HVDC

Efficient Power Transmission

ABB Power Systems
Considered internationally, ABB is by far the most experienced supplier of HVDC equipment. By the end of 1997 ABB had been selected to design and supply equipment for about two thirds of the total world HVDC transmission capacity, representing all the different HVDC applications, such as long distance overhead transmission, long cable links and power system interconnections. At the end of 1997, 38 different HVDC projects undertaken by ABB were in commercial operation, several times more than any other single supplier. In addition, three new links were under construction.

**Let our experience work for you**

ABB pioneered the HVDC field as early as 1929 and since then has set up a whole series of milestones. This extensive experience has served as a solid foundation for advanced technical development. Some examples of ABB's accomplishments:

- Commissioning of the Gotland transmission in 1954, the first commercial HVDC link in the world
- Installation of the first HVDC thyristor valve
- First water cooled thyristor valves
- Thyristor valves for 400, 500, 600 kV DC voltage
- Redundant control for increased reliability and maintainability
- Suspended valves originally developed for seismically active areas
- The first large multi-terminal project: the Quebec-New England multiterminal scheme
- 450 kV, 600 MW submarine cable for the Baltic Cable Project between Sweden and Germany
- Microcomputer based control equipment for HVDC
- Delivery of the Itaipu project with 6300 MW capacity
- First in the world to use single phase three winding transformers
- First to introduce active DC filters for outstanding filtering performance
- First with air-insulated outdoor thyristor valves for minimized civil works and reduced field activities.

Measured harmonic currents on pole-line after 12/24 th DC filters. With and without active DC filter.

The control equipment for the active DC filter is housed and delivered in a container.
Development of HVDC technology

Fig. 1. Mercury valve 50kV, 200A.
Fig. 2. Control equipment based on vacuum tubes.
Fig. 3. First thyristor valve 50kV, 200A.
Fig. 4. Control equipment based on microcomputers.
Fig. 5. Suspended thyristor valve, 150kV, 914 A.
Fig. 6. Video display Units are replacing the traditional mimic panels.
Fig. 7. Out-door thyristor valve, 275 kV, 1000 A.
WHAT IS HVDC?

HVDC stands for High Voltage Direct Current and is a well proven technique employed for power transmission.

The power is taken from one point in an AC network and converted to DC in a converter station (rectifier) and in most cases transmitted over a line or cable and converted back to AC again in another converter station (inverter) before it is injected into the receiving AC network.

The reasons behind a choice of HVDC instead of AC are in most cases numerous and complex. Each individual project will display its own set of reasons justifying the choice of HVDC. The most common arguments favouring HVDC are:

**Lower line costs**
A DC line with two conductors is more economical to build than an AC one with three. Over a certain distance, the break-even distance, the economical DC line will pay for the investment cost for the DC stations.

**Lower losses**
With HVDC we have direct voltage and direct current and thus no reactive power is transmitted. This is one of the reasons why the line losses are lower with DC than with AC. The losses in the converter terminals are approximately 1.0-1.5% of the transmitted power, which is low compared with the line losses.

**Asynchronous connection**
Sometimes it may be impossible to connect two AC networks due to stability reasons, or because they operate at different AC frequencies. In such cases the obvious solution is HVDC since it is an asynchronous connection.

**Controllability**
Today’s advanced semiconductor technology, utilized both in power thyristors and microprocessors for the control system, has yielded a substantial improve-
ABB HVDC projects around the world

- Vancouver Island Pole 1
  - Pole 1
  - 312 MW

- CU-Project
  - 1000 MW

- Chateauguay
  - 2x500 MW

- Highgate
  - 200 MW

- Konti-Skan
  - 1) 250 MW
  - 2) 300 MW

- Gotland
  - 1) 20 MW+10 MW
  - 2) 130 MW
  - 3) 130 MW

- Gezhouba-Shanghai
  - 1200 MW

- Sakuma
  - 300 MW

- Nelson River 2
  - 2000 MW

- Quebec-New England
  - 3x2000 MW +2x690 MW

- Skogerrak
  - 1) 250 MW
  - 2) 250 MW
  - 3) 440 MW

- Kontek
  - 600 MW

- Fenno-Skan
  - 500 MW

- Baltic Cable
  - 600 MW

- Vindhyachal
  - 2x250 MW

- Inter-Mountain
  - 1920 MW

- Blackwater
  - 200 MW

- Dürmrohr
  - 550 MW

- SwePol
  - 600 MW

- Cahora Bassa
  - 1930 MW

- Rhand-Delhi
  - 1500 MW

- Bakun
  - 2130 MW

- Leyte-Luzon
  - 440 MW

- Pacific Intertie
  - 1440 MW
  - Upgrading 400 MW
  - Expansion 1100 MW

- Itaipu
  - 6300 MW

- English Channel
  - 160 MW

- Sardinia-Italy
  - 200 MW

- Inga-Shaba
  - 560 MW

- Chandrapur-Padgha
  - 1500 MW

- Broken Hill
  - 40 MW

- New Zealand
  - 1) 600 MW
  - 2) 560 MW
ABB's HVDC department employs more than 250 well qualified engineers, many of them having more than 10-15 years of HVDC experience. The majority of ABB's highly trained staff are to be found at the HVDC Center in Ludvika, Sweden. Most of ABB's power transmission products such as HVDC thyristor valves, transformers, circuit breakers, surge arresters, CTs etc., are manufactured in Ludvika. The short communication lines between various system engineers and product specialists have proved to be essential in achieving optimum design of complex systems.

The HVDC simulator has always been an important tool in studying the performance of an HVDC transmission link in the AC system environment. ABB's resources in this area are unequalled in the industry. Besides the traditional analog simulator, new techniques, software and hardware, for real time digital simulation are being developed. ABB is taking an active role in this development which will make it possible to reduce set up times and to have a closer model of the real components. In addition a digital simulation can be run from a PC which will make it possible to download new cases in a matter of seconds.

These simulators are of the most advanced design; extremely flexible and equipped with sophisticated computer programs for processing of the results.

The simulator facilities are supplemented by a broad array of advanced computer programs for the study of various aspects of HVDC and power systems technology. These programs are available at all ABB HVDC Centres.

ABB has an unparalleled background in designing large, complex HVDC transmission projects, where the HVDC transmission represents a major portion of the infed to or load on the AC systems to which it is connected. These situations require careful attention to the interaction between the DC transmission and the AC networks.

The unique combination of capability and experience which ABB can offer in this respect is of great value, ensuring optimum performance in projects of a less demanding nature as well.
The station design, including the lay-out of the AC and DC switchyards, is performed using state-of-the-art CAD technique.

The design of the control system is fully computerized, using high level languages. The logic function is drawn on the screen, the program then automatically generates codes and produces the documentation.
The thyristor valves constitute the heart of a converter station. Valve technology has undergone tremendous development since the very first thyristor valve was commissioned by the former ASEA in 1967.

The most significant development has perhaps been that of the thyristor element itself. Silicon wafer sizes have increased from 5 cm² to about 90 cm² (from 25 to 125 mm diameter) and voltage ratings from about 2 kV to more than 9 kV.

ABB’s earlier generation of HVDC thyristor valves used air as the cooling medium but when the larger thyristor sizes (75-100 mm diameter) became available, water cooling proved to be the optimum choice.

ABB has always recognized the importance of extensive testing of new designs prior to their introduction on the market. Therefore each new generation of thyristor valves has been tested over long periods in commercially operating installations.

For more than 15 years ABB has used fibre optic transmission for communication of control pulses to the individual thyristors and for verification of the correct performance of each thyristor. The later generations of ABB thyristor valves are also provided with voltage protective firing for each thyristor, a feature that simplifies the valve control equipment and results in reduced thyristor failure rates.

Light triggered thyristors (LTTs) are being closely studied and the world’s first thyristor valve with light triggered, self-protected thyristors is in commercial operation as a test valve in Konti-Skan 2 since 1988.

The thyristors are assembled in modules containing voltage dividers as well as control and supervision circuits. No parallel connection of thyristors is needed to carry the total current. The thyristors, the electronics and the voltage divider components can easily be exchanged without opening the water cooling circuit.

ABB has a mechanical thyristor valve design that is especially suitable for areas with high seismic stresses. Stiff base-mounted structures are not well
suited to withstanding high seismic accelerations. The ABB patented design is suspended from the valve hall ceiling and is flexible. The suspended valve design has also proved to possess other advantages that makes it suitable also in areas with little or no seismic activity.

The behaviour of the valve structure under various seismic stresses has been carefully studied. A highly sophisticated computer model has been created to verify the design and to simulate the frequency response of the valve structure under different seismic conditions.

**Out-door valves**

ABB has set a new milestone in HVDC technology by putting into operation an out-door air insulated, water cooled HVDC thyristor valve. The outdoor valve eliminates the need for traditional valve halls and it also reduces field activities to a minimum.

The concept for this new out-door valve is to place the thyristor and reactor modules in a livetank on post insulators with all other functions placed on ground potential.

An out-door valve can be used in all normal high voltage applications, both for point to point transmission schemes and back-to-back stations. Total flexibility in designing the lay-out is achieved. The size requirements are similar to the lay-out with a traditional valve hall.

From a technical point of view an out-door valve offers advantages compared with the traditional design using valve halls. The DC operating voltage, due to the live tank design, across the bushing is only 1/4 compared to a wall bushing through a valve hall wall. Furthermore, the out-door valve lends itself to a lay-out which reduces the outage time.

No building permits will be needed for the outdoor valve and no local building codes has to be adhered to. The out-door valve is a piece of equipment which comes to the site ready for installation and commissioning.

The out-door valve at the test installation at Stenkullen converter station in the Konti-Skan 2 scheme.
ABB has always been one of the world's leading manufacturers of transformers and has a long history as a manufacturer of converter transformers.

ABB has hundreds of converter transformers installed and its accumulated service experience, amounting to about 2500 transformer years, is impressive.

The converter transformers are the largest single pieces of equipment in a converter station and are among the most costly items. Four types of design can be used:

- Three phase three winding
- Three phase two winding
- Single phase three winding
- Single phase two winding

From the electrical point of view there is no difference between the alternatives, the distinction being in the mechanical design. The decisive factors are normally transport restrictions, spare unit philosophy and lay-out considerations. ABB has experience of all the above types. In many cases, bushings that extend into the valve hall have been used.

The purpose of the transformer is to achieve galvanic separation between the DC and AC side and also to adopt the AC voltage to the DC voltage. The requirements imposed on converter transformers differ from those on normal AC transformers in two respects:

- the currents have a high harmonic content
- the valve side windings must be able to withstand direct voltage stresses in addition to AC, switching surges and lightning impulses.

The converter transformers are extremely important to the availability of HVDC transmissions due to the relatively long outage times required in case of a major transformer failure. Thus the performance requirements of the converter transformer is an important factor in the design criteria.

Single-phase three winding transformer for 402 MVA, 345 kV AC for the Quebec-New England project. The bushings of the valve windings protrude into the valve hall where they are connected to the thyristor valves. The weight is 420 tons.
SWITCHGEAR FOR RELIABLE OPERATION UNDER ALL CONDITIONS

The switchgear is an active part of the converter station. It is used for clearing faults but also to a great extent for configuration of the converter station equipment to meet different operating conditions. It may be operated frequently and must therefore fulfill stringent demands regarding reliability and maintainability.

When filter banks and shunt banks are switched in and out, high recovery voltages will occur on the AC bus. A filter breaker may be operated several times a day during normal operation in order to meet reactive power and AC filtering requirements.

On the DC side, high speed switches are used to meet dynamic performance demands during normal operation and fault conditions. Rapid isolation of the converter station or reconfiguration of the DC circuit may be necessary in order to restore operation after a disturbance.

ABB delivers the reliable switchgear that is a must when the requirements of reliable and safe operation are to be met.

AC breakers and current transformers at Radisson converter station, James Bay, Canada. Design temperature is -50°.
The control and protection equipment for HVDC has undergone dramatic improvements during the past few years. In 1978 ABB installed the first computer-based control system for the CU project.

Today's solutions are entirely based on microcomputer technology using a high-level programming language. This development has led to a substantial improvement in the controllability of the HVDC systems. These new possibilities for control of electric power are unique to the HVDC concept and are now commonly utilized to lower the total investment in the interconnected grids and increase reliability and availability.

Redundancy is used to a large extent in order to increase reliability. The redundant control system means that the majority of control equipment and protection malfunctions will not lead to outages of the HVDC transmission since instantaneous switch-over to the stand-by systems is made automatically, with no disturbance in the transmission. It also allows maintenance to be performed on the control equipment while the transmission is in full operation.

Its controllability gives the HVDC system the following advantages:
Emergency power support. If one of the AC systems experiences a disturbance such as loss of generation, resulting in a drop in frequency, then the HVDC system can provide power support to restore the frequency. This can be done in milliseconds.

Stabilization of parallel AC lines. The fast HVDC control system can be used for dynamic stabilization of interconnected AC systems operating in parallel with the DC system. The Pacific Intertie is a good example where it has been possible to increase the power transmitted on the 500 kV AC lines parallel to the DC line by approximately 400 MW through a small modulation of the DC line power.

Reactive power control. The reactive power consumption of a converter station is dependent on the control angle and the direct current level. Thus the DC link can be used for reactive power control and voltage control in the connected AC networks.

The list of HVDC advantages is a long one but the most significant difference between an AC system and an HVDC system is that the power transmitted over the DC line can be absolutely controlled as to both amount and direction at every instant.
MULTI-TERMINAL TRANSMISSION SYSTEMS USING THE SAME TECHNIQUE AS TWO TERMINAL SYSTEMS

Multi-terminal HVDC systems have been discussed for many years and several simulator and computer studies have been performed and reported on. It has been found that the technique used for two terminal transmission systems is suitable for multi-terminal schemes too. In general, there are three areas where a multi-terminal scheme requires more equipment than a two terminal system:

- master control for balancing of the current orders fed into the converters. The sum of the orders should be equal for both the rectifiers and the inverters.
- communication terminal to terminal and between the master controllers in all terminals requires more communication equipment.
- DC side switching arrangements may be more extensive, depending on different system requirements such as power reversal in one station leaving the others unchanged. HVDC breakers can be used for rapid isolation of one terminal from the DC bus, preventing one station from disrupting the whole multiterminal system.

When ABB was awarded the contract for the Quebec-New England Phase II HVDC project in 1986, this was the first large multi-terminal HVDC system ever contracted.

The power is generated at the La Grande II hydro power station in the James Bay area and converted into DC at the Radisson Converter terminal and transmitted over the multi-terminal system down to load centres in Montreal and Boston.

Phase I of the bipolar HVDC transmission consists of two converter terminals, each rated 690 MW and the interconnecting 172 km, ±450 kV DC line. One terminal, Des Cantons is located near Sherbrooke, Quebec, and the other, Comerford, near Monroe, New Hampshire. The phase I converter terminals were placed in service on October 1, 1986.

The contract for Phase II included three additional converter terminals as well as modifications to the existing ones. The line was extended north from Des Cantons over a distance of 1,100 km to the 2,250 MW Radisson terminal, located within the La Grande hydroelectric generating complex. Furthermore, the line was also extended over a distance of 214 km south from Comerford to a new 1,800 MW converter terminal at Sandy Pond, Massachusetts. This extension was taken into full commercial operation in 1991.

In 1992 another terminal was placed in service on the multi-terminal HVDC system. This terminal is rated 2,138 MW and located at Nicolet in the Montreal area.

The Comerford and Des Cantons converter stations were originally to have been integrated into the multi-terminal scheme to enable even more operating flexibility, allowing five stations to operate simultaneously. After reassessing the benefits of this additional flexibility, however, Hydro-Quebec and New England Hydro finally elected to suspend the commercial multi-terminal integration of Des Cantons and Comerford.

The operational experience is good. The system has been operated with the terminals at Radisson, Nicolet and Sandy Pond as a multi-terminal system, fulfilling the performance requirements. This shows that multi-terminal HVDC systems now is a reality, confirming ABB’s position as the leader in HVDC technology, having delivered and commissioned the first full-scale multi-terminal HVDC system in the world.

The valve hall at Radisson showing the three suspended quadruple valves, each rated 500 kV DC and having a weight of approx. 20 tons.
The Quebec – New England multiterminal HVDC project. The reasons for using HVDC are:
- long distance transmission, 1500 km between Radisson and Boston
- the Quebec and New England AC networks are not synchronized
- stabilisation of parallel 735 kV lines in Quebec

The converter station at Radisson, 2000 MW +/-500 kV DC.
ABB’s Quality Assurance Programme covers all links in the chain of HVDC project activities, from tendering to customer acceptance of the plant. The Quality system has been certified by an accredited body according to the international standard ISO 9001. This, together with long experience of HVDC projects and good technical and project management resources, ensures superior products and compliance with the customer contract.

Built-in margins, redundancies and continuous, careful monitoring throughout the entire manufacturing process are essential means to produce reliable components with the lowest possible failure rate, thus ensuring a minimum of lost time due to forced outages.

The large volume of HVDC orders received by ABB in recent years has resulted in the build-up of large, modern production and testing facilities. The thyristor valve and control equipment assembly plant in Ludvika has a production capacity, which can meet the world market need.

The high power thyristors are manufactured with the utmost accuracy and are subjected to an extremely stringent testing programme including a computerized test for all the electrical parameters of each individual thyristor.

The thyristors are then subjected to further tests at different levels: in the thyristor module, in the complete valve and in the complete installation.

The thyristor modules are production-tested as individual units and power-tested in a 6-pulse converter circuit where all possible operating conditions, both steady-state and transient, can be represented accurately.

High voltage and high power testing facilities are conveniently located adjacent to the manufacturing plants. Special DC test equipment and test circuits are available for the highest voltage and current levels. STRI; Swedish Transmission Research Institute and Switchgear High Power Laboratory are also located in Ludvika, making Ludvika the ABB High Voltage Center of the world.

In addition to the standard testing procedures applied to all individual control cubicles, ABB has developed a system where the complete control and protection system is connected to the HVDC simulator prior to delivery. Through an extensive functional test programme all system functions, control hardware and software are verified, disturbance tests are performed and all components are exposed to a thorough burn-in period during both normal operation and abnormal fault conditions.

This minimizes the final commissioning time and ensures optimum performance with the highest possible availability.

The printed circuit boards are carefully inspected and tested before they are installed in the control cubicles.
Factory system test for the Skagerrak 3 HVDC project.

Thyrister modules at the factory. Each module consists of 6 thyristors with auxiliary circuits. After completion of all tests the modules are individually packed before they are shipped to site.
COMPLETE TURNKEY PROJECTS REQUIRE EXPERIENCED MANAGEMENT

ABB possesses the technical skills, the resources and the experience necessary to assume full responsibility for complete turnkey converter station projects. ABB’s total responsibility undertaking includes all civil works and buildings. In such cases ABB utilizes competent local contractors to ensure maximum utilization of local labour and materials. In all key positions, ABB’s HVDC project teams have engineers with a broad HVDC background and experience gained in previous projects. The project management system is characterized by its method of keeping the customer in focus through short communication lines to achieve efficient handling of all matters related to the project.

Prior to contract award, a project group is formed and presented to the customer. It administers the project work such as system and station design, manufacturing, purchasing, shipping, etc. It is normal practice for people involved in preparation of the proposal to continue with the project work. This guarantees a smooth transfer from the proposal stage and a good start for the project. The project team is supported by skilled, experienced line units for execution of the work. This ensures continuous feedback to the line organization, which can then utilize this experience in future projects.

A separate Quality Assurance department ensures that quality requirements are respected throughout the course of the project; all in line with our ISO 9001 certification.

Time Based Management with a well structured project plan is one of the keys to successful completion of large projects. Computer-based planning, production and follow-up routines mean that the projects are controlled down to the smallest detail. This is a condition for dependable deliveries at the correct time.

In the early 90s ABB initiated a process mapping approach which resulted in a substantially reduced overall project schedule. Projects can now be delivered within 2 years of contract award.

ABB has been contracted for more than 38 HVDC projects since 1954 and all have been delivered on time or ahead of schedule. This represents a guarantee of professional project management.

Conceptual design
Before award of contract, a major part of the design work has already been completed during proposal preparation. All main circuit parameters are defined and conceptual drawings for buildings and lay-out have been discussed with the customer.

Detailed design
The design work done during the proposal preparation is continued and finalized. Detailed designing of all systems, civil works and switchyards is performed. For this work the most advanced CAD systems available are used, which ensures fast work of a very high quality.

<table>
<thead>
<tr>
<th>Award</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studies/specifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design/procurement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commissioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial operation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Typical project schedule.
Civil works
The civil works are by their nature the first activities on site and have a considerable impact on the total schedule. Efficient management of civil works design and construction is crucial to project success. At the site, experienced ABB personnel manage the work, but all civil contractors are local. Coordination with other activities at site is very important and a must for the successful performance of the project work.

Manufacturing
Upon completion of the design work, purchasing and manufacturing can commence. Our sub-suppliers, the majority of which are other ABB companies, are well experienced and must be approved by our QA department.

Installation
Installation work is vital to timely completion of a project. ABB is always using qualified local erectors under the supervision of experienced ABB personnel. All deviations or damages during the installation are reported to the QA department by filling out a Deviation Report. This procedure is a guarantee that the fault is being corrected and it is also a feedback to the line organisation, in order to ensure that the problem will not reoccur in future projects.

Commissioning
This is the part of the project when the complete system is tested as an entity, calling for skilled, experienced personnel to ensure a smooth and dependable commissioning process. Our commissioning engineers have extensive experience of previous, similar tasks. The tests are divided into low voltage and high voltage tests. During low voltage tests, all connections and functions in the equipment are tested, and in the high voltage tests, all operating modes as well as fault conditions are tested. Filter performance, losses and capacity are also measured during the high voltage tests.
The Itaipu Project in Brazil is by far the most impressive HVDC transmission in the world. It has a total rated power of 6300 MW and a world record voltage of +/-600 kV DC. The Itaipu HVDC transmission consists of two DC transmission lines bringing power generated at 50 Hz in the 12,600 MW hydro power plant to the 60 Hz network at Sao Paulo in the industrial centre of Brazil.

Power transmission started on bipole 1 in October 1984 with 300 kV and in July 1985 with 600 kV and on bipole 2 in July 1987. The converter stations were commissioned stepwise in order to constantly match the generating capacity build-up at the Itaipu generating station.

The converter stations Foz do Iguazu and Itauna represent a considerable step forward in HVDC technology. The two stations are unique in their combination of size and advanced technology.

The thyristor valves, of which there are a total of 192, are assembled into 48 quadruple valves. Each valve contains 96 series-connected water-cooled thyristors, which makes a total of 18,432 thyristors.

The converter transformers are of single-phase three-winding type, half of them rated 300 MVA, 600 kV DC.
Itaipu transmission system.

Foz do Iguaçu converter station, 6300 MW +/-600 kV DC.

The dam at Itaipu.
NEW ZEALAND HVDC LINK UPGRADED TO 1240 MW

The HVDC link between the South and the North Islands of New Zealand was upgraded 1992 from 600 MW to 1240 MW. The existing link, with its mercury arc valves, was modified to operate in a bipolar "hybrid" scheme together with a new thyristor converter. The first stage of the upgrade was to add the 700 MW thyristor converter and the second step was to operate the old and new equipment as a bipole rated 1240 MW.

THE INTERMOUNTAIN POWER PROJECT

The Intermountain HVDC transmission system brings power from a coal fired station in Utah to the Los Angeles area. The original rated power was 1600 MW at ±500 kV DC, but the link has been upgraded to 1920 MW. Each pole has a 1200 MW continuous and 1600 MW short term overload capacity, to minimize the impact on the power system in the event of a pole outage.

The receiving station at Adelanto is located in a seismically active area. Suspended thyristor valves are therefore used for both projects to achieve maximum security. Extremely stringent requirements have been imposed on reliability. The ABB redundant converter control system is an important factor in meeting these performance requirements. ABB had complete turnkey responsibility for the converter stations, which were commissioned in April 1986.
THE BALTIC CABLE PROJECT

The world's longest and most powerful submarine cable links the Swedish and German power systems. The capacity of the cable is 600 MW at 450 kV DC. The great advantages of the Baltic Cable are that new power production plants can be postponed and that existing production plants can be used more efficiently by the owners. Both the converter stations and the cable has been delivered by ABB. Baltic Cable was put into commercial operation 1994.

The Kruseberg converter station.

THE VINDHYACHAL BACK-TO-BACK HVDC PROJECT

A back-to-back station at Vindhyachal links the northern and western regions of India since 1989. The station permits power exchange between the regions with optimize use of hydro and thermal resources, thus effectively stabilizing the grids.

The station is rated 500 MW and consists of two 250 MW blocks. The AC voltage is 400 kV on each side and the DC voltage is 70 kV.

The contract was awarded to ABB on a turn-key basis and is the first commercial HVDC project in India.

The Vindhyachal converter station.

THE CHANDRAPUR–PADGHE HVDC BIPOLE PROJECT

An HVDC link between Chandrapur and Padghe near Bombay, that has the purpose of transmitting bulk power of 1500 MW. By 1997-98 the total generation at Chandrapur will be 2340 MW.

This power is evacuated over the 752 km ±500 kV DC long HVDC link and three existing parallel 400 kV AC lines. HVDC was selected due to lower cost and superior stability performance.

The Chandrapur-Padghe HVDC bipole link will be in commercial operation in 1998. The converter stations are supplied by ABB and BHEL.

Type test of the quadruple valve.
HVDC projects have grown in scope and size and increased demands have been imposed on the reliability and availability of transmission equipment. ABB's HVDC projects have performed extremely well in this respect and have an average energy availability with regard to forced outages in the 99.5-99.8% range, which is well above the average for other comparable projects according to the official Cigré statistics.

ABB is constantly working to reduce the forced outage rate and our goal is to bring down the number of forced outages to not more than 1 per year.

Outage time necessary for scheduled maintenance can for today's designs be limited to less than 1% per year. This owes to the fact that most of the inspection and maintenance work can be performed while the converters are in operation. Specially developed test equipment for valves and control equipment also help shorten the scheduled outage time.
PLANT DOCUMENTATION

The documentation is a vital part of any complex system. Therefore, ABB has over the years developed and refined a structured documentation system for HVDC plants, which enables the user to easily and quickly find the desired information.

Thus, the plant documentation, consisting of the operation and maintenance section, as well as extensive sections for equipment information, system descriptions, buildings and switchyards, form a complete encyclopaedia of the HVDC converter station.

Plant documentation for the Skagerrak 3 HVDC Intertie.

DEPENDABLE AFTER SALES SUPPORT

Through ABB world-wide, the HVDC after sales organization is always available to support your operating and maintenance staff.

Critical spare parts for HVDC projects are kept in stock to ensure expedient delivery when needed.

Customized training courses can be organized to further develop your capacity for trouble-shooting and maintenance of equipment and ensure the highest possible availability of your HVDC transmission.

Upgrading of old installations and retrofit of obsolete equipment are other areas where ABB can contribute to making existing HVDC transmissions more efficient.

The over-all objective is to have a continuous dialogue with our customers in order to suggest improvements and/or modifications to maximize the availability of their HVDC projects.

It is in ABB’s interest to make sure that the plants it delivers perform to the full satisfaction of the owners. Their good service record is one important reason why several customers already operating ABB HVDC stations have entrusted us with further large contracts for HVDC equipment.
ABB activities within HVDC research and development are comprehensive. The technology is being steadily developed and the capability and the performance of the components are being continuously increased. New benchmarks are being established at a faster rate than ever.

The power handled by each thyristor is increasing rapidly due to higher voltage and current capabilities. Losses are decreasing because of more efficient, fewer components and the reduction in valve complexity and size.

HVDC control systems are becoming increasingly sophisticated as microprocessors are fully utilized. Flexibility in changing control parameters allows constant optimization of the performance of the HVDC link, taking into consideration altering network conditions. Highly intelligent protective systems can minimize the impact on power systems during disturbances. Exact and economic control of the power flow can always be achieved.

The first active DC filter was developed and installed by ABB, and we expect that the development of new technologies for filtering that is taking place will result in further standardized filters on the AC and DC sides. Today’s stringent filtering requirements can be met without extensive, complicated filter circuits, thus resulting in reduced costs and shorter delivery times.

Development in project management is as important as the technical development in order to minimize the technical and economical risks and to secure on time deliveries and short project times. ABB has through its customer focus program, succeeded in drastically reducing delivery times and to improve availability of delivered HVDC systems.

ABB’s R&D programme is the key to future success in the HVDC field. The latest ABB innovations, product and system features, are always at your disposal.

Development of light-triggered self protected thyristors is on-going.
ABB Power Systems is a member of the Asea Brown Boveri Group, the world’s largest electrotechnical company.

With our resources and experience in the field of reactive power compensation and HVDC, ABB Power Systems can offer you the most complete product range on the market. We can supply you with reliable systems that fulfill your most demanding network availability requirements.

We have an accumulated outstanding experience and know-how. Our extensive development program is a guarantee that we intend to maintain our position as technical leaders. We have a staying power with a firm commitment to the power transmission business.

You can reach us through ABB offices worldwide.