FACTS – **F**lexible **A**lternating **C**urrent **T**ransmission **S**ystems

For Cost Effective and Reliable Transmission of Electrical Energy

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Flexible alternating current transmission systems (FACTS) devices are used for the dynamic control of voltage, impedance and phase angle of high voltage AC lines. FACTS devices provide strategic benefits for improved transmission system management through: better utilization of existing transmission assets; increased transmission system reliability and availability; increased dynamic and transient grid stability; increased quality of supply for sensitive industries (e.g. computer chip manufacture); and enabling environmental benefits. Typically the construction period for a facts device is 12 to 18 months from contract signing through commissioning. This paper starts by providing definitions of the most common application of FACTS devices as well as enumerates their benefits (focussing on steady state and dynamic applications). Generic information on the costs and benefits of FACTS devices is then provided as well as the steps for identification of FACTS projects. The paper then discusses seven applications of FACTS devices in Australia, Brazil, Indonesia, South Africa and the USA. The paper concludes with some recommendations on how the World Bank could facilitate the increased usage of FACTS.

Introduction

The need for more efficient electricity systems management has given rise to innovative technologies in power generation and transmission. The combined cycle power station is a good example of a new development in power generation and flexible AC transmission systems, FACTS as they are generally known, are new devices that improve transmission systems.

Worldwide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded and are being operated in ways not originally envisioned. Transmission systems must be flexible to react to more diverse generation and load patterns. In addition, the economical utilization of transmission system assets is of vital importance to enable utilities in industrialized countries to remain competitive and to survive. In developing countries, the optimized use of transmission systems investments is also important to support industry, create employment and utilize efficiently scarce economic resources.

Flexible AC Transmission Systems (FACTS) is a technology that responds to these needs. It significantly alters the way transmission systems are developed and controlled together with improvements in asset utilization, system flexibility and system performance.

What are FACTS devices?

FACTS devices are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. Below the different main types of FACTS devices are described:

Static Var Compensators (SVC's), the most important FACTS devices, have been used for a number of years to improve transmission line economics by resolving dynamic voltage problems. The accuracy, availability and fast response enable SVC's to provide high performance steady state and transient voltage control compared with classical shunt compensation. SVC's are also used to dampen power swings, improve transient stability, and reduce system losses by optimized reactive power control.

Thyristor controlled series compensators (TCSCs) are an extension of conventional series capacitors through adding a thyristor-controlled reactor. Placing a controlled reactor in parallel with a series capacitor enables a continuous and rapidly variable series compensation system. The main benefits of TCSCs are increased energy transfer, dampening of power oscillations, dampening of subsynchronous resonances, and control of line power flow.

STATCOMs are GTO (gate turn-off type thyristor) based SVC's. Compared with conventional SVC's (see above) they don't require large inductive and capacitive components to provide inductive or capacitive reactive power to high voltage transmission systems. This results in smaller land requirements. An additional advantage is the higher reactive output at low system voltages where a STATCOM can be considered as a current source independent from the system voltage. STATCOMs have been in operation for approximately 5 years.

Unified Power Flow Controller (UPFC).
Connecting a STATCOM, which is a shunt connected device, with a series branch in the transmission line via its DC circuit results in a UPFC. This device is comparable to a phase shifting transformer but can apply a series voltage of the required phase angle instead of a voltage with a fixed phase angle. The UPFC combines the benefits of a STATCOM and a TCSC.

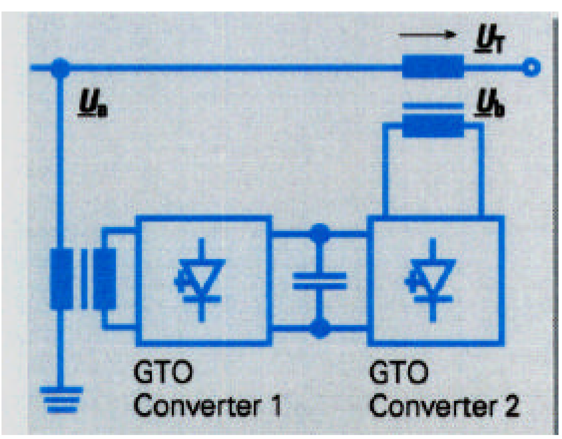

Exhibit 1: UPFC circuit diagram

The section on *Worldwide Applications* contains descriptions of typical applications for FACTS devices.

Benefits of utilizing FACTS devices

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows:

- **Better utilization of existing transmission system assets**
- **Increased transmission system reliability and availability**
- **Increased dynamic and transient grid stability and reduction of loop flows**
- **Increased quality of supply for sensitive industries**
- **Environmental benefits**

Better utilization of existing transmission system assets

In many countries, increasing the energy transfer capacity and controlling the load flow of transmission lines are of vital importance, especially in de-regulated markets, where the locations of generation and the bulk load centers can change rapidly. Frequently, adding new transmission lines to meet increasing electricity demand is limited by economical and environmental constraints. FACTS devices help to meet these requirements with the existing transmission systems.

Increased transmission system reliability and availability

Transmission system reliability and availability is affected by many different factors. Although FACTS devices cannot prevent faults, they can mitigate the effects of faults and make electricity supply more secure by reducing the number of line trips. For example, a major load rejection results in an over voltage of the line which can lead to a line trip. SVC's or STATCOMs counteract the over voltage and avoid line tripping.

Increased dynamic and transient grid stability

Long transmission lines, interconnected grids, impacts of changing loads and line faults can create instabilities in transmission systems. These can lead to reduced line power flow, loop flows or even to line trips. FACTS devices stabilize transmission systems with resulting higher energy transfer capability and reduced risk of line trips.

Increased quality of supply for sensitive industries

Modern industries depend upon high quality electricity supply including constant voltage, and frequency and no supply interruptions. Voltage dips, frequency variations or the loss of supply can lead to interruptions in manufacturing processes with high resulting economic losses. FACTS devices can help provide the required quality of supply.

Environmental benefits

FACTS devices are environmentally friendly. They contain no hazardous materials and produce no waste or pollutanse. FACTS help distribute the electrical energy more economically through better utilization of existing installations thereby reducing the need for additional transmission lines.

Applications and technical benefits of FACTS devices

Exhibits 2 to 4 below describe the technical benefits of the principal FACTS devices including steady state applications in addressing problems of voltage limits, thermal limits, loop flows, short circuit levels and subsynchronous resonance. For each problem the conventional solution (e.g. shunt reactor or shunt capacitor) is also provided (as well as for dynamic applications – see below), as well as dynamic applications of FACTS in addressing problems in transient stability, dampening, post contingency voltage control and voltage stability. FACTS devices are required when there is a need to respond to dynamic (fast-changing) network conditions. The conventional solutions are normally less expensive than FACTS devices – but limited in their dynamic behavior. It is the task of the planners to identify the most economic solution.

In Exhibits 3 and 4 information is provided on FACTS devices with extensive operational experience and widespread use such as SVC, STATCOM, TCSC and UPFC. In addition, information is provided on FACTS devices that are either under discussion, development or as prototype in operation such as the thyristor controlled phase-angle regulator (TCPAR); the thyristor controlled voltage limiter (TCVL); and the thyristor switched series capacitor (TCSC).

Technical benefits of the main FACTS devices

	Load Flow Control	Voltage Control	Transient Stability	Dynamic Stability
SVC	●	●●●	●	●●
STATCOM	●	●●●	●●	●●
TCSC	●●	●	●●●	●●
UPFC	●●●	●●●	●●	●●

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Exhibit 2: Benefits of FACTS devices for different applications

Steady state applications of FACTS

Issue	Problem	Corrective Action	Conventional solution	FACTS device
Voltage limits	Low voltage at heavy load	Supply reactive power	Shunt capacitor, Series capacitor	SVC, TCSC, STATCOM
	High voltage at light load	Remove reactive power supply	Switch EHV line and/or shunt capacitor	SVC, TCSC, STATCOM
		Absorb reactive power	Switch shunt capacitor, shunt reactor	SVC, STATCOM
	High voltage following outage	Absorb reactive power	Add shunt reactor	SVC, STATCOM
		Protect equipment	Add arrestor	SVC
	Low voltage following outage	Supply reactive power	Switch shunt capacitor, reactor, series capacitor	SVC, STATCOM
		Prevent overload	Series reactor, PAR	TCPAR, TCSC
	Low voltage and overload	Supply reactive power and limit overload	Combination of two or more devices	TCSC, UPFC, STATCOM, SVC
Thermal limits	Line or transformer overload	Reduce overload	Add line or transformer	TCSC, UPFC, TCPAR
			Add series reactor	SVC, TCSC
	Tripping of parallel circuit (line)	Limit circuit (line) loading	Add series reactor, capacitor	UPFC, TCSC
Loop flows	Parallel line load sharing	Adjust series reactance	Add series capacitor/reactor	UPFC, TCSC
		Adjust phase angle	Add PAR	TCPAR, UPFC
	Post-fault sharing	Rearrange network or use “Thermal limit” actions	PAR, Series Capacitor/Reactor	TCSC, UPFC, SVC, TCPAR
	Flow direction reversal	Adjust phase angle	PAR	TCPAR, UPFC
Short circuit levels	Excessive breaker fault current	Limit short circuit current	Add series reactor, new circuit breaker	SCCL, UPFC, TCSC
		Change circuit breaker	Add new circuit breaker	
		Rearrange network	Split bus	
Subsynchronous resonance	Potential turbine /generator shaft damage	Mitigate oscillations	series compensation	NGH, TCSC

Legend for Exhibit 3

NGH = Hingorani Damper
PAR = Phase-Angle-Regulator
SCCL = Super-Conducting Current Limiter
SVC = Static Var Compensator
STATCOM = Static Compensator
TCPAR = Thyristor Controlled Phase-Angle Regulator
TCSC = Thyristor Controlled Series Capacitor
TCVL = Thyristor Controlled Voltage Limiter
TSBR = Thyristor Switched Braking Resistor
TSSC = Thyristor Switched Series Capacitor
UPFC = Unified Power Flow Controller

Exhibit 3: Steady state applications of FACTS

FACTS are a well-proven technology.

The first installations were put into service over 20 years ago. As of January 2000, the total worldwide installed capacity of FACTS devices is more than 40,000 MVAr in several hundred installations. While FACTS devices are used primarily in the electricity supply industry, they are also used in computer hardware and steel manufacturing (SVC’s for flicker compensation), as well as for voltage control in transmission systems for railways and in research centers (e.g. CERN in Geneva).

Dynamic applications of FACTS

Issue	Type of System	Corrective Action	Conventional Solution	FACTS device
Transient Stability	A, B, D	Increase synchronizing torque	High-response exciter, series capacitor	TCSC, TSSC, UPFC
	A, D	Absorb kinetic energy	Braking resistor, fast valving (turbine)	TCBR, SMES, BESS
	B, C, D	Dynamic load flow control	HVDC	TCPAR, UPFC, TCSC
Dampening	A	Dampen 1 Hz oscillations	Exciter, Power system stabilizer (PSS),	SVC, TCSC, STATCOM
	B, D	Dampen low frequency oscillations	- Power system stabilizer (PSS)	SVC, TCPAR, UPFC, NGH, TCSC, STATCOM
Post Contingency Voltage Control	A, B, D	Dynamic voltage support	-	SVC, STATCOM, UPFC,
		Dynamic flow control	-	SVC, UPFC, TCPAR
		Dynamic voltage support and flow control	-	SVC, UPFC, TCSC
	A, B, C, D	Reduce impact of contingency	parallel lines	SVC, TCSC, STATCOM, , UPFC
Voltage Stability	B, C, D	Reactive Support	shunt capacitor, shunt reactor	SVC, STATCOM, UPFC
		Network control actions	LTC, reclosing, HVDC controls	UPFC, TCSC, STATCOM
		Generation control	High-response exciter	-
		Load control	Under-voltage load shedding Demand-Side Management Programs	-

Legend for Exhibit 4:

A. Remote Generation – Radial Lines (e.g. Namibia)
B. Interconnected Areas (e.g. Brazil)
C. Tightly meshed network (e.g. Western Europe)
D. Loosely meshed network (e.g. Queensland, Austr.)

BESS = Battery Energy Storage System
HVDC = High Voltage Direct Current
LTC = Transformer-Load Tap Changer
NGH = Hingorani Damper
PAR = Phase-Angle Regulator
SCCL = Super-Conducting Current Limiter
SMES = Super-Conducting Magnetic Energy Storage
STATCOM = Static Synchronous Compensator
SVC = Static Var Compensator
TCPAR = Thyristor Controlled Phase-Angle Regulator
TCSC = Thyristor Controlled Series Capacitor
TCVL = Thyristor Controlled Voltage Limiter
TSBR = Thyristor Switched Braking Resistor
TSSC = Thyristor Switched Series Capacitor
UPFC = Unified Power Flow Controller

Exhibit 4: Dynamic applications of FACTS

Investment costs of FACTS devices.

The investment costs of FACTS devices can be broken down into two categories:
(a) the devices' equipment costs, and (b) the necessary infrastructure costs.

Equipment costs

Equipment costs depend not only upon the installation rating but also upon special requirements such as:

- redundancy of the control and protection system or even main components such as reactors, capacitors or transformers,
- seismic conditions,
- ambient conditions (e.g. temperature, pollution level): and
- communication with the Substation Control System or the Regional or National Control Center.

Infrastructure Costs

Infrastructure costs depend on the substation location, where the FACTS device should be installed. These costs include e.g.

- land acquisition, if there is insufficient space in the existing substation,
- modifications in the existing substation, e.g. if new HV switchgear is required,
- construction of a building for the indoor equipment (control, protection, thyristor valves, auxiliaries etc.),
- yard civil works (grading, drainage, foundations etc.), and
- connection of the existing communication system with the new installation.

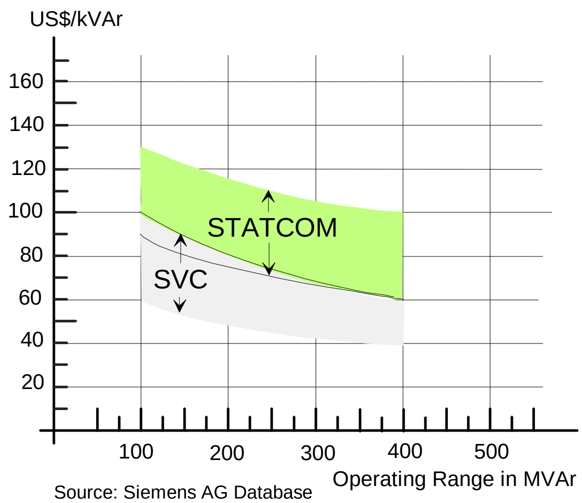

Exhibit 5: Typical investment costs for SVC / Statcom

What are the financial benefits of FACTS devices?

There are three areas were the financial benefits could be calculated relatively easily.

1. **Additional sales** due to increased transmission capability.
2. **Additional wheeling charges** due to increased transmission capability.
3. **Avoiding or delaying of investments** in new high voltage transmission lines or even new power generation.

Exhibit 7 gives indicates the possible additional sales in US$ per year based on different energy

For typical devices' ratings, the lower limit of the cost areas shown in Exhibits 5 and 6 indicates the equipment costs, and the upper limit indicates the total investment costs including the infrastructure costs. For very low ratings, costs can be higher and for very high power ratings costs can be lower than indicated. The total investment costs shown, which are exclusive of taxes and duties, may vary due to the described factors by –10% to +30%. Including taxes and duties, which differ significantly between different countries, the total investment costs for FACTS devices may vary even more.

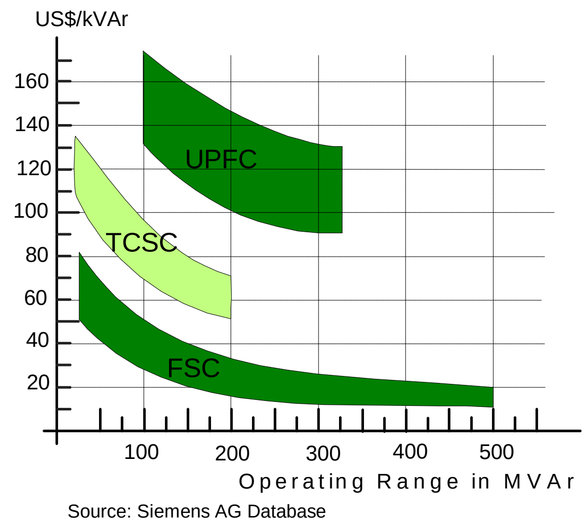

Exhibit 6: Typical investment cost for SC, TCSC and UPFC

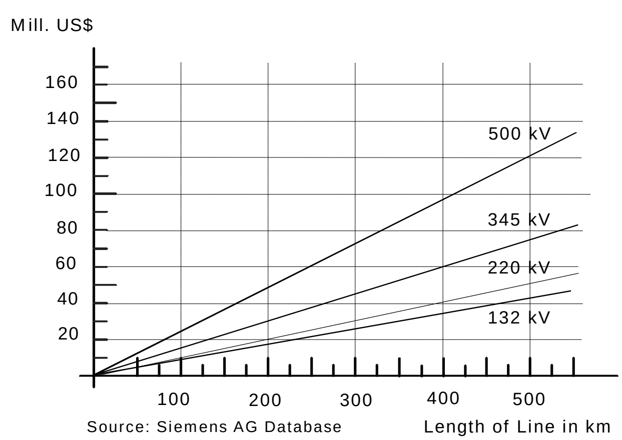

Exhibit 7: Overview yearly sales

costs / prices when a transmission line capacity can be increased.

Exhibit 8 below gives some indication of typical investment costs for new high voltage AC transmission lines.

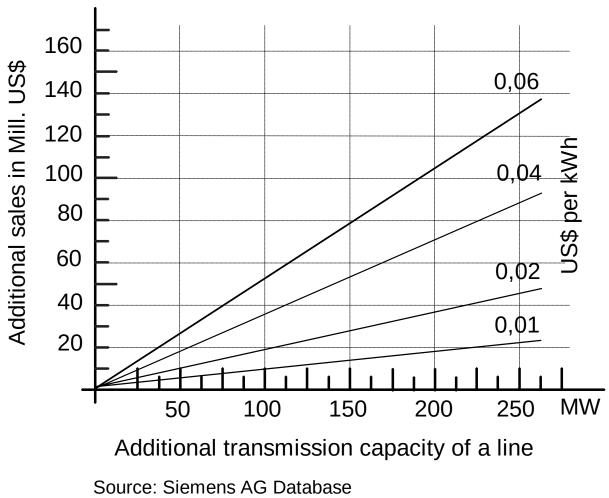

Exhibit 8: Typical costs of new AC transmission lines

Example 1:
If through using a FACTS device, a fully loaded transmission line's capability could be increased by 50 MW (e.g. for transmission lines of 132 kV or higher), this could generate additional sales of 50 MW equivalent. Assuming a 100% load factor and a sales price of 0.02 US$ per kWh, this would result in **additional annual electricity sales of up to US$ 8.8 million.**

Example 2:
Assume that the investment costs of a 300 km long 400 kV line are approx. US$. 45 million. At an interest rate of 10%, this results in annual interest costs of US$ 4,5 million. Installation of a FACTS device for e.g. US$ 20 million could be economically justified, if such an investment can be avoided or delayed by at least 5 years (5 times 4,5 = 22.5).

The above examples are only rough calculations to indicate the possible direct economical benefits of FACTS devices.

There are also indirect benefits of utilizing FACTS devices, which are more difficult to calculate. These include avoidance of industries' outage costs due to interruption of production processes (e.g. paper industry, textile industry, production of semi-conductors / computer chips) or load shedding during peak load times.

Maintenance of FACTS devices

Maintenance of FACTS devices is minimal and similar to that required for shunt capacitors, reactors and transformers. It can be performed by normal substation personnel with no special procedures. The amount of maintenance ranges from 150 to 250 man-hours per year and depends upon the size of the installation and the local ambient (pollution) conditions.

Operation of FACTS devices

FACTS devices are normally operated automatically. They can be located in unmanned substations. Changing of set-points or operation modes can be done locally and remotely (e.g. from a substation control room, a regional control centre, or a national control centre).

Steps for the Identification of FACTS Projects

1. The first step should always be to conduct a detailed network study to investigate the critical conditions of a grid or grids' connections . These conditions could include: risks of voltage problems or even voltage collapse, undesired power flows, as well as the potential for power swings or subsynchronous resonances.
2. For a stable grid, the optimized utilization of the transmission lines – e.g. increasing the energy transfer capability – could be investigated.
3. If there is a potential for improving the transmission system, either through enhanced stability or energy transfer capability, the appropriate FACTS device and its required rating can be determined.
4. Based on this technical information, an economical study can be performed to compare costs of FACTS devices or conventional solutions with the achievable benefits.

Performance Verification

The design of all FACTS devices should be tested in a transient network analyzer (TNA) under all possible operational conditions and fault scenarios. The results of the TNA tests should be consistent with the results of the network study, which was performed at the start of the project. The results of the TNA study also provide the criteria for the evaluation of the site commissioning tests.

The consistency of the results
- of the network study in the beginning of the project,
- of the TNA study with the actual parameters and functions of the installation before going to site and
- of the commissioning tests on site

ensures the required functionality of the FACTS devices.

Worldwide Applications

Seven projects are described below, where FACTS devices have proven their benefits over several years. These descriptions also indicate how the FACTS devices were designed to meet the different requirements of the seven transmission systems. The investment costs for these devices are consistent with the information presented in Exhibits 4 and 5 above.
The construction period for a FACTS device is typically 12 to 18 months from contract signing through commissioning. Installations with a high degree of complexity,, comprehensive approval procedures, and time-consuming equipment tests may have longer construction periods.

The Australian Interconnector

The interconnection of the South Australian, Victoria and New South Wales Systems involved transmission at voltages up to 500 kV over distances exceeding 2200 km. The interconnection is for interchange of 500 MW. Two identical – 100 MVAr (inductive) /+ 150 MVAr (capacitive) SVC's at Kemps Creek improve **transient stability**. Here each SVC consists of two thyristor-switched capacitors and a thyristor-switched reactor that can be switched in combination to provide uniform steps across the full control range.

To ensure reliable operation under all power system conditions, the implementation of the SVC design had to be carefully evaluated prior to installation. The behavior of the SVC was examined at a transient network analyzer under a wide range of system conditions.

The three-state interconnected system and the two SVC's were successfully put into commercial operation in spring 1990. The two SVC's are equipped only with thyristor-switched reactors and capacitors with the advantage that no harmonics are generated and therefor no filters are necessary.
The system operates as expected and proved the original concepts. As part of the interconnected system, the compensators at Kemps Creek have been called upon on several occasions to support the system and have done so in an exemplary manner.

SOUTH AFRICA: Increase in Line Capacity with SVC

The Kwazulu-Natal system of the Eskom Grid, South Africa, serves two major load centers (Durban and Richards Bay) at the extremities of the system. In 1993, the system was loaded close to its voltage stability limit, a situation aggravated by the lack of base load generation capacity in the area. The 1000 MW Drakensberg pumped storage scheme, by the nature of its duty cycle and location remote from the main load centers, does not provide adequate capacity.

Exhibit 9: SOUTH AFRICA: SVC, Illovo.

The installation of three SVCs in the major load centers provides superior voltage control performance compared to an additional new line subject to load switching.
A further motivation for choosing SVCs in this case are their lower capital cost, reduced environmental impact, and the minimization of fault-induced voltage reductions compared to building additional transmission lines. Fault-induced voltage reductions cause major disruption of industrial processes, and mainly result from transmission line faults. The frequency of such reductions is proportional to the total line length exposed to the failure mechanisms (viz. sugar cane fires), resulting in

a desire to minimize the total length of transmission lines. These SVCs went into commercial operation in 1995.

BRAZIL: North – South Interconnection

In Brazil there are two independent transmission grids, the North grid and the South grid. These two grids cover more than 95% of the electric power transmission in the country.
Detailed studies demonstrated the economic attractiveness of connecting the two grids. Inter alia they compared the attractiveness of building an AC or a HVDC (High Voltage Direct Current) connection of more than 1.000 km long passing through an area with a fast growing economy and also with a high hydropower potential. As it is technically much easier and more economical to build new connections to an AC line than to an HVDC line it was decided to build a new AC line.

Exhibit 10: BRAZIL: TCSC, Serra de Mesa

The line, which is now in operation since beginning of 1999, is equipped with SC's (Series Capacitors) and **TCSC's** (Controlled Series Capacitors) to reduce the transmission losses and to stabilize the line.

Initial studies indicated the potential for low frequency power oscillations between the two grids which **TCSC's** can dampen and thereby mitigate the risk of line instability. In addition, the application of **TCSCs** can effectively reduce the risk of subsynchronous resonances (SSRs) caused by the application of SC's in a line. SSRs in a transmission system are resonance phenomena between the electrical system and the mechanical system of turbine – generator shafts in thermal power stations. Under certain conditions SSRs can damage the shaft of the turbine – generator unit, which results in high repair costs and lost generation during the unit repair time.

USA: More Effective Long-Distance HVDC-System

A major addition to the 500 kV transmission system between Arizona and California, USA, was installed to increase power transfer. This addition includes two new series - compensated 500 kV lines and two large SVC's. These SVC's are needed to provide system security, safe and secure power transmission, and support the nearby HVDC station of the Los Angeles Department of Water and Power (LADWP). By installing the SVCs, the LADWP ensured its capability to supply high quality electric power to ist major customers and to minimize the risk of supply interruptions.

The control design for these SVC's, based on detailed analysis, is driven by the unique system requirement of dampening the complex oscillation modes between Arizona and California. Extensive testing on a real-time simulator was done, including the HVDC system originally delivered by another manufacturer before the controls were delivered on site. Field tests during and after commissioning verified these results. These SVC's, ones of the largest installations ever delivered, went into commercial operation early 1996.

INDONESIA: Containerized Design

Load flow and stability studies of the Indonesian power system identified the need for a SVC with a control range of – 25 MVAr to + 50 MVAr at Jember Substation(Bali). The SVC provides fast voltage control to allow enhanced power transfer under extreme system contingencies, i. e. loss of a major 150 kV transmission line. Fast implementation of the SVC was required to ensure safe system operation within the shortest time achievable. To achieve the tight schedule, a unique approach was chosen comprising a SVC design based on containerization to the greatest extent possible to allow prefabrication, pre-installation and pre-commissioning of the SVC system at the manufacturer's workshop. This reduced installation and commissioning time on site and is a step forward for transportable SVC's that can be easily and economically relocated. The Jember SVC was put into commercial operation 1995 in only 12 months after contract signature.

USA: The Lugo SSR Damper

The SSR (Subsynchronous Resonances) damper scheme is a high voltage-thyristor circuit designed to solve a complex problem which in 1970 and 1971 caused damage to the shafts of a turbine-generator connected to the 500 kV transmission network of the Southern California Edison System. Analysis of the cause of the failure identified the SSR phenomenon. SSR can occur in electrical networks, which utilize high levels of conventional SCs to increase transmission lines power carrying capability by compensating the line series inductance. The SSR problem occurs when the amount of SC compensation results in an electrical circuit natural frequency that coincides with, and thereby excites, one of the torsional natural frequencies of the turbine-generator shaft.

Dampening is achieved by using anti-parallel thyristor strings to discharge the SCs at controlled times. Network configurations involving Southern California Edison's Mohave generator were simulated and used to study the worst case SSR problem. In this case, with a high level of SC (70 percent), the effectiveness of the NGH scheme (comprising outdoor valves at high-voltage potential platforms) was evaluated. This device is in successful commercial operation since the 1980's.

USA: The Kayenta TCSC

In the Western Area Power Administration (WAPA) system, USA, transmission of low-cost and renewable hydroelectric energy was limited by a major bottleneck in its high-voltage transmission network. To overcome this limitation, WAPA installed a TCSC device at Kayenta Substation, Arizona – the first ever three-phase thyristor-controlled series compensator. The Kayenta installation, in successful commercial operation since 1992, provides for a power transfer increase of 33 % while maintaining reliable system operation. The Kayenta ASC has operated successfully under all system conditions, including several transmission line faults. This installation provides the technology demonstrator for this type of FACTS device, which, in addition to making better use of existing line capacity, obviated the need for installing an extra transmission line by the local electrical utility.

Future Developments in FACTS

Future developments will include the combination of existing devices, e.g. combining a STATCOM with a TSC (thyristor switched capacitor) to extend the operational range. In addition, more sophisticated control systems will improve the operation of FACTS devices.
Improvements in semiconductor technology (e.g. higher current carrying capability, higher blocking voltages) could reduce the costs of FACTS devices and extend their operation ranges. Finally, developments in superconductor technology open the door to new devices like SCCL (Super Conducting Current Limiter) and SMES (Super Conducting Magnetic Energy Storage).

There is a vision for a high voltage transmission system around the world – to generate electrical energy economically and environmentally friendly and provide electrical energy where it's needed. FACTS are the key to make this vision live.

How the World Bank can facilitate increased usage of FACTS devices

Since **FACTS** devices facilitate economy and efficiency in power transmission systems in an environmentally optimal manner, they can make a very attractive addition to the World Bank's portfolio of power projects. In spite of its attractive features, FACTS technology does not seem to be very well known in the World Bank. The following is a proposed action plan for giving FACTS technology increased exposure in the World Bank:

(a) informing Bank staff and its stakeholders on FACTS technology, including case studies through publishing relevant papers (such as this one) on its "Home Page" and as part of its **Energy Issues** series;

(b) organizing presentations/workshops/training activities in connection with high profile events (such as Energy Week) on FACTS technology as well as in the field to provide information to Borrowers. This has now occurred for the Greater Mekong Subregion (GMS) Workshop on Energy Trade in Bangkok February 2000;

(c) conducting a review of its power sector portfolio over the last twenty years to quantify the level of usage of FACTS devices in Bank projects and identifying lessons learned: and

(d) reviewing its lending pipeline to identify opportunities for increased usage of FACTS technology.

Box

Design, Implementation, Operation and Training Needs of FACTS Devices

Network studies are very important for the implementation of a FACTS device to determine the requirements for the relevant installation. Experienced network planning engineers have to evaluate the system including future developments. Right device – right size – right place – right cost.

Reliable operation of FACTS devices require regular maintenance in addition to using equipment of the highest quality standards. Maintenance requirements are minimal but important.

Optimal use of FACTS devices depend upon well-trained operators. Since most utility operators are unfamiliar with FACTS devices (compared with for example switched reactors or capacitors), training on the operation of FACTS devices is therefore very important. What is important for the operators to know is are the appropriate settings of FACTS devices, especially the speed of response to changing phase angle and voltage conditions as well as operating modes. This training would normally last one to two weeks.

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