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500 MW CITY CENTER INFEED WITH VOLTAGE SOURCE CONVERTER BASED HVDC

by

Björn Jacobson* **Paulo Fischer de Toledo** **Gunnar Asplund**

ABB Power Technologies AB, Ludvika, Sweden

Göran Isacsson

ABB Power Technologies Ltd., India

ABSTRACT

Urban electrical power systems with steep demand increase needs easily located solutions with short lead time from decision to transmission. Voltage source converter based technology using DC-cables for transmission, such as HVDC Light®, offers up to 500 MW per station with small footprint, ideal for infeed to city centers. Fast implementation is possible thanks to modular pre-assembled design and extruded polymer underground cables. System benefits from the VSC technology, such as independent full active and reactive power control and no added short circuit power makes it easy to apply in a heavily loaded grid. The use of VSC-HVDC transmission enables long cable distances, higher transmission capability through the polymer cables as compared to equivalent AC-cables and the possibility to remove obsolete and polluting generating plants from the city center. Step-wise expansion can be built in small or large increments. A number of different topologies are possible for single or multi-infeed, giving large freedom of design to adapt to each specific network situation.

1. INTRODUCTION

The evolving power systems of the world face enormous challenges in the areas of generation, transmission and distribution of the rapidly increasing amounts of electrical energy in demand. This paper addresses the specific problem of supplying electricity to the urban areas. The development of urban networks stands to address the issues of congestion, voltage stability, pollution, acoustical and electrical noise, short-circuit power restriction, permits and scarcity of land area for siting among others.

When more AC-circuits are added to a city center network, the short circuit power increases, especially if AC-cables are added. In extreme cases, this may lead to an upgrading need on several substations to cope with the new network situation.

The development in the past ten years of compact converters and extruded cable systems for Voltage Source Converter (VSC) based HVDC [1] has given the grid designer an extended palette of possibilities to solve the problems with city center infeed, compared to solely AC alternatives. Since the inauguration of the first installation of a VSC based HVDC system March 1997 in Hellsjön-Grängesberg, Sweden, the available power rating and the power density of the system has steadily increased thanks to incremental developments in cable system, control system and in IGBT valves, making VSC based HVDC a realistic alternative today.

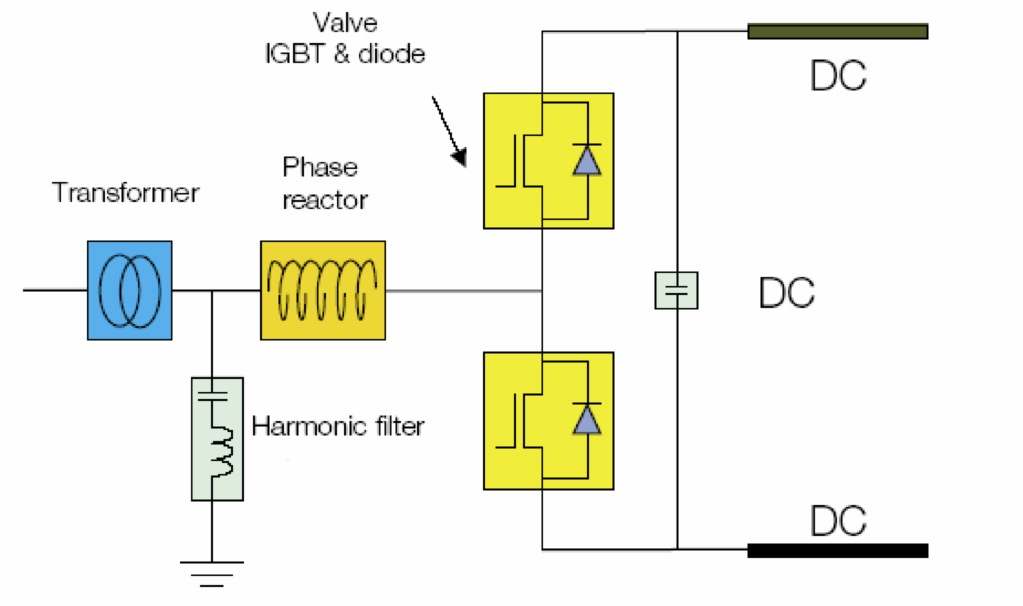

Figure 1: Simplified circuit diagram of one phase of a two-level Voltage Source Converter. The DC-capacitor is common for all three phases. The valves consist of several series connected Press Pack IGBT's.

Lead time for delivery is improving; the Cross Sound Cable system was delivered to the customer 24 months after order, 2002. The EstLink project will be handed over 19 months after signing of the contract, meaning end of 2006.

The converter valves, control system and cooling system are built in pre-assembled modules, reducing the assembly time on site to a minimum. The laying procedure and jointing of extruded dc-transmission cables is very fast compared to oil-impregnated cables.

2. POWER HANDLING

The largest VSC based HVDC system so far built is Cross Sound Cable, located close to New York City in the sound between Long Island and New Haven, Connecticut in the United States [2]. The power rating is 330 MW at a nominal dc link voltage of ±150 kV. The dc-current is maximum 1175 A.

The recent development of presspack IGBT's capable of handling up to 1780 Arms at the phase terminal [3] of the converter and capable of continuously switching at peak currents up to 4000 A at the thermal limit gives an opportunity to expand the power rating of the station by current increase, while retaining the same voltage class of the converter valves and other equipment. The area requirement of the station is not affected, consequently the power density of the HVDC converter station is increased by 50% or more. System power transmission capability, receiving end, may be between 525 - 555 MW depending on cable length and possible thermal restrictions. If more power is needed, more circuits may be added in parallel. Some of the apparent power handling may be reserved for voltage support/reactive power balancing since the VSC system can be used as a combined Statcom and HVDC. A typical diagram of the reachable area of reactive and active power handling, considering relevant limitations of voltage and current, is shown in the following graph.

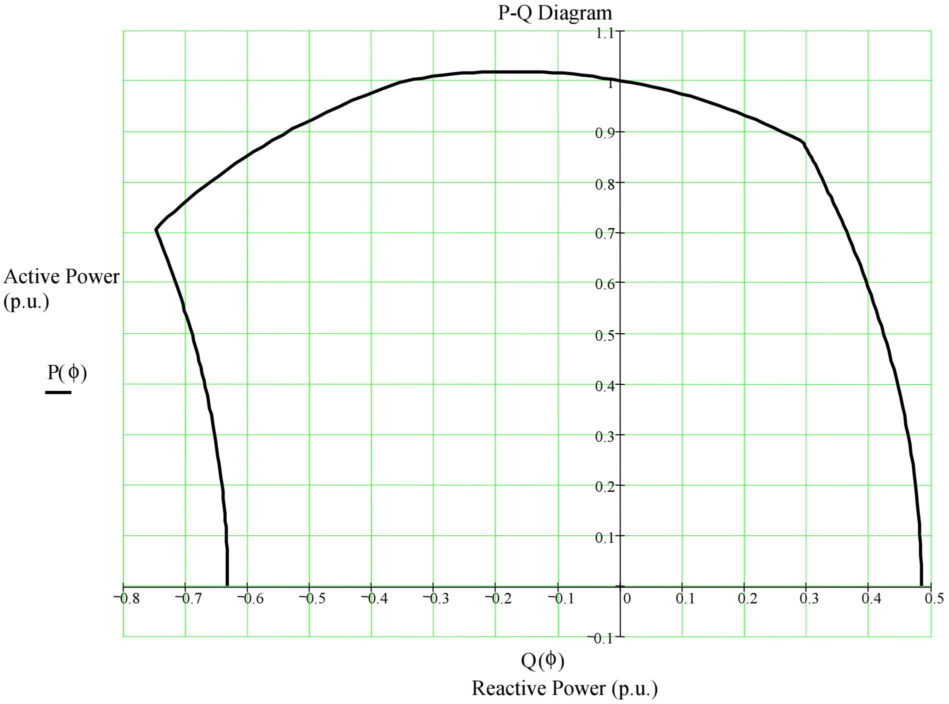

Figure 2. PQ-diagram for inverter side in Back-to-Back, in "per unit" notation. Positive reactive power is defined as reactive power from the converter to the AC-network.

The reactive and active power may be controlled independently, as long as the total power vector is within the envelope of the allowable apparent power. The controllability of the HVDC link may be used to control the power flow in the AC network, thus optimizing the load flow through the existing lines. This could be used to reduce losses, to increase the capacity and to improve stability [4], [9].

3. FOOT-PRINT OF CONVERTER STATION

To reduce the visual impact and to reduce the insulation requirements on the equipment, the station is built as an enclosed building containing all equipment except power transformer and cooling fans. The previously mentioned Cross Sound Cable project has a relatively compact design that was necessitated by the available sites.

Figure 3. Cross Sound Cable, Shoreham converter station, 330 MW, aerial view. Building dimensions are 80 x 25 x 11 m (L x W x H).

To minimize the foot-print and the total volume, the converter may be built in two or more floors.
This design principle gives a new station design suitable for high power handling on a very compact site that would be useful where land area is at a premium.
If the sending station is in an area where space requirements are not so strict, the conventional design could be used there.

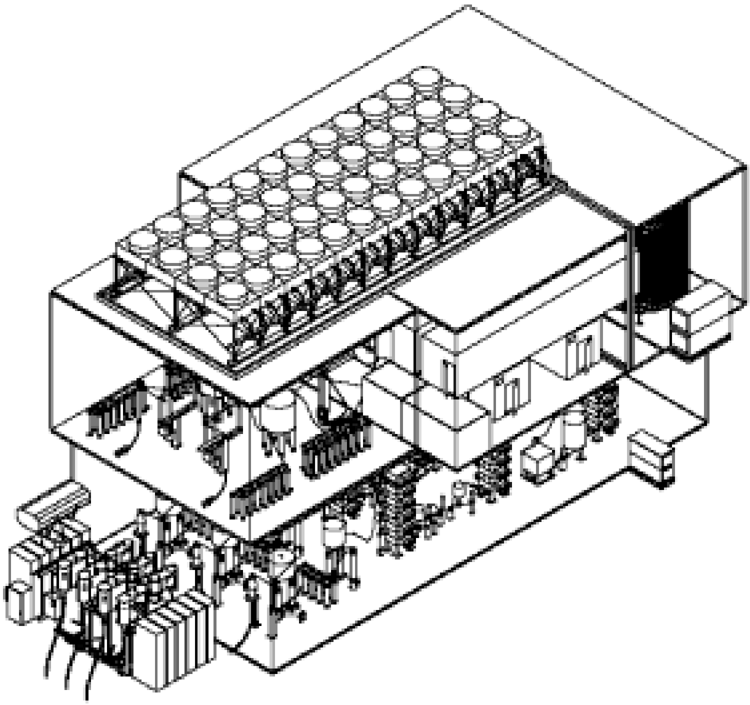

Figure 4. Possible layout of compact VSC station for 500 MW. Dimensions in this configuration are 48 x 25 x 27 m (L x W x H). Ground floor: Transformer and AC-side filters. First floor: Phase reactors, converter valves, control and cooling equipment, DC-side filters and cable terminations. Second floor: Cooling fans, which may be omitted if a nearby river or other water is available for cooling.

4. UNDERGROUNDING AND RIGHT-OF-WAY

Entering an urban or sub-urban area with a new high-voltage overhead line may in some cases be very difficult or even impossible due to scarcity of available land. Then some of the alternatives may be increased generation capacity in the city, installing AC-cables or installing DC-cables.

Increasing the generation may be less suitable due to risk for pollution and problems to feed the power station with the necessary amounts of fuel. Space requirements may also make this alternative less appealing.

The congestion problem is one of the main problems for adding transmission capacity to city centers. A new overhead line requires a much larger right-of-way than a corresponding cable, for electrical safety. For higher voltages, the audible noise from a 400 kV line, especially in warm and humid conditions, may necessitate a width of the right-of-way of up to 100 – 200 m depending on if the line passes residential or commercial areas. Another issue that is coming more and more into focus is the possible health risks related to exposure to Electro Magnetic Fields, EMF. In some countries, the exposure limits lead to a width of 360 m for a 400 kV line, when passing schools [8].

Neighboring property is likely to be devaluated by the overhead line, inversely proportional to the distance to the line, which makes the economical width of influence larger than the physical/health related limits. The effect is larger with residential than with commercial property. The effect may be significant up to 2 km from the line.

AC-cables would solve the problem of right-of-way but may be difficult to implement due to reactive power balancing problems, added short circuit power and limited transmission distance [4]. An AC-cable network has a large generation of reactive power during low-load, which gives problems with the voltage level, forcing measures such as shunt reactors to be implemented.

There is a technical limit to the useable length with AC-cables, due to the capacitive charging current. This limitation is increasingly severe at higher voltages.

The DC cable alternative gives no technical limit to the transmission distance, adds no short circuit power and actually enables improved reactive power balance due to the properties of the converters. The power handling of a given cable dimension is higher for DC than for AC due to better utilization of the insulation and lower losses in conductor and shield.

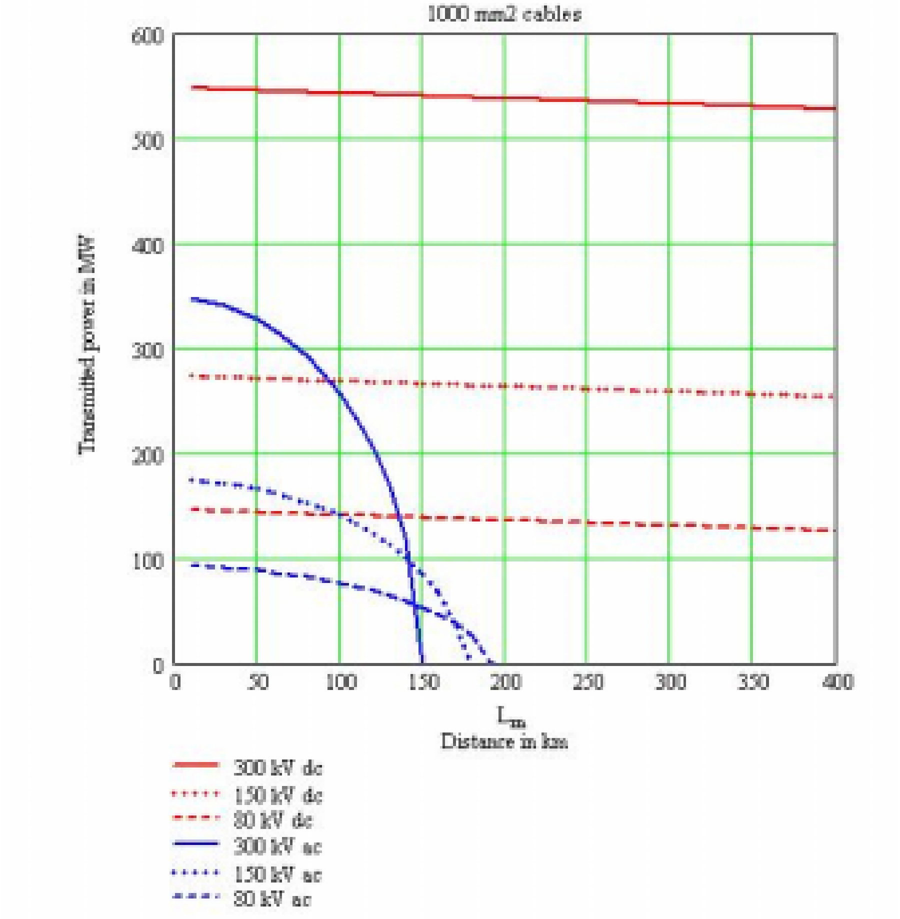

Figure 5. Principle diagram of technical distance limits for transmission through dry DC-cables and dry AC-cables. AC-cables are assumed to be ideally compensated at each end. The main limiting factor for AC-cables is capacitive charging current. This example: 1000 mm^2 aluminum conductor, no losses in shield, no losses in insulation, XLPE insulation, conductor losses50 W/m, 50 Hz line frequency. In the practical case, the reachable distance with AC-cables may be significantly shorter, especially with oil-impregnated paper insulated cables.

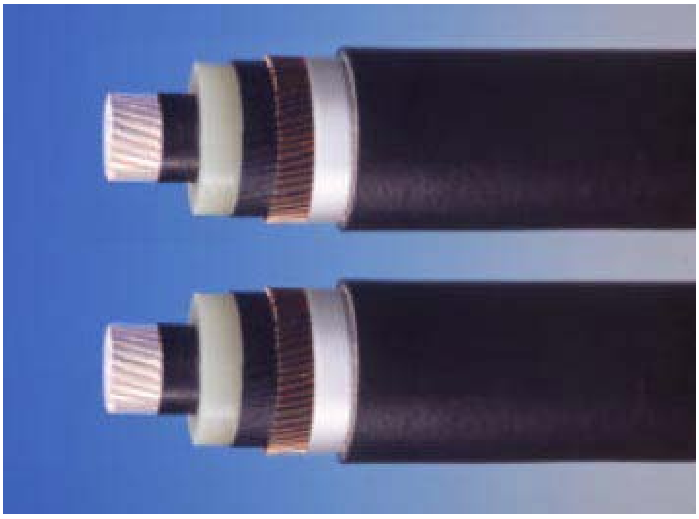

Figure 6. Pair of extruded land DC cables showing from center outward: aluminum conductor, conducting XLPE- layer, dc-insulation XLPE, ground side conductive XLPE, copper shield wires, aluminum outer wrapping and outer sealing and mechanical protection..

Today, cables for VSC based HVDC are manufactured with extruded plastic insulation, meaning that they are oil-free by design. The extruded cables are more flexible than their oil-impregnated counterparts and they are much more easily jointed using pre-fabricated joints.

Extruded cables may be plowed down into the ground by a fast semi-automatic process if the soil is suitable. The use of water ways, road banks, railroad track banks and OH-line ways are some possible alternatives for the cable route. When crossing roads, the cables may be passed through by using directional drilling.
Replacing existing OH-lines with DC-cables is an opportunity to make valuable land available for other uses.

Figure 7: Example of cable laying in a corridor already used by OH-lines. AC PEX-cable in Qatar.

The technical factor limiting long high voltage cable AC connections is the capacitive charging current that reduces the available active power transfer capability of the conductor at a given maximum power dissipation per meter. In the extreme limit, all conductor capacity is used for capacitive charging current and none is available for transmission. If the cable length is further increased beyond this limit, the thermal limits of the cable will be exceeded. In DC-cables, on the other hand, all the available conductor capacity is used for active power transfer.

5. REACTIVE POWER SUPPORT

The consumption of reactive power at the city center varies during the day. The resulting voltage fluctuations may be counteracted by using switched capacitor banks and shunt reactors or by using Static VAR Compensators. Switched passive components can however not handle dynamic phenomena from period to period, like faults and transients in the system.

An innovative approach was taken by Austin Energy in Texas, U.S., by installing a VSC based Statcom in place of an obsolete oil/gas-fuelled power plant in the city center of Austin. In this case, the dynamic reactive power support was taken over by the Statcom and the active power was taken from outside circuits. [5]

Figure 8. VSC based Statcom in Austin City Center.

HVDC with VSC converters have the dual function of controllable active and reactive power injection or consumption as needed. The system can be regulated quickly and respond to transients and other sudden changes in the network conditions [6].

The dynamic abilities of VSC based HVDC may be very useful in stabilizing the network, reducing the probability of a black-out and in the case of a network breakdown, to speed up the re-construction of the network.

6. TOPOLOGIES AND EXPANSION

The basic VSC HVDC topology is simply a converter at each end of a pair of extruded DC-transmission cables. The station feeding energy into the dc-circuit is called the rectifier, the converter taking energy from the dc-circuit and feeding it into the receiving AC-network is called the inverter. In VSC, the roles of inverter and rectifier can be interchanged between the stations at any time without delay, without breaker switching and without polarity reversal. Both stations can independently generate or consume reactive power as suitable at the connection point.

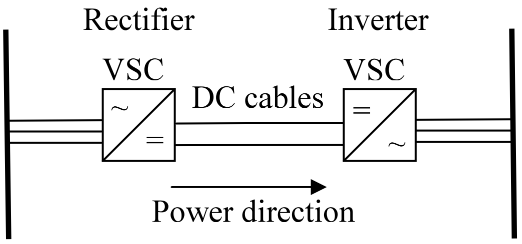

Figure 9: Basic topology of a VSC HVDC transmission with cables.

The VSC technologies facilitates the connection of several converters to a common bipolar dc-bus.
The VSC converters may be arranged as a multi-terminal HVDC-system [7]. This is easier with VSC compared to Current Source Converters, since the voltage polarity is not reversed when reversing the power direction. The VSC technology gives entirely new possibilities to enhance the city grid. A multi-terminal HVDC cable grid could be used to improve or partly replace an existing network or be used when large scale expansions of a city is foreseen. Some examples are given in the following [4].

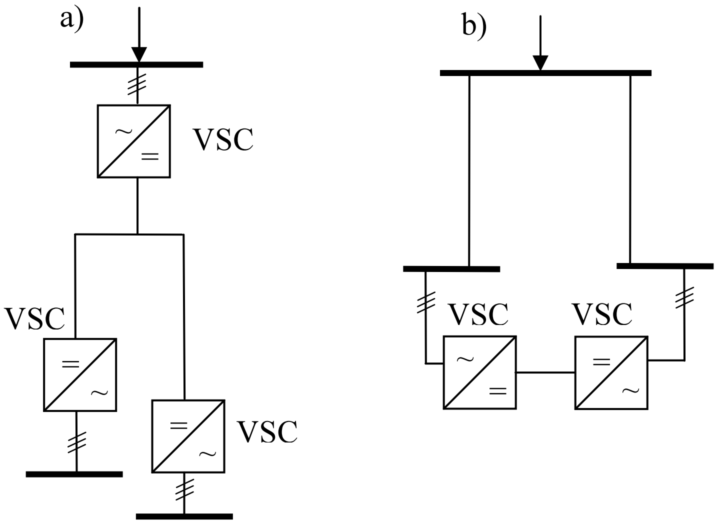

Figure 10. Examples of topologies for City Infeed using VSC based HVDC. Example b) gives increased overall reliability of supply. In both a) and b) the VSC will give increased voltage performance with reactive power control in the HVDC converters. Alternative b) is topologically equivalent to closing an open loop circuit, which with HVDC gives an extended system without increasing the short circuit power.

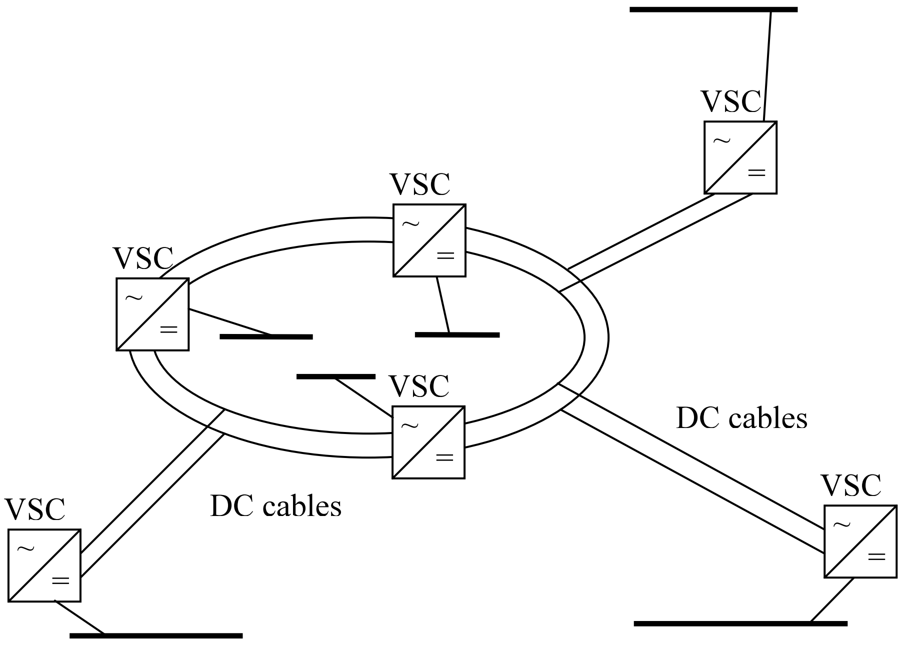

Figure 11: Vision of a modern multi-terminal HVDC network with VSC converters and extruded cables. This could be a new system or an expansion of an existing city network. In this example power is fed in radially by DC-cable and distributed through a dc-cable ring to inverter stations.

The installation cost of a cable can be a significant part of the total cable system cost or even dominate it [4]. Thus it may be suitable for a planned expansion to install cables of the final current rating at once but to install just the amount of converters necessary at each given instant.

7. CONCLUSIONS

Voltage source converter based technology using DC-cables for transmission, such as HVDC Light®, offers up to 500 MW per station with small footprint, ideal for infeed to city centers. Fast implementation is possible thanks to modular pre-assembled design and extruded polymer underground cables. System benefits from the VSC technology, such as independent full active and reactive power control and no added short circuit power makes it easy to apply in a heavily loaded grid. The use of VSC-HVDC transmission enables long cable distances, higher transmission capability through the polymer cables as compared to equivalent AC-cables and the possibility to remove obsolete and polluting generating plants from the city center. Step-wise expansion can be built in small or large increments. A number of different topologies are possible for single or multi-infeed, giving large freedom of design to adapt to each specific network situation.

8. REFERENCES

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9. AUTHORS

Björn Jacobson was born in Uppsala on September 13, 1964. He got his M.Sc. in Engineering Physics from the University of Uppsala in 1988. From 1988 to 1997 he worked for ABB Components in Ludvika, with development and insulation design of high voltage bushings. In 1997 he joined the HVDC division of ABB in Ludvika to work with development of Voltage Source Converter valves for among others Hagfors SVC Light, Gotland HVDC Light and Cross Sound Cable. 2002-2004 he headed the mechanical design departments for valves and plant design. December 2004 he became project manager for development of the next generation of HVDC Light systems.

Gunnar Asplund was born in Stockholm, Sweden on September 23, 1945. He got his M. Sc. 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 twelve years he is manager of the development of HVDC within ABB.

Göran Isacsson graduated as Master of Science in Electrical Engineering from the Technical University of Chalmers in 1981. Göran joined ASEA´s HVDC division in 1982 as a trainee. Göran has worked with every aspect of HVDC: System design, project engineering, control and protection design. He has been responsible for commissioning and site management, he has also worked as Project Manager for two large HVDC projects. During 2000 to 2004 he was responsible for design and manufacturing of transformers in Ludvika. Since 2004 he is responsible for HVDC sales in Asia apart from China**.**

Paulo Fischer de Toledo, Lic.Eng., M.Sc.E.E: Paulo Fischer de Toledo graduated at Mauá Engineering Institute in São Paulo in Electrical Engineering. He has most of the time been working in the field of HVDC (High Voltage Direct Current) for Promon Engenharia and ASEA/ABB. Since 1996 he has been working with the system development and system design group in Ludvika, Sweden for ABB. He is Project Manager. He is also at Royal Institute of Technology in Stockholm perusing for PhD degree.