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An Overview of UPFC with PSS for Power Flow Control and System Stability

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Abstract

The expanding industrialization, urbanization of lifestyle has prompted increasing dependency on the electrical energy. These days' power system networks are large in size, perplexing and interconnected, which comprise of many buses and numerous generators. FACTS controllers are introduced in numerous spots for enhancing the functionalities of power system. This paper explores the various FACTS controllers in particular Unified power flow controller (UPFC), its adaptability and capabilities in the power system operation and control. Additionally the Power System Stabilizer (PSS) is a supplementary excitation controller used to damp generator electro-mechanical oscillations. Within the ever changing utility condition, from power system operation and control perspective this review emphasizes the importance of UPFC and PSS. UPFC with PSS will offer improved Transient stability & Dynamic Stability of the system.

Keywords: FACTS, UPFC, VSC, PSS, real and reactive power flow.

INTRODUCTION

The growing Industrialization, urbanization of lifestyle has incited expanding dependence on the electrical energy. These days' power system networks are large in size, perplexing and interconnected, which comprise of many buses and numerous generators. This quick development has brought about couple of vulnerabilities. The significant issues looked by power enterprises in building the match among free market activity are:

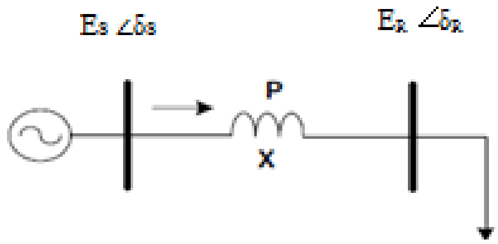
- Supply of desired electric power without surpassing the transmission and distribution thermal limit.
- In substantial Power System, security issues inflicting power disturbances and power outages resulting to huge losses.
- New establishments of power stations and different services are exceptionally determined based on different factors basically on environmental and economic factors.
- Installing new transmission lines are very high priced and require lot of time.

With these conditions, keeping in mind the goal to take care of generally increasing load demand, electric utilities want to be counted upon existing facilities and to plan new approaches to improve the power transmission limit & security [1], [2], [3].

FACTS devices can be a solution to these issues in a substantial way. They can give fast responsive active and reactive power compensation also can be utilized to give power flow control and voltage support, enhanced transient stability and security. The ongoing advancement and utilization of FACTS controllers in power transmission system have prompted numerous uses of these controllers to give operating flexibility and control to the power system [4],[5],[6].

Governable factors of power flow control in power system:

To demonstrate that the power flow in power system simply has definite factors that can be affected via control. Consider the basic and renowned power-angle curve diagram as shown in Fig.1.



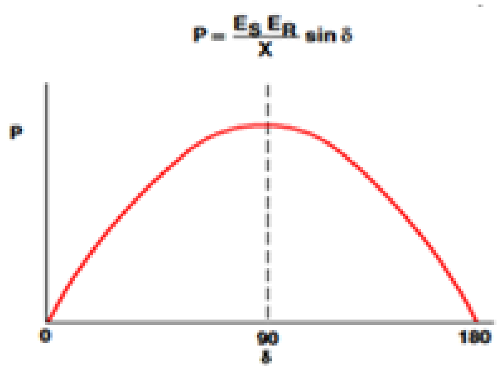


Figure 1. Power angle curve diagram of power system.

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Despite the fact that this is a steady-state curve and the execution of FACTS is principally for dynamic issues. This figure demonstrates the point that there are on a very basic level three primary factors that can be specifically managed in the power system. These are:

- Voltage (E)
- Angle (δ)
- Impedance (X)

One could likewise make the point that fourth factor is the controllability of power. With the establishment of "what" factors can be controlled in a power system, the succeeding inquiry is "the way" these factors can be controlled. The appropriate response is as mentioned in two sections, viz: conventional apparatus and FACTS controllers.

Models of traditional apparatus for improving Power System Control with controllable factor:

- Series Connected Capacitor-Controls impedance
- Switched Shunt connected Capacitor and Reactor-Controls voltage
- Load Tap Changer Transformer -Controls voltage
- Phase Shifting Transformer-Controls angle
- Synchronous Condenser-Controls voltage

Example of FACTS Controllers for improving Power System Control:

- Static Synchronous Compensator (STATCOM) -Controls voltage
- Static Var Compensator (SVC) -Controls voltage
- Unified Power Flow Controller (UPFC)
- Convertible Series Compensator (CSC)
- Inter-phase Power Flow Controller (IPFC)
- Static Synchronous Series Controller (SSSC)
- Thyristor Controlled Series Compensator (TCSC) -Controls impedance
- Thyristor Controlled Phase Shifting Transformer (TCPST) -Controls angle
    - Each of the previously named controllers affect voltage, angle (and power), and/or impedance.

The conventional equipments work out of fixed or mechanically switch capable components like resistance, inductance or capacitance in conjunction with transformers. The FACTS-controllers contain these components and also utilize extra power electronic switches or converters to switch the components in smaller steps or with precise and faster control [7],[8].

THE FACTS CONTROLLERS CLASSIFICATION

The FACTS controller devices are broadly categorized as:

- FACTS controllers based on Thyristor controller, for example, TSC, TCR, SVC, TCSC, and so on.
- FACTS controllers based on Voltage Source Converter, for example, SSSC, STATCOM, UPFC, IPFC and so on.

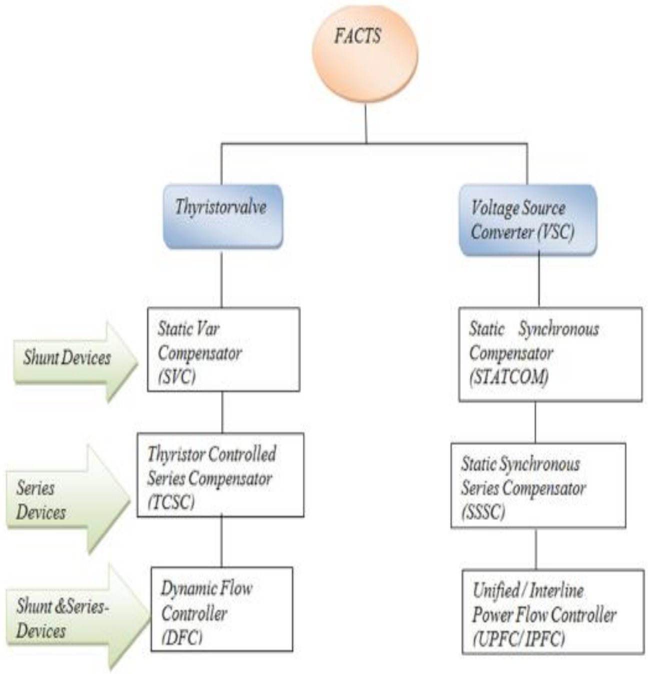


Fig1.1 Overview of categorization of major FACTS devices.

Keeping in mind the end goal to have a superior utilization of the transmission abilities of the transmission lines, distinctive sorts of FACTS controllers have been contemplated: Static VAR Compensator (SVC), Thyristor switched capacitor (TSC), Thyristor controlled reactor (TCR), Thyristor controlled series capacitor (TCSC), Static compensator (STATOM), Static synchronous series compensator (SSSC), Unified Power Flow Controller (UPFC), etc. Various FACTS-controllers are being used for different applications in power system [9],[10],[11] [12].

General categorization of Facts controllers:

i) Series FACTS Controllers

ii) Shunt FACTS Controllers

iii) Combined Series-Series FACTS Controllers

iv) Combined Series-Shunt FACTS Controllers

Series FACTS Controllers:

The series controllers have the quality of being alterable impedance like a capacitor, reactor with power electronics controls. On a basic level, in normal all series controllers infuse voltage in series with the line. Infused series voltage so represented is the result of alterable impedance and the current passing through it. For whatever length of time that the voltage is in phase quadrature with the line current, the series Controller only feeds or absorbs varying reactive power. Some other phase displacement will involve management of real power as well. The different important series compensators are: Static Synchronous Series Compensator (SSSC), Thyristor-Controlled Series Compensation (TCSC).

Shunt FACTS Controllers:

The shunt Controllers might be alterable impedance, for example, Capacitor, reactor or power electronic based variable source, which is shunt associated with the line keeping in mind the end goal to infuse variable current. For whatever length of time that the infused current is in stage quadrature with the line voltage, the shunt Controllers just feeds or absorbs variable reactive power. The important shunt compensators are StaticVar Compensator (SVC), Static Synchronous Compensator (STATCOM).

Combined Series-Series FACTS Controllers:

These Controllers are the blend of individual Series FACTS Controllers, which are controlled in an organized way in a multiline transmission network. The arrangement of Combined Series-Series FACTS Controllers gives autonomous arrangement series reactive power compensation for each line yet in addition transfers real power among the lines via power link. The presence of power link between series controllers names this arrangement as “Combined Series-Series Controller”. The important component is Interline Power Flow Controller (IPFC).

Combined Series-Shunt FACTS Controllers:

These are blend of isolable shunt and series controller, which are controlled in a co-ordinate way or a Unified Power Flow Controller with series and shunt components. When the Shunt and Series FACTS Controllers are brought together; there can be a real power exchange between the series and shunt controllers by means of power link. The important component is Unified Power Flow Controller (UPFC).

Table 1 gives the different FACTS controllers used and their technical contribution to the power system.

Table 1. FACTS controllers and their Technical contribution:

Sl. No.	**FACTS Controller**	**Technical Contribution**
1.	Static synchronous Compensator (STATCOM)	Voltage control, VAR compensation, Transient and dynamic Stability Voltage stability Damping oscillations
2.	Static VAR Compensator (SVC, TSC, TCR)	Voltage control, VAR compensation, Transient and dynamic Stability Voltage stability, Damping oscillations
3.	Static synchronous series Compensator (SSSC)	current control, Transient and dynamic Stability Voltage stability Damping oscillations
4.	Thyristor Controlled series Compensator (TCSC/TSSC)	current control, Transient and dynamic Stability, Voltage stability, Damping oscillations
5.	Unified power flow controller (UPFC)	Active and reactive power control, Voltage control, VAR compensation, Transient and dynamic Stability, Voltage stability, Damping oscillations
6.	Interline power flow controller (IPFC)	Voltage control, Reactive power control, Transient and dynamic, Stability Voltage stability, damping oscillations

CONTROL STRATEGY

Generally a control methodology should have the accompanying characteristics:

1. Steady state objectives (i.e., real & reactive power flows) should be instantly achievable by setting the references of the controllers.
2. Dynamic & transient stability enhancement with the aid of the controller references.

Power system stability is the capacity of an electric power system, for a given preliminary working condition, to recoup a state of working harmony in the wake of being exposed to a physical disturbance, with most system factors having the limits so that for all intents and purposes the whole system remains in equilibrium condition.

Stability of power system continues to be of major interest in system operation. Under normal working conditions the speed of the considerable number of generators essentially remain the same any place of the system. It is known as the synchronous operation of a system any small scale or large scale disruption can disturb this synchronous operation. For instance there can be a sudden change or increment in the load or loss of generation. Another kind of disruption is the changing out of a transmission line which may happen because of overburdening or a line fault. The disruption can be dividing into small and large depending on their magnitude and place of origin. The small disruptions are due to small variations in the load or generation. Transmission line faults sudden load variations loss of generating units and line changing out are the cases of large disruption [13],[14].

A disturbance in the electrical system will produce power fluctuations between the generating units and the electrical network system. Fig.2. shows a typical generator excitation control system functional block diagram for a large synchronous generator [15][16].

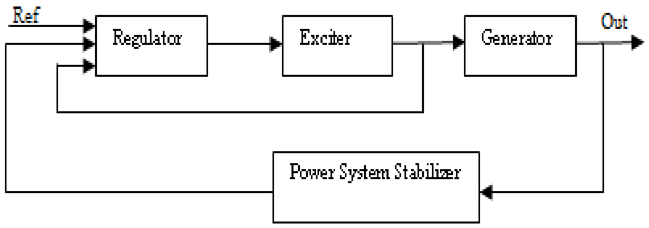


Figure 2. Function block diagram of a generator excitation control system.

Operating Principle of PSS-

The Power System Stabilizer (PSS) is an auxiliary excitation controller accustomed to damp generator electro-mechanical oscillations with a particular goal to safeguard the shaft and stabilize the grid. The overall purpose of power system stabilizer (PSS) is to supplement damping to the generator rotor oscillations by controlling its excitation. Supported by the automatic voltage regulator (AVR) and utilizing frequency deviance, power deviance or speed deviance as extra control signals, power system stabilizer is intended to present an extra torque coaxial with the rotational speed deviation, in order that it will build low-frequency oscillation damping and increase the dynamic stability of the power system. By controlling the magnitude of current supplied to the generator by the exciter, the AVR adjusts the generator terminal voltage. The traditional approach for damping of low frequency electromechanical oscillations causing both local area oscillations (1hz to 2 Hz) and inter area oscillations (0.1 Hz to 1 Hz) is to employ Power System Stabilizer (PSS).

PSS are useful, however they are normally intended for damping local modes and in vast power systems they may not give sufficient damping for inter area modes. Hence in order to enhance damping of these modes, it is important to contemplate FACTS power oscillation damping (POD) controllers [17],[18],[19].

In vast power systems the number of inter area modes are normally larger than the number of control devices available. Broadly, damping of power system oscillations is not the essential rational motive of installing FACTS devices in the power system, but instead power flow control. However, when introduced extra control can be applied to existing devices with the end goal to enhance damping, and in addition fulfill the special requirements of the device. With the end goal to address this issue, analysts over the years, have proposed distinctive methodologies for versatile control structures for PSS and in addition for FACTS devices[20][21][22][23].

UPFC

Among all FACTS controllers, UPFC is the most far reaching multifunctional FACTS device. Unified power flow controller (UPFC) is one of the distinctive FACTS devices that can give concurrent control of all parameters of power system (bus voltage, line impedance and phase angle) and provide dynamic offset to the power system. The UPFC can satisfy the roles of STATCOM, SSSC and phase shifter, and substance various control goals can be used for power flow control, loop-flow control, parallel load sharing among corridors, improvement of transient stability and voltage (reactive power) control.

UPFC operation:

The UPFC comprises of two voltage sourced converters, labeled VSC1 or "Converter 1" and VSC2 "Converter 2" in the figure, is regulated from a common dc link interface given by a dc storage capacitor V_{dc} [Fig.3]. It infuses an AC series voltage into the transmission line and manages the power flow by regulating the amplitude and phase of the infused voltage. The series inverter is regulated to infuse a set of synchronous voltages, V in series with the line. During the time spent doing this, the series inverter will interchange real and reactive power with the line. The series inverter will provide the reactive power electronically and the real power is transmitted to the dc terminals. The shunt inverter functions so as to request this dc terminal power (positive or negative) from the line, consequently controlling the voltage of the dc bus. The total real power consumed from the line by the UPFC is consequently equivalent to the losses of the two inverters and their transformers. The rest of the ability of shunt inverter can be utilized to interchange reactive current with the line.

The shunt inverter is operated in such a way as to draw a regulated current from the line. One part of this current is naturally controlled by the necessity to adjust the real power of the series inverter. The remaining current part is reactive and can be set to any intended point of reference (inductive or capacitive) within the capacity of the inverter. The reactive compensation control modes of the shunt inverter are fundamentally same as those regularly utilized on conventional static VAR compensators [24], [25], [26], [27].

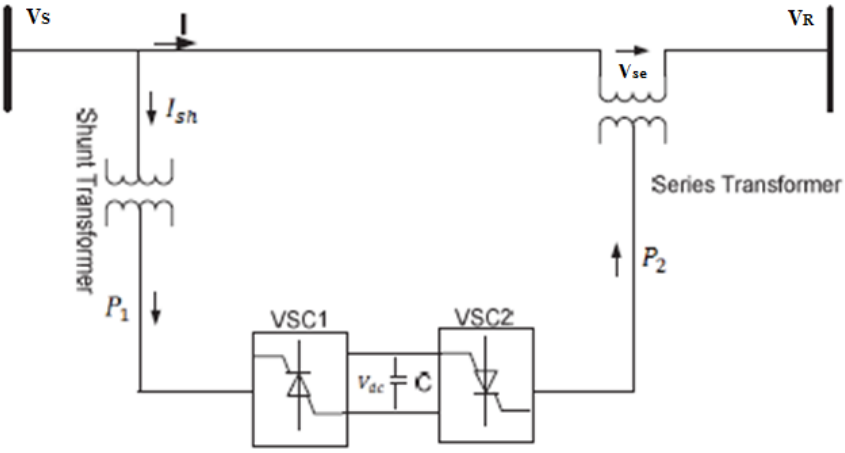
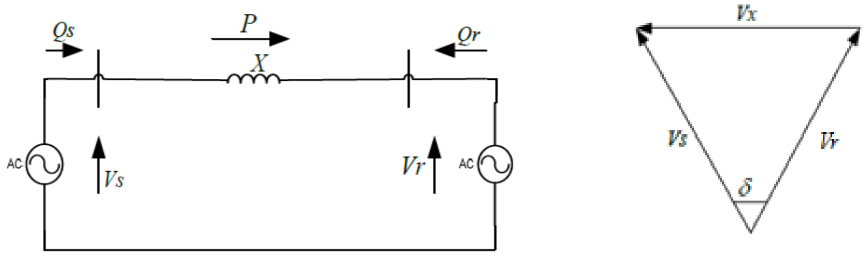


Figure 3. UPFC Connection diagram.

Active and Reactive Power Control by UPFC:

In Fig. 4 (a) elementary two machine (or two bus) system with sending-end voltage Vs, receiving-end voltage Vr, and line (or tie) impedance X (assumed, for simplicity, inductive) is shown. At (b) the voltages of the system in form of a phasor diagram are shown with transmission angle δ and Vs = Vr = V. At the receiving ends of the line the transmitted active and reactive power are P= $\{\frac{V2}{X}\}$ sinδ and Q =Qs= Qr=$\{\frac{V2}{X}\}$ (1 − cosδ). Where P and Q are the active and reactive power in the ac system with voltage magnitudes V_s and V_R between two electrical nodes. The variables δ and X are the phase-angle difference and line reactance between the two nodes respectively. From equations for P and Q it is clear that the active power is principally connected to the phase angle δ, while the reactive power is connected with the difference in voltage-magnitude. The given mathematical relationships are the base of power-angle control. Therefore, the active power is controlled by altering the voltage phase angle. Likewise, the reactive power is regulated by changing the voltage magnitude.



(a) **(b)**

Figure 4. (a) Elementary two machine system (b) Corresponding voltage phasors.

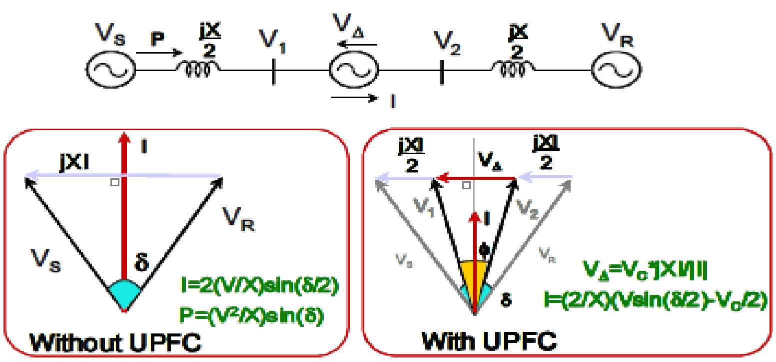


Figure 5. UPFC operation

Fig. 5 demonstrates the phasor diagrams illustrating the UPFC action and its effect on the power system.

It is exceptionally important to enumerate here that these controllers assist the power system with the controlling of vast majority of the parameters. Contributed specialized advantages are following.

- Power flow control.
- Increment in the loading of lines to their thermal limits.
- Increase the transient and dynamic stability, reducing overloads and subsequently making more secure the power system..
- Make a reduction in reactive power flows, in this way enabling the lines to carry more real power.
- Contribute better adaptability for new generation.
- Reduce undesired loop flows.
- Worthwhile improvement of capacity utilization, in this way permit expanded utilization with minimum cost of generation.

Table 2. gives a comparative performance of major FACTS controllers for different applications in power system.

Table 2. Comparative performance of major FACTS controller applications in power system.

FACTS Controller	**Load Flow Control**	**Voltage Control**	**Transient Stability**	**Dynamic Stability**
TCSC	**	*	***	**
SVC/ STATCOM	*	***	**	**
SSSC	***	*	***	**
UPFC	***	***	**	**

*

** Better

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With the advancements in feedback control signals and advanced intelligent control signals, the Power System Stabilizer (PSS) can be tuned to get effective damping and stability enhancement of the system. UPFC with tuned PSS can provide improved Transient stability & Dynamic Stability of the system.

CONCLUSION

This paper presents an overview of different FACTS controllers and their control attributes. The basic highlights of UPFC, its capability to enhance power flow control and system stability influence. Within the ever changing utility condition, UPFC is a highly noticeable amongst FACTS controllers for the operational adaptability and controllability. UPFC with PSS will offer improved Transient stability & Dynamic Stability of the system. In perspective of the different power system contingencies, UPFC gives the preeminent decisive and effective result. Along these lines this review obviously shows that there is an extraordinary potential for UPFC application in the years to come.

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