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HVDC and Facts in Power System

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Abstract: ***The development of electrical power supplies began more than hundred years ago. At the beginning stage, there were only small DC networks within the local boundaries, which were able to cover of industrial plants. An increasing demand on energy, technology changed to be transmitted from DC to AC power and voltage levels. The driving force for the development of power systems is the increase of electrical power demand. Therefore, power system developed from the regional to national systems. To achieve technical and economic advantages, extend further to large continental systems by applying interconnections to the neighbouring systems. This paper will treat benefits of HVDC and FACTS devices applied in power systems such as increased power transmission capability, improved static and dynamic stability, an increase of a availability and a decrease of transmission losses by using power Electronics techniques.***

Keywords: Development of HVDC & FACTS, Current status of power electronics techniques, Future development of HVDC & FACTS.

1. Introduction

The development of power system is increased demand for electrical energy in industrial countries. In next 20 years, the power consumption is developing and emerging countries is expecting more than double [1, 2]. The basic energy consumption of driven factors is shown in figure 1.

As an energy demand growth, high voltages are needed. In industrialised countries, the demand level is increased. There is a gap between transmission capacity and actual power demand, which leads to technical problem in the system like voltage problem, stability limitation etc. This problem can be solved by using interconnection of separated grids. In large AC transmission and synchronous interconnection, technical problems can be expected [3, 4].

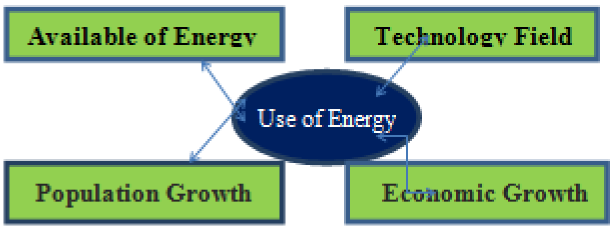

Figure 1: Energy driven factor diagram

This problem is achieved by using Power electronic devices such as IGTO, IGBT and HVDC light etc., and then the power system will be improved. The main idea of FACTS and HVDC can be explained by the basic power flow concept for transmission in fig 2.

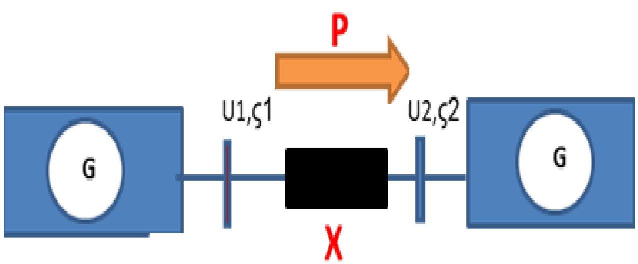

Figure 2: Basic power flow diagram for power transmission

2. Development of HVDC

HVDC has been introduced in the second half of the past century for long transmission area. The magnitude of transmission power is increased (from few hundred MW into 3-4 GW) by using proper HVDC connections. Basically, back- back and two terminal long distance schemes are used. However, multi terminal HVDC scheme is planned for the future system [3, 5]. The design is illustrated in fig 3.

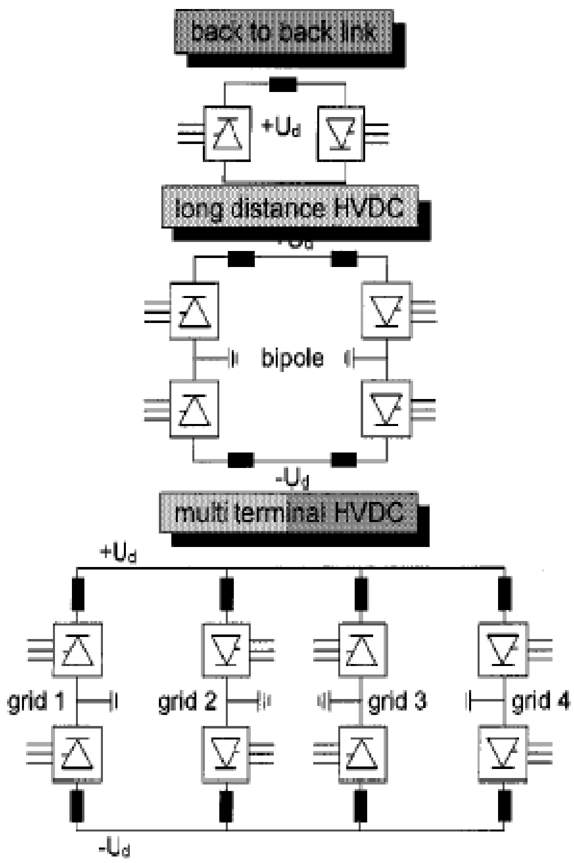

Figure 3: HVDC connections

HVDC became a more reliable technology by these developments HVDC transmission has been installed worldwide still. Recently, the survey of HVDC has been declared from IEEE source as shown in fig4.

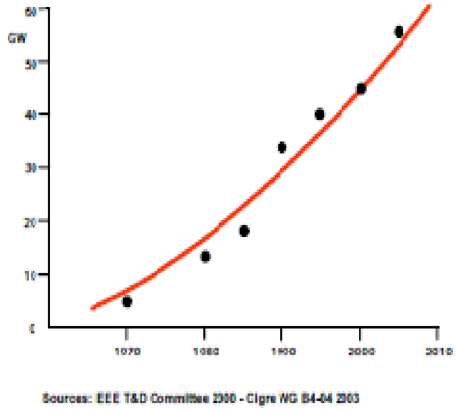

Figure 4: HVDC usage in worldwide

Advantages

Technical and economic benefits of HVDC are:

- Lower line costs
- No need for common frequency control
- Stable operation even with a low-power interconnection
- Improved dynamic conditions in ac systems

3. Development of Facts

Earlier, large AC system with long transmission and synchronous interconnection had some technical limitations [6].These factors are given in fig 5.Later, the performance of long distance AC transmission system was improved by FACTS (Flexible AC Transmission system) with help of power electronics. This FACTS system was introduced by Dr. N. G. Hingorani, from EPRI, USA [7].

FACTS devices are based on solid - state control that performances are control transmission line power flow and magnitude and phase of line end voltages. Now, FACTS technology has been extended and excellent operating performances are available worldwide. It became more mature and reliable.

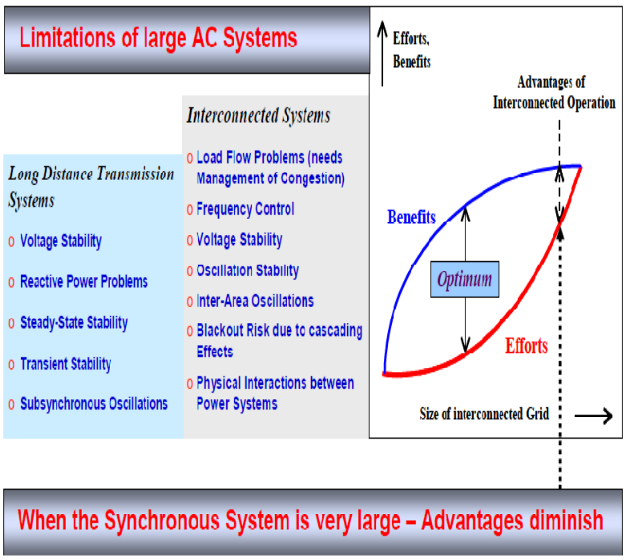

Figure 5: Limitations –AC systems

3.1 Facts Controllers

FACTS Controllers for Enhancing Power System Control:

- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
- Static Synchronous Series Controller (SSSC)
- Unified Power Flow Controller (UPFC)
- Inter-phase Power Flow Controller (IPFC)
- Hybrid power flow controller (HPFC)

3.2 Basic Types of Controllers

3.2.1. Series controller

A variable inductor or a capacitor in series with a transmission line and it imitates inductive or capacitive reactance in turn to regulate effective line reactance between the two ends. Series controller in general controls current injection [6, 7, 8]. **Example: SSSC**

3.2.2. Shunt controller

A variable inductor or can be a capacitor in shunt or parallel connection in the transmission line. This type of device is capable of imitating inductive or capacitive reactance in turns to regulate line voltage at the point of coupling. Shunt controller in general controls the voltage injection [6, 7, 8]. **Example: SVC, STATCOM**

3.2.3. Series-Shunt controller

This type of controller is a reactive compensator with the exception of producing its own losses. It is also recognized as "unified" controller and requires small amount of power for DC circuit exchange occurring between the shunt and series converters [6, 7, 8]. **Example: UPFC**

3.3 SVC (Static Var Compensator)

The SVC is a reactive power compensation device based on high power thyristor technology. It is a static shunt reactive device, the reactive power generation or absorption of which can be varied by means of thyristor switches. Unlike the synchronous compensator, it has no moving parts and hence the denomination "static". Already in the first half of the 1970s the SVC became a well-established device in high-power industrial networks, particularly for the reduction of voltage fluctuation caused by arc furnaces. In transmission systems the breakthrough came at the end of the 1970s. Since then, there has been an almost explosive increase in the number of applications, in the first place as an alternative to synchronous compensators, but also for a more extensive use of dynamic i.e. of easily and rapidly controllable shunt compensation. A typical circuit diagram of SVC as shown in figure 6.

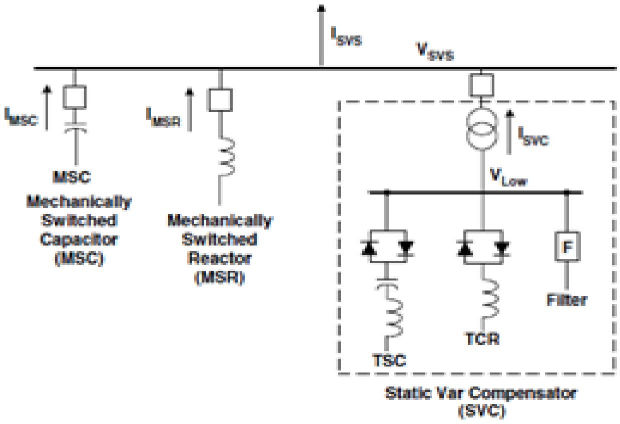

Figure 6: Circuit diagram for SVC

At present approximately 300 SVCs with a total control range of about 40000 MVAR have been installed or are under construction worldwide. Compensators in use range in size from some tens up to several hundred MVAR control range with nominal voltages up to 765 kV.

An SVC can improve power system transmission and distribution performance in a number of ways. Installing an SVC at one or more suitable points in the network can increase transfer capability and reduce losses while maintaining a smooth voltage profile under different network conditions. The dynamic stability of the grid can also be improved, and active power oscillations mitigated [7].The application of SVC gives the following benefits.

In power transmission
- Stabilized voltages in weak systems
- Reduced transmission losses
- Increased transmission capacity, to reduce or remove the need for new lines
- Higher transient stability limit
- Increased damping of minor disturbances
- Greater voltage control and stability

In power distribution:
- Stabilized voltage at the receiving end of long lines
- Increased productivity as stabilized voltage better utilizes capacity
- Reduced reactive power consumption, gives lower losses
- Balanced asymmetrical loads reduce system losses
- Fewer stresses in asynchronous machinery
- Reduced voltage fluctuations and light flicker

Figure 7: SVC installation model- source: Siemens

3.4 STATCOM (Static Synchronous Compensator)

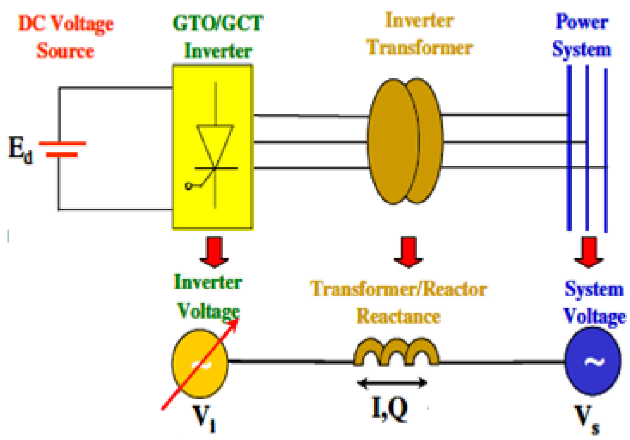

Figure 8: Circuit diagram for STATCOM

A STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals [7,8].

A STATCOM can improve power-system performance in such areas as the following:

- The dynamic voltage control in transmission and distribution systems
- The power-oscillation damping in power-transmission systems
- The transient stability
- The voltage flicker control
- The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC).

3.5 SSSC (Static Synchronous Series Compensator)

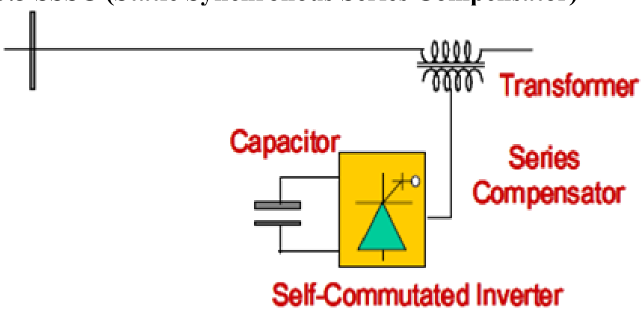

Figure 9: Circuit diagram for SSSC

The SSSC, sometimes called the S3C, is a series-connected synchronous-voltage source that can vary the effective impedance of a transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current. It has the capability of exchanging both real and reactive power with the transmission system [7, 8, 9]. For instance, if the injected voltage is in phase with the line current, then the voltage would exchange real power. On the other hand, if a voltage is injected in quadrature with the line current, then reactive power—either absorbed or generated—would be exchanged. The SSSC emerges as a potentially more beneficial controller than the TCSC because of its ability to not only modulate the line reactance but also the line resistance in consonance with the power swings, thereby imparting enhanced damping to the generators that contribute to the power oscillations. The SSSC comprises a multi-phase VSC with a dc-energy storage controller. Here, the controller is connected in series with the transmission line. A series capacitor compensates the transmission-line inductance by presenting a lagging quadrature voltage with respect to the transmission-line current. This voltage acts in opposition to the leading quadrature voltage appearing across the transmission-line inductance, which has a net effect of reducing the line inductance.

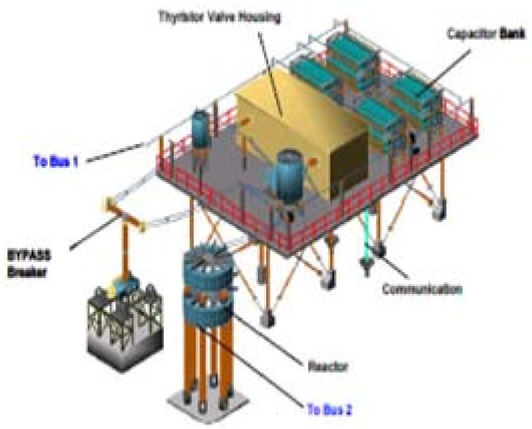

Figure 10: SSSC 3D - view

3.6 UPFC (Unified Power Flow Controller)

The UPFC is the most versatile FACTS controller developed so far, with all-encompassing capabilities of voltage regulation, series compensation, and phase shifting. It can independently and very rapidly control both real- and reactive power flows in a transmission line. It comprises two VSCs coupled through a common dc terminal. One VSC—converter 1—is connected in shunt with the line through a coupling transformer; the other VSC—converter 2—is inserted in series with the transmission line through an interface transformer. The dc voltage for both converters is provided by a common capacitor bank. The series converter is controlled to inject ta voltage phase, Vpq, in series with the line, which can be varied from 0 to Vpq max. Moreover, the phase angle of V_{pq} can be independently varied from 08 to 3608. In this process, the series converter exchanges both real and reactive power with the transmission line. Although the reactive power is internally generated/ absorbed by the series converter, the real-power generation/ absorption is made feasible by the dc-energy–storage device—that is, the capacitor [7, 9].

The shunt-connected converter 1 is used mainly to supply the real-power shunt converter maintains constant voltage of the dc bus. Thus the net real power drawn from the ac system is equal to the losses of the two converters and their coupling transformers. In addition, the shunt converter functions like a STATCOM and independently regulate the terminal voltage of inter connected bus by generating/ absorbing a requisite amount of reactive power. A circuit diagram of UPFC as shown in figure 8.

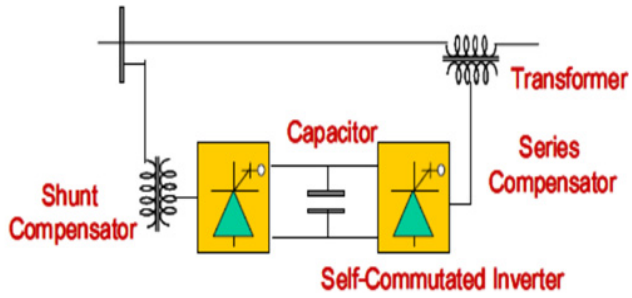

Figure 11: Circuit diagram of UPFC

4. Current Status of Power Electronics Techniques

4.1. HVDC Light

At the beginning stage, HVDC operation was performed by Mercury arc methods. Later, the power system was improved by using power electronics devices like high-power thyristors, GTO, IGBT etc.

Currently, HVDC light is introduced and utilized in the transmission system in order to improve the system reliability. It is also called as direct light –triggered thyristors (LTT). HVDC light is a DC transmission system based on voltage source converter (VSC) technology. In a VSC, the current is switched ON and OFF at any time- the converter is self-commutated [10, 11].This type of converters is able to switch off the DC current independent of the AC voltage. The ± DC voltages are kept constant to an ordered value by high frequency switching of the rectifier valves, which thereby charges the DC side capacitors. Furthermore, the VSC inverter can create its own AC voltage in case of a black AC network, through high frequency switching between the ± DC voltages. The light-triggered thyristors (LTTs) used are not able for their very high current carrying capacity and blocking voltage. Direct light-triggered thyristors make it possible to reduce the number of electronic components in the converter valves by about 80 %. A further advantage of this modern thyristor design is that all the firing and monitoring electronics are at earth potential; the equipment is consequently accessible during operation [9, 10].

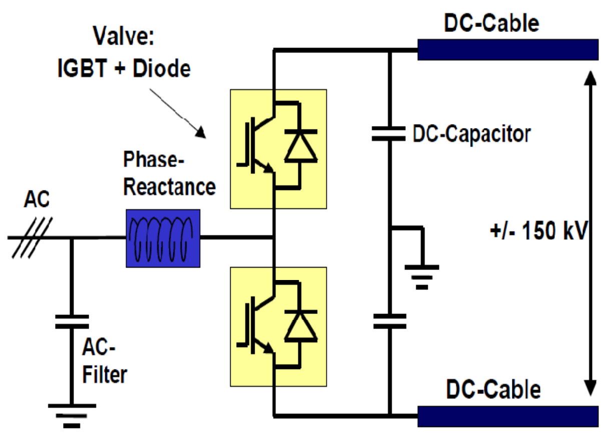

Figure 12: HVDC Light- schematic diagram

Advantages - HVDC Light

- Possible to feed totally islanded and passive AC networks
- Separately control of active and reactive power
- No contribution to short circuit current
- Intercommunication not needed
- Environmental-friendly
- Underground cables instead of OH lines
- Low maintenance requirements

4.2. Facts

The history of power electronics started from 1965 with the first Thyristor rectifiers, and development has not stopped since. Power electronics have evolved to the present modularized IGBT, IGCT, IEGT or ETO voltage source converters [7, 10].

4.2.1. Thyristor

The thyristor is a device, which can be triggered with a pulse at the gate and remains in the on-stage until the next current zero crossing. Thyristors have the highest current and blocking voltage, and are still the device with the highest voltage and power levels. This means that fewer semiconductors need to be used for each application thyristors can be used as switches for capacitors or inductors, and in converters for reactive power compensators. HVDC based thyristor technology is still the only possible AC-DC transmission approach with a voltage level above 500 kV and power above 3000 MW.These devices are being used in high-voltage direct-current transmission systems. At present, no other device type can match the performance of thyristors, and their application for long distance and large power transmission with very high power is expected to continue in the foreseeable future.

4.2.2. IGCT

To increase controllability, GTO (Gate Turn Off) Thyristors were developed, and can be switched off with a voltage peak at the gate. These GTO based devices are now replaced by IGCT (Insulated Gate Commutated Thyristors), which combine the advantages of low on stage losses and low switching losses. These semiconductors are used in smaller FACTS devices and drive applications. The GTO thyristors have also been developed over the past 30 years. Their main advantages over thyristors have been in the higher switching the anode to cathode voltage. These attributes have led to the use of GTOs in high power inverter systems.

4.2.3. IGBT

The IGBT (Insulated Gate Bipolar Transistor) has become an important power electronic technology in FACTS applications. The device takes advantage of the high voltage bipolar transistor with MOS gate. Basically an IGBT can be switched on with a positive voltage and switched off with a zero voltage. This characteristic allows a very simple gate drive unit to control the IGBT. The voltage and power level of the applications is up to 300 kV and 1000 MVA for VSC HVDC.

4.2.4. IGET

The IEGT (Injection Enhancement Gate Transistor) chips are the latest in fast recovery diode technology, and are an advanced standard package design. They create a compact, high-efficiency and high-isolation 6.5kV, 1.2kA IEGT module, which uses trench gate semiconductor technology. The IEGT has high power ratings comparable to the GTO and can be operated at high speed comparable to the IGBT. The latest IEGT module combines low thermal resistances with reduced on-state losses and a 3000 reduction of off-state losses is realized when compared with conventional modules. In addition, the size of an IEGT module is about one third of that of GTO module [10].

4.2.5. ETO Thyristor

An ETO (Emitter Turn-Off) thyristor combines the best characteristics of IGCT and IGBT with a high current carrying capability and a medium voltage of GTO is considered as one of the emerging high-power semiconductor devices. The ETO thyristor was initially developed as an extremely high-power switching device to be used in power conversion systems within electric utility grids. The ETO thyristors are capable of switching up to 4 kA of electric current and 6 kV of electric voltage [7, 10].

The ETO Thyristor has the following technical characteristics:

- 5000A snubber-less turn-off capability
- Low switching losses & conduction losses
- Low cost device and circuit
- Easy for series and parallel operation
- Low gate drive power
- Built-in over-current protection and current sensor
- Easy for mass-production.

All FACTS devices and HVDC links are helpful in stability control of power systems. The shunt type FACTS device is more useful to control system voltage and reactive power while the series type FACTS device is more suitable for power flow control. The series- shunt type controller: UPFC can be used to control the active and reactive power flow of a transmission line and bus voltage independently. The series type FACTS controller - IPFC (Interline Power Flow Controller) can be used to control power flows of two transmission lines while the active power between the two transmission lines can be exchanged[10,12]. The newly developed VSC HVDC, which has similar control capability as that of the UPFC, can control both the independent active and reactive power flows of a transmission line and the voltage of a local bus. However, the HVDC based conventional line commutated converter technique cannot provide voltage control and independent reactive power flow control. Another very important feature of VSC HVDC technique is that it can be very easily configured into a multi-terminal VSC HVDC. FACTS devices based on VSC techniques can be interconnected to implement various configurations and structures for different control purposes.

4.2.6 SVC Light

SVC Light is a product name for an IGBT based STATCOM. The Light technology is based on the principle that the plant topology should be simple. A minimum of conventional apparatus should be used. These components are replaced by high technology devices such as IGBT valves and high performance computer systems. By use of high frequency switching PWM (about 2 kHz), it has become possible to use a single converter connected to a standard power transformer via air-core commutating reactors. The core parts of the plant have been located inside a container. In it, the IGBT valves, DC capacitors, control system and the valve cooling system reside. The outdoor equipment is limited to heat exchangers, commutation reactors and the power transformer. In case a wider range is required additional fixed capacitors, thyristor switched capacitors or an assembly of more than one converter may be used [9, 10].

5. Future Development of Facts and HVDC

The primary control objectives of future power systems are:

- To facilitate electricity trading
- To optimize the overall performance and robustness of the system
- To react quickly to disturbances to minimize their impact and prevent the system against blackouts
- To restore the system to the normal operating level after a disturbance.

The development of future FACTS and HVDC requires:

- Reduction of overall costs
- Improvement of reliability
- Structural modularity and scalability
- Mobility and capability
- Internal fault-detecting and protection capabilities

6. Conclusion

In order to avoid large cascading system outages, transmission systems and system inter connections have to be improved by new investments, including the use of Power Electronics like HVDC, FACTS and other advanced technologies. Further developments in the future will be also influenced by the liberalization of power industry. FACTS and HVDC controllers have been developed to improve the performance of long distance AC transmission. 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 inter connections are demonstrated.

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