

A novel approach to providing on route power supplies to rural and urban communities in close proximity to the extra high voltage DC transmission line

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Abstract—Article on a novel approach to providing on route power supplies to rural and urban communities in close proximity to the extra high voltage DC transmission line; in addition to on route country bulk transfers and country point to point bulk transfers.

Index Terms—Electric generation, electric transmission, HVDC, VSC, hydropower, rural electricity

I. INTRODUCTION

The energy consumption in the world is growing and far distance energy resources are needed..

Use of renewable resources such as hydropower, wind and sun is normally not possible without the use of electric transmission since these resources, at least new ones, are normally located far away.

In many cases there is a need to transfer bulk power through areas with comparatively little consumption. Especially when HVDC is used it is not obvious how to supply power along the route.

This paper will describe the state of the art of bulk power transfer and how supply can be arranged to those living along the line.

II. AC TRANSMISSION

AC is by far the most used way of transmitting electric power and has been so since very early in the development of the electro technology.

Typical action to make ac more suitable for transmission of power is to use series compensation of the lines. This works quite well when the power is transmitted from one point to another, but is normally not used inside a meshed.net.

In developing countries ac is used to build grids as in other countries but also to a certain extent for transmission of power from distant generation sources.

If the task is to transfer power to far away places one has to design the system that are stable and will survive faults on the ac lines.

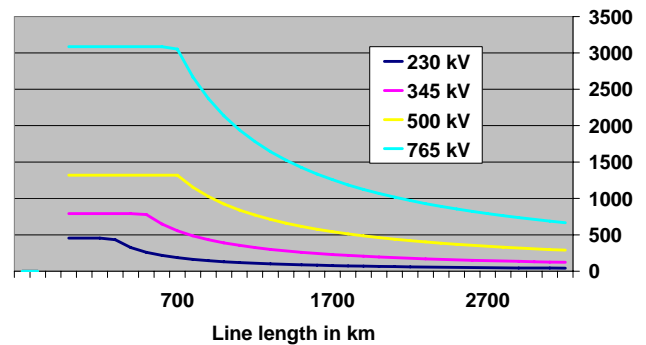
AC lines have quite high power handling capability if they are short. The capability depends on the voltage and the thermal rating of the conductors. Longer lines have higher impedance and this reduce the power transfer capability. See the equation for transfer of active power:

$$P = \frac{U1 \cdot U2 \cdot \sin(\delta)}{X}$$

where P is the active power, U1 and U2 the voltage in each end of the line, delta the phase angle between the two ends and X the line impedance.

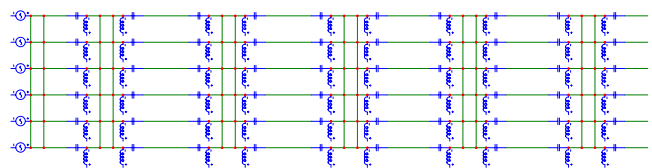
The figure shows transmission capability of one ac transmission line with 50 percent compensation and 30 degrees angle between the terminals.

Transmission capability in MW of ac lines with 50 % compensation



When a line is loaded below SIL (Surge Impedance loading) it will produce reactive power and the voltage might get too high if shunt compensation is not added. If the line is loaded above SIL it will consume reactive power and the voltage might become too low.

From a reliability point of view it is necessary to build ac transmission in sections with both series and shunt compensation as well as interconnection between the sections in order to assure that the full power can be transmitted all the time.



The picture shows six parallel ac lines in six sections with series and shunt compensation.

III. HVDC TRANSMISSION

HVDC is presently used for transmission of power up to 3000 MW per bipole with voltages up to +/- 600 kV. Development is just being finished of 800 kV HVDC for transmission of bulk power up to at least 6000 MW per bipole.

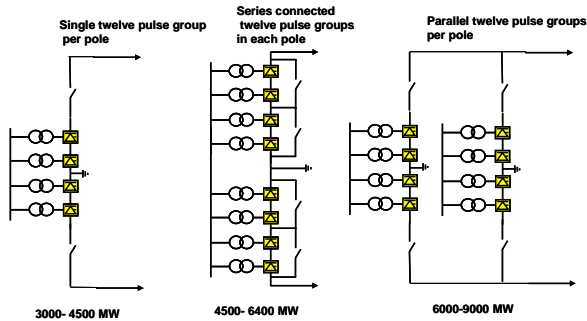
A. System aspects

DC transmission is made by converting ac to dc in a rectifier station, transmitting the power in a dc bipolar line and converting the power back into ac in an inverter station.

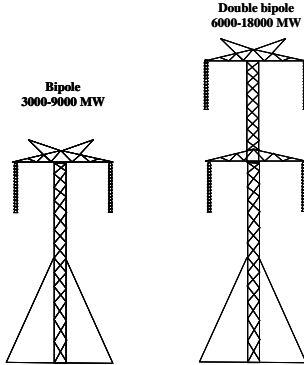
From a system point of view dc is for transmission over long distances. The rectifier and inverter stations can control current and voltage very fast and thereby control the power. The phase angle difference between the sending and receiving end is of no importance if the only connection is dc. Also asynchronous networks can be connected without causing any problems as dc has no phase angles and is not depending on the frequency. Disturbances in the sending end where generation is lost and the frequency deviates will not influence the dc transmission.

B. Configurations

For 800 kV HVDC several converter configurations are possible as can be seen below.



Also different line configurations could be considered:



With 800 kV HVDC power transfer of up to 18000 MW could be made on one single right of way.

Technical challenges

The highest voltage of HVDC today is 600 kV. The Itaipu project was commissioned more than 20 years ago and is operating with two bipoles of +/- 600 kV and transmitting

6300 MW over a distance of 800 km. 800 kV HVDC requires development of the following equipment:

- Transformers
- Transformer bushings
- Valve hall wall bushings
- Thyristor valves
- Arresters
- Voltage dividers
- DC filter capacitors
- Support insulators

Development has been going on at ABB since several years and all equipment that is exposed to 800 kV has been designed, manufactured and tested. Some examples are shown below:

1) Transformer prototype

A simplified transformer prototype has been manufactured, including all the insulation details for an 800 kV converter transformer. The initial testing of the transformer prototype so far includes :

- DC withstand 1250 kV
- AC withstand 900 kV

The tests were successfully passed.



Transformer prototype in test room

2) Transformer bushing

A prototype of the transformer bushing for the highest 6-pulse group has been produced, fig. 3. The bushing has passed all type and routine tests, including:

- DC withstand 1450 kV
- AC withstand 1050 kV



Transformer bushing testing

3) Wall bushings

Also the wall bushing design is based on the well proven design that is used for the recent installations at 500 kV. Besides the electrical requirements, the length of the wall bushing, 18 m, figure 4, has been a mechanical challenge. However, all electrical and mechanical type and routine tests have passed successfully. Also the seismic withstand has been verified by calculations. The design and manufacturing of the 800 kV wall bushing is completed, and the completed bushing is installed in the 800 kV test circuit, including:

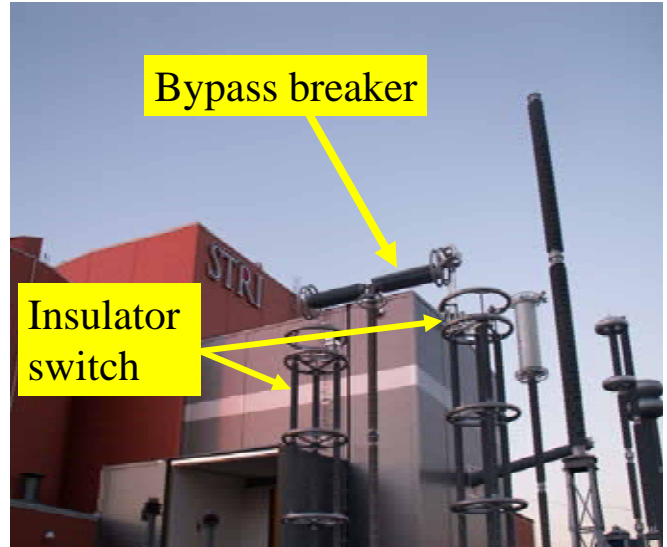
- DC withstand 1250 kV
- AC withstand 910 kV



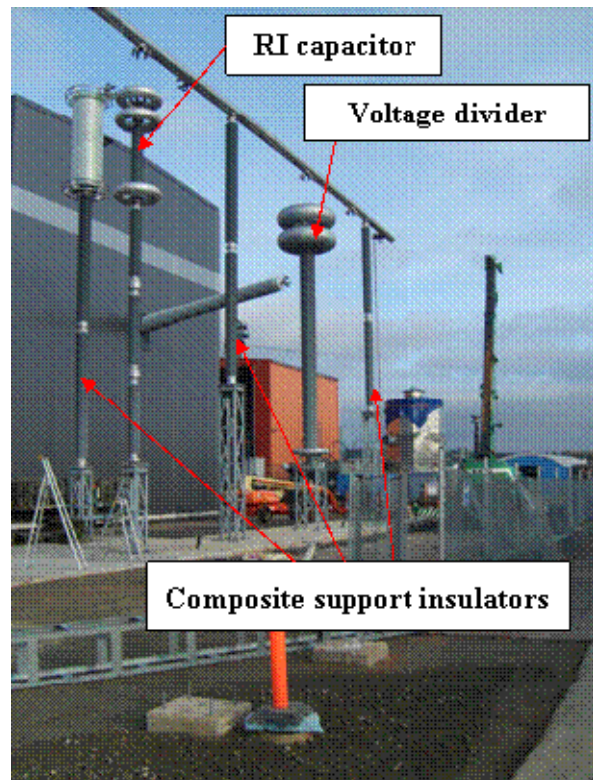
Valve hall bushing testing

4) Long term test station

As a final proof that everything works a long term test station has been built where all equipment is tested at 855 kV for at least half a year.



By-pass breaker and Disconnector installed at the 800 kV test circuit at STRI, Ludvika



RI-capacitor, voltage divider and composite support insulators installed at the 800 kV test station at STRI, Ludvika

C. Development status

The present status is that 800 kV is now fully developed and available for commercial transmissions.

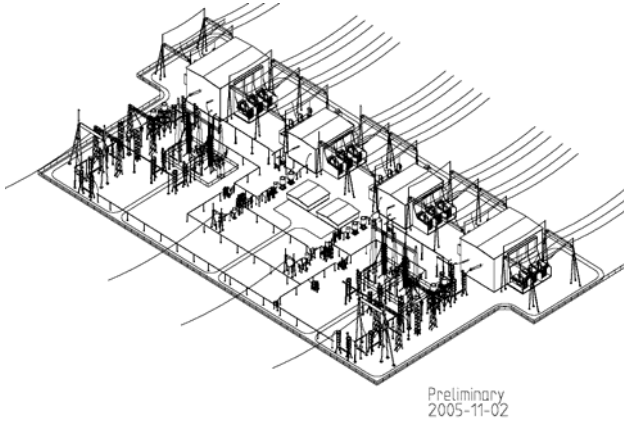
D. Station design

When designing 800 kV HVDC with a power of 6000 MW it is important to design the station so that a failure of a single

critical component results in a loss of only a fraction of the power. The figure below shows a station with four power blocks. This can be made by using the configurations:

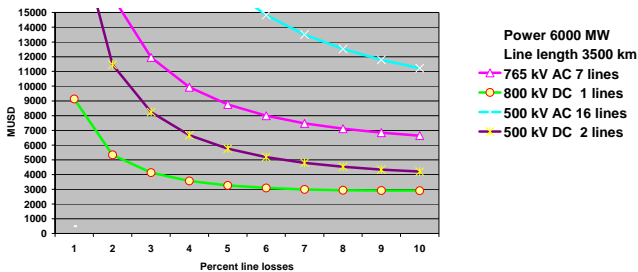
1. Two poles each consisting of two series connected groups
2. Two poles each consisting of two parallel groups

The layout of number 1 could look as below:



IV. COST OF AC AND DC

A cost comparison has been made of transmitting 6000 MW over a distance of 3500 km with ac and with dc.



The figure shows the cost of stations, lines and losses as a function of the line losses. This makes it possible to see which line loss gives the lowest total cost.

As can be seen 800 kV HVDC gives the lowest overall cost and at the lowest losses in the lines.

V. PROVIDING ON ROUTE POWER SUPPLY

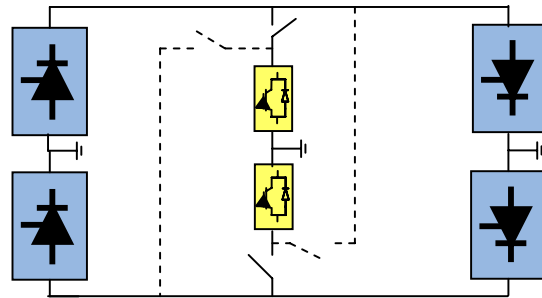
Combined ac and dc

As was mentioned above the main disadvantage with HVDC is the high cost of tapping power along the line. However, a combination of HVDC transmission in parallel with a low voltage ac network could in many cases be the optimal solution. This can give both low cost and high flexibility to supply customers along the route.

VI. HVDC TAPPING

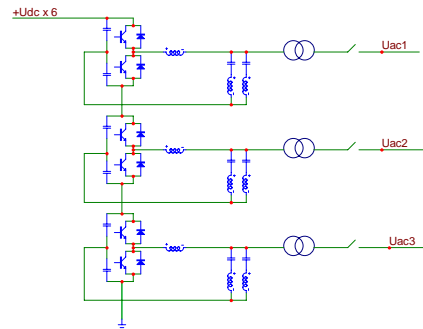
Tapping of bulk transmission HVDC has been seen as quite costly. The reason is that using tapping stations of the same type as the main transmission inverter will cost almost the same as the full size inverter. Feeding into networks without own generation will require synchronous machines.

However, by using Voltage Source Converters in the tapping stations much smaller stations can be built and the influence on the main transmission will be very small. There is no need of generation in the network as VSC converters create their own voltage.



The figure shows a VSC tapping on an HVDC transmission

The figure below shows the VSC converter. By connecting the phases in series high voltage can be achieved at low power.

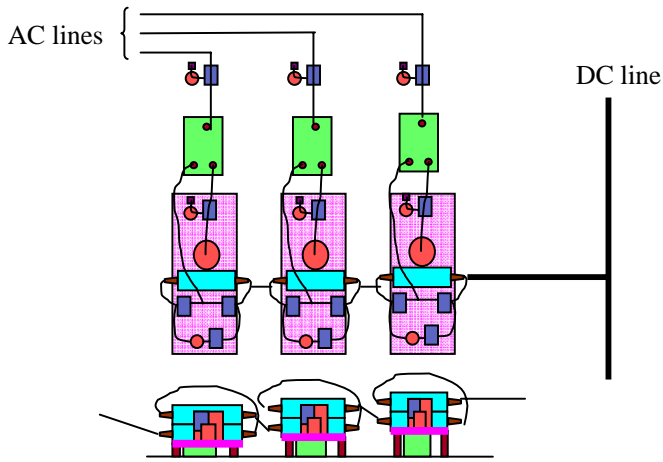


The figure shows VSC converter using series connected phases to reduce the number of semiconductors.

The table below shows the power and voltage that can be achieved by using the present standard VSC with series connected phases.

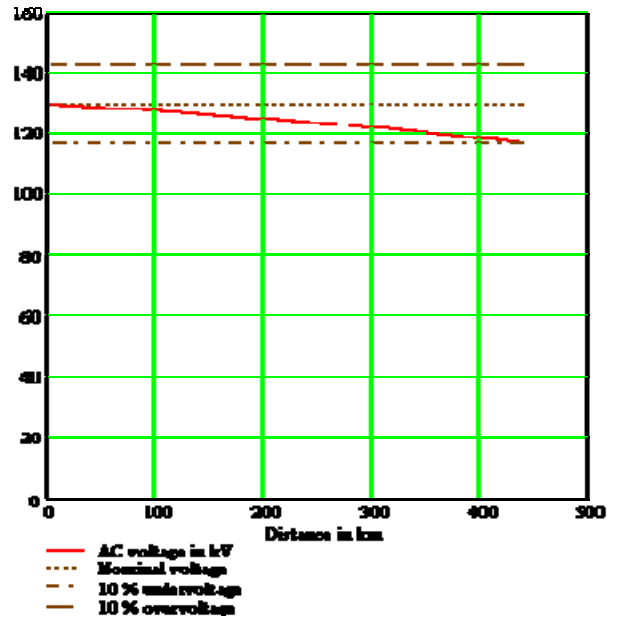
DC voltage	200 A dc current	400 A dc current	600 A dc current
+/-500 kV	2 X 100 MW	2 X 200 MW	2 X 300 MW
+/- 800 kV	2 X 160 MW	2 X 320 MW	2 X 480 MW

A preliminary layout is shown below (note that outdoor valves are proposed in order to drastically reduce the size)



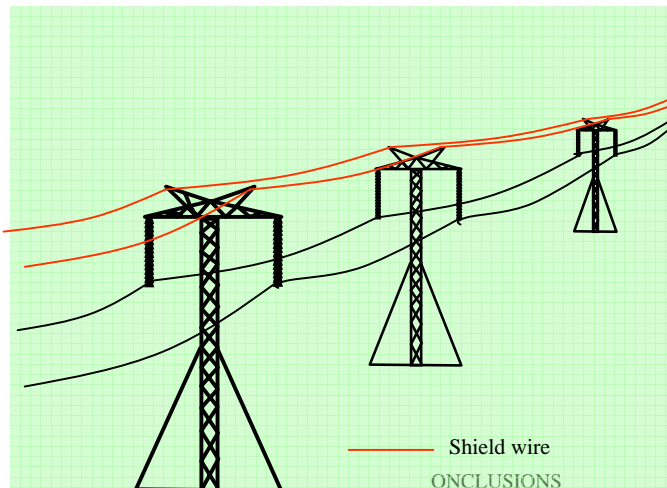
The figure above shows an arrangement where power is fed in into the line in each end via rectifiers and distributed along the line via inverters.

Assume three tapings along 3000 km line with two shield wires of aluminium with 500 mm² area. Below is shown the voltage profile of the 130 kV line up to 400 km from the tapping station.



VII. USE OF HVDC ON ISOLATED SHIELD WIRE

If less power is needed the shield wires could be insulated and VSC HVDC could be used to supply multiple smaller loads along the line at a comparatively low cost.

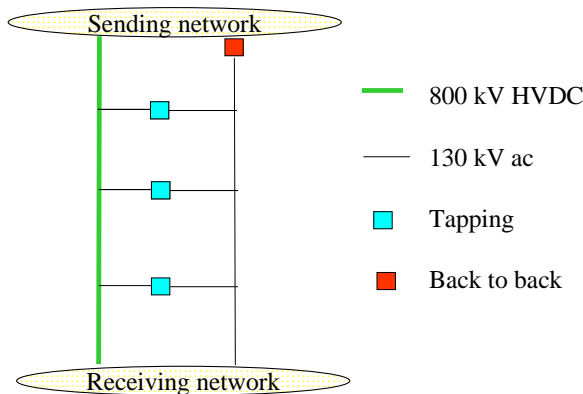


The figure shows shield wires of a bulk power HVDC bipole

If the taps are evenly distributed and with the same power in each we could get at least 120 MW anywhere along the line. In the tapping stations themselves the power is only limited by the tapping station rating.

VIII. 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. Transmission of bulk power over long distances can now be made economically in large scale using 800 kV HVDC. The biggest draw back with HVDC has been the difficulty to supply power along the route. This can be solved either by parallel ac transmission or by tapping of the HVDC with VSC converters and/or supplying power by VSC converters from isolated ground wires.



IX. REFERENCES

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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 IEEE Uno Lamm award for the development of HVDC based on voltage source converters



Andrew Williamson was born in Johannesburg, South Africa on May 26, 1966. He received a BSc in Electrical Engineering from the University of the Witwatersrand in 1987.

He worked for Eskom as an engineer in the fields of high voltage substations, power capacitors and reactive power compensation, and then for ABB in various engineering and management capacities. He is currently a Consultant to ABB South Africa in the fields of HVDC, reactive power compensation and high voltage substations.

Williamson is a professional engineer in South Africa, and a Senior Member of the South African Institute of Electrical Engineers.