

# Sustainable energy systems with HVDC transmission

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**Abstract**—Article on the necessity of efficient electric transmission on electricity to make sustainable generation of energy possible. In this respect High Voltage Direct Current has a important role.

**Index Terms**—Sustainable energy, electric generation, electric transmission, HVDC, VSC, hydropower, wind power, solar power, cables, converters

## I. INTRODUCTION

Sustainable energy generation like hydro, wind, sun and waves are normally not located close to the consumption. This fact makes transmission of the power as almost as essential as the generation.

Non sustainable ways of generating electricity does not normally have this problem. Coal can be transported by boat or train. Oil is transported around the world by tankers and shorter distances by pipeline. Gas is normally transported by pipeline but can also be transported by boat in liquid form. Of the sustainable resources only biomass can be transported by truck or train. Hydro, wind, sun and wave energy have to be transmitted as electricity.

Electricity has been used for more than 100 years mainly by alternating current. However, transmission of large amounts of power over long distances the use of high voltage direct current, HVDC has in many cases been found very economical.

## II. WHAT IS HVDC

HVDC was first used commercially 50 years ago. Since then a growing number of transmission schemes have been constructed around the world.

HVDC differs from high voltage alternating current, HVAC, that the voltage is not alternating 50 or 60 cycles per second but is constant. The advantage of HVDC is that long distance transmission is more efficient as there is no need to charge the capacitance of a transmission line with the alternating voltage. The drawback of HVDC is that one need more expensive terminals at the line ends

The HVDC converter station is made up of a number of equipment known from ac transmission schemes. It also contains some special features of which the most important one is the converter valves.

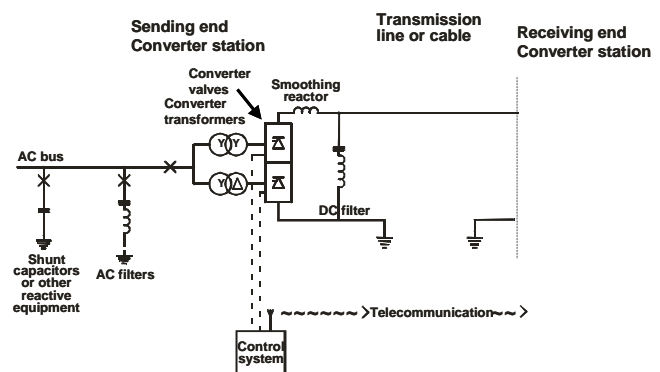


Figure 1. Typical HVDC converter station using thyristor valves

In the beginning the converters were equipped with mercury arc valves. Later thyristor valves have been developed and has made the design of HVDC more flexible and also increased the power that is possible to transfer.

HVDC has a number of properties that makes it different from ac-transmission. The most important are:

- The two stations can be connected to networks that are not synchronized or does not even have the same frequency
- Power can be transmitted over very long distances without compensation for the reactive power. Reactive power is power that does not add to the transmitted power, but is a byproduct at ac- transmission as the line or cable capacitances has to be charged 50 or 60 times per second. As HVDC has constant voltage it does not generate reactive power. See also figure 2.
- Only two conductors are needed (or even one conductor if the ground or the sea is used as return) for HVDC compared to three conductors for alternating current.

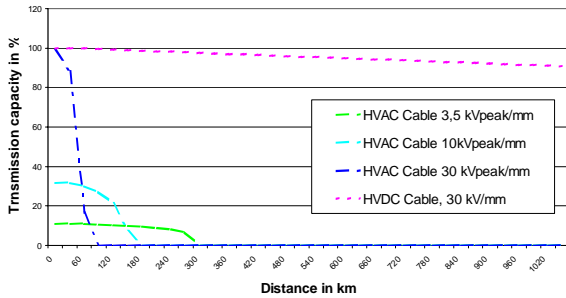


Figure 2. Shows the power that is possible to transmit as a function of the distance for ac- cables of various voltage stress compared to HVDC. With ac high power can be transmitted short distances or low power long distances. HVDC cables can transmit high power over long distances.

The same situation is valid for lines, but here the effect is seen at longer distances than with cables.

#### A. Voltage source converters

A new type of HVDC using transistors for the ac/dc conversion has been developed. By using components that can not only switch on the current but also switch it off, making it possible to build voltage source converters (VSC)

This type of converters offer many advantages when it comes to transmission of power especially from sustainable energy systems.

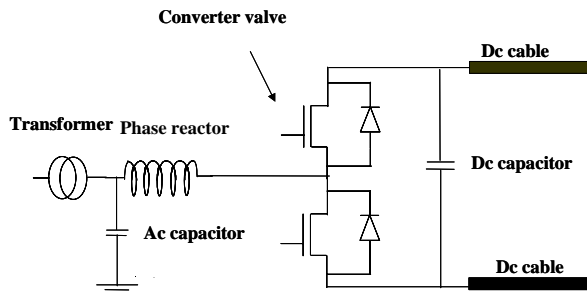


Figure 3. VSC converter valve

VSC HVDC has the following additional advantages:

- Simultaneous control of both active and reactive power. The ac- voltage can be controlled at both stations. See also figure 4.
- No need for short circuit power for commutation. Can operate against even black networks.
- Can operate without communication between the stations

- Can operate from control the power continuously from one direction
- No change of voltage polarity when the power direction is changed. this makes easier to build multi terminal schemes
- Possibility to use robust and economical extruded cables both for land and sea.
- Small converters that reduce the requirement for space

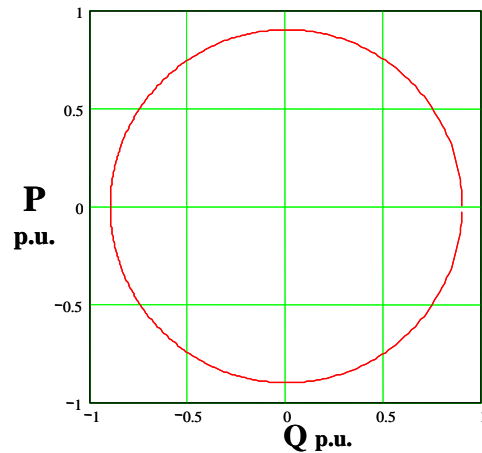


Figure 4. In a voltage source converter the active and reactive power can be controlled at the same time like in a synchronous converter, but the control is much faster, in the millisecond range.

### III. HYDROPOWER

The by far most important generation of sustainable energy comes from hydropower. This has been the situation from the very beginning of electric generation. The result of this is that most hydropower close to consumption areas is already utilized.

#### A. Present situation

During the last 50 years many HVDC projects utilizing converters with thyristor valves have been constructed in order to transmit power from hydro plants. Some of the most important of these transmissions are listed below.

#### IV. WIND POWER

The second most important sustainable type of energy where electricity is needed for the transportation is wind power. Until today most wind power has been small scale generation connected to the most nearby ac grid. This constitutes no problem as long as the wind power in feed is small compared to the total power installed in the network. However, if wind shall constitute a more substantial part of the power in the network, big wind parks will have to be constructed. To construct such big parks on land will both meet big opposition as well as problems to find sites with good wind conditions. Most probably new big sites will have to be constructed at shallow sites at the sea.

As long as the distances are a few tenth of kilometers and the powers are up to some hundred megawatts, ac cable connections will be sufficient. But with increasing power and distance, dc-connections will be more competitive. In this case HVDC with voltage source converters seems to be best suited for the transmission.

##### A. Present situation

Already a couple of projects have been constructed where the suitability of VSC HVDC in conjunction with wind power has been demonstrated.

Project	Power MW	Distance km	Voltage +/- kV
Cabora Bassa, South Africa, Mozambique	1930	1420	550
Inga- Shaba, Republic of Congo	560	1700	500
Nelson River Canada	4000	940	500
Itaipu Brazil	6300	790	600
Quebec- New England	2000	1480	450
Pacific Intertie USA	3000	1360	500
Geszuba- Shanghai	1200	1000	500
New Zealand	560	600	350
Skagerrak Denmark	440	240	250/350
TSQ China	2000	800	500
Three Gorges- Changzhou	3000	890	500
Three Gorges- Guandong	3000	940	500

##### B. Future situation

There is a tendency that new project are situated further away but also have more available power. We here talk about more than thousand kilometers of lines transporting several thousand megawatts of power

This is the situation in China where hydro resources are located in the middle of the country and the consumption is in the east and in the south.

Another country where long distance transmission has been discussed is Brazil where the affluences of the Amazon river have grand potentials of hydro power. Also here the main consumption areas are located several thousand kilometers away.

Another country is India where large hydro resources in Assam are only possible to explore if much of the power could be transmitted to other states several thousand kilometers away.

Still another area of interest is Africa and the Congo river, which has the largest potential worldwide for hydropower. Also here the population situation is such that very long transmission is needed if exploration should be possible.

Project	Power MW	Distance km	Voltage +/- kV
Gotland Sweden	60	70	80
Tjaereborg Denmark	7	4	10

##### B. Gotland VSC HVDC project

The Swedish island of Gotland is situated in the middle of the Baltic sea an the island earlier got all its power though two HVDC-cables from the Swedish mainland. Actually, Gotland had in 1954 the first commercial HVDC project in the world.

As the wind conditions on the island are excellent a large number of wind power stations were built on the southern part of the island. This made it possible to reduce the need for import of power. However, the ac- network on the island was not designed for feeding power from the south to the center of the island. Normally, this could have been solved by constructing a new ac- line, but due to the crossing through a bird protection area it was judged to be less suitable with overhead lines. Instead an VSC HVDC system using underground extruded cables was built. This solved the problem to transmit the power and made very important contributions to stabilize the voltage in the ac network on the whole island.

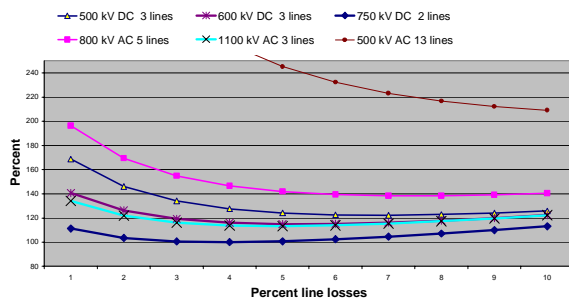


Figure 4. The cost of transmitting 10000 MW of power over 2000 km. AC and DC at various voltages are compared. All costs including cost of losses are included. As can be seen 750 kV dc is the most cost efficient alternative. However, this voltage level is still not in use.



Figure 5. The Gotland VSC HVDC project in the foreground. Wind power in the background

With this reinforcement of the ac grid on Gotland the wind power can continue to be expanded on the island. In fact, already today it happens that more power is produced by the wind mills on the island than what is consumed (there are around 50 000 inhabitants) and the surplus is exported to the mainland. So Gotland already today could be taken as an example of what might happen in the future more generally.

### C. The Tjaereborg project

In Denmark wind power has grown more and more important over the last decades. Today, Denmark is one of the countries in the world with the largest proportion of wind power. This has also led to problems to find new sites for new wind farms and locating them at the sea has attracted a lot of interest. Also VSC HVDC has attracted interest of several reasons. Both for transmitting the power from sea to shore, but also to supply the wind generators with reactive power. As most wind generators are asynchronous machines, they consume a lot of reactive power and this can cause voltage stability problems in the generator end.

In the other end where the transmission line is connected to the ac grid, there might also be problems in the short circuit power of that point is not very strong.

It is also favorable if one can adopt the frequency of the wind generator to the speed of the wind. By this it is possible to get more power out of the wind.

All this together led to the construction of a demonstration plant in conjunction to a small park of four wind generators. This plant has demonstrated operation with variable frequency and serves as a demonstrator for a bigger wind park far out at sea.



Figure 6. The Tjaereborg VSC HVDC transmission

## V. SOLAR ENERGY

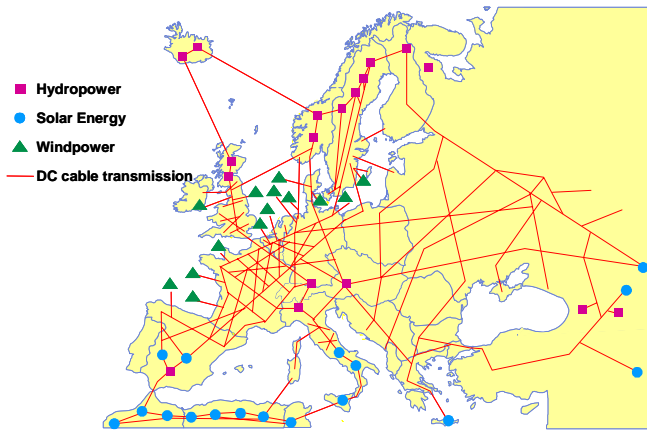
Today solar generation is not explored in a large scale, but the installed power is growing at a high rate each year. When the development of solar panels gets to a certain efficiency and cost, solar energy might become a very important contribution to the electricity generation. As with other sustainable energy, suitable sites for solar plants are most certainly located in deserts where the efficiency will be the best and the land is not used for agriculture, forestry or urban settlement. In this case it becomes even more important to be able to transmit very large power of energy from sites with very good sunlight to consumption areas. The deserts often has a very difficult environment for overhead lines this risk of salt contamination of the insulators. In this case underground cables would be very advantageous. As was mentioned above, VSC HVDC is very suited for cable transmission on land and with a further development of extruded cables there are possibilities to transmit very large amounts of power over long distances even to supply whole continents with power.

## VI. FUTURE SCENARIO

If one looks into the future fossil fuels will be more scarce and more power will have to come from sustainable energy systems. This will pose new requirements on not only generation of this power but also on transmission and storage of the energy as both wind and solar energy is not available when the wind blows or when the sun shines and not when there is a need for electricity. In order to illustrate a possible future situation when there only sustainable generation a scenario has been made showing how Europe could be supplied by electricity.

In this scenario all Europe is connected with a very efficient transmission network with capability to transmit power all over Europe. The backbone of this network could be HVDC. Power is supplied by hydropower (already existing), wind power along the coasts and finally big bulk generation of solar energy from the Sahara desert.

In the best areas of Sahara the energy that reach the surface is around 300 Watts per square meter. With a efficiency of 30 percent and a covering of 30 percent of the area with solar panels the total installed power of Europe (700 GW) need a space of 26000 square kilometers. As Sahara has a surface of 10 million square kilometers the power plants would only occupy 03 percent of the area.



. Figure 7. A scenario showing the possible transmission of solar power from the Sahara, wind power from the sea and hydropower with storage capability in Scandinavia and the Alps to consumption areas in Europe.

## VII. CONCLUSION

Even if we still produce most of our electric power by fossil fuels, there will come a day when this is no longer possible. Then sustainable energy generation will be needed. Characteristic of such generation is that it is often located in very sparsely inhabited areas and normally very far from the place where the energy will be consumed. Here it will be very important to find efficient ways to transport large amounts of electricity long distances. Today, HVDC seems to be the best solution to this problem.

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## IX. BIOGRAPHIES



Gunnar Asplund was born in Stockholm, Sweden on September 23, 1945. He got his MS in Electrical Engineering at the University of Lund in 1969.

His employment experience is with ASEA and later ABB. He has worked in the fields of high voltage testing, thyristor valve development, project management, commissioning of the Itaipu HVDC project in Brazil, system studies, engineering and since ten years he is manager of the development of HVDC within ABB.

Asplund has received the Polhem price and the gold medal from the Swedish academy of engineering science for the development of HVDC based on voltage source converters