ABSTRACT:

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 (focusing 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, South Africa and the USA. The paper concludes with some recommendations that could facilitate the increased usage of FACTS.
**Introduction:**

The need for more efficient electricity system 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:

1. 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.

2. **Thyristor controlled series compensators (TCSCs):**

These are an extension of conventional series capacitors through adding a thyristor-controlled reactor. Placing a controlled reactor in parallel FACTS – For cost effective and reliable transmission of electrical energy 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 sub synchronous resonances, and control of line power flow.

3. **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.

4. **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.

Fig.1: - UPFC Circuit Diagram

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.

<table>
<thead>
<tr>
<th>FACTS Device</th>
<th>Load Flow Control</th>
<th>Voltage Control</th>
<th>Transient Stability</th>
<th>Dynamic Stability</th>
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<tr>
<td>UPFC</td>
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</table>

Increased dynamic and transient grid stability:

- Long transmission lines, interconnected grids, impacts of changing loads and line faults can create instabilities in transmission systems.
- Increased transmission system reliability and availability is affected by many different factors.
- FACTS devices stabilize transmission systems resulting in higher energy transfer capability and reduced risk of line trips.

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 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 pollutants. 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:**

As well as dynamic applications of FACTS in addressing problems in transient stability, dampening, post contingency voltage control and voltage stability. FACTS devices are 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 sub synchronous resonance. For each problem the conventional solution (e.g. shunt reactor or shunt capacitor) is also provided (as well as for dynamic 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).

**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.

Fig.2: FACTS devices are a high-end power technology providing more flexibility in power transmission.

The Tabular column shown in the next page clearly depicts and picturises the applications of various FACTS devices, methods to debug the problems occurring in the Flexible AC Transmission of Electrical Power.
<table>
<thead>
<tr>
<th>ISSUE</th>
<th>Problem</th>
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<tr>
<td></td>
<td>Absorb Reactive Power</td>
<td>Switch Shunt capacitor, Shunt Reactor</td>
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<td></td>
<td>High voltage following outage</td>
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<td>Add shunt reactor</td>
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<tr>
<td></td>
<td>Protect Equipment</td>
<td>Add arrester</td>
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<tr>
<td></td>
<td>Low Voltage following Outage</td>
<td>Supply reactive power</td>
<td>Switch Shunt capacitor, reactor, series capacitor</td>
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<td></td>
<td>Low Voltage and Overload</td>
<td>Supply reactive power and limit overload</td>
<td>Combination of two or more devices</td>
<td>TCSC, UPFC, STATCOM, SVC</td>
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<td></td>
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<td>Add series reactor</td>
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<td></td>
<td>Tripping of Parallel circuit (line)</td>
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</tr>
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<td>Rearrange network or use “Thermal Limit” actions</td>
<td>PAR, Series Capacitor/ Reactor</td>
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</tr>
<tr>
<td>Flow Direction Reversal</td>
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<td>Excessive breaker fault currents</td>
<td>Limit Short-circuit currents</td>
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<td></td>
<td>Change Circuit breaker</td>
<td>Add new circuit Breaker</td>
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<td>Rearrange network</td>
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<td>Sub Sync. resonance</td>
<td>Potential Turbine</td>
<td>Mitigate Oscillations</td>
<td>Series Compensation</td>
<td>NGH, TCSC</td>
</tr>
</tbody>
</table>

**NGH** = Hingorani Damper  **TCSC** = Thyristor Controlled Series  **PAR** = Phase-Angle-Regulator  **TCVL** = Thyristor Controlled Voltage Limiter
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:
- 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),
- Communication with the Substation Control System or the Regional or National Control Center.

Equipment costs depend not only upon the installation rating but also upon special requirements such as:
- FSC
**Fig. 3**: Typical investment cost of statcom & svc

Typical investment cost of UPFC, T CSC, and FSC.

**Fig. 4**: Sales

500kv

345kv

220kv

320kv

3. Avoiding or delaying of investments in new high voltage transmission lines or even new power generation.

**Example:**

Statcom

TCSC

SVC

**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.

Example:

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 these conditions could include: risks of voltage problems or even voltage collapse, undesired power flows, as
well as the potential for power swings or sub synchronous 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 Interconnect:

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...

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.

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

**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).

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 since 1996.

**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.

**CONCLUSION:**

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’s portfolio of power projects. In spite of its attractive features, FACTS technology does not seem to be very well known nowadays.

**Some of recommendations are:**

So there is prerequisite of conducting workshops and seminars both at international and national level on the FACTS devices.

Network studies are very important for the implementation of a FACTS device to determine the requirements for the relevant installation. 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.

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