



RESEARCH ARTICLE

REVIEW AND UTILITY OF VARIOUS FACTS DEVICES IN TRANSMISSION SYSTEM

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ABSTRACT

In developing countries, a pressure associated with environmental and economical constraints has forced the power utilities to meet the future demand by completely utilizing the currently present resource of transmission facilities without building new transmission system. Flexible alternating current transmission systems (FACTS) devices are used to control the phase angle, voltage and impedance of high voltage AC lines. By using FACTS devices maximum benefits of transmission system can be managed i.e. utilization of existing transmission assets; increased transmission system availability and enabling environmental benefits. These FACTS devices have many applications for enhancing and maintaining different parameters such as generation cost, transmission losses, system security and voltage stability in power system. In this paper a brief description about various facts devices is given along with power quality problems and their applications.

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INTRODUCTION

In the present day scenario, transmission systems are becoming increasingly stressed, more difficult to operate, and more insecure with unscheduled power flows and greater losses because of growing demand for electricity and restriction on the construction of new lines. However, many high-voltage transmission systems are operating below their thermal ratings due to constraints, such as voltage and stability limits. Now, more advanced technology is used for reliable and operation of transmission and distribution in power system. To achieve both reliable and benefit economically, it has become clearer that more efficient utilization and control of the existing transmission system infrastructure is required. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics has developed the flexible AC transmission system (FACTS) devices. FACTS devices are effective and capable of increasing the power transfer capability of a line and support the power system to work with comfortable margins of stability. FACTS devices are used in transmission system to control and utilize the flexibility and system performance. To achieve all, the insertion of FACTS devices required in plant in order to control the main parameters namely voltage, phase angle and

impedance, which is affecting ac power transmission. The power system should be capable to for line support of power transfer with comfortable and stable for marginally. Flexible AC Transmission Systems (FACTS) technology help utilities in reducing transmission congestion and in utilizing more efficiently the existing transmission system without compromising the reliability and security of the system. Their fast response offers high potential for power system stability enhancement apart from steady state flow control. The benefits of employing FACTS are aplenty: (a) They help to increase the power transfer capability of existing transmission systems, (b) They can directly control real and reactive power flow, (c) Provide fast dynamic reactive power support and voltage control, (d) Improve system stability and damp power system oscillations, (e) Reduce financial costs and environmental impact by possible deferral of new transmission lines. FACTS devices have been defined by the IEEE as "alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability" (1). There are few well known FACTS devices namely: Static Var Compensator (SVC), Static Synchronous Compensator, Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC). Each of them have their own characteristics and limitations. It would be

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very effective if we could improve voltage stability by incorporating the most beneficial FACTS device for a given operating condition.

Power quality problems

Various Power Quality Problems are as follows

a) **Impulse:** Narrow pulse with fast rise and exponential or damped oscillatory decay; 50 V to 6 kV amplitude, 0.5 μ s to 2 ms duration can be defined as impulse as shown in Fig. 1(a). Its causes are load switching, fuse clearing, utility switching, arcing contacts etc.

b) **EMI:** It can be depicted from Fig. 1(b) and is defined as the repetitive low energy disturbances in the 10 kHz to 1 GHz band, with 100 μ V to 100 V amplitude. It can be caused by normal equipment operation (switching power supplies, motor speed controllers etc) carrier power line communication and wireless broadcasting.

c) **SAG:** It is defined as the decrease in voltage between 0.1pu to 0.9pu and it can be seen in Fig. 1(c). It is due to the starting of heavy load, utility switching and ground fault.

d) **Swell:** An increase in voltage between 1.1pu to 1.8pu can be termed as swell as shown in Fig. 1(d). The main causes of swell are load reduction, utility switching.

e) **Flicker:** Small repetitive fluctuation in voltage level is called flicker. Flicker has been shown in Fig. 1(e). Pulsating load is its main cause.

f) **Notches:** It is known as repetitive dips in the line voltage, with short durations and it can be seen in Fig. 1(f). The main reasons for its occurrence are current commutation in controlled or uncontrolled three-phase rectifier circuit.

g) **Waveform distortion:** The deviation from ideal sine wave due to the presence of harmonics or inter harmonic is called as waveform distortion. Fig. 1(g) represents waveform distortion. It can be caused by rectifiers, phase-angle controllers, other nonlinear and/or intermittent loads.

h) **Outage:** Zero-voltage condition of a single phase or several phases in a multi-phase system, for more than a half-period is known as outage and can be seen from Fig. 1(h). Load equipment failure, ground fault, utility equipment failure, accidents, lightning and other acts of nature are major causes of outage.

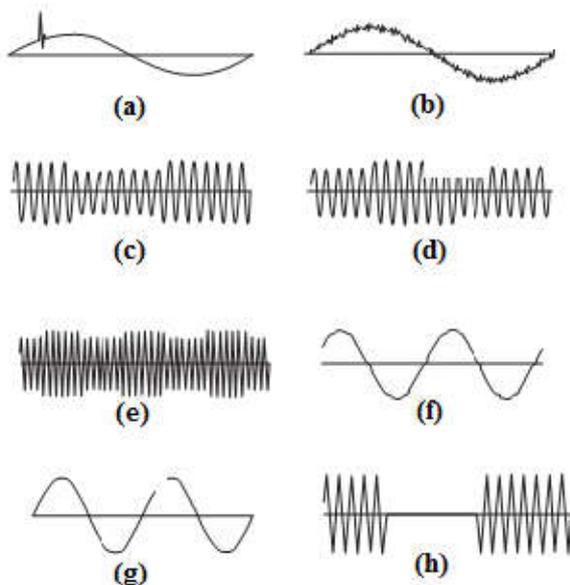


Fig. 1. Power Quality Problems

Classification of facts devices

In power system basically there are only four types of FACTS Controller Devices that are mostly used. They can be classified as:-

- Series Controller
- Shunt Controller
- Combined Series-Series Controller
- Combined Series-Shunt Controller

Series controllers

It may be capacitor or reactor or power electronic based variable source. These controllers inject voltages in series with the line. When voltage and current are in 90 degree phase shift controller only supply or consume variable reactive power. For any other phase real power also considered. (Narain Hingorani and Gyugi, 2000)

Shunt Controllers

Shunt controller also may be capacitor or reactor or power electronic based variable source or a combination of these. Shunt controller inject current in the system. When voltage and current are in 90 degree phase shift controller only supply or consume variable reactive power. for any other phase real power also considered. (Narain Hingorani and Gyugi, 2000) Advanced Facts devices like hybrid facts Controllers are also being used. In order to enhance the performance of the line the location of the controllers device (Nikhlesh Kumar Sharma *et al.*, 2003). FACTS technologies are used for improved dynamic and transmission grid stability by limiting the loading of the transmission lines. Also it balances the active power in the system by balancing the reactive power in the system. The FACTS devices can be further classified on the basis of power electronic device used in controlling are:-

- Variable Impedance Type
- Voltage Source Converter

The VSC based controllers have certain advantage over the Variable Impedance Type controllers. The VSC based controllers are compact in design than the variable impedance controller. The only drawback of the VSC based is that it requires a self commutating circuit which consist of various power electronics devices that requires gate pulses for its operation. The Variable Impedance Type controller comprises of:-

- Static Var Compensator (SVC)
- Thyristor Controlled Series Capacitor or Compensator (TCSC)
- Thyristor Controlled Phase Shifting Transformer (TCPST)

The Voltage Source Controllers can be classified as follows:-

- Static Synchronous Compensator (STATCOM)
- Static Synchronous Series Compensator (SSSC)
- Interline Power Flow Controller (IPFC)
- Unified Power Flow Controller (UPFC)

Some Special Purpose FACTS devices that are listed as below:-

- Thyristor Controlled Braking Resistor (TCBR)

- Thyristor Controlled Voltage Limiter (TCVL)
- Thyristor Controlled Voltage Regulator (TCVR)
- Interphase Power Controller (IPC)

Some of the above mentioned FACTS devices can be explained briefly:-

Static Var Compensator (SVC)

It is basically a first generation Facts device. It consists of variable impedance device, where the control is done by back to back connected thyristors using current control technique. SVC are basically used for the load compensation of fast changing loads. There are basically two types of SVC- Fixed Capacitor-Thyristor Controlled Reactor and Thyristor Switched Capacitor- Thyristor Controlled Reactor. Static VAR compensator used for high voltage power system. There are many advantages using SVC like it improve system stability, reduce losses, maintain the line voltage variation within limits and better utilization of equipments. It consists of shunt capacitors and shunt reactors. Shunt reactor and TCRs is to prevent voltage rise under low load and no load condition. Static capacitor and TSCs (Thyristor switch capacitor) are to prevent voltage sag for peak load. There are two combination uses in practice first one is TCR parallel with fixed capacitor (FC) and another one is TSC in parallel with TCR. If compare with TCR it is better than TCR as TCR only generate reactive power but SVC not only generate but also absorb reactive power. Fig 2 shows the structure of SVC.

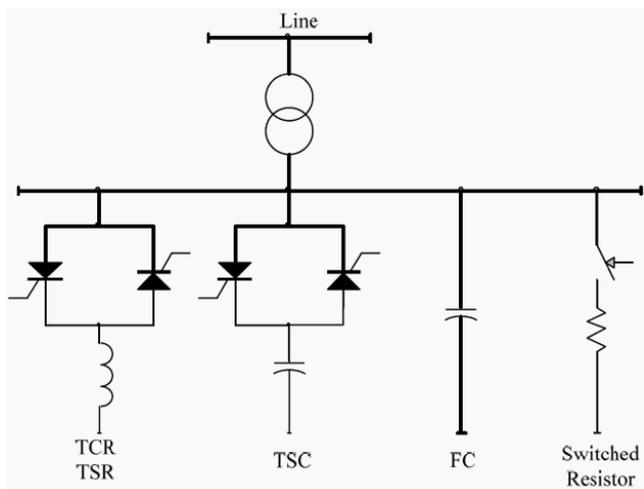


Fig. 2. Static VAR Compensator

Thyristor Controlled Series Capacitor (TCSC)

It basically consists of a series capacitor bank which is connected in parallel with the Thyristor Control Reactor. It can be used as an alternative of SSSC. Fig. 3. shows the structure of TCSC. Thyristor controlled series capacitor (TCSC) is very important series compensator like SSSC. Especially in this FACTS (Flexible alternating transmission system) device, thyristor with gate turn-off capability is not required. Fig 3 shows schematic diagram of a TCSC controller. In TCSC, capacitor is inserted directly into the transmission line and TCR are mounted in parallel with the capacitor. As the capacitor is inserted in series with the line, there is no need of using high voltage transformer and thus it gives better economy. Firing angle of back to back thyristors is controlled to control the reactor. At 180° firing angle TCR, is non-conducting and at 90° firing angle TCR is in full conduction (Abhijit Chakrabarti and Sunita Halder, 2006).

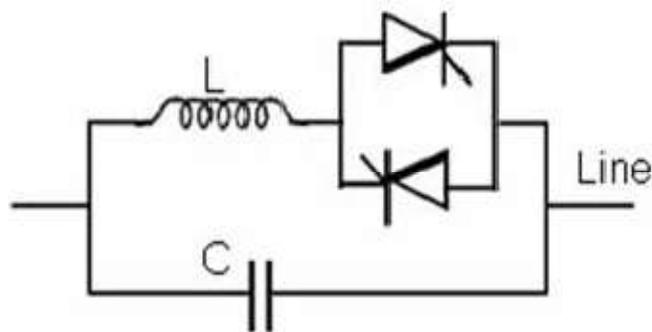


Fig. 3. Thyristor controlled series capacitor

Thyristor Controlled Phase Shifting Transformer (TCPST)

In order to provide a rapidly changing phase angle a phase shifting transformer controlled by thyristor switches are being used. It has been used in order to increase the transient and dynamic stability of the power system .Structure of thyristor controlled phase shifting transformer is shown in Fig.4.

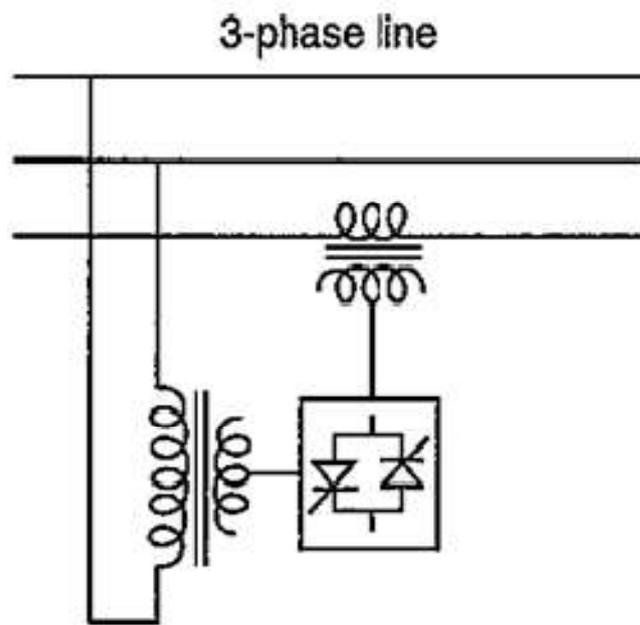


Fig. 4. Thyristor controlled phase shifting transformer

Static Synchronous Compensator (STATCOM)

The concept of STATCOM is proposed in (Narain Hingorani and Gyugi, 2000). STATCOM consist a voltage source controller and shunt connected transformer. it is a voltage source converter that dc power into ac power of variable phase angle and magnitude. It supply desire reactive power by varying the phase angle and magnitude. For industrial application unity power factor can be obtain by using it. The basic structure of STATCOM is shown in Fig. 6. The static synchronous compensator (STATCOM) is another shunt connected GTO based FACTS device. STATCOM is a static synchronous generator operated as a static VAR compensator which can inject lagging or leading var into the system. STATCOM have several advantages. It has no rotating parts, very fast in response, requires less space as bulky passive components are eliminated, inherently modular and relocatable, less maintenance and no problem as loss of synchronism (5). The dc source voltage is converted into ac voltage by the voltage source converter using GTO and ac voltage is inserted

into the line through the transformer. In heavy loaded condition if. Output of VSC is more than the line voltage, converter supplies lagging VARs to the transmission line. During low load condition if line voltage is more than then converter absorbs lagging VAR from the system. If o/p voltage of converter is equal to line voltage, then the STATCOM is in floating condition and this shunt device does not supply or absorb reactive power to the system or from the system.

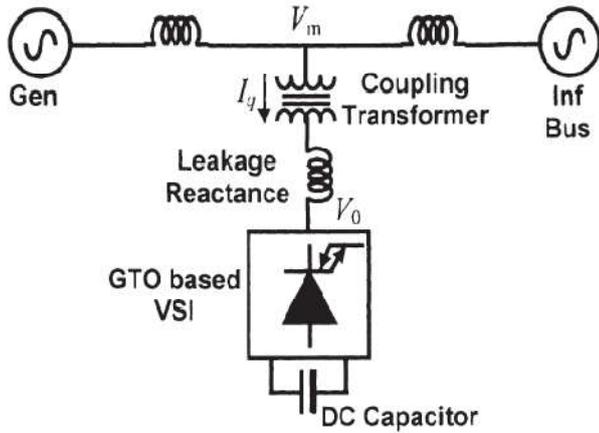


Fig. 6. Basic Structure of STATCOM

Static Synchronous Series Compensator (SSSC)

This is basically a voltage source device. This series connected device injects a series voltage in series with the device. It consists of voltage source inverter and a coupling transformer. For series compensation of power SSSC is used. It is one of the most important FACTS controller in present time. In series compensation the capacitor which is connected in series compensates the inductive reactance of the transmission line. SSSC line current (I) and output voltage (V_c) is at quadrature with each other. The voltage across series capacitor is $-jX_c I$ (where X_c is the capacitive reactance of the series capacitor) and voltage drop across line inductance (X_L) is $+jX_L I$ cancel each other thus reducing the effect of line inductance. Due to this, power transfer capability is increased (5). The symbolic representation of SSSC using voltage source converter is shown in fig.7. Supply voltage from a dc source is converted into ac voltage using VSC (voltage source converter). Coupling transformer is used to inject Quadrature voltage into the line. This injected voltage (V_c) lags the line current (I) by 90° and series compensation is done. Flow of real and reactive power through the system is controlled by SSSC.

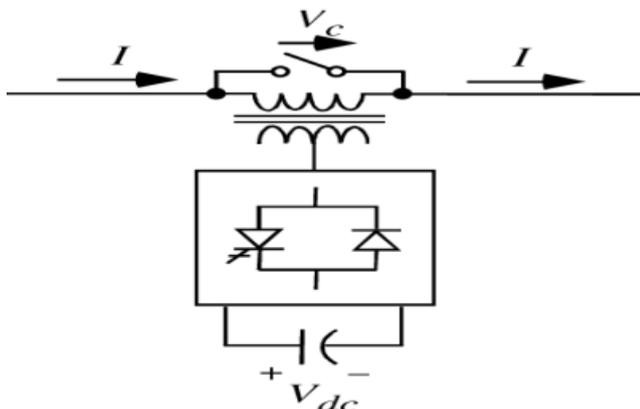


Fig. 7. Static synchronous series compensator

Fixed Capacitor Thyristor Controlled Reactor (FC-TCR)

Simple FC-TCR type SVC configuration is shown in fig.8. In FC-TCR, a capacitor is placed in parallel with a thyristor controlled reactor. I_s , I_r and I_c are system current, reactor current and capacitor current respectively which flows through the FC-TCR circuit. Fixed capacitor- Thyristor controlled reactor (FC-TCR) can provide continuous lagging and leading VARs to the system (5). Circulating current through the reactor (I_r) is controlled by controlling the firing angle of back-back thyristor valves connected in series with the reactor. Leading var to the system is supplied by the capacitor. For supplying lagging vars to the system, TCR is generally rated larger than the capacitor.

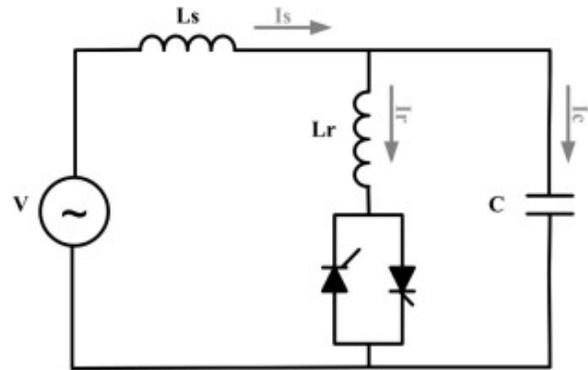


Fig. 8. Fixed capacitor thyristor controlled reactor

Unified Power Flow Controller (UPFC)

Unified Power Flow Controller (UPFC) is the most versatile FACTS device among the entire available one that can be used for enhance steady state stability, dynamic stability and transient stability. The basic configuration of a UPFC is shown in Fig. 8. It consists of two VSC controller one series connected and the other shunt connected. Basically it is a combination of STATCOM and SSSC. It provides series as well as shunt control in the power system. The UPFC is capable of both supplying and absorbing real and reactive power and it consists of two ac/dc converters. The converters are connected in series and shunt with the transmission line along with transformers in the both the converters. The dc side of the two converters is connected through a common capacitor, which provides dc voltage for the converter operation. The power balance between the series and shunt converters is a prerequisite to maintain a constant voltage across the dc capacitor. As the series branch of the UPFC injects a voltage of variable magnitude and phase angle, it can exchange real power with the transmission line and thus improves the power flow capability of the line as well as its transient stability limit. The shunt converter exchanges a current of controllable magnitude and power factor angle with the power system. It is normally controlled to balance the real power absorbed from or injected into the power system by the series converter plus the losses by regulating the dc bus voltage at a desired value.

Comparison of various facts devices

Table 1. Shows the comparison among SVC, STATCOM, UPFC, TCSC, TCPAR and SSSC on the basis of their load flow, voltage control, transient stability and dynamic stability in the form of low, medium, and high.

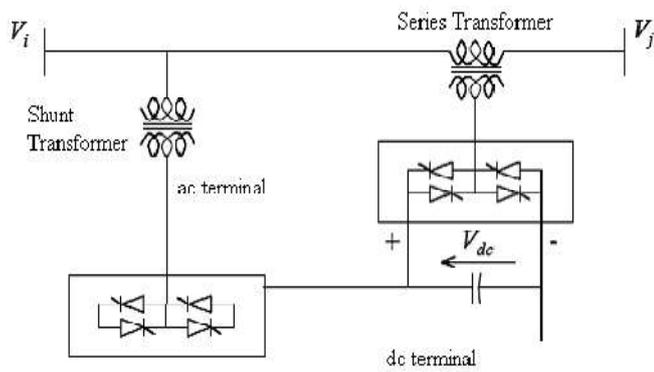


Fig. 8. Configuration of UPFC

Table 1. Comparison table of various Facts devices

Controller	Voltage control	Transient stability	Damping power oscillation	Reactive power comp.	Power flow control	SSR mitigation
SVC	X	X	X	X		
STATCOM	X	X	X	X		
TCSC	X	X	X		X	X
SSSC	X	X	X	X	X	X
TCPAR		X	X		X	X
UPFC	X	X	X	X	X	X

On comparison it is found that UPFC used for higher load flow and voltage control where as STATCOM is used for voltage control in small distribution system and the UPFC shows better results for power system stability improvement compared to the other FACTS devices such as SVC, TCSC, and SSSC.

Facts Application

FACTS APPLICATION FACTS controllers can be used for various applications to enhance power system performance. One of the greatest advantages of using FACTS controllers is that it can be used in all the three states of the power system, namely:

- (1) Steady state,
- (2) Transient and
- (3) Post transient steady state (FACTS Application, 1998).

However, the conventional devices find little application during system transient or contingency condition.

Steady State Application

Various steady state applications of FACTS controllers includes voltage control (low and high), increase of thermal loading, post-contingency voltage control, loop flows control, reduction in short circuit level and power flow control. SVC and STATCOM can be used for voltage control while TCSC is more suited for loop flow control and for power flow control.

1) Congestion Management: Congestion management is a serious concern for Independent System Operator (ISO) in present deregulated electricity markets as it can arbitrarily increase the prices and hinders the free electricity trade. FACTS devices like TCSC, TCPAR (Thyristor Controlled Phase Angle Regulator) and UPFC can help to reduce

congestion, smoothen locational marginal prices (LMP) and to increase the social welfare by redirecting power from congested interface to underutilized lines (Singh and David, 2001; Verma *et al.*, 2001).

2) ATC Improvement: In many deregulated market, the power transaction between buyer and seller is allowed based on calculation of ATC. Low ATC signifies that the network is unable to accommodate further transaction and hence does not promote free competition. FACTS controllers like TCSC, TCPAR and UPFC can help to improve ATC by allowing more power transactions (Xia *et al.*, 2003; Canizares *et al.*, 1998).

3) Reactive Power and Voltage Control: The use of shunt FACTS controllers like SVC and STATCOM for reactive power and voltage control is well known (Gupta *et al.*, 1999; Rao *et al.*, 2000; Song *et al.*, 2000).

4) Loading Margin Improvement: Several blackouts in many part of the world occur mainly due to voltage collapse at the maximum loadability point. Series and shunt compensations are generally used to increase the maximum transfer capabilities of power networks. The recent advancement in FACTS controllers have allowed them to be used more efficiently for increasing the loading margin in the system (Canizares and Faur, 1998; Gyugyi, 1994).

5) Power Flow Balancing and Control Facts: controllers, especially TCSC, SSSC and UPFC, enable the load flow on parallel circuits and different voltage levels to be optimized and controlled, with a minimum of power wheeling, the best possible utilization of the lines, and a minimizing of overall system losses at the same time.

Dynamic Application

Dynamic application of FACTS controllers includes transient stability improvement, oscillation damping (dynamic stability) and voltage stability enhancement. One of the most important capabilities expected of FACTS applications is to be able to reduce the impact of the primary disturbance. The impact reduction for contingencies can be achieved through dynamic voltage support (STATCOM), dynamic flow control (TCSC) or both with the use of UPFC.

1) Transient Stability Enhancement: Transient instability is caused by large disturbances such as tripping of a major transmission line or a generator and the problem can be seen from the first swing of the angle. FACTS devices can resolve the problem by providing fast and rapid response during the first swing to control voltage and power flow in the system (Nelson *et al.*, 1996).

2) Oscillation Damping: Electromechanical oscillations have been observed in many power systems worldwide and may lead to partial power interruption if not controlled. Initially, power system stabilizer (PSS) is used for oscillation damping in power system. Now this function can be more effectively handled by proper placement and setting of SVC, STATCOM and TCSC (Mithulananthan *et al.*, 2003; Yang *et al.*, 1997).

3) Dynamic Voltage Control: Shunt FACTS controllers like SVC and STATCOM as well as UPFC can be utilized for dynamic control of voltage during system contingency and save the system from voltage collapse and blackout.

4) SSR elimination: Sub-synchronous resonance (SSR) is a phenomenon which can be associated with series compensation under certain adverse conditions. TCSC have dynamic characteristics that differ drastically from conventional series capacitors especially at frequencies outside the operating frequency range.

5) Power System Interconnection: Interconnection of power systems is becoming increasingly widespread as part of power exchange between countries as well as regions within countries in many parts of the world. In cases of long distance AC transmission, as in interconnected power systems, care has to be taken for safeguarding of synchronism as well as stable system voltages, particularly in conjunction with system faults. With series compensation, bulk AC power transmission over distances of more than 1,000 km are a reality today. With the advent of TCSC, further potential as well as flexibility is added to AC power transmission.

Application in deregulated environment

Apart from its traditional application for voltage control, power flow control and enhancing steady state and dynamic limits, FACTS controllers are finding new applications in the present deregulated environment. One of the applications is in controlling the "parallel flow" or "loop flow". Loop flow results in involuntary reduction in transmission capacity that may belong to some other utility and hence foreclose beneficial transactions through that line. Utilities can also make use of FACTS controllers in their tie lines, either to shield it from the neighbouring effects, such as wheeling transactions or to participate in such transaction. FACTS devices can also be implemented to ensure the economy in operation by placing it in a suitable line such that least cost generators can be dispatched more. It can also be used to reduce the losses in the system. Yet, another application is to use FACTS to relieve the congestion in the system. FACTS devices can be strategically placed such that congestion cost is reduced, curtailment is decreased and price volatility due to congestion is minimized.

Conclusion

This paper focus on the technical benefits of FACTS devices application in ac transmission system .For the present operating environment of power sector ,FACTS is a viable solution. Each FACTS devices has its own applications in the power system for improving the various parameters of the power system. Facts devices are used for flexible transmission of power and this could be possible by using various facts devices as per the requirement of the system. These devices provide series and shunt compensation or both which balances the reactive power in the system, hence balancing the power transmission in the system.

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