"Classical" HVDC: still continuing to evolve

During the last 20 years, HVDC has become the dominating technology for long distance transmission of bulk power. In the 1960s and 1970s, 800 kV HVAC was introduced in several countries. But that technology has come to a halt. In contrast, HVDC technology has developed rapidly and so has confidence in it, resulting in a shift from ac to dc for bulk power transmission systems.

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Since 1990, HVDC technology development can be characterised as follows:

- Traditional "classical" HVDC technology dominates, but with improved equipment and sub-systems (eg, valves, dc-bushings, ac-filters, dc-filters etc).
- The new concept of CCC (capacitor commutated converter), within classical HVDC technology, significantly improves the performance of the traditional converter.
- Major advances in the use of VSC (voltage source converters) with insulated gate bipolar transistors (IGBTs) in place of thyristors.

In each of these three lines of development, the industry has taken maximum benefit from the dramatic pace of technological development in the computer field.

The cutting edge of today's development efforts focus on VSC technology, for example the ABB-developed HVDC Light. HVDC Light is presently deployed below about 300 MW, where it has found many interesting transmission uses in addition to HVDC applications.

It is believed that, in a few years, VSC systems such as HVDC Light will take over a large portion of the traditional HVDC market presently covered by thyristor technology.

However, for the moment, thyristor based HVDC technology still dominates the bulk power dc transmission markets and this is the "classical" technology reviewed here.

Valve developments

Thyristor areas (silicone wafer active area) have risen from 60 to 90 cm^2 in the last 10 years, with ratings now reaching 10 kV. There appears to be a tendency not to tailor-make for every project but to concentrate on standard designs covering the whole range.

Figure 1. The outdoor HVDC valves at Garabi are placed on top of each other to save space

Fire-safe material has been introduced in all structural parts of the thyristor valve. This was in response to fires that occurred over ten years ago. Even the voltage dividing capacitors are now built oil-free with solid insulation.

Some manufacturers have introduced light fired thyristors in their valves, a concept that ABB has been testing in a commercially operating project (Konti-Skan 1) since 1988. In spite of this, ABB continues with electrical triggering of HVDC valves (ETT technology). A wealth of positive experience has now been amassed with ETT and ABB cannot see any good technical or commercial reason to change over to a system that can do no more than the present system and still requires electronics at each thyristor level for protection and monitoring.

For ABB's HVDC plants with water-cooled ETT valves, commissioned during the 1980s and 1990s, only 0.025 per cent of the thyristors have failed in recent years – and only a fraction of these failures are related to the valve firing system.

In 1992, ABB placed the first air-insulated outdoor prototype valve in service. This was in the Swedish station of the Konti-Skan 1 HVDC transmission link. The test valve was very successful, and has proven the adequacy of the concept. The prototype valve has also proved to be important in the development of HVDC Light.

The Garabi HVDC back-to-back converter station of the Brazil–Argentina interconnector was the first commercial installation to be equipped with ABB's air-insulated outdoor HVDC valves (Figure 1). Each of the two 1100 MW stages is divided into two blocks of 550 MW apiece. The first stage has been in commercial operation since June 1999 and the second phase is currently entering operation.

Another project that will have outdoor valves is the 2 x 100 MW station in Rapid City, South Dakota, USA, scheduled to be in service in 2003.

Filter development

The ac and dc filters occupy a considerable portion of the converter station area (40-60 per cent). Therefore much emphasis has been put on increasing the efficiency of these components, for example, continuously tuned filters and active filters. These developments have led to a considerable reduction in the site area needed for a converter station.

ConTune filter. In 1993, the first ac ConTune prototype filter was installed in Konti-Skan 2 by ABB. In ConTune AC the tuning frequency is automatically adjusted to provide perfect tuning irrespective of network frequency excursions and filter component variations (Figure 2).

The high performance of the ConTune filter is achieved by using a filter reactor with variable inductance. The variable inductance is achieved with an iron core, which is placed inside the reactor. Around the iron core there is a control winding. By feeding a corrective direct current into the control winding, the total magnetic flux in the reactor is influenced, thereby changing the inductance, which tunes the filter to the correct frequency of the harmonic.

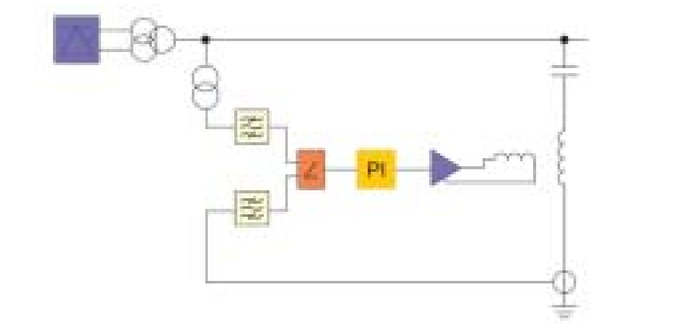

Figure 2. Principle of continuous tuning

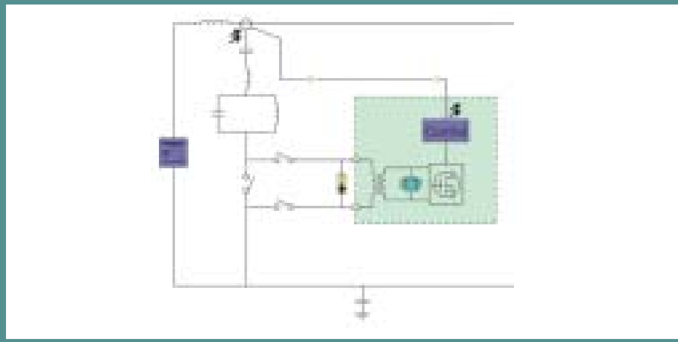

Figure 4. Circuit diagram of an active DC filter

Following the first prototype, ConTune filters are now operating in the Pacific Intertie (Figure 3), SwePol and Garabi HVDC projects.

Active filter. The principle of the active DC filter (Figure 4) is to inject a current generated by a power amplifier into the DC circuit cancelling the DC side harmonics coming from the HVDC converter. A high-speed digital signal processor controller controls the amplifier.

Following installation of the first prototype, in Konti-Skan 2 in 1991, active dc filters have been in used in the Skagerrak 3, Baltic Cable and Chandrapur–Padghe (India) projects.

In the first two installations the role of the filters is to eliminate disturbances from monopolar DC lines terminating in submarine cables, while Chandrapur–Padghe is a ±500 kV bipole, where disturbances come not only from one converter pole but also from the remote station and are induced from the other pole. This meant that more work had to be done developing the control system of the active DC filter.

Composite insulation

Composite insulators are used increasingly in converter stations, eg in transformer and wall bushings, arresters, voltage and current measuring units etc. Their use means that the risk of creepage flashovers is practically eliminated. Recently, dry-type bushings (with SF_6 insulation) have been developed. These are easier to handle and safer from a fire risk and explosion point of view.

Current measurement

Current measurement transducers now use optical fibres (OCT) for transmitting data to ground potential, which has proved to be safe with regard to creepage flashover. The DC-OCT is less complicated than the zero-flux transducer used previously. The DC-OCT meets or exceeds the performance requirements normally prescribed for direct current transducers. The accuracy is better than 0.5 per cent in the frequency range from dc up to 7kHz.

Capacity commutated converter

The most fundamental change to classical HVDC has come about with the introduction of Capacitor Commutated Converters (CCC).

Figure 3. ConTune filter installed in the Celilo station of the Pacific Intertie HVDC transmission system

The CCC alters and improves the behaviour of the traditional HVDC converter. The concept involves the connection of commutation capacitors between the valve bridge and the converter transformers (Figure 5) – a location that has been found to be advantageous for several reasons.

The use of CCC results in:

- Significantly better stability, in particular when connected to AC networks with low short circuit capacity and in transmission systems with long DC cables.
- Dependable performance in the event of AC system disturbances, with reduced risk of commutation failures.
- Lower load rejection overvoltages.
- Elimination of the need to switch AC filters or shunt capacitor banks to compensate for converter reactive power consumption.

The CCC is now an attractive concept when considered in conjunction with the development of automatically tuned AC filters (ConTune). These filters can be built to generate small quantities of reactive power but still provide good filtering. These properties match the characteristics of the CCC, which has a much-reduced need for reactive power due to the commutation capacitors.

CCC technology was used in the Garabi back-to-back project, for power exchange between Argentina and Brazil.

The 500 kV AC line from Garabi to Itá has a length of 354 km, quite challenging for operation of a converter station where there is guaranteed delivery of 1000 MW into a rather weak point. The short circuit capacity at the Garabi 60 Hz side is about 1500 MVA, dropping even lower under contingency conditions. The CCC concept made it possible to avoid building a synchronous compensator plant at Garabi.

The commutation capacitors at Garabi are shown in Figure 6.

Another HVDC project that will have CCC is the Basin Electric Power Co-operative’s 2 x 100 MW station at Rapid City, South Dakota. This will be part of the Rapid City Tie, a joint project between Basin Electric Power Co-operative and Black Hills Power. The Rapid City Tie will interconnect the power system of eastern USA with the western system. These two AC grids do not operate synchronously.

As well as increasing the capacity for HV power exchange between the two grids by 200 MW, it will also provide voltage and frequency support for disturbances in either one of the grids.

Because of the low short circuit power in the 230 kV networks that are to be connected, the CCC concept was the ideal choice.

HVDC 2000

In 1995, “HVDC 2000” was presented by ABB as the new generation of HVDC converter stations incorporating, amongst other things:

- Capacitor Commutated Converter;
- ConTune AC filter;
- active DC filter;
- outdoor HVDC valves; and
- optical direct current transducers.

The aim was:

- less equipment in the converter station (= increased availability and reliability);
- elimination of the need for large and complex valve buildings;
- reduction in area required;
- reduced visual impact;
- less need for specialised engineering for each project;
- simplified interface between high voltage equipment and civil works; and reduced lead times.

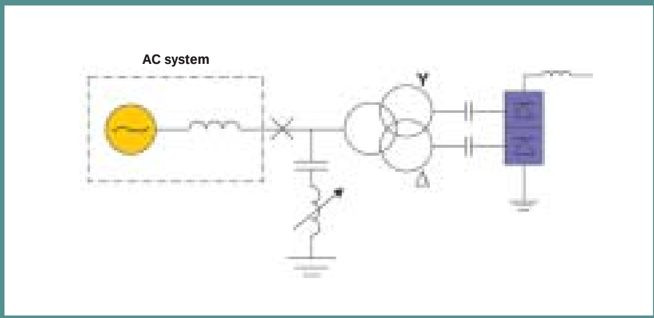

Figure 5. Commutation capacitors are connected between the valve bridge and the converter transformers

Although some specific elements of HVDC 2000 have been installed in a number of HVDC projects, the first project where the specifications permitted us to take full advantage of potential HVDC 2000 benefits is the Garabi back-to-back project connecting Argentina and Brazil.

The schedule for the completion of the first phase of this HVDC interconnection, from signing of the contract between CIEN and ABB, to commercial operation, was only 22 months. The converter valves are in modular housings, factory assembled, tested and shipped to site ready for operation (Figure 7).

The control equipment and auxiliaries were similarly factory assembled and tested, reducing the installation and commissioning time. All converter bus breakers are of the modular Compact type, with breaker, disconnects, and optical current transformer integrated in one unit. The Compact breaker can be quickly installed or removed, allowing efficient maintenance as well as facilitating future changes in substation layout due to planned expansion.

Control and protection systems

HVDC has always been at the forefront when it comes to the use of microprocessors in control and protection systems. However, it was not until the beginning of the 1990s that the increased capabilities of microprocessors allowed for any significant reduction in the number of cubicles in HVDC control systems.

Today, the most important part of ABB's MACH 2 control system, the converter firing control, is built around a host 700 MHz Pentium III dual-processor system and six high performance digital signal processors. This gives an unequalled calculation capacity (above 1 GFlop), which is used to fine-tune the performance of the converter firing control system during various system disturbances.

The fact that high performance industrial computer components are used ensures that HVDC technology can continuously benefit from the extremely rapid pace of development in the field of microprocessors, enabling control and protection systems to be always designed for the highest possible performance levels.

MACH 2 is today also used in conventional SVC, HVDC Light, SVC Light and a number of other applications.

Integrated with the MACH 2 control and protection equipment is the Station Control and Monitoring (SCM) system. Workstations (PCs) are interconnected by a local area network. The distributed system for remote I/O, for control as well as for process interfacing with the SCM system, is built up with a field bus network.

The SCM system integrates a large number of features such as:

- control of the HVDC from process images;
- sequence of event recorder;
- archiving of events;
- powerful alarm handling via list windows;
- effective user defined data filtering;
- flexible handling of both on-line and historical trends;
- on-line help functions and direct access to plant documentation;
- transient fault recorder analysis;
- remote control;
- instant access to standard applications such as e-mail, word processing, spreadsheet, Internet; and
- automatic performance report generation developed with a versatile graphical package.

Reaping the benefits

Many of the recent developments in HVDC have undoubtedly resulted in performance improvements, for example better filtering on the ac and dc sides.

The fire safe materials in the valve and more comprehensive fire detection systems have put a stop to valve hall fires.

Microprocessor development has led to major reductions in the size of control and protection equipment, to equipment which is virtually maintenance free and to better station control and monitoring tools for the operator.

Garabi paved the way to a new generation of HVDC converter station building, with no valve hall but with valves and other equipment in modular housings shipped to site ready for operation. This has led to a marked reduction in the time needed to get the installation ready for operation, enabling the owners to earn revenue sooner by transmitting power at an early date.

A look into the future

Research studies on the feasibility of having a DC system voltage of 800 kV took place as a co-operative effort between ABB and the Brazilian research institute Cepel.

It was found that 800 kV is a reliable voltage, for which suitable equipment can be made. However, presently the worldwide market appears to be showing little interest in adopting DC voltages any higher than 500-600 kV.

Independent transmission providers (ITPs) are emerging in an increasing number of countries. The majority of the ITPs are more interested in short delivery times, and in ensuring that the contractor fulfills the functional requirements, including specific requirements on reliability and availability, than they are in the details of the detailed design of the equipment.

Interestingly, CIEN, owner of the innovative and unconventional Garabi plant, the first true HVDC 2000 station, is an ITP.

We predict that the traditional utilities will have to follow the same route, leading to increased deployment of classical HVDC with the advanced features that have already been developed.

Even if we believe that classical thyristor HVDC technology will be around for a good few years yet, we predict that VSC systems such as HVDC Light will eventually take over a large portion of the market.

Figure 6. Commutation capacitors at Garabi

Figure 7. Aerial view of the central part of stage 1 of the Garabi 2 x 550 MW back-to-back station