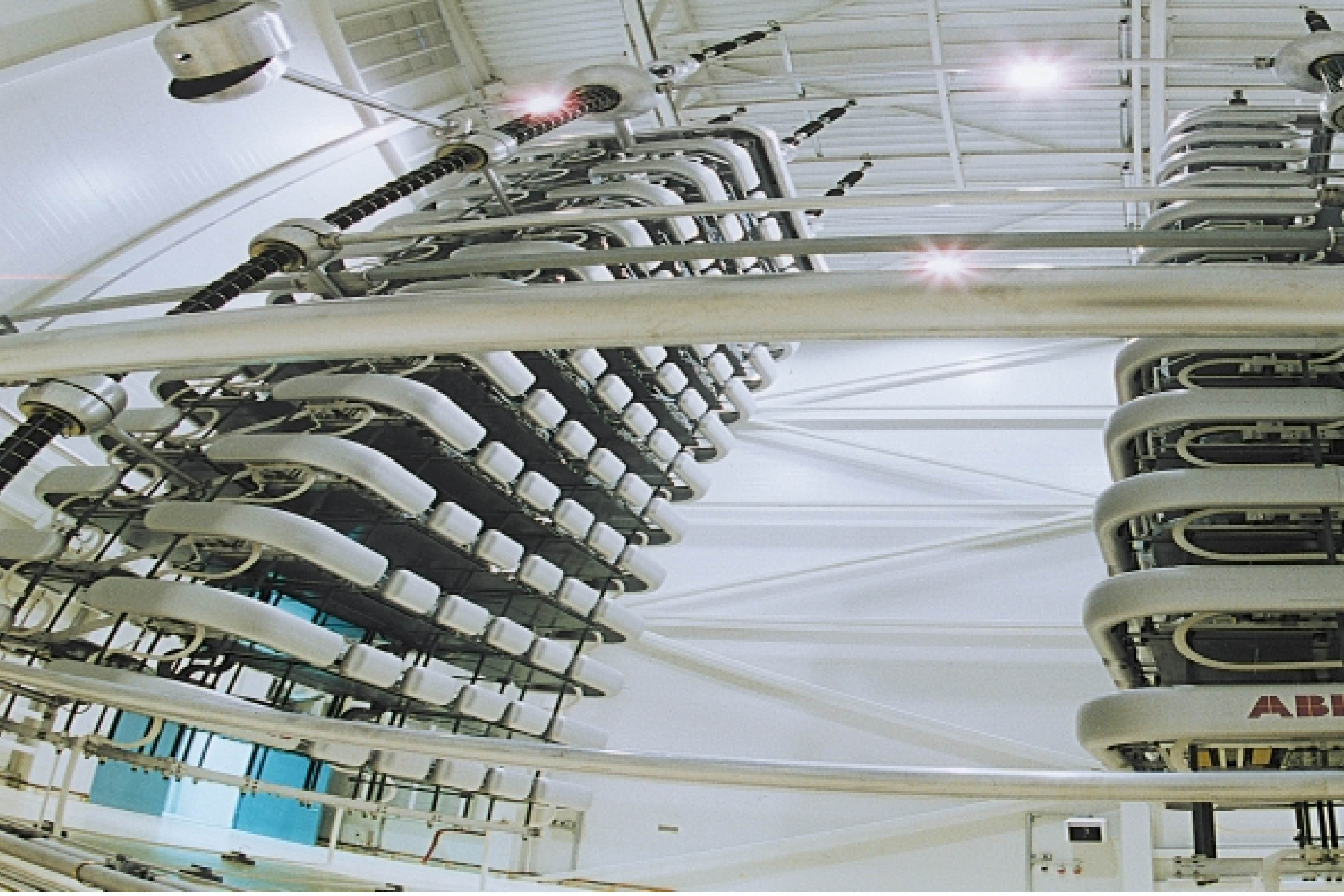
Visible parts of the link

The visible parts of the link are the two converter stations at Stärnö and Slupsk. Located just a small distance from the center of Karlshamn, the Stärnö station is next to an oil-fired power plant that completely dominates the landscape. By siting the tall valve building in a former quarry some 10 meters deep, the station's impact on the skyline is reduced even more. The power cables run 2.3 km from the station to the sea.

At the Polish end, the valve building is a prominent, but by no means ugly, landmark in the flat agricultural countryside. The Slupsk station is just over 20 meters high and is situated about 12 km from the Polish coast.

Both the high-voltage and return cables run underground almost all the way between the stations. On land this required clearing a five-meter wide swathe through the landscape when the cables were being laid. This will soon be hidden, partly thanks to forest replanting. At sea about 85% of the cable could be laid in a trench about one meter deep to avoid damage by trawlers and anchors.

The converter stations cannot only be seen, but heard too. This is because the eddy currents that flow in all power transformers generate noise at a frequency of 100 Hz. Converter stations also produce higher frequency noise that can be irritating to people living nearby. It was clear that special soundproofing would be necessary. Following calculations and measurement of the noise level and noise propagation, the transformers and reactors were enclosed. The filter capacitor cans are equipped with a noise-reducing device 5.



A magnetic field with minimal effect on the surroundings

Whenever electricity is transmitted through a conductor it generates a magnetic field around it. Since DC is used, the field is of the same type as the earth's natural magnetic field. This is completely different to the AC fields normally produced, for example, around overhead lines.

Measurements have shown that the magnetic field around the cable at a distance of six meters is equal in strength to the earth's natural magnetic field, while at a distance of 60 meters its intensity drops to just one tenth of that field.

The magnetic field resulting from the combination of 1 + 2 cables varies with the depth and relative spacing of the cables. It is not practicable to lay the high-voltage cable at the same time as the two return cables, which means that they cannot be laid right next to each other. They also have to be separated because of the heat they generate. In shallow water the HV cable is laid 5–10 meters from the return cables. The resulting magnetic field measured on the surface of the sea is typically 80% of that obtained around a high-voltage cable in a monopolar installation. The equivalent figure at 100 meters depth with 20–40 meters separation is typically 50%.

Further away from the cables there is an even greater percentage reduction in the magnetic field, added to the fact that the absolute value of the magnetic field at this distance is insignificant compared with the earth's magnetic field. Thus, the use of return cables has no major effect on magnetic field strength. And, anyway, modern ships no longer depend on magnetic compasses.

But what are the possible effects on animal life? Experience with previous cable links has shown that they do not affect fish or other marine organisms. Nor do they affect the vital homing ability of eels and salmon. This is especially important since these fish migrate regularly during the course of their lives and it is essential that their sense of direction remain unimpaired.

Back in 1959 a study was carried out to determine how the Gotland cable had affected the marine environment [2]. This was followed by exhaustive studies on the Fenno-Skan link (Sweden–Finland) and the Baltic Cable (Sweden–Germany)

[3]. The reports were unanimous: marine life is affected neither by the magnetic field nor by any chemical reactions. The facts speak for themselves. Eels continue to find their way to the Baltic Sea, despite having to cross seven cables on the way [4, 5].

No chlorine formation

The originally proposed monopolar solution, which would have used electrodes to transmit the return current undersea, has been replaced by an alternative solution in which return cables form a closed circuit. Any concerns about chlorine formation have therefore been entirely eliminated, since no electrolysis can occur.

The electrodes that would have been used have an anode made of fine titanium mesh and copper cables for the cathode. The following competing reactions take place at the anode:

$$2\ H_2O \Rightarrow 4H^+ + O_2\ (g) + 4e^-$$

$$2\ Cl^- \Rightarrow Cl_2\ (g) + 2e^-$$

(g) in the above formulae indicates that these elements are in gaseous form.

The amount of chlorine gas generated depends on the temperature, the chloride content of the seawater and the reaction energies. It reacts almost exclusively with water as follows:

$$Cl_2\ (g) + H_2O \Rightarrow HClO + Cl^- + H^+$$

At low pH the hypochlorous acid that is formed could be ionized, but in seawater it mostly occurs in molecular form. In time it breaks down into its component parts.

There was a suspicion that the chlorine gas and hypochlorous acid that are formed would react with biological material in the vicinity of the electrodes, resulting in the formation of compounds such as polychlorinated hydrocarbons, which include PCBs. Studies on the Baltic Cable have ruled out this concern [3]. No accumulation of organic chlorine was observed in the surrounding biomass.

To put things in the right perspective it is worth comparing the described process with the common chlorination of drinking water, in which the hypochlorite concentration is at least 100 times higher than the value measured at the anode.

Table 2: Identified metal objects on Swedish coast that could have been affected by the SwePol Link

Object length	*Distance from electrode*	*Example*
More than 25 m	Less than 5 km	Cable support
More than 200 m	5 – 10 km	Sewage pipe Ø 1.2 m
More than 1000 m	10 – 20 km	10-kV cable District heating Copper shield around building
More than 5000 m	20 – 50 km	Protective shield (Cu)

No corrosion

The return cables used for the SwePol Link eliminate the risk of corrosion, and this would seem to be the only tangible advantage they offer.

DC cable links that use electrodes, do lead to leakage currents in the earth. The return current passing through the earth takes the shortest path. On its route between the electrodes some of the current may pass through long metal objects, such as railway tracks, gas pipes and cable shielding. Electrolytic reactions could occur between this metal and its surroundings, possibly leading to corrosion. During the planning of the SwePol Link a list was therefore made of all the metal objects that could be at risk (*Table 2*).

Objects that are at risk of corrosion due to leakage currents require some form of active protection, such as sacrificial or cathodic protection.

The return current can also find a route through other power distribution systems that have multiple earth points close to the electrode. This gives rise to a DC component in the AC grid, which can lead to undesirable DC magnetization of transformers. The problem can generally be solved by modifying the grounding of the AC system.

Benefits versus cost

Using the described return cables does, of course, have some advantages, among them the reduced magnetic field strength along the cable route and the fact that they cause neither chlorine formation nor corrosion of underground metal objects. And they also allowed a solution that addressed the environmental concerns of various groups of society. In any final count, however, these benefits have to be measured against the extra cost. In the case of the SwePol Link, for example, they added about 5% to the cost of the project.

Authors

Leif Söderberg
SwedPower AB
SE-162 16 Stockholm
Sweden
leif.soderberg@swedpower.vattenfall.se
Fax: +46 (0) 8 739 62 31

Bernt Abrahamsson
ABB Power Systems AB
SE-771 80 Ludvika
Sweden
bernt.abrahamsson@se.abb.com
Fax: +46 (0) 240 807 63

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