Recent classic HVDC development

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***Abstract*-During the latest 20 years, HVDC has become the dominating technology for long distance transmission of bulk power. The use of 800 kV HVAC that was introduced in several countries during the 1960´s and 1970´s has come to a halt [9]. The rapid development and the increased confidence in the HVDC technology have caused the transition from ac to dc. This paper will cover the classic thyristor based HVDC technology. The newer HVDC Light^{TM} technique will be covered in a companion paper.**

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

I. INTRODUCTION

The development of HVDC systems in the last 10 years has three main avenues compared with the technology of 1990:

1. The traditional classic HVDC technology is still dominating 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.

Today’s development is to a significant extent directed to the VSC technology (in the ABB case the HVDC Light™) that presently is developed in the lower power range (below ≈300 MW), where it has found many interesting transmission uses besides the traditional HVDC applications. It is believed that VSC systems such as HVDC Light™ in a few years will take over a large portion of the traditional HVDC market, that presently covered by thyristor technology.

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This paper deals with the recent developments of the classic, thyristor based, HVDC technology that still is dominating the bulk power dc transmissions. A companion paper Ref. [1] treats the development of HVDC Light™.

II. VALVE DEVELOPMENT

A. Thyristor development

The thyristor area has gone up from 60 to 90 cm^2 in the last 10 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 some standard designs that covers the whole range.

B. Fire safe materials

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

C. Thyristor firing method

Some manufacturers have introduced light fired thyristors in their valves, a concept that ABB is 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 is in commercial operation since June 1999 [6] and the second phase will go in operation in 2002.

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

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

In 1993 the first ConTune prototype filter was installed in Konti-Skan 2. In ConTune AC the tuning frequency is automatically adjusted to provide prefect tuning irrespective of network frequency excursions and filter component variations.

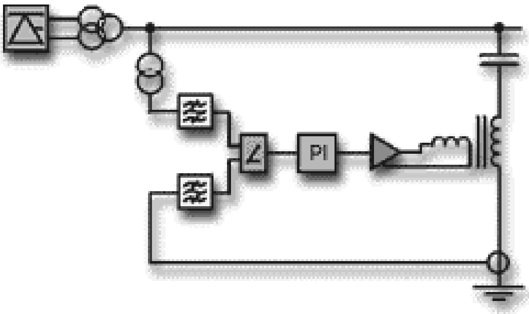

Fig. 2 Principle of continuos tuning

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.

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

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

B. DC filter

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.

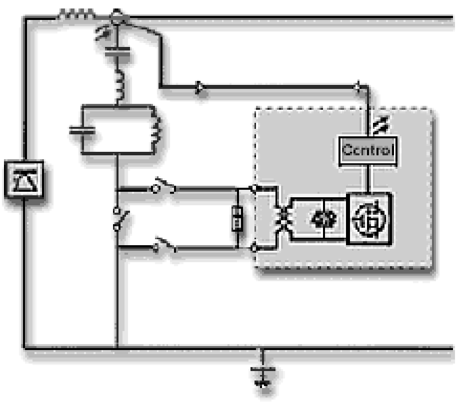

Fig. 4 Circuit diagram of active DC filter

Following the first prototype in Konti-Skan 2 in 1991, active DC filters have been in Skagerrak 3, Baltic Cable and Chandrapur – Padghe. In the first two projects the filters are to 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 material

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

B. DC current measurement

The current measurement transducer 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 CONVERTER (CCC)

The most fundamental change of the classic HVDC circuit was made with the 1995 introduction of Capacitor Commutated Converters (CCC) [3]. The CCC alters and improves the normal behaviour 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.

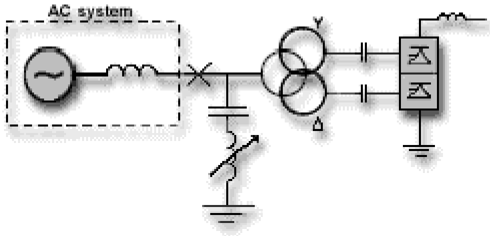

Fig. 5 Commutation capacitors are connected between the valve bridge and the converter transformers

CCC results in:

- Significantly better stability, in particular 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.

The 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.

The 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 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.

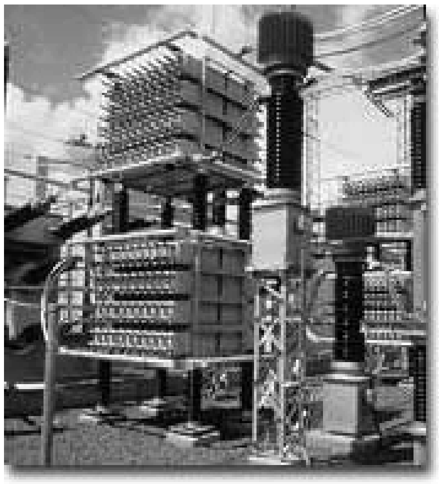

Fig. 6 Commutation capacitors at Garabi.

VI. HVDC 2000

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

- Capacitor commutated converter (CCC)
- ConTune AC filter
- Active DC filter
- Outdoor HVDC valves
- Optical direct current transducer (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 specialised engineering for each project
- Simplified interface between high voltage equipment and civil works
- Reduced delivery time

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

Fig. 7 Overview over the central part of stage 1 of the Garabi 2*550 MW back-to-back station.

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, disconnects, 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 the control and protection systems. However it was not until the beginning of the 90s that the increased capabilities of the 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 host 700 MHz Pentium III dual-processor system and six high performance digital signal processors. This gives an unequalled calculation capacity (above 1 GFlops) 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 assures 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.
MACH 2™ is today also used in conventional SVC, HVDC and 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 by 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 (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 Obtained by the Recent Technical Development

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 the valve hall fires.

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

Garabi has paved the way to a new generation of building a HVDC converter station with no valve hall but with valves and other equipment in modular housings shipped to site ready for operation. This has lead 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, presently 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

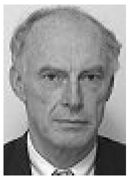
Lennart Carlsson (born 1942) graduated with a M.Sc. in Electrical Engineering from the Chalmers Institute of Technology, Gothenburg, Sweden in 1967. He joined ASEA in Västerås and worked in the Power Systems Consulting Department in until 1975.

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 of the company's HVDC Market Development Department.

In 1997 he joined the Staff Exchange Program of the World Bank in Washington DC as Sr. 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 230 Million US$ Power Sector Development Loan to Pakistan.

In January 1999 he returned to ABB Power Systems as Manager, Business Development. After a cerebral hemorrhage in September 1999 that resulted in aphasia and in his right arm and hand having an impaired function, he is now working half time in the Marketing and Sales of the HVDC Division.

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



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

He joined ASEA in Ludvika 1966 for work in 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 certain patents in equipment and systems for HVDC technology. He has authored several papers for technical conferences and journals.