Use of FACTS for System Performance Improvement

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ABSTRACT

The performance of power systems decreases with the size, the loading and the complexity of the networks. This is related to problems with load flow, power oscillations and voltage quality. Such problems are even deepened by the changing situations resulting from deregulation of the electrical power markets, where contractual power flows do not follow the initial design criteria of the existing network configuration any longer. Power Systems have not been designed for “wide-area” energy trading with daily varying load patterns, and the systems are “close to their limits”.

Flexible AC Transmission Systems (FACTS) based on power electronics have initially been developed to improve the performance of long distance AC transmission. Later, the technology has been extended to the devices which can also control power flow. Excellent operating experiences are available world-wide, and the technology became mature and reliable. FACTS are applicable in shunt connection, in series connection, or in a combination of both.

In this paper, solutions with FACTS for system enhancement and for system interconnections are presented, and their advantages are explained. Examples of large project applications in Asia, America and Europe are depicted, including hybrid configurations with parallel operation of FACTS and HVDC (High Voltage Direct Current).

KEY WORDS:
System Stability, Blackout Prevention, Increase of Transmission Capacity, Power-Flow Control, Short-Circuit Current Limitation, Parallel Operation of FACTS and HVDC

1. INTRODUCTION

The development of power systems follows the requirements to transmit power from generation to the consumers. With an increased demand for energy and the construction of new generation plants, first built close and then at remote locations from the load centers, the size of power systems has grown. Examples of large interconnected systems are the Western and Eastern European systems UCTE (installed capacity 530 GW) and IPS/UPS (315 GW), which are planned to be interconnected in the future [1-3].

With an increasing size of the interconnected systems, the technical and economical advantages diminish. This is related to problems regarding load flow, power oscillations and voltage quality. If
power is to be transmitted through the interconnected system over long distances, transmission needs to be supported.

Fig. 1 and Fig. 2 summarize the perspectives of power system developments. In the future, an increasing part of the installed capacity, however, will be connected to the distribution levels (dispersed generation), which poses additional challenges on planning and safe operation of the systems, see Fig. 2. In such cases, power electronics can clearly strengthen the power systems and improve their performance [2].

**Fig. 1: Trends in High Voltage Transmission Systems**

**Fig. 2: Perspectives of Transmission and Distribution Network Developments**

Problems with congestion and transmission bottlenecks are even deepened by the deregulation of the electrical power markets, where contractual power flows do not follow the initial design criteria of the existing network configuration any longer. Large blackouts in America and Europe confirmed clearly that the favorable close electrical coupling might also include the risk of uncontrollable cascading effects in large and heavily loaded interconnected systems [2], see Fig. 3.
Fig. 3: Blackouts 2003 - Example United States
a) The Blackout Area - and a Satellite View
b) Congestion and Loop Flows - Forecasting Studies and Cascading Events

System Enhancement necessary!

Giant Loop Flows
2.2 - 4.8 GW

Problems only in the synchronous interconnected Systems

PTDF = Power Transfer Distribution Factor


Source: EPRI 2003

Source: Blackout Summary, U.S./Canada Power Outage Task Force 9-12-2003

Québec's HVDCs assist for Power Supply and System Restoration

Before the Blackout

However, some Islands still have local Supply

Before the Blackout

Additional problems are expected when renewable energies such as large wind farms have to be integrated into the system, especially when the connecting AC links are weak and when there is no sufficient reserve capacity in the neighboring system available [3].

Based on the global experience with large blackouts [2], strategies for the development of large power systems go clearly in the direction of hybrid transmissions consisting of DC and AC interconnections including FACTS. Such hybrid interconnected systems offer significant advantages, both technical and in terms of reliability [2, 4].

Fig. 4 shows schematically such a hybrid system using FACTS as well as HVDC. Power exchange in the neighboring areas of interconnected systems offering most advantages can be achieved by AC links, preferably including FACTS for increased transmission capacity and for stability reasons [4]. The transmission of large power blocks over long distances should, however, be utilized by the HVDC transmissions directly to the locations of power demand. HVDC can be implemented as direct coupler – the “Back-to-Back” solution (B2B) – or as point-to-point long distance transmission via DC line. In addition to FACTS, the HVDC links can strengthen the AC interconnections at the same time in order to avoid possible dynamic problems which exist in such huge interconnections [3]. The “Firewall” function of HVDC [2], as mentioned in Fig. 4, is explained in the next section.

2. ELIMINATION OF TRANSMISSION BOTTLENECKS BY MEANS OF POWER ELECTRONICS

Fig. 5 shows an “Application Guide” for grid enhancement with power electronics (ref. to Fig. 3 b). Depending on the grid structure, there are four basic cases:

- Load displacement in case of parallel lines by impedance variation (series compensation)
- Fast load-flow control in meshed structures with HVDC/GPFC (or very slow with phase shifting transformer)
- Voltage collapse: reactive/active power injection by means of FACTS/HVDC
- Excess of allowed short-circuit level: short-circuit current limitation (FACTS/HVDC)
GPFC (Grid Power Flow Controller) is a special DC back-to-back link which is designed for fast power and voltage control at both terminals [4]. The GPFC features are explained in the following.

The basic equation for power transmission (Fig. 6) explains the solutions for system enhancement in a more detailed way. The power transmitted between two subsystems depends on voltages at both ends of the connecting line, the line impedance and the phase angle difference between the connecting points. Power electronics can actively influence one or more of these parameters and control or direct the power flow through the interconnection.

\[
P = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2)
\]

Each of these Parameters can be used for Load-Flow Control and Power Oscillation Damping

**Load Displacement by Series Compensation**

**Parallel Compensation**

**Series Compensation**

**Short-Circuit Current Limitation for Connection of new Power Plants**

**SVC & HVDC for Prevention of Voltage Collapse**

**Load Management by HVDC**

**The FACTS & HVDC “Application Guide”**

**Fig. 5: Use of Power Electronics for System Enhancement**

**Fig. 6: Power Transmission – The basic Equation**
By using FACTS for reactive power compensation, the impedances and voltages of the system can be influenced: by adding series compensation (fixed or controlled) into the line, its reactance $X$ can be reduced or modulated (for power oscillation damping, ref. to the equation); with FACTS parallel compensation, e.g. SVC (Static Var Compensator), the voltage can be stabilized (at constant values, or modulated for damping of oscillations). The transmission angle can be influenced by using HVDC for power-flow control. These methods are explained in Figs. 7-8.

Fig. 7: FACTS for Reactive Power Compensation

Fig. 8 shows that HVDC is also well suitable for short-circuit current limitation (fault current blocking). Furthermore, in case of cascading events, HVDC acts like an automatic “Firewall” by fast decoupling of the interconnected systems during a disturbance and by immediate restarting power transmission after the fault. Systems directly coupled by AC links need time-consuming re-synchronization, which can take many hours. Alongside its main function of power-flow control, the HVDC incorporates also voltage control (by reactive power injection) for both sides of the system. It decouples the transmission equation by forcing the power to flow in a similar way like the well known phase-shifting transformer, however, much faster and independent from the frequencies and angles of the two coupled systems.

Using an extended control range of HVDC, the B2B can fully “feature” FACTS functions, e.g. fast voltage control, in the same way as an SVC. This new idea of GPFC as a “FACTS B2B” is explained in Fig. 9, in comparison to the “standard” HVDC control range. As indicated in the figure, these features have been successfully applied in a project at Lamar substation, USA.
3. FACTS TECHNOLOGIES AND APPLICATIONS

The main shunt connected FACTS application is the Static Var Compensator (SVC). SVC provides fast voltage control, reactive power control and power oscillation damping features. As an option, SVC can control unbalanced system voltages. World-wide, there are hundreds of these devices in operation. For decades, it has been a well developed technology, and the demand for SVCs is further increasing.

For long AC lines, series compensation is used for reducing the transmission angle, thus providing stability enhancement. Fixed series compensation (FSC) is widely used to improve the stability and to increase the transmission capacity for long distance transmissions. A huge number of these applications are in operation. In case of more complex system conditions, Thyristor Controlled Series Compensation (TCSC) is used if fast control of the line impedance is required to adjust the load flow on parallel lines, or for damping of power oscillations. TCSC has already been applied in different projects for load-flow control, stability improvement and to damp oscillations in interconnected systems.

The rating of shunt connected FACTS controllers is up to 800 MVAr, series FACTS devices are implemented on 550 and 735 kV levels to increase the transmission capacity of the lines up to several GW.

Fig. 10 shows the basic configurations of FACTS devices. The SVC uses line-commutated thyristor technology, where the maximum switching frequency in each phase element is limited by the “driving” system frequency. A further development is STATCOM (Static Synchronous Compensator) using voltage-sourced converters (VSC, [4]). Both devices provide fast voltage control, reactive power control and power oscillation damping features (POD). As an option, SVC can control unbalanced system voltages. The developments of FACTS technologies are depicted in Fig. 11. Special FACTS devices are UPFC (Unified Power Flow Controller) and the GPFC [4]. UPFC combines a shunt connected STATCOM with a series connected STATCOM (also named S3C, Solid-State Series...
Compensator), which can exchange energy via a coupling capacitor. GPFC is, at lower costs, less complex than UPFC. For most applications in AC transmission systems and for network interconnections, SVC, FSC, TCSC and GPFC/B2B are fully sufficient to match all 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.

Recent developments are the TPSC (Thyristor Protected Series Compensation, Fig. 10) and the Short-Circuit Current Limiter (SCCL) [4, 5], both innovative solutions that use high power thyristor technology.

**FACTS - Flexible AC Transmission Systems: Support of Power Flow**

- **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
- **TPSC** - Thyristor Protected Series Compensation
- **GPFC** - Grid Power Flow Controller (**FACTS-B2B**)
- **UPFC** - Unified Power Flow Controller

**Fig. 10: FACTS – Basic Configurations**

**Fig. 11: FACTS – Technology Developments**
Figs. 12-13 show today’s FACTS applications including mechanically switched devices such as MSC/MSR, which are frequently used for voltage support and blackout prevention [2]. Actual ratings and voltage levels of the solutions are also indicated in the figures.

**Fig. 12: FACTS for Parallel Compensation**

- **MSC / MSR**
  - *Mechanical Switched Capacitors / Reactors*
  - Switchgear
  - Capacitors
  - Reactors
  - $52 \leq kV \leq 800$
  - $50 \leq \text{MVAr} \leq 500$

- **SVC**
  - *Static Var Compensator*
  - Thyristor Valve(s)
  - Control & Protection
  - Transformer
  - Capacitors
  - Reactors
  - $52 \leq kV \leq 800$
  - $50 \leq \text{MVAr} \leq 800$

- **STATCOM**
  - *Static Synchronous Compensator*
  - GTO/IGBT Valves
  - Control & Protection
  - Transformer
  - DC Capacitors
  - $52 \leq kV \leq 800$
  - $50 \leq \text{MVAr} \leq 800$

**Fig. 13: FACTS for Series Compensation**

- **FSC**
  - *Fixed Series Compensation*
  - Capacitors
  - Protection
  - Arresters
  - Circuit Breakers
  - $220 \leq kV \leq 800$
  - $200 \leq \text{MVAr} \leq 800$

- **TPSC**
  - *Thyristor Protected Series Compensation*
  - Capacitors
  - Protection
  - Thyristor Valves
  - Circuit Breakers
  - $220 \leq kV \leq 800$
  - $100 \leq \text{MVAr} \leq 500$

- **TCSC**
  - *Thyristor Controlled Series Compensation*
  - Capacitors
  - Control & Protection
  - Thyristor Valves
  - Circuit Breakers
  - $220 \leq kV \leq 800$
  - $100 \leq \text{MVAr} \leq 200$
A large number of different FACTS and HVDC controllers have been put into operation either as commercial projects or as prototypes. Fig. 14 gives an example of the Siemens applications worldwide. Thus it appears that some areas are still “blank”, which is expected to change in the future. For comparison reasons, the number and the increase of large HVDC long-distance transmission projects are also indicated in the figure. The CSC (Convertible Synchronous Compensator), as mentioned in Fig. 14, uses a flexible combination of two STATCOMs, of which each controller (+/- 100 MVAr) can be switched individually from shunt to series mode. By these means, CSC provides a multiple of operation modes including UPFC operation for the two transmission lines passing Marcy substation in the area of New York, USA.

Fig. 14: FACTS & HVDC worldwide – Example Siemens (ref. to Text)

4. USE OF FACTS FOR TRANSMISSION ENHANCEMENT

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, see Fig. 15-1). To strengthen the transmission system, a total number of 27 SVCs have been installed because there was no right of way for new lines or higher transmission voltage levels [3]. Fig. 15-1c) shows the very effective power oscillation damping (main control function) with two of these SVCs, installed in Harker Substation in a parallel configuration. Additional SVCs were implemented in the southern part of the grid, of which Fig. 15-2) shows a view of one of the two Pelham SVCs (left side of the figure). The single line diagram for both Harker and Pelham SVCs is attached in the right part of Fig. 15-2).

An increasing number of SVCs are also going to be installed on other continents. In Fig. 16, an example of a large SVC in South America is depicted. The SVC was implemented to improve system stability of the extended transmission grid. The installed containerized solution offers additional benefits such as reduction in installation and commissioning time, as well as space and cost savings compared with conventional building technologies.
1) Harker Substation, 1993 – 2 SVCs for Power Oscillation Damping
2) Pelham Substation, 1991 - 2 SVCs for Voltage Control (ref. to Text)

The Transmission System:

Benefits:
- Improvement of Voltage Quality
- Increased Stability

Results of Dynamic System Tests:
- a) No SVC connected
- b) Both SVCs in Voltage Control Mode
- c) Both SVCs in Power Oscillation Damping Mode

Increase of Transmission Capacity
Prevention of Outages

Verified by Computer and Real-Time Simulation

Harker: 275 kV
Pelham: 400 kV

Benefits:
- Voltage Control
- Reactive Power Control
- Power Oscillation Damping
- Unbalance Control (Option)

Deregulation caused Transmission Problems

Fig. 15: Europe - UK goes ahead with FACTS - 27 SVCs
1) Harker Substation, 1993 – 2 SVCs for Power Oscillation Damping
2) Pelham Substation, 1991 - 2 SVCs for Voltage Control (ref. to Text)
In Figs. 17-19, the features and cost savings of series compensation due to grid enhancement are summarized. The mentioned SSR (subsynchronous resonances) topic is a crucial issue for large thermal generators with long shafts [5].

The flexibility of modern FACTS technologies under extremely harsh environmental conditions is indicated in Figs. 18-19: the operating range for FSC begins at -50°C, for TCSC it can reach up to +85°C. This is necessary due to the outdoor installation on high voltage potential, with the isolated platform mounted directly in series with the transmission line.

In Fig. 20, two projects with series compensation in China are presented. Picture a) gives a view of one phase element of the two Pingguo TCSCs. The 3D view b) and the photo c) (from Barberton FSC, RSA) demonstrate how easily series compensation can be mounted to the existing line: when the equipment installation is finished but not yet connected to the line, a line interruption and a jumper connection from the line to the platform is made with a short interruption of power transmission of 1-3 days only.

For Thyristor Protected Series Compensation TPSC, innovative developments in Thyristor-Technology have been applied: LTT (Light-triggered Thyristors, now state-of-the-art for FACTS and HVDC) by applying a special heat-sink to enable very fast self-cooling of the valves, within half a
second only. By these means, TPSC is fully suitable for multiple fault conditions as it is often the case under hot climate conditions due to brush-fires leading to repetitive line faults. In the TPSC, the thyristor replaces the conventional MOV (metal oxide arrester) for fast capacitor protection against over-voltages due to short-circuit currents. During faults, the MOV heats up heavily. Due to an upper temperature limit, the MOV must cool down before the next current stress can be absorbed. Cool-down requires a substantial amount of time, time constants of several hours are typical. During this time, the series compensation must be taken out of service (bypass breaker closed) and consequently the power transfer on the related line needs to be reduced dependent on the degree of compensation, leading to a significant loss in transmission capacity. Therefore, it appears that by using the TPSC with fast cooling-down time instead of conventional series compensation with MOV, a significant amount of money for each application can be saved.

Fig. 21 shows a site-view of one of the 5 TPSCs installed at 500 kV in California, USA.

Fig. 18: FSC at EHV 735 kV plus harsh Environment

- Current Control
- Impedance Control
- Power Oscillation Damping (POD)
- Mitigation of SSR (Option)

Fig. 19: 500 kV TCSC Serra da Mesa, Furnas/Brazil – Essential for Transmission

Fast-growing generation in high load density networks on one hand, and interconnections among the systems on the other hand, increase the short-circuit power. If the short-circuit capacity of the
equipment in the system is exceeded, the switchgears must be uprated or replaced, which is a very cost and time-consuming procedure. In such cases, short-circuit current limitation offers clear benefits. Limitation by passive elements, e.g. reactors, is a well known practice. It reduces, however, the system stability, and there is an impact on the load flow.

By combining the proven TPSC application with an external reactor (see Fig. 22), whose design is determined by the allowed short-circuit current level, this device can also be used very effectively as short-circuit current limiter (SCCL, ref. to [4, 5]).

Fig. 20: China goes ahead – Transmission Enhancement with FACTS
a) Photo of Pingguo TCSC, commissioned in June 2003
b) 3D View on Fengjie 500 kV Fixed Series Compensation, China
   2 x 600 MVAr, Line Compensation Level 35%
c) Demonstration of the FSC-Jumper Connection to the Line - from Barberton FSC, RSA

Fig. 23 shows the basic function and the operating principle of the SCCL, including a 3D view of the SCCL. In comparison with the TPSC site photo, it can be seen that the TPSC is complemented by just an additional reactor for current limitation. Further details on the SCCL solution are described in [5].

This new device operates with zero reactance in steady-state conditions, and in case of short-circuit it is switched over to the current limiting reactance within a few ms.

Fig. 24 depicts an example of an on-site fault recording of one of the Vincent TPSCs. The measured currents and the calculated junction temperature rise of the valve in Phase B for a line fault in phase BC are recorded. The figure shows that there is still a huge margin for higher current stresses.
In Fig. 25, a brief overview on today’s solutions for fault-current limitation is given, including the new SCCL. Basically, there are two methods for fault-current reduction: limitation and interruption. The constraints and the benefits of the different solutions are indicated in the figure.

It can be seen that the SCCL offers numerous advantages.

A comparison of the new SCCL with the conventional solution using a current limiting reactor is depicted in Fig. 26. The main concerns are related to a risk of voltage collapse in case of dynamic system conditions, which can lead to cascading disturbances (blackout).

Fig. 21: TPSCs Vincent & Midway/USA: five Systems at 500 kV - fully proven in Practice, plus two new Projects (El Dorado)

Fig. 22: SCCL - an Innovative FACTS Solution using TPSC
Fig. 23: SCCL - Short-Circuit Current Limitation with FACTS

Fig. 24: TPSC and SCCL – up to 110 kA
In the next section, examples for parallel operation of FACTS and HVDC in large interconnected transmission systems are depicted.

5. FACTS AND HVDC IN PARALLEL OPERATION

With the Mead-Adelanto and the Mead-Phoenix Transmission Project (MAP/MPP), a major 500 kV transmission system extension was carried out to increase the power transfer opportunities between Arizona and California, USA [3]. The extension includes two main series compensated 500 kV line segments and two equally rated Static Var Compensators (supplied by Siemens) at the Adelanto and Marketplace substations – ref. to Fig. 27.

The SVCs enabled the integrated operation of the already existing highly compensated EHV AC system and the large HVDC system. The SVC installation was an essential prerequisite for the overall system stability at an increased power transfer rate.
Upgrade of a large AC and DC Transmission System with 2 SVCs & FSCs

- Increase of Transmission Capacity
- Improvement of System Stability

Fig. 27: HVDC plus SVC - Mead-Adelanto, USA

Each SVC: 388 MVar for Voltage and POD Control

Fig. 28: Mead-Adelanto Studies – Comparison of SVC Voltage- and POD-Control Mode

a) Both SVCs in Voltage Control Mode
b) Both SVCs in Coordinated Voltage & Power Oscillation Damping Control Mode
An example of the intensive project testing with computer and real-time simulator facilities for a fault application at Marketplace 500 kV bus is given in Fig. 28. The figure shows the computer test results with both SVCs active. The influence of the HVDC can be seen from the DC voltage $E_{dc}$. Figure a) is with both SVCs only in voltage control mode (POD blocked); Figure b) shows an improved damping with the coordinated POD function enabled.

In Fig. 29, a view on the SVC installation in Marketplace is given.

Fig. 29: Static Var Compensators Mead-Adelanto – View on Marketplace Substation

Similar studies have been carried out for a number of large transmission projects world-wide. In Figs. 30-32, an innovative FACTS application with SVC in combination with HVDC for transmission enhancement in Germany is shown [3, 6].

It’s a matter of fact that this project is the first high voltage FACTS controller in the German network. The reason for the SVC installation at Siems substation nearby the landing point of the Baltic Cable HVDC were unforeseen right of way restrictions in the neighboring area, where an initially planned new tie-line to the strong 400 kV network for connection of the HVDC was denied. Therefore, with the existing reduced network voltage of 110 kV (see the dotted black lines in Fig. 31), only a limited amount of power transfer of the DC link was possible since its commissioning in 1994, in order to avoid repetitive HVDC commutation failures and voltage problems in the grid. In an initial step towards grid access improvement, an additional transformer for connecting the 400 kV HVDC AC bus to the 110 kV bus was installed (see the figure). Finally, in 2004, with the new SVC equipped with a fast coordinated control, the HVDC could fully increase its transmission capacity up to the design rating of 600 MW. In addition to this measure, a new cable to the 220 kV grid was installed to increase the system strength with regard to performance improvement of the HVDC controls.

In Fig. 32, a view of the Siems SVC in Germany is depicted.
Prior to commissioning, intensive studies have been carried out; first with the computer program NETOMAC and then with the RTDS real-time simulator by using the physical SVC controls and simplified models for the HVDC [3].

Fig. 30: SVC Siems, Germany - Support of HVDC Baltic Cable

Fig. 31: The Problem – no Right of Way for 400 kV AC Grid Access of Baltic Cable HVDC - and Solutions
Table 1 summarizes the market expectations for FACTS and HVDC solutions today and in the future. Today, the market for series compensation, for SVC and for B2B/GPFC for load-flow control is in fact large and, as a result of liberalization and deregulation in the power industry, is developing fast in the future. Further, the market in the HVDC long distance transmission field is progressing fast. A large number of high power long distance transmission schemes using either overhead lines or submarine cables have been put into operation or are in the stage of installation.

| Table 1: Markets for FACTS and HVDC |
|-------------------------------------|-----------------|-----------------|-----------------|
| **Shunt Compensation**             | **Series Compensation** | **Combined Device** | **Power Transmission** |
| **Excellent Market**               | **Excellent Market** | **Excellent Market** | **Excellent Market** |
| **Upcoming Market**                | **Upcoming Market** | **Upcoming Market** | **Upcoming Market** |
| **Small Market**                   | **Small Market**  | **Small Market**  | **Small Market**  |
| **MSC/R**                          | **SVC**          | **FSC**          | **UPFC**         |
| **SVC**                            | **SVC**          | **FSC**          | **HVDC**         |
| **STATCOM**                        | **STATCOM**      | **TCSC / TPSC**  |                  |
| **Series Compensation**            | **Series Compensation** | **Combined Device** | **Power Transmission** |
| **Excellent Market**               | **Excellent Market** | **Excellent Market** | **Excellent Market** |
| **Upcoming Market**                | **Upcoming Market** | **Upcoming Market** | **Upcoming Market** |
| **Small Market**                   | **Small Market**  | **Small Market**  | **Small Market**  |
| **Power Transmission**             | **Power Transmission** | **Combined Device** | **Power Transmission** |
| **Excellent Market**               | **Excellent Market** | **Excellent Market** | **Excellent Market** |
| **Upcoming Market**                | **Upcoming Market** | **Upcoming Market** | **Upcoming Market** |
| **Small Market**                   | **Small Market**  | **Small Market**  | **Small Market**  |

Fig. 32: The Solution – the first HV SVC in the German Grid at Siemens Substation

6. POWER ELECTRONICS FOR HVDC AND FACTS – MARKET EXPECTATIONS AND RELIABILITY ISSUES
Concerning reliability of high voltage power electronics, Table 2 gives an example of two SVC projects installed in South Africa. The same high reliability is also achieved for HVDC as the technology applied uses the same components. Excellent on-site operating experience is being reported, and the FACTS and HVDC technology became mature and reliable.

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Recordings from NATAL SVCs / RSA (2 TCR & 3 Filter)
Guarantied Availability: 98 - 99 %

Table 2: Availability of Power Electronics - Example FACTS: close to 100 % - same for HVDC

7. CONCLUSIONS

Deregulation and privatization is posing new challenges on high voltage transmission systems. System elements are going to be loaded up to their thermal limits, and wide-area power trading with fast varying load patterns will contribute to an increasing congestion. To keep the power supply reliable and safe, system enhancement will be essential.

In conclusion to the previous sections, Table 3 summarizes the impact of FACTS on load flow, stability and voltage quality when using different devices. The evaluation is based on a large number of studies and experiences from projects. For comparison, HVDC as well as mechanically switched devices (MSC/R) are included in the table.

As a consequence of “lessons learned” from the large blackouts in 2003, FACTS and HVDC will play an important role for the system developments, leading to “Smart Grids” [4] with better controllability of the power flows.

High voltage power electronics provide the necessary features to avoid technical problems in the power systems, they increase the transmission capacity and system stability very efficiently and they assist in prevention of cascading disturbances.
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<td><img src="image" alt="Impact" /></td>
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<tr>
<td></td>
<td>TPSC (Thyristor Protected Series Compensation)</td>
<td><img src="image" alt="TPSC Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
<tr>
<td></td>
<td>TCSC (Thyristor Controlled Series Compensation)</td>
<td><img src="image" alt="TCSC Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
<tr>
<td><strong>Voltage Control: Shunt Compensation</strong></td>
<td>MSC/R (Mechanically Switched Capacitor / Reactor)</td>
<td><img src="image" alt="MSC/R Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
<tr>
<td></td>
<td>SVC (Static Var Compensator)</td>
<td><img src="image" alt="SVC Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
<tr>
<td></td>
<td>STATCOM (Static Synchronous Compensator)</td>
<td><img src="image" alt="STATCOM Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
<tr>
<td><strong>Load-Flow Control</strong></td>
<td>HVDC (B2B, LDT) (Unified Power Flow Controller)</td>
<td><img src="image" alt="HVDC Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
<tr>
<td></td>
<td>UPFC (Unified Power Flow Controller)</td>
<td><img src="image" alt="UPFC Scheme" /></td>
<td><img src="image" alt="Impact" /></td>
</tr>
</tbody>
</table>

Based on Studies & practical Experience

**Influence:**

- ○ no or low
- ⬤ small
- ⬤ ⬤ medium
- ⬤ ⬤ ⬤ strong

Table 3: FACTS & HVDC – Overview of Functions & “Ranking”

8. REFERENCES