Power Electronics Based Controllers for HVDC and FACTS: An Overview

P.V.Chopade and D.G.Bharadwaj

ABSTRACT

Power electronics based controllers, built on solid state silicon switches, offer control of the power grid with the speed and precision of a microprocessor, but at a power level of 500 million times higher. They allow utilities to direct power along specific corridors, aligning the physical flow of power with commercial transactions. In a multi terminal system, HVDC can also be connected at several points with the surrounding three-phase network. This paper throws light on some of the major aspects in Power System network leading to the following areas:

Planning, modeling, and economics of power electronics based controllers

Technology development and field demonstration of power electronics based controllers, innovative concepts and new power semiconductor switching devices

Diagnostics and operation and maintenance of power electronics based controllers

Education, information, and knowledge-sharing about power electronics based controllers, in-service installations, installations under development, new concepts, and future research and developments.

Keywords: Power Electronics Based Controllers, FACTS, HVDC

1. INTRODUCTION

Around the middle of the 20th century, transmission systems were designed for simple power transactions within limited service territories. Deregulation in the 21st century is bringing far more complex transactions over vast distances, demanding a different approach to managing power flows and transfers. Anticipating this need, The Electric Power Research Institute, USA (EPRI) pioneered development and demonstration of power electronics based transmission controllers, known as Flexible AC Transmission System (FACTS) controllers, bringing them from infancy to commercial readiness in several forms. This family of controllers, built on solid state silicon switches, offers control of the power grid with the speed and precision of a microprocessor, but at a power level of 500 million times higher. Power electronic based controllers (PEBC) allow utilities to direct power along specific corridors, aligning the physical flow of power with commercial transactions.

With an increasing demand on energy and the construction of large generation units, typically built at remote locations from the load centers, the technology has changed from DC to AC. Power to be transmitted, voltage levels and transmission distances have increased. DC transmission and FACTS have been developed to a viable technique with high power ratings since the 60s. As a multi terminal system, High Voltage DC network can also be connected at several points with the surrounding three-phase network.

The development of Electric Power Industry follows closely the increase of the demand on electrical energy [1, 7]. Main driving factors for energy consumption are listed in Fig. 1. In the early years of power system developments this increase was extremely fast, even in industrialized countries, with doubling of energy consumption each 10 years. Such a fast increase is nowadays still present in the emerging countries, especially in Far-East. In the industrialized countries the increase is, however, only about 1 to 2 % per year with an estimated doubling of the demand in 30 to 50 years.

In the next 20 years, power consumption in developing and emerging countries is expected to more than double, whereas in industrialized countries, it will increase only by about 40 %. Fast development and further extension of power systems can therefore be expected mainly in the areas of developing and emerging countries. However, because of a lack of available investments, the development of transmission systems in these countries does not follow the increase in power demand. Hence, there is a gap between transmission capacity and actual power demand, which leads to technical problems in the overloaded transmission systems

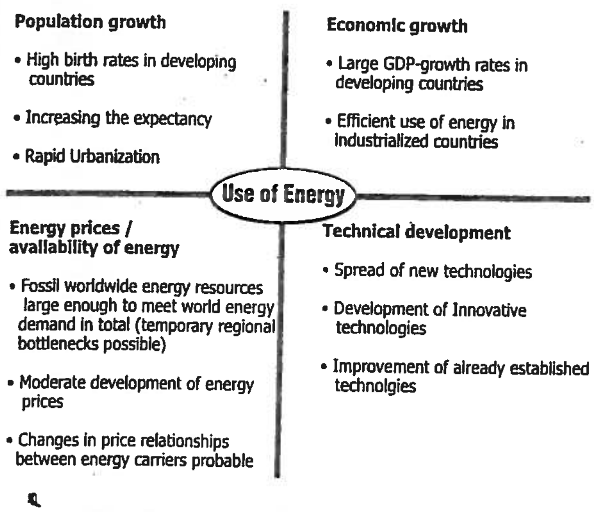


Fig. 1: Main driving Factors for Energy Consumption

Interconnection of separated grids in the developed countries can solve some of these problems, however, when the interconnections are heavily loaded due to an increasing power exchange, the reliability and availability of the transmission will be reduced.

In large AC Systems with long distance transmission and synchronous interconnections, technical problems can be expected [9, 17, 21, 24], which are summarized in Fig. 2. Main problems occur regarding load flow, system oscillations and inter-area oscillations. If systems have a large geographic extension and have to transmit large power over long distances, additional voltage and stability problems can arise. System problems listed in Fig. 2 can be improved by use of power electronic components, ref. to the next section

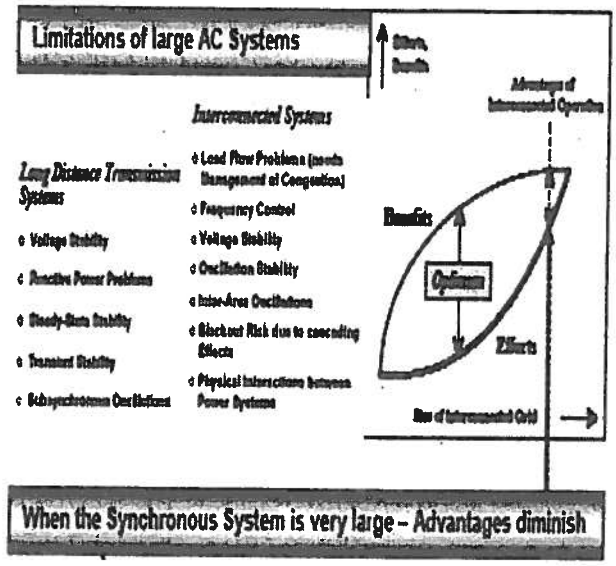


Fig. 2: Large AC Systems - Benefits versus Efforts

1.1 Use of HVDC and FACTS for Transmission of Power

In the second half of the past century, High Voltage DC Transmission (HVDC) was introduced, offering new dimensions for long distance transmission. This development started with the transmission of power in an order of magnitude of a few hundred MW and was continuously increased to transmission ratings up to 3 - 4 GW over long distances by just one bipolar line. By these developments, HVDC became a mature and reliable technology. Almost 50 GW HVDC transmission capacities have been installed worldwide up till now (Fig.3). Transmission distances over 1,000 to 2,000 km or even more are possible with overhead lines. Transmission of power up to 600 - 800 MW over distances of about 300 km has already been realized using submarine cable, and cable transmission lengths of up to 1300 km are in the planning stage.

To interconnect systems operating with different frequencies, back-to-back (B2B) schemes have been applied [6]. As a multi terminal system, HVDC can also interconnect at several locations in the surrounding AC network.

Flexible AC Transmission Systems (FACTS), based on power electronics have been developed to improve the performance of long distance AC transmission [1, 5]. Later, the technology has been extended to the devices which can also control power flow [8, 12]. Excellent operating experiences are available world-wide and also FACTS technology has become mature and reliable.

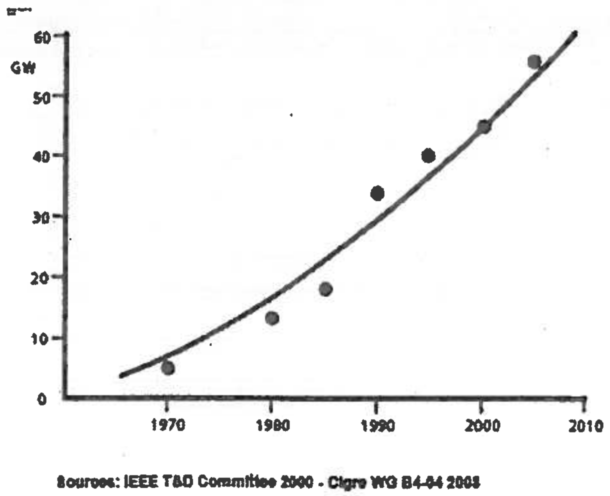


Fig. 3: Worldwide installed Capacity of HVDC Links

The main idea of FACTS and HVDC can be explained by the basic equation for transmission in Fig. 4. Power transmitted between two nodes in the systems depends on voltages at both ends of the interconnection, the impedance of the line and the angle difference between the systems. Different FACTS devices can actively influence one ore more of these parameters and control the power flow through the interconnection. Fig. 5 shows the principal configurations of FACTS devices. Main shunt connected FACTS application is the Static Var Compensator (SVC) with line-commutated thyristor technology. A further development is the static synchronous compensator (STATCOM) using voltage source converters. Both devices provide fast voltage control, reactive power control and power oscillation damping features. As an option, SVC can control unbalanced system voltages.

For long AC lines, series compensation is used for reducing the transmission angle, thus providing stability enhancement. The simplest form of series compensation is the Fixed Series Compensation (FSC). Thyristor Controlled Series Compensation (TCSC) is used if fast control of the line impedance is required to adjust the load flow or for damping of power oscillations.

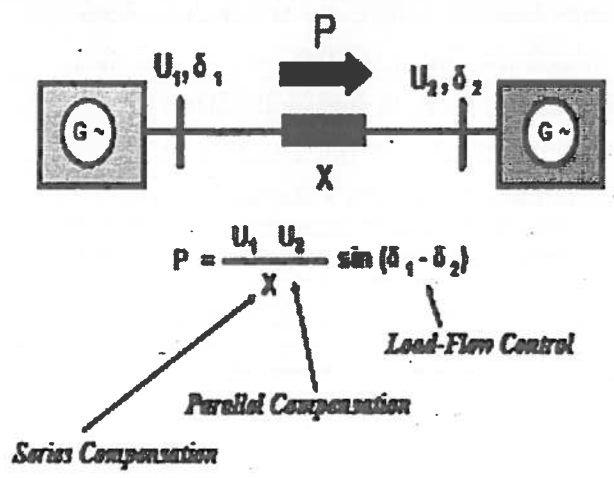


Fig. 4: The Use of Power Electronics for Power Transmission

- SVC - Static Var Compensator (Standard for Parallel Compensation)
- STATCOM - Static Synchr. Compensator (Fast SVC, Flicker Compensation)
- FSC - Fixed Series Compensation
- TCSC - Thyristor Controlled Series Compensation
- GPFC - Grid Power Flow Controller (FACTS-B2B)
- UPFC - Unified Power Flow Controller

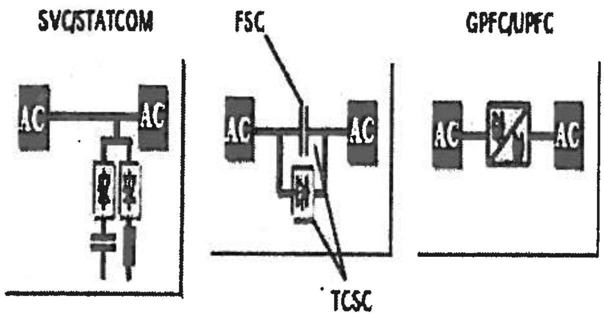


Fig. 5: Basic Configurations of FACTS Devices

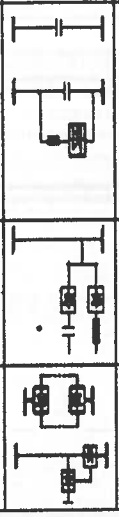
Special FACTS devices are the Unified Power Flow Controller (UPFC) and Grid Power Flow Controller (GPFC). UPFC combines a shunt connected STATCOM with a series connected STATCOM, which can exchange energy via a coupling capacitor. GPFC is a DC back-to-back link, which is designed for power and fast voltage control at both terminals [10]. In this way, GPFC is a "FACTS Back-to-Back", which is less complex than the UPFC at lower costs.

For most applications in AC transmission systems and for network interconnections, SVC, FSC, TCSC and GPFC are fully sufficient to match the essential requirements of the grid. STATCOM and UPFC are tailored solutions for special needs. FACTS devices consist of power electronic components and conventional equipment which can be combined in different configurations. It is therefore relatively easy to develop new devices to meet extended system requirements. Such recent developments are the Thyristor Protected Series Compensation (TPSC) [13, 14] and the Short-Circuit Current Limiter (SCCL) [11]), both innovative solutions using high power thyristor technology.

Fig. 6 summarizes the impact of FACTS and HVDC on load flow, stability and voltage quality when using different devices. Evaluation is based on large number of studies and experiences from projects.

A large number of different FACTS and HVDC have been put into the operation either as commercial projects or prototypes. Static Var Compensation (SVC) is mainly used to control the system voltage. There are hundreds of these devices in operation world-wide. Since decades, it has been a well developed technology and the demand on SVC is increasing further. Fixed series compensation is widely used to improve the stability in long distance transmissions. A huge number of these applications are in operation. If system conditions are more complex, Thyristor Controlled Series Compensation is used. TCSC has already been applied in different projects for load-flow control, stability improvement and to damp oscillations in interconnected systems.

The market of FACTS equipment for load-flow control is expected to develop faster in the near future, as a result of the liberalization and deregulation in the power industry. The market in the HVDC field is also progressing fast. A large number of high power long distance transmission schemes using either overhead lines or submarine cables, as well as back-to back(B2B) projects have been put into operation or are in the stage of installation.



Principle	Devices	Scheme	Impact on System Performance		
			Load Flow	Stability	Voltage Quality
Variation of the Line Impedance: Series Compensation	PSC (Fixed Series Compensation)		•	•••	•
	TPSC (Thyristor Protected Series Compensation)		•	•••	•
	TCSC (Thyristor Controlled Series Compensation)		••	•••	•
Voltage Control: Shunt Compensation	SVC (Static Var Compensator)		o	••	•••
	STATCOM (Static Synchronous Compensator)		o	••	•••
Load-Flow Control	HVDC (B2B/GPFC, LDT)		•••	•••	••
	UPFC (Unified Power Flow Controller)		•••	•••	•••

Influence: *

o low or no
• small
•• medium
••• strong

* Based on Studies & practical Experience

Fig. 6: Use of Power Electronics in High-Voltage Systems "Ranking" of the Controllers

1.2 ROLE OF POWER ELECTRONICS BASED CONTROLLERS

Power electronicsbased controllers provide immense value by:

Increasing the capacity of existing transmission network by as much as 50% by allowing energy companies to direct power along specific corridors, meaning that the physical flow of power can be aligned with the commercial transactions;

Eliminating or relieving power bottlenecks, which will result in extending the market reach of competitive generation;

Eliminating the need for new construction, which reduces capital expenditures, allows rapid payback of capital, and in many cases, eliminates the need to site new line, a growing problem; and

Maintaining power grid reliability by optimally directing power flow and providing wide-area voltage support, a benefit that is increasingly important as the grid is stressed to its limits.

This project set is expected to provide a number of benefits:

On the transmission grid, benefits include increased power transfer capability, power management flexibility and controllability. In operation terms, this translates into a robust transmission grid capable of withstanding contingencies. On distribution grid, this capability solves power quality problems, such as voltage dips and sags, voltage flicker, and harmonics. In economic terms, benefits include more transactions, less construction, reduced capital expenditure, rapid payback of capital, and in many cases, an alternative to growing difficulty of installing new transmission lines.

Project work will support planners in identifying the most viable solution, both technically and economically, for increasing transmission capacity and improving system stability.

A new operator training simulator will help operators maximize the use of the power electronicsbased controllers. The operator will be able to determine the right control set points for maximizing the power transfer capability of the transmission grid and maintaining a specific grid voltage profile.

Based on the ability to control different system parameters such as voltage, impedance and angle between the system voltages, FACTS can ensure reliable operation of AC transmission up to extremely long distances. If the AC systems are linked at different locations, power loop-flows can occur dependent on the changing conditions in both networks and in case of outages of lines. Fig. 7 gives an example how FACTS (in this case UPFC or GPFC as Power-Flow Controller) can direct power flow across the interconnection between two systems. In case that power should be transmitted through a meshed system, undesired load flow occur which loads other parts of the system. This can lead to bottlenecks in the system. In such cases FACTS and HVDC could help to improve the situation.

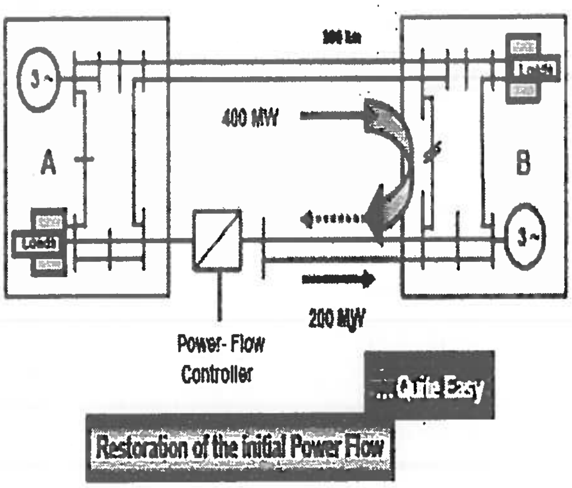


Fig. 7 : Avoidance of Loop-Flows with Power-Flow Controller (B2B/GPFC or UPFC)

Power electronics based controllers can increase the capacity of existing transmission network by allowing energy companies to direct power along specific corridors, aligning the physical flow of power with the commercial transactions. In many instances, power electronicsbased controllers can increase power transfer capability by up to 50% while maintaining transmission system security and stability.

The "long-term" benefits of these controllers include

Increased transmission capacity, through controllability and power management flexibility, and

Increased robustness of transmission grid, when exposed to major disturbances and faults.

The short-term benefits are: improved reliability, lowered cost, and expanded functionality of the in service power electronics based controllers.

The objectives of this study are as follows:

Implementation and field demonstration of power electronicsbased controllers using emerging power semiconductor switches

Introduction of innovative design concepts

Enhanced versatility, reliability, and functionality of existing power electronicsbased controllers

1 SIMULATION RESULTS OF SOME CASE STUDIES [15] [16]

PSCAD/EMTDC Software is used for Simulation of 500 Kv, 1000 km long distance AC Transmission system. Simulation results are shown in Fig 8..

Fig. 7 highlights, how problems with inter-area oscillations have been solved in the Brazilian System. There, the situation is even more critical because of a very long transmission distance between the interconnected systems: a 1000 km 500 kV AC interconnection between North and South systems has been realized. In the interconnection two TCSC devices have been installed at both ends of the line which damp the inherent oscillations that occur between the systems. Additionally, 5 FSC have been necessary to reduce the transmission angle.

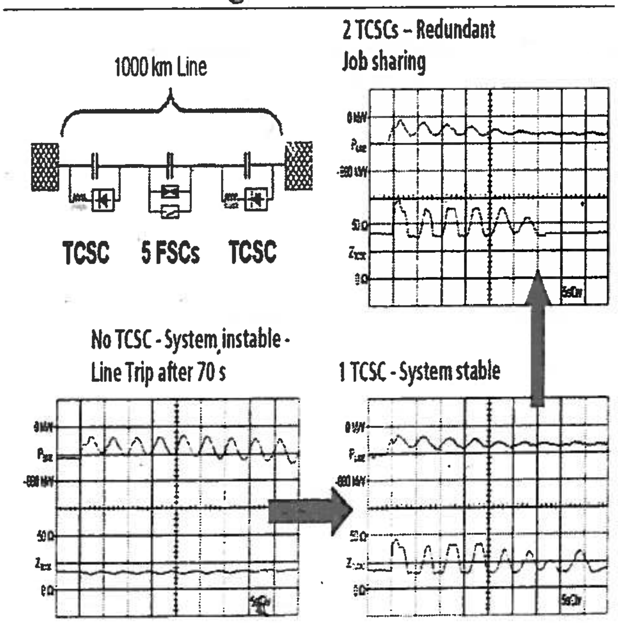


Fig. 8 : PSCAD/EMTDC Simulation results for 500 kV, 1000 km Long Distance AC Transmission in Brazil (Staged-Fault Tests)

The recordings from on-site tests show that the interconnection would become unstable without the damping function of TCSC. If only one TCSC is in operation, the interconnection becomes stable, with both devices acting the inter-area oscillations are quite well damped, and redundancy is provided [15]. From site experience, it has been reported, that under increased load conditions, the TCSC damping function is activated up to several hundred times per day.

In Great Britain, in the course of deregulation, new power stations where installed in the north of the country, remote from the southern load centers and some of the existing power stations in the south were shut down due to environmental constraints and for economic reasons [16].

To strengthen the transmission system, a total number of 27 SVC have been installed, because there was no right of way for new lines or higher transmission voltage levels. Fig. 9 gives an example for two of these SVCs, installed in Harker substation in a parallel configuration. PSCAD/EMTDC Software is used for Simulation of this system for which the results are shown in Fig.9. Both Harker SVCs have been designed mainly for Power oscillation damping (POD, Fig. 9 c).

The reinforcement of the British transmission grid by means of FACTS controllers has proven its feasibility during many years of experience successfully. However, for a further increase of the north-south power transfer, additional measures will be needed with regard to the relatively low transmission line voltage levels of only 400 and 275 kV [16].

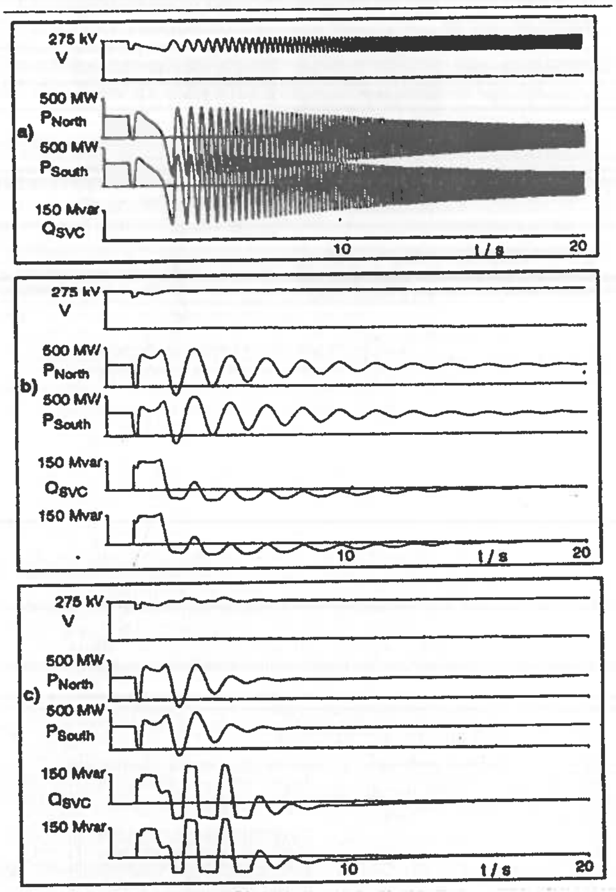


Fig 9 : PSCAD/EMTDC Simulation Results for SVCs installed at Harker substation Strengthening the Transmission System in UK with SVC [16]

a) No SVC connected

b) SVCs in Voltage control

c) SVCs in POD control

3 DEVELOPMENTS IN POWER ELECTRONICS COMPONENTS [22]

By the use of new, high power direct light-triggered thyristors (LTT), significant benefits can be achieved, as shown in the Fig. 10.

Siemens uses this innovative technology for both HVDC and FACTS controllers.

Highlights are less electronic components, leading to an increased reliability, in combination with a unique wafer-integrated thyristor over-voltage protection.

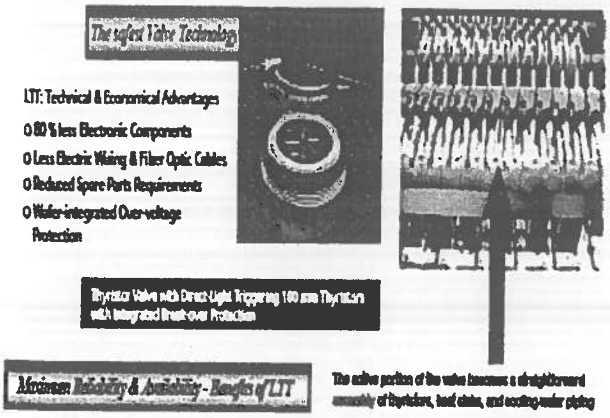


Fig. 10 : Benefits of LTT-Thyristor Technology and View on the Thyristor Stack (right side)

In Fig. 11, the stepwise assembly of the thyristors in modules and valve group is shown. An additional, important feature of these high power electronic components is a flame-retardant design of the elements.

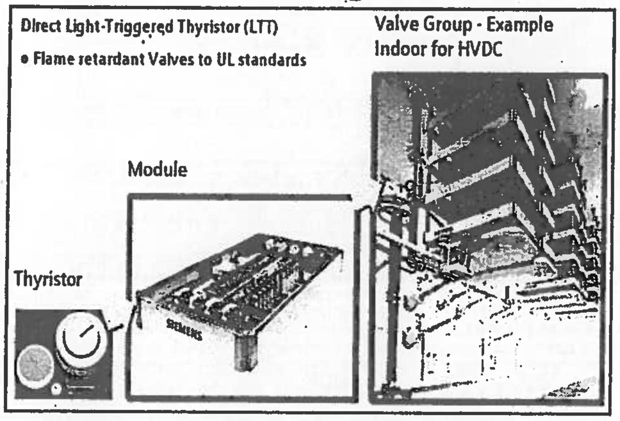


Fig. 11: Advanced Power Electronic Components (Example HVDC)

4. CONCLUSION

HVDC and FACTS have their own merits and demerits with reference to the complex power system network. Keeping in mind the better utilization of the transmission assets the salient features have been brought out by using simulation of system on PSCAD/EMTDC.

FACTS and HVDC controllers have been developed to improve the performance of long distance AC transmission. Later their use has been extended to load-flow control in meshed and interconnected systems. Excellent on-site operating experience is being reported, and the FACTS and HVDC technology became mature and reliable.

In the paper, highlights of innovative FACTS and HVDC solutions are depicted and their benefits for new applications in high voltage transmission systems and for system interconnections are demonstrated.

Power electronicsbased controllers provide transmission grids powerful tools to increase transmission capacity and offer unprecedented control capabilities. However, these controllers, with their multiple control and configuration modes, represent new challenges. Energy companies need to quantify their technical and economic benefits. Further, ensuring successful integration and operation of power electronicsbased controllers in a transmission grid requires development and implementation of a well-structured computation and analysis.

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