HVDC 2000 – a new generation of high-voltage DC converter stations

Improved performance and robustness, shorter lead times and faster delivery, plus reduced maintenance needs, were the development goals set by ABB Power Systems for its new generation of HVDC converter stations. Dubbed 'HVDC 2000', it is based on an existing concept and proven know-how. Newly developed components combining advanced, high-speed electronics, modern overvoltage protection and state-of-the-art computer software, make HVDC 2000 an attractive alternative to conventional HVDC station design.

HVDC 2000 is the name of a new generation of high-voltage DC converter stations that utilize capacitor commutated converters, outdoor valves, automatically tuned AC filters, active DC filters, optical current transducers and deep-hole ground electrodes. In the following, a look will be taken at the design concept of the HVDC 2000 stations. The individual parts of the stations will be discussed in more detail in forthcoming articles.

Series compensation of converters

The advantages of series-compensated converters have been described often over the past 40 years. One of the main benefits of this technology, viewed from the standpoint of the AC system supply, is the reactive power consumption, which besides being low remains practically constant over the full load range. Development of the automatically tuned AC filter 'ConTune', which can be built to generate only small quantities of reactive power and at the same time still ensure good filtering, has now made series-compensated converters a practical proposition **1**.

A major difference between the new equipment and a conventional installation is that the ConTune filter can be switched in and disconnected from the circuit with the converter. In the case of a standard, line-commutated converter, it is normal to have several filter and reactor banks connected by breakers which can be opened and closed as required **2**. Another precondition for series compensation of converters is met by the new monitoring systems, which are based on high-speed microcomputers and digital signal processors.

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HVDC 2000 also contributes to a major improvement in the dynamic stability of the transmission scheme, especially when it is linked to an AC supply network having a relatively low short-circuit power rating. Better dynamic stability also helps to improve the performance of HVDC transmission over long cables. The converter is less susceptible to AC network disturbance, which reduces the probability of commutation failure. What is more, the transient overvoltages occurring during load rejection are lower, while DC as well as AC filtering is improved.

HVDC projects can be completed faster

The use of standard concepts allows HVDC 2000 projects to be completed in a shorter time. Another benefit is that the converter stations have more flexible layouts. Fewer individual parts translate into easier and faster completion of assembly work.

An HVDC 2000 station also requires less space, since the new components are more compact. As a result, site costs are reduced. Also, since they are lower in height, HVDC 2000 stations can be sited in locations where conventional converter stations have been considered to have too big an impact on the landscape in the past.

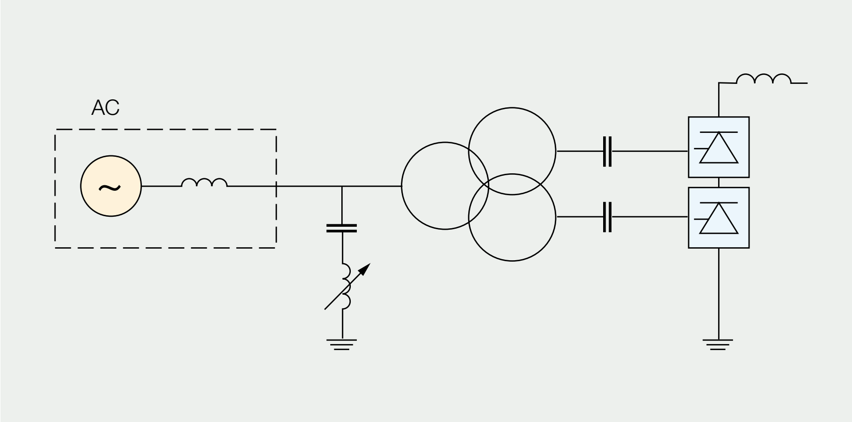
Capacitor commutated converter

The term 'capacitor commutated converter', or CCC, is used by ABB, since series capacitors connected between the valve bridge and the converter transformers influence the commutation direct. This location for the commutation capacitors was chosen as being the best of three possible positions, namely:

- On the AC side of the converter transformers

- Between the filter busbar and the converter transformers
- Between the valve bridge and the converter transformers

There were several reasons for ABB's choice of circuit. The capacitor stresses are much lower both in steady-state operation and in the event of transients, since the current flowing through the capacitor is defined by the valve with which it is connected in series. Also, the circuit eliminates both the risk of ferroresonance due to overvoltages and load increases due to high zero-sequence currents caused by earth faults in the AC system. Only small varistors are required to protect the commutation capacitors from overvoltage.



Single-line diagram of a monopolar converter station with capacitor commutated converters and the automatically tuned 'ConTune' filter **1**

Benefits of capacitor commutated converters

The use of CCCs significantly improves the dynamic stability of HVDC transmission. As a result, HVDC schemes can be connected to networks with a much lower short-circuit capacity than in the past **3**.

The commutation capacitor adds to the power system voltage, so that a somewhat higher and out-of-phase commutation voltage is experienced by the valve. The valve side sees this as an increase in commutation margin for the inverter but no major difference for the rectifier. Viewed from the line side, both the rectifier and inverter experience a reduction in the delay angle, causing the reactive power consumption to be reduced. During inverter operation, the changed commutation conditions mean that the U_d/I_d characteristic is positive **4**, resulting in a significant improvement in dynamic stability. A station with CCC is less susceptible to disturbance than conventional HVDC converter stations, and will continue operating normally even during major AC voltage disturbances. A CCC can tolerate a sudden 15 to 20 percent drop in voltage without causing commutation failure.

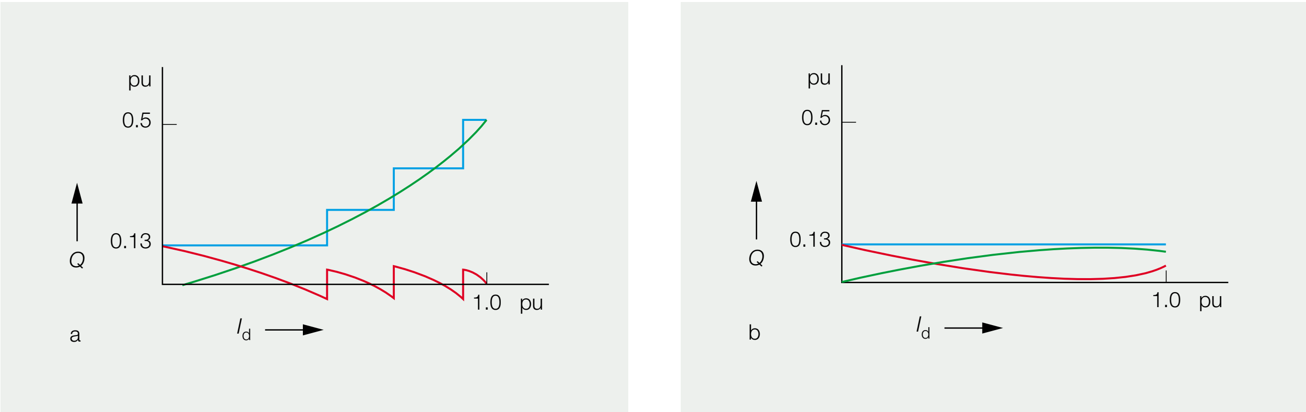
ConTune AC filter

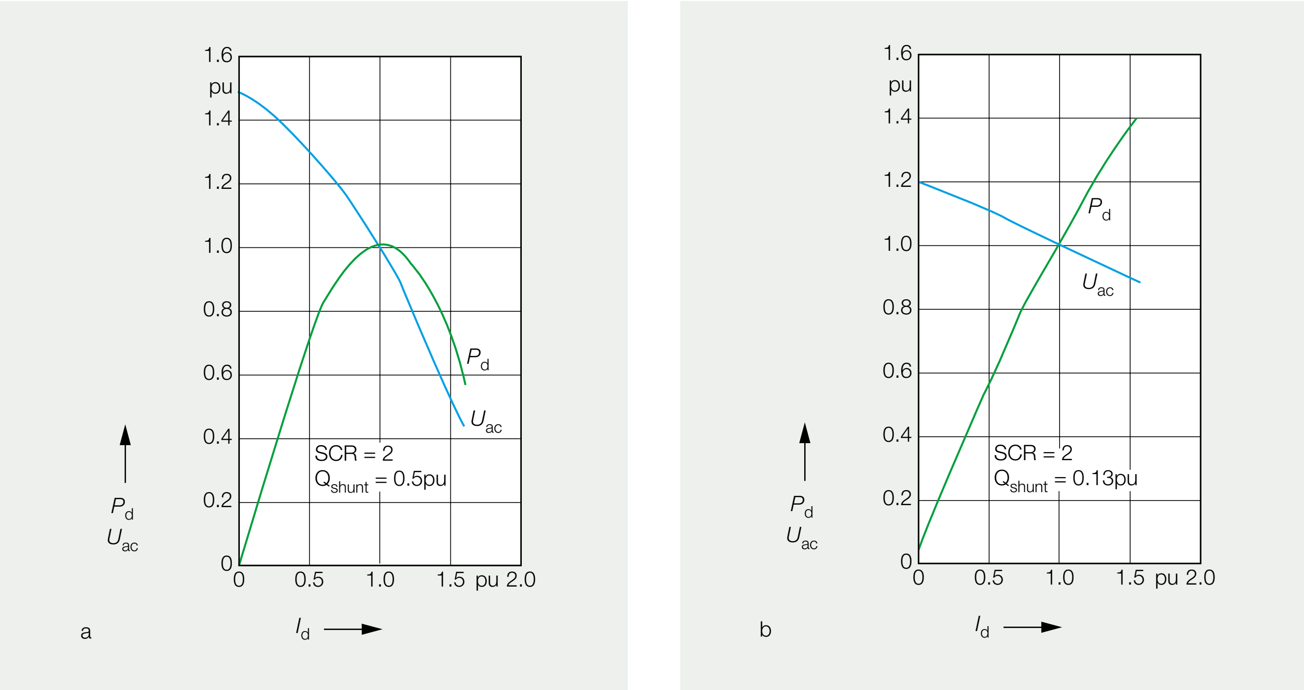
As has been said, a converter station with CCC requires only a single small harmonics filter to satisfy the filtering requirements (the size refers to the amount of reactive power generated, a large

Reactive power conditions for a conventional converter (a) and a CCC (b) **2**

Q *Reactive power*
I_d *Direct current*

Blue *Filter*
Green *Converter*
Red *Unbalance*





Maximum available power (MAP) curves for a conventional HVDC converter station (a) and a station with CCC (b) **3**

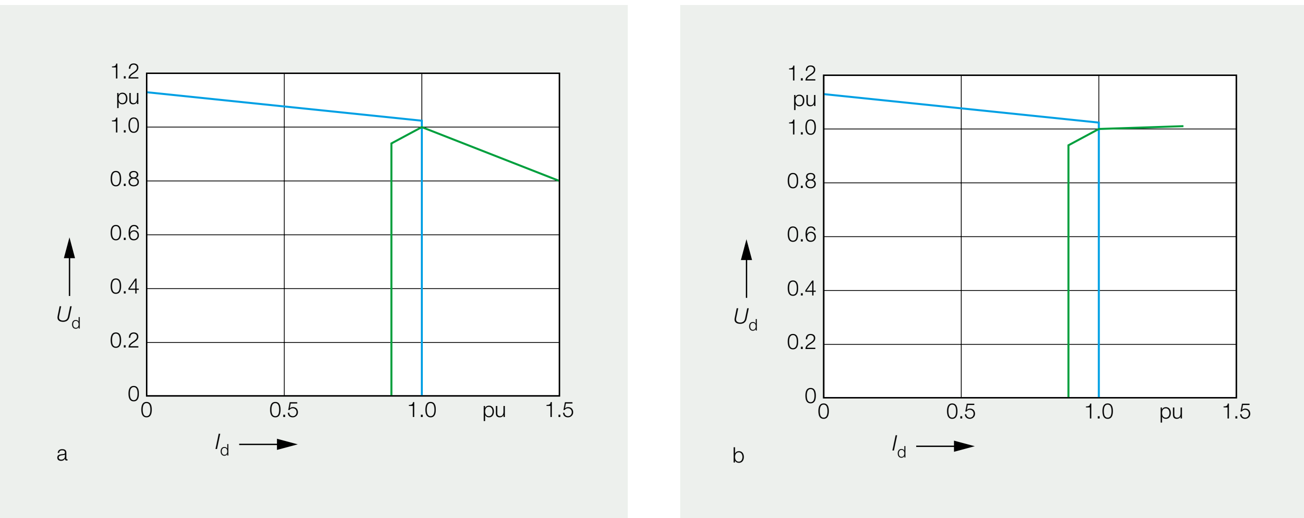
I_d	*Direct current*	*SCR*	*Short-circuit ratio*
P_d	*DC power*	Q_{shunt}	*Reactive power of shunt*
U_{ac}	*Alternating voltage*		

amount being required for a low filter impedance). ConTune, an automatically tuned filter developed by ABB, fulfils this need **5**. The tuning frequency of the filter is automatically adjusted to the frequency of the generated harmonic, allowing the filter to be designed with a high *Q*-factor. As a result, a very small filter with a low, well-defined impedance is possible **6**.

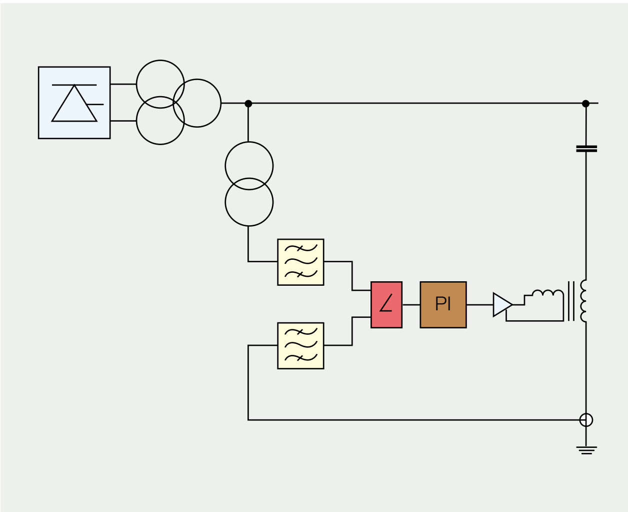
Automatic tuning is made possible by a filter reactor with variable inductance. The

U_d/I_d characteristics of a conventional HVDC converter station (a) and a station with CCC (b) **4**

I_d	*Direct current*	U_d	*Direct voltage*



Prototype ConTune AC filter in the Lindome terminal of the Konti-Skan HVDC link **5**



Basic circuit diagram of an automatically tuned filter **6**

variable inductance is achieved with an iron core which is placed inside the reactor. Around the iron core are two windings, one for the harmonics and the other for the control. The latter turn is wound perpendicular to the first one. By feeding a variable direct current into the control winding, the total magnetic flux in the reactor is influenced, thereby changing the inductance **7**. The change in inductance is controlled fast enough and with sufficient precision to ensure perfect tuning even in cases of major frequency excursions in the AC system.

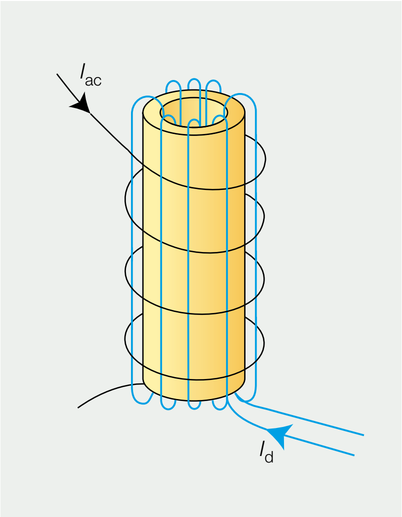
Control of the tuned AC filter is by means of current and voltage measuring equipment, plus an amplifier which regulates the output current fed into the control winding by a small 6-pulse rectifier. The inductance is controlled such that a minimum phase difference exists between the harmonic current in the filter and the harmonic voltage in the busbar.

A ConTune filter for a 12-pulse converter consists of two branches, one for the 11th and one for the 13th harmonic. Alternatively, a double-tuned ConTune filter can be used for both these harmonics. Besides the 11/13 harmonic filter, a conventional highpass filter is required for the higher-order harmonics. At the present time this filter still consists of passive components, but it will be replaced in the future by an active highpass filter of the same type as the active DC filter.

If redundancy is required, a single-phase filter bank can be connected to any one of the phases.

Reactor of the ConTune filter. The horizontally wound winding filters the harmonics. The winding wound perpendicular to it is the control winding. **7**

I_d *Direct current*
I_{ac} *Alternating current*



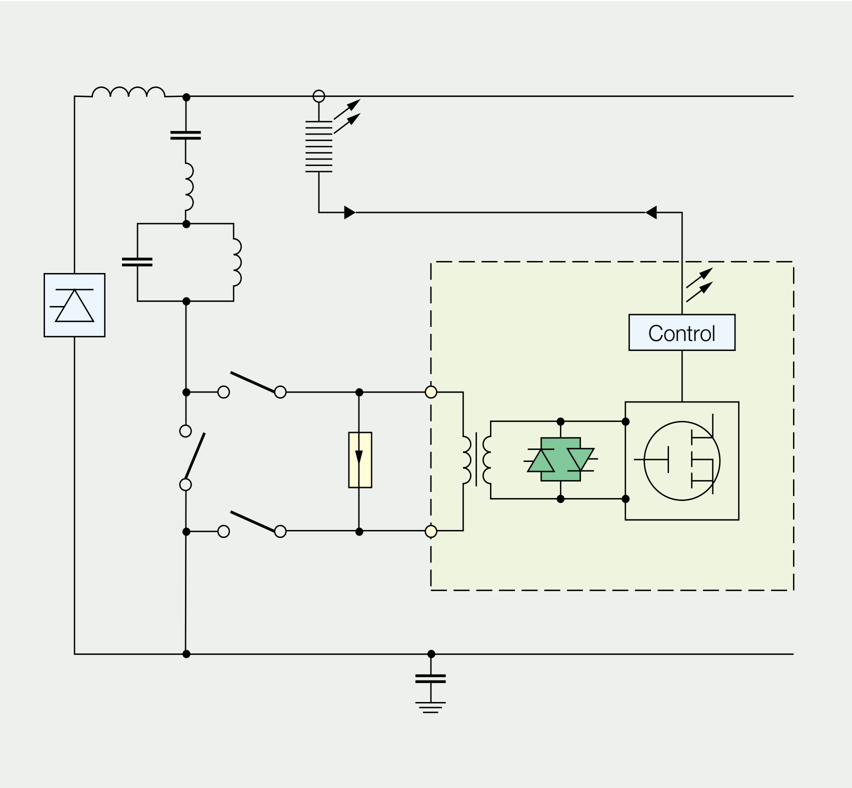
Active DC filter

In recent years, the demands made on the telephone interference levels of DC lines have become increasingly stringent, leading to not only larger but also more complex traditional passive filters. To reduce the size and complexity of the equipment, ABB has developed a compact, efficient active DC filter **8**.

The active part of the filter consists of a high-speed digital signal processor which controls a power amplifier. Its input signal is the measured harmonic current in the DC line. The amplifier generates harmonic currents which are injected into the DC circuit with such an amplitude and phase angle that they cancel the DC-side harmonics produced by the converter. The amplifier is connected at the low-voltage end of a small, passive bypass filter.

Outdoor valves

The valve hall is a dominant factor in conventional HVDC projects because of its cost and the space it takes up. Its only purpose, however, is to house the thyristor valves. It cannot easily be standardized, as it is subject to local building codes and must satisfy the architectural wishes of the customer. Also, the interface between the



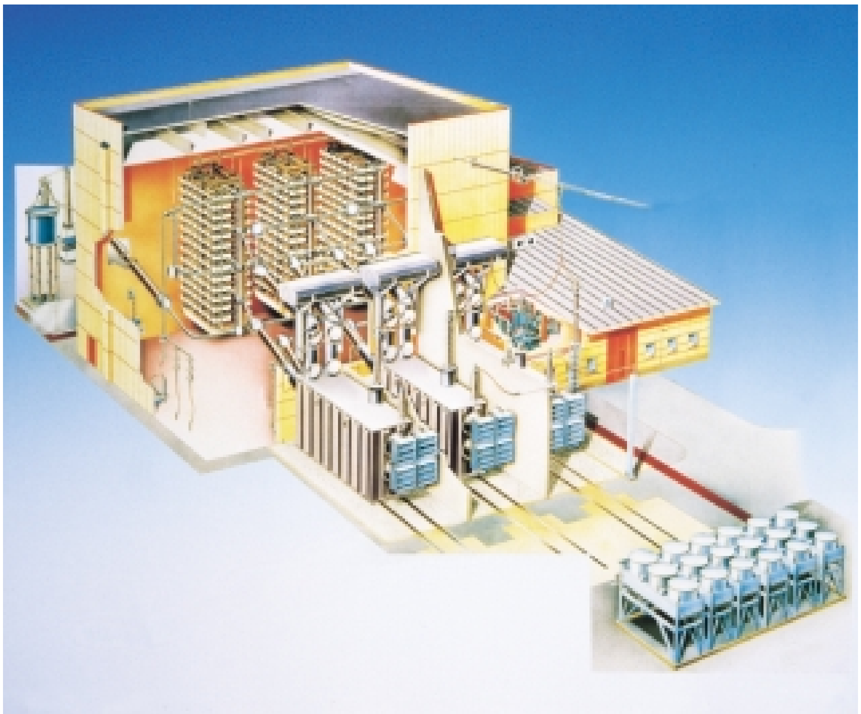
Circuit diagram of an active DC filter **8**

Advantages of HVDC 2000

HVDC 2000 offers the following advantages over conventional high-voltage DC converter stations:

- Shorter delivery times
- Fewer component parts, easier assembly
- Less space required due to more compact equipment
- More flexibility in the design of station layouts
- Reduced visual impact
- Reduced maintenance and service costs
- Improved dynamic stability
- Increased transmission reliability with long DC cables
- Reduced susceptibility to interference in the AC circuit, lowering probability of commutation failure
- Lower transient overvoltages during load rejection

Conventional valve hall belonging to the 600-MW HVDC Baltic Cable link between Sweden and Germany **9**



valve hall and the electrical equipment is complicated and has to be defined at an early stage in the project **9**.

To simplify the converter station design, ABB has developed a thyristor valve which can be installed outdoors **10**. Transport and assembly are easier, since a 500-kV outdoor valve, assembled in the factory and ready for connection, can be transported to the station site by truck on normal roads. The outdoor valves can also be more easily standardized than the indoor types. In addition, they can be delivered faster and take up less space. Stations with the outdoor valves are also easier to upgrade.

Each outdoor valve unit has a single-valve function, ie, 12 units are needed for a 12-pulse converter. The outdoor valve unit has a traditional electrical configur-

Prototype outdoor valve **10**

ation with thyristor and reactor modules, making maintenance of the new valves as easy as for ABB indoor valves.

Optical DC transducer

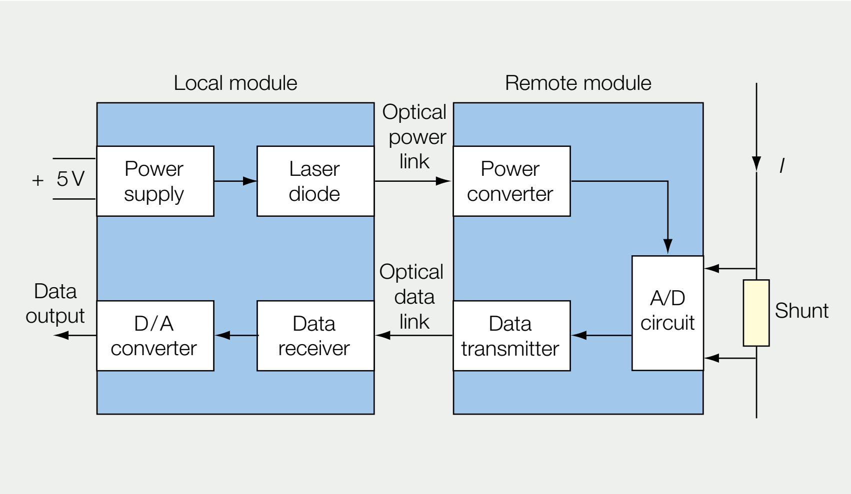
ABB has developed a simple, reliable, high-precision optical DC transducer, dubbed the DC-OCT, to replace the more complex DC measuring equipment used in conventional stations **11**. The DC-OCT's measurement principle is based on a high-precision shunt, across which the voltage is measured. The measured value is transmitted in digital form by a fiber optic wire to the detection equipment (at ground potential) in the control room. Light from a laser light source in the control room powers the A/D converter, which is at a high potential. This light is transmitted to the device over a separate fiber optic wire which can be as long as 300 m. The accuracy is better than 0.5 percent at frequencies of up to 7 kHz **12**.

Deep-hole ground electrodes

The ground electrode is an important component of every HVDC transmission scheme. In the case of submarine cable links, it is often possible to install relatively compact electrodes in or close to the sea. Traditional land electrodes, on the other hand, generally take up a large space and must be located where there is a low earth resistivity. In addition, they have to be sited several tens of kilometers away from the converter station in order to make sure that transformers or other apparatus will not be affected by the direct current.

ABB has worked together with other parties to develop a deep-hole ground electrode that helps to solve this problem. However, the geological conditions must be favourable (ie, the upper strata must have a high and the lower strata a low resistivity) **13**.

A deep-hole ground electrode can be located closer to the converter station, allowing shorter electrode lines or cables and a reduction in power losses. It is also easier to find suitable electrode sites for deep-hole ground electrodes, since they have less impact on the lanscape. A deep-



Block diagram of the optical DC transducer 11

Optical direct current transducer, DC-OCT, developed by ABB especially for HVDC converter stations 12

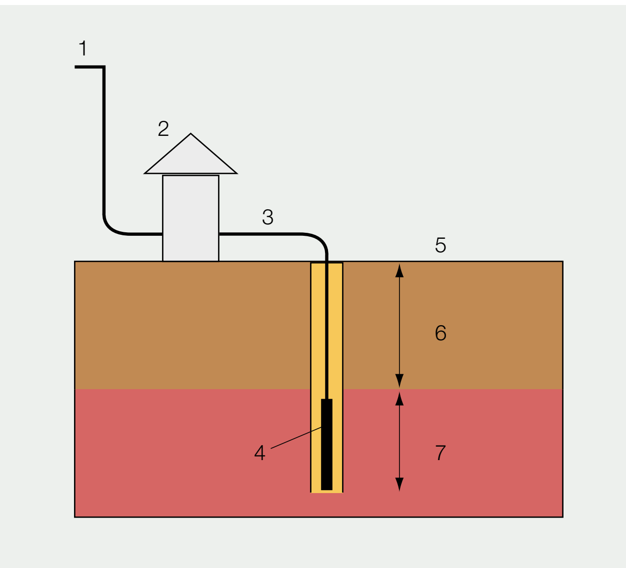
hole ground electrode may also help to facilitate monopolar HVDC transmission schemes in the future 14.

HVDC 2000 today

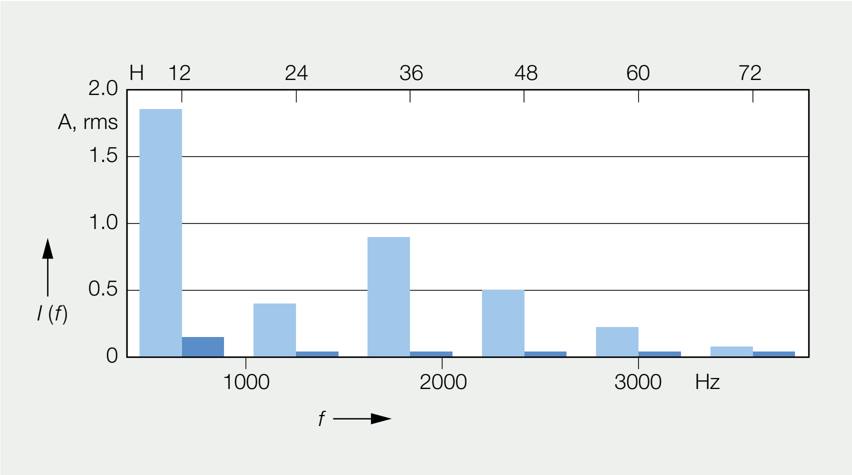
With the exception of the commutation capacitors, all of the HVDC 2000 components are either already in service or in trial operation. A prototype of the ConTune filter has been in operation in one of the converter stations of the Konti-Skan HVDC link since 1993. This trial has been so successful that other units are planned for further stations. A prototype of the

Deep-hole ground electrode 13

1 *Electrode line*
2 *Switch house*
3 *Cable*
4 *100–200 m long electrode element*
5 *Surface*
6 *500–1000 m thick earth layer with high resistivity*
7 *Low-resistivity earth layer (≈1 Ω mm²/m)*



Deep-hole electrode undergoing testing 14



How active and passive filters influence the harmonic currents **15**

Light-blue	*Passive filter only*
Dark-blue	*Active filter*
f	*Frequency*
I(f)	*Harmonic currents*
H	*Harmonics*

active DC filter was also installed in December 1991 in a converter station of the Konti-Skan 2 HVDC link, where it helped to significantly reduce the harmonic currents in the DC circuit **15**. The active DC filter [1] is already a standard feature of HVDC links having to meet rigorous DC filtering requirements. For example, it is in commercial operation in the recently commissioned Baltic Cable link between Germany and Sweden **16**, and is also being included in current deliveries.

Active DC filter in the Swedish terminal of the Baltic Cable HVDC link between Sweden and Germany **16**

A 280-kV air-insulated outdoor prototype valve has been operating successfully since July 1992 in the Swedish station of the Konti-Skan 1 transmission link. A 500-kV outdoor valve is currently under development and will be tested this year.

Optical DC transducers are in operation in several recent HVDC projects.

Early 1995 saw the start-up of trial operation of a deep-hole ground electrode at the Swedish end of the Baltic Cable HVDC transmission link.

In recent years, ABB has successfully carried out extensive testing of circuit configurations with capacitor commutated converters using a HVDC transmission simulator. Full-scale testing of the CCC is under way in ABB's thyristor valve module circuit.

Outlook for HVDC 2000

The development of a new generation of HVDC links that will further improve the competitiveness of HVDC over AC transmission is the declared goal of the HVDC 2000 project. ABB Power Systems is committed to developing smaller, less complex converter stations with fewer component parts for a reduction in operational outages and significantly reduced service and maintenance costs.

Reference

[1] **G. Asplung, W. Zhang:** Active DC filters for HVDC systems. ABB Review 6/7–95, 17–21.

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