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Recent evolution in classic HVDC

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Abstract **- Over the last 20 years, HVDC has become the dominating technology for long-distance transmission of bulk power. The use of 800 kV HVAC, which was introduced in several countries during the 1960s and 1970s, has largely come to a halt [9]. The rapid development and increased confidence in HVDC technology have encouraged the transition from AC to DC. This is apparent in China for bulk power transmissions.**

This paper will cover the classic thyristor-based HVDC technology. The newer HVDC Light™ technique, for lower powers (up to ≈350 MW), is not covered.

Keywords: AC filters, Capacitor-Commutated Converter, Control systems, DC filters, Development, Garabi, HVDC converters, HVDC systems, Power transmission, Thyristor valves

I. Introduction

Over the last ten years, HVDC systems have developed along three main lines, relative to the technology of 1990:

1. The traditional classic HVDC technology is still dominant, but with improved equipment and sub-systems (e.g. valves, DC bushings, AC filters, DC filters etc.)

2. The new circuit concept of CCC (capacitor-commutated converter) in the classic HVDC technology, that significantly improves the performance of the traditional converter.

3. The new HVDC using VSC (voltage source converters) using IGBTs in place of thyristors.

In all of the three lines of development the industry has taken maximum benefit of the dramatic development that is taking part in the part in the computer field.

To a significant extent, current development is concentrated on VSC technology (in the ABB case, the HVDC Light™), which at present is available in the lower power range (up to ≈350 MW), where it has found many interesting transmission uses besides traditional HVDC applications. It is believed that, in a few years, VSC systems such as HVDC Light™ [1]**,** will take over a large portion of the traditional HVDC market, which is at present covered by thyristor technology.

This paper deals with the recent developments of the classic, thyristor-based, HVDC technology that still dominates bulk power DC transmission.

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II. Valve development

Fig. 1 Valve hall at Zhengping in the 3000 MW Three Gorges - Changzhou HVDC Transmission

A. *Thyristor development*

Thyristor wafer area has increased from 60 to 90 cm^2 in the last ten years, and voltage ratings are now reaching 10 kV. There appears to be a tendency not to tailor-make for every project but to concentrate on a number of standard designs that cover the whole range.

B. *Fire-safe materials*

Following the fires that occurred more then ten year ago, fire-resistant materials have been introduced in all structural elements of the valve. Even the voltage-dividing capacitors are now oil-free, with solid insulation.

C. *Thyristor firing method*

Some manufacturers have introduced light-triggered 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 the extremely successful electrical firing of HVDC valves that we are using today. With the overwhelming experience record with this system, we cannot see any good technical or commercial reasons to change over to a system that can do no more than our present system and still require electronics at each thyristor level for the protection and monitoring [8].

D. Outdoor valves

In 1992, ABB placed an air-insulated outdoor prototype valve in service in the Swedish station of the Konti-Skan 1 HVDC transmission link [2]. The test valve was very successful, and has proven the adequacy of the concept. The prototype valve has also proved to be important for the development of HVDC Light™.

The Garabi HVDC back-to-back converter station [5] in the Brazil - Argentina interconnection is the first commercial plant that has been equipped with ABB's air-insulated outdoor HVDC valves. Each of the two 1100 MW phases is divided into two blocks of 550 MW each. The first phase has been in commercial operation since June 1999 [6], and the second phase went into operation in August 2002 [10].

Fig. 2 The outdoor HVDC valves at Garabi are placed on top of each other to save space.

Another project with outdoor valves is the 2 x 100 MW station in Rapid City, South Dakota, USA.

III. AC AND DC FILTER DEVELOPMENT

The AC and DC filters occupy a considerable portion of the converter station area (40-60 %). A great emphasis has been put to develop more efficient filters e g:

- active filters
- continuously tuned filters

The above-mentioned developments have enabled a considerable reduction of the size of the site area of a converter station.

A. AC filter

The first ConTune prototype filter was installed in Konti-Skan 2 in 1993. ConTune automatically adjusts the tuning frequency to provide prefect tuning, regardless of network frequency excursions or filter component variations.

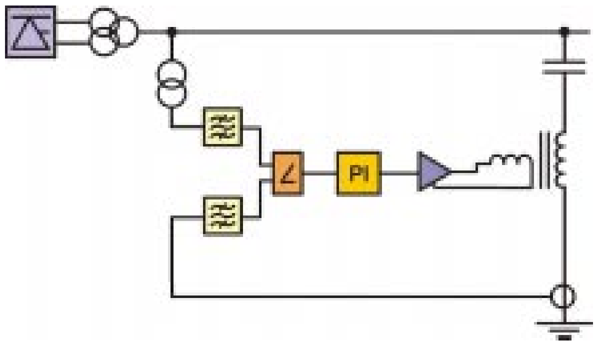

Fig. 3 Principle of continuous tuning

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

Following the first prototype, ConTune filters are operating in the Pacific Intertie, SwePol and Garabi HVDC projects.

Fig. 4 ConTune filter installed in the Celilo station of the Pacific Intertie HVDC transmission, USA.

B. DC filters

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

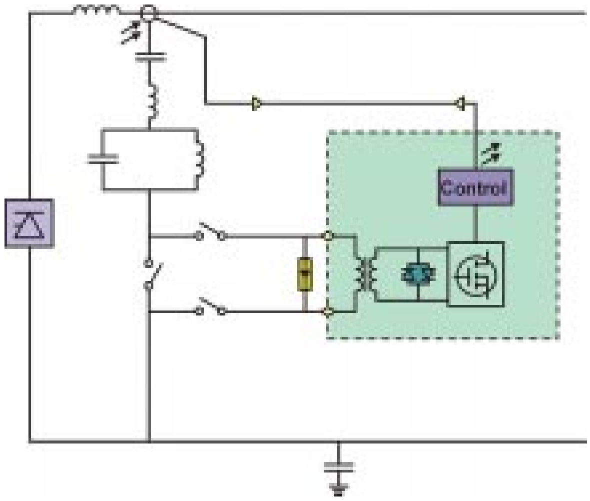

Fig. 5 Circuit diagram of an active DC filter

Following the first prototype in Konti-Skan 2 in 1991, active DC filters have been fitted in Skagerrak 3, Baltic Cable and Chandrapur – Padghe. In the first two projects, the filters eliminate disturbances from monopolar DC lines terminating in submarine cables. But Chandrapur - Padghe is a ±500 kV bipole, where disturbances come not only from one converter pole but also from the remote station and induced from the other pole. This meant that more development had to be done in the control of the active DC filter.

IV. Other Development of Main Circuit Apparatus

A. Composite insulation materials

Composite insulators are used increasingly in converter stations e.g. in transformer and wall bushings, arresters, voltage and current measuring units etc. This practically eliminates the risk of creepage flashovers. The recently developed dry-type bushings (SF_6- insulation) are easier to handle and safer from fire risk and explosion points of view.

B. DC current measurement

The current measurement transducers now use optic 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 then the earlier used zero-flux transducer. The DC-OCT meets or exceeds the performance requirements normally prescribed for direct current transducers. The accuracy is better than 0.5% in the frequency range from DC up to 7kHz.

V. Capacitor Commutated Converters (CCC)

The most fundamental change of the classic HVDC circuit was made with the 1995 introduction of Capacitor-Commutated Converters (CCC) [3]. CCC alters and improves the normal behavior of the traditional HVDC converter. In ABB's concept, commutation capacitors are connected between the valve bridge and the converter transformers. This location has been found to be advantageous for several reasons.

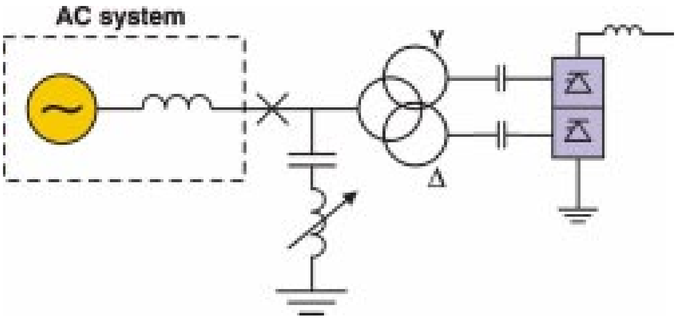

Fig. 6 Commutation capacitors are connected between the valve bridge and the converter transformers

CCC results in:

- Significantly better stability, particularly when connected to AC networks with low short-circuit capacity and in transmissions with long DC cables.
- Dependable performance in the event of AC system disturbances, with reduced risk of commutation failures.
- Lower load rejection overvoltages
- No need to switch AC filters or shunt capacitor banks to compensate for converter reactive power consumption.

CCC is now an interesting solution 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.

Fig. 7 Commutation capacitors at Garabi, Brazil

CCC technology has been used in the Garabi back-to-back project for energy exchange between Argentina and Brazil. The 500 kV AC line to 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 quite weak point. The short-circuit capacity on 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.

Another HVDC project that has CCC is the Basin Electric Power Co-operative's 2 x 100 MW station at Rapid City, South Dakota, USA. The Rapid City Tie interconnects the power system of eastern USA with the western system.

VI. HVDC 2000

In 1995, ABB presented [7] "HVDC 2000" as the new generation of HVDC converter stations, incorporating:

- Capacitor commutated converters (CCC)
- ConTune AC filters
- Active DC filters
- Outdoor HVDC valves
- Optical direct current transducers (OCT)
- Etc.

The aim was:

- Less equipment in the converter station (= increased availability and reliability)
- No need for large and complex valve buildings
- Reduced area requirements
- Reduced visual impact
- Less specialized engineering for each project
- Simplified interface between high-voltage equipment and civil works
- Reduced delivery time

Fig. 8 Overview over the central part of two blocks in the Garabi 4*550 MW back-to-back station, Brazil.

Although some specific elements of HVDC 2000 are installed in a number of HVDC projects, the Garabi back-to-back project between Argentina and Brazil is the first project where the specification has permitted us to take full advantage of the HVDC 2000 benefits.

The time 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.

The control equipment and auxiliaries are similarly factory-assembled and tested, reducing the installation and commissioning time. All converter bus breakers are of the modular Compact type, with breaker, disconnectors and optical current transformer (OCT) 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.

VII. CONTROL AND PROTECTION SYSTEMS

HVDC has always been in the forefront as regards the use of microprocessors in control and protection systems. However, it was not until the beginning of the 90s that the increased capabilities of microprocessors allowed for any significant reduction in the number of cubicles in the HVDC control system.

Today, the most important part of ABB's MACH 2™ control system, the converter firing control, is built around a 1.3 GHz Pentium III dual-processor host system and six high-performance digital signal processors. This gives an unequalled calculation capacity that 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 means that HVDC can fully utilize the extremely fast development in the field of microprocessors and always design the control and protection system for the highest possible performance.

Today, MACH 2™ is also used in conventional SVC, HVDC and SVC Light™ and a number of other applications. The Station Control and Monitoring (SCM) system is integrated with the MACH 2 control and protection equipment, and workstations (PCs) are interconnected by a local area network. A field bus network provides the distributed system for remote I/O, for control and for process interfacing with the SCM system.

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

- Control of the HVDC system from process images
- Sequence of Event Recorder (SCR)
- 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
- TFR analysis

- Remote control
- Instant access to standard applications such as e-mail, word processing, spreadsheet, Internet
- Automatic performance report generation developed with the most versatile graphical package

VIII. Benefits of Recent Technical Developments

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 resulted in a large size reduction of the control and protection equipment, in virtually maintenance-free equipment and in better SCM tools for the operator.

Garabi has paved the way to a new generation of building an HVDC converter station 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 to make the plant ready for operation, so that the owners could earn revenue from transmitting power at an early date.

IX. A Look into the Future

Research studies of 800 kV DC system voltage took place as a cooperation between ABB and the research institute Cepel in Brazil. It has been found that 800 kV is a reliable voltage for which equipment can be made. However, at present there appears to be little interest in adopting any higher DC voltage than 500 – 600 kV in the worldwide market.

Independent transmission providers (ITPs) appear in an increasing number of countries. The majority of them are more interested in a short delivery time, and in making the contractor fulfil the functional requirements, including specific requirements on reliability and availability, then they are in the details of the detailed design of the equipment. The owner, CIEN, of the unconventional Garabi plant, the first true HVDC 2000 station, is an ITP. We predict that the traditional utilities will have to follow the same way, which would lead to an increasing deployment of the HVDC developments already made.

Even if we believe that the classical thyristor technology HVDC will remain during the coming years, we predict that VSC systems such as HVDC Light™ will take over a large portion of the traditional HVDC market.

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XI. Biographies

Lennart Carlsson (born 1942) graduated with a M.Sc. in Electrical Engineering from Chalmers Institute of Technology, Gothenburg, Sweden in 1967. He joined ASEA in Västerås and worked in the Power Systems Consulting Department until 1975.

From 1975 to 1983, he was Manager of the ASEA HVDC Marketing Office in Ludvika. In 1983, he was appointed Manager of the company's HVDC Systems Engineering and Development Department. In 1986, he was appointed Project Manager for the ASEA (later ABB) deliveries of the converter stations for the 500 MW Fenno-Skan project between Sweden and Finland. After the completion of this project in 1990, he assumed responsibility for the company’s HVDC Market Development Department.

In 1997 he joined the Staff Exchange Program of the World Bank in Washington DC as Senior Power Engineer in the Bank’s Energy Sector Unit of the South Asia Region. In this position, he was assigned as Task Manager for the Bank’s US$ 230 million Power Sector Development Loan to Pakistan.

In January 1999, he returned to ABB Power Systems as Manager, Business Development. After a stroke in 1999, he is now working half time in the HVDC Marketing and Sales Division.

He has authored or co-authored some 30 papers for technical conferences and journals.

Gunnar Flisberg (born 1942) graduated with an M.Sc. in Electrical Engineering from Chalmers Institute of Technology in Gothenburg, Sweden in 1967.

He joined ASEA in Ludvika 1966 for work in the HVDC systems design office until 1974. In 1974, he was appointed Project Manager for the Inga-Shaba 500 kV HVDC Transmission Project in Zaire. In 1980, he was appointed Manager for sales of switchgear equipment for ABB.

Between 1984 and 1996, he was Manager of Sales and Marketing of HVDC Transmission converter stations. Since 1996, he has served as Manager of Business Development within ABB Power Systems.

He has received a number of patents in equipment and systems for HVDC technology. He has authored several papers for technical conferences and journals.

Lars Weimers (born 1949) graduated with a M.Sc. degree in Electrical Engineering from Chalmers University of Technology in Gothenburg, Sweden, 1975.

In 1979, he joined the HVDC department at ABB in Ludvika, Sweden. Since than, he has held several positions in the design, construction and marketing of HVDC. In 1994, he was appointed project manager for the development of Voltage Source Converters for HVDC, (HVDC Light). In 1998, he continued as the project manager for the Directlink HVDC Light project in Australia.

He is currently responsible for the marketing of HVDC systems in China.

Mr. Weimers is a member of IEEE, and has been the author or co-author of many papers for HVDC and HVDC Light.