ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 1, Issue 6, August 2012

Real and Reactive Power flow Control Using Flexible Ac Transmission System connected to a Transmission line: a Power Injection Concept

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***Abstract*—FACTS technology reveals up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The literature shows an increasing interest in this subject for the last two decades, where the enhancement of system stability using FACTS controllers has been extensively investigated and Performance comparison of different FACTS controllers has been discussed. This paper presents a comprehensive review on the developments in the power system stability enhancement using FACTS damping controllers. In addition, some of the utility experience, real-world installations, and semiconductor technology development have been reviewed and summarized. The Unified Power Flow Controller (UPFC) is a second generation FACTS device, which enables independent control of active and reactive power besides improving reliability and quality of the supply. This paper describes the basic principle of operation of UPFC, its advantages and to compare its performance with the various FACTS equipment available.**

***Index Terms* - Flexible AC transmission systems (FACTS), FACTS Controllers, Power flow, Real and reactive power, SSSC, TCSC, Unified power flow controller (UPFC).**

I. INTRODUCTION

The main objective of the power system operation is to match supply/demand, provide compensation for transmission loss, voltage and frequency regulation, reliability provision etc. The need for more efficient and fast responding electrical systems has given rise to innovative technologies in transmission using solid-state devices. These are called FACTS devices which enhance stability and increase line loadings closer to thermal limits.

Flexible AC transmission systems (FACTS) have gained a great interest during the last few years, due to recent advances in power electronics.

FACTS devices have been mainly used for solving various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement [1].

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The development of power semiconductor devices with turn-off capability (GTO, MCT) opens up new perspectives in the development of FACTS devices. FACTS devices are the key to produce electrical energy economically and environmental friendly in future.

The latter approach has two inherent advantages over the more conventional switched capacitor- and reactor-based compensators. Firstly, the power electronics-based voltage sources can internally generate and absorb reactive power without the use of ac capacitors or reactors. Secondly, they can facilitate both reactive and real power compensation and thereby can provide independent control for real and reactive power flow.

Its main objectives are to increase power transmission capability, voltage control, voltage stability enhancement and power system stability improvement. Its first concept was introduced by N.G.Hingorani[2] in April 19, 1988. Since then different kind of FACTS controllers have been recommended. FACTS controllers are based on voltage source converters and includes devices such as Static Var Compensators (SVC), static Synchronous Compensators (STATCOM), Thyristor Controlled Series Compensators (TCSC), Static Synchronous Series Compensators (SSSC) and Unified Power Flow Controllers (UPFC)[2].Among them UPFC is the most versatile and efficient device which was introduced in 1991. In UPFC, the transmitted power can be controlled by changing three parameters namely transmission magnitude voltage, impedence and phase angle.

In this context, the high power switching devices applied at the transmission level is bringing utilities new opportunities as well as new challenges for controlling the main parameters related to power flow and voltage control. Continuous and fast improvement of power electronics technology has made FACTS as a promising concept for power system applications during the last decade. With the application of FACTS technology, power flow along the transmission lines can be more flexibly controlled.

The UPFC concept provides a powerful tool for the cost effective utilization of individual transmission lines by facilitating the independent control of both the real and reactive power flow, and thus the maximization of real power transfer at minimum losses in the line [2].

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II. CONTROL OF POWER SYSTEMS

A. Generation,Transmission,Distribution

When discussing the creation, movement, and consumption of electrical power, it can be separated into three areas, which traditionally determined the way in which electric utility companies had been organized. These are illustrated as;

- Generation
- Transmission
- Distribution

B. Power System Constraints

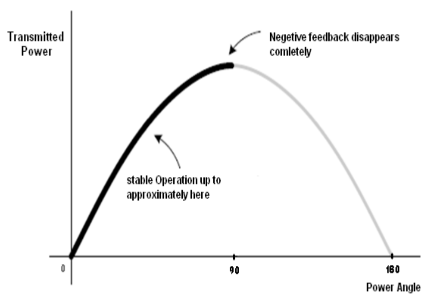
As noted in the introduction, transmission systems are being pushed closer to their stability and thermal limits while the focus on the quality of power delivered is greater than ever. The limitations of the transmission system can take many forms and may involve power transfer between areas (referred to here as transmission bottlenecks) or within a single area or region (referred to here as a regional constraint) and may include one or more of the following characteristics:

- Voltage Stability Limit
- Dynamic Voltage Limit
- Steady-State Power Transfer Limit
- Transient Stability Limit
- Short-Circuit Current Limit
- Power System Oscillation Damping Limit
- Thermal Limit
- Short-Circuit Current Limit

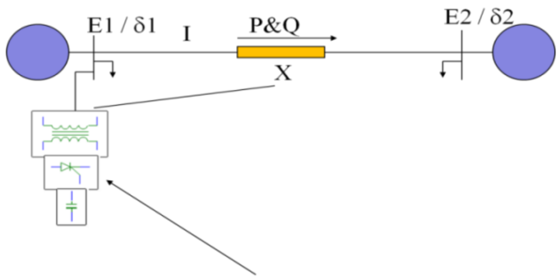
Each transmission bottleneck or regional constraint may have one or more of these system-level problems[3].

C. Controllability of Power Systems

To illustrate that the power system only has certain variables that can be impacted by control, consider the basic and well-known power-angle curve, shown. Although this is a steady-state curve and the implementation of FACTS is primarily for dynamic issues, this illustration demonstrates the point that there are primarily three main variables that can be directly controlled in the power system[4,5] to impact its performance. These are:



- Voltage
- Angle
- Impedance



$$P1 = \frac{E1.E2 \sin(\delta)}{X} \qquad (1)$$

Fig. 1 power flow in Power System

With the establishment of "what" variables can be controlled in a power system, the next question is "how" these variables can be controlled. The answer is presented in two parts: namely conventional equipment and FACTS controllers[6].

Some of the examples of Conventional Equipment For Enhancing Power System Control like,Transformer LTC, Switched Shunt-Capacitor and Reactor, Synchronous Condenser etc, which Controls voltage. Phase Shifting Transformer, and Series Capacitor which Controls angle and impedance respectively. Special Stability Controls, Typically focuses on voltage control but can often include direct control of power.

Some of the examples of FACTS Controllers for Enhancing Power System Control are Thyristor Controlled Series Compensator (TCSC), which Controls Impedance. Static Var Compensator (SVC) which Controls Voltage. Static Synchronous Compensator (STATCOM) which Controls Voltage. Static Synchronous Series Controller (SSSC), Unified Power Flow Controller (UPFC), Inter-phase Power Flow Controller (IPFC) Each of the aforementioned (and similar) controllers impact voltage, impedance, and/or angle (& power)) Thyristor Controlled Phase Shifting Transformer (TCPST) which Controls angle.

D. Benefits of Control of Power Systems

Once power system constraints are identified and through system studies viable solutions options are identified, the benefits of the added power system control must be determined. The following offers a list of such benefits[3].

- Improved Power System Stability
- Increased System Reliability
- Increased System Security
- Increased Loading and More Effective Use of Transmission Corridors
- Added Flexibility in Siting New Generation

The advantages in this list are important to achieve in the overall planning and operation of power systems. However, for justifying the costs of implementing added power system control and for comparing conventional

ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
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solutions to FACTS controllers, more specific metrics of the benefits to the power system are often required.

III. GENERAL PRINCIPLES OF FACTS DEVICES

A. Basic Types of Facts Controller

FACTS controllers may be based on thyristor devices with no gate turn-off, or with power devices with gate turn-off capability. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. FACTS controllers can be divided into four categories:

1. Series controllers.
2. Shunt controllers.
3. Combined series-series controllers.
4. Combined series-shunt controllers.

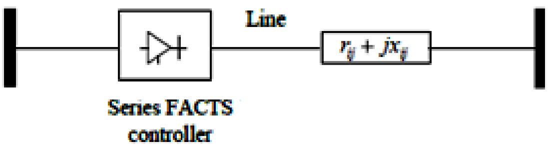


Fig. 2 Static facts controller

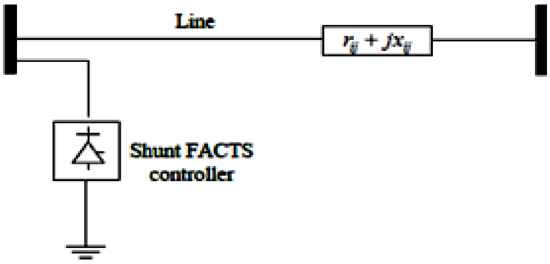


Fig.3 Shunt facts controller

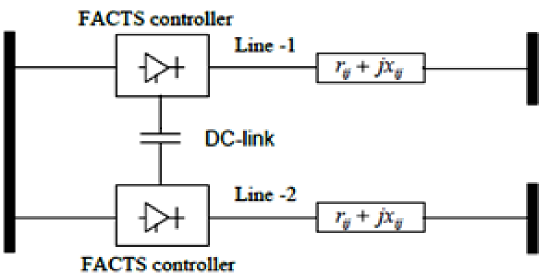


Fig.4 Combined Series-Series Facts Controllers

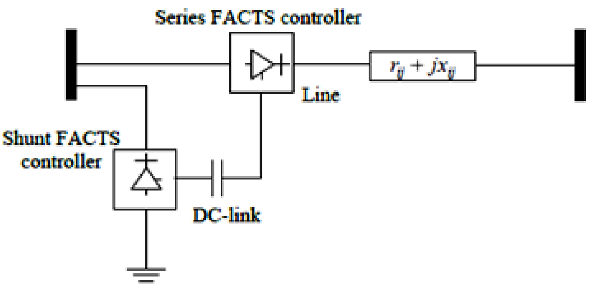
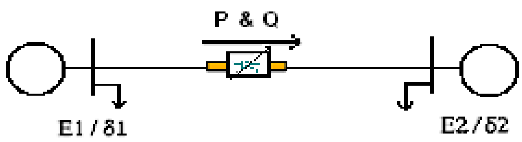


Fig.5 Combined Series-Shunt Facts Controllers

3.2 Thyristor-Controlled Series Capacitor (TCSC)

A. *FACTS Implementation – TCSC*

It is obvious that power transfer between areas can be affected by adjusting the net series impedance. One such conventional and established method of increasing transmission line capability is to install a series capacitor, which reduces the net series impedance, thus allowing additional power to be transferred. Although this method is well known, slow switching times is the limitation of its use. Thyristor controllers on the other hand, are able to rapidly and continuously control the line compensation over a continuous range with resulting flexibility. Controller used for series compensation is the Thyristor Controlled Series Compensator (TCSC) [8].



Line Impedance Compensation Can Control Power Flow Continuously

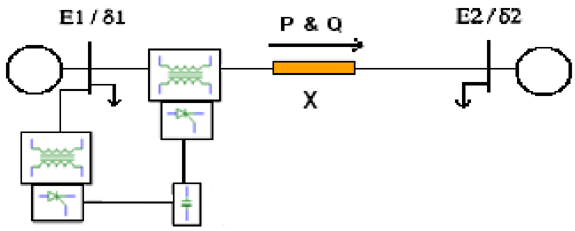
$$P1 = \frac{E1\,(E2.\sin(\delta))}{Xeff} \qquad (2)$$

$$Xeff = X - Xc \qquad (3)$$

TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line [9].

A TCSC is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. The functioning of TCSC can be comprehended by analyzing the behavior of a variable inductor connected in series with a fixed capacitor.

B. *FACTS Implementation – UPFC*



Regulating Bus Voltage and Injecting Voltage in Series with the Line Can Control Power Flow

$$P1 = \frac{E1\,(E2.\sin(\delta))}{Xeff} \qquad (4)$$

$$Xeff = X - Vinj / I \qquad (5)$$

$$Q1 = \frac{E1\,(E2 - E2.\cos(\delta))}{X} \qquad (6)$$

A combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC [1], by means of angularly unconstrained series voltage injection [2, 7, 13] is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt-reactive compensation [14, 15].

IV. FACTS DEVICES MODEL

FACTS devices are varied by particular basic topology and fabricated power electronics elements structure. These make the comparison among each of FACTS hard to be done. General topology [11] or developing of general model is needed for this problem.

A. Power Injection Concept

From the power electronics viewpoint, FACTS employs self-commutated, voltage-sourced switching converters to realize rapid controllable, static, synchronous ac voltage or current sources. This approach provides superior performance characteristics and uniform applicability for transmission voltage, effective line impedance, and angle control. From the power system viewpoint, it also offers the unique potential to exchange active power directly with the ac system, in addition to providing the independently controllable reactive power compensation, thereby giving a powerful new option for flow control and the counteraction of dynamic disturbance. To simplify FACTS devices model, refer to operating of FACTS in the power system viewpoint, it is therefore represented as a power injection device.

B. Basic Elements

To interface FACTS devices into a power system, there are 4 simple configurations as discussed previously. FACTS devices model proposed in this paper is based on active-reactive power injection controlled. Injected active and reactive powers are transformed into currents injected to the bus connecting for shunt configuration

C. General Model

A FACTS device is practically considered as a coordinated and interconnected set of shunt and series configuration models. By coordinating of basic models described in the previous section,

A general model is developed as shown in Fig. The feasible installing location of FACTS defined in this paper, to mitigate power system oscillatory modes in low frequency range (inter-area modes), has been designed to install in between transmission line and near to a bus.

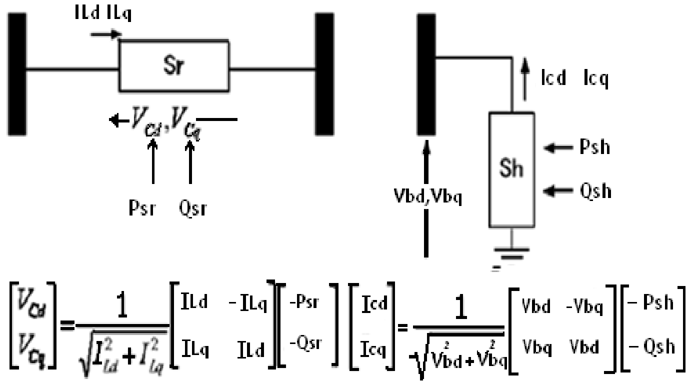


Fig. 6 Basic Elements of Facts Device Modeling

D. Type Definition

In modern world, FACTS is not restricted to be only the power electronic based control reactive compensator. In this paper, FACTS has been defined and categorized into seven types by Power controlled function and power system connecting configuration [11] as follow:

Type 1 Reactive power controlled series configuration

Type 2 Active-Reactive power controlled series configuration

Type 3 Reactive power controlled series configuration

Type 4 Active-Reactive power controlled series configuration

Type 5 Active-Reactive power controlled series-shunt configuration

Type 6 Active-Reactive power controlled series-shunt configuration - Series controlling active power

Type 7 Active-Reactive power controlled series-shunt configuration - Shunt controlling active power

Merging technology of energy storage allows us to control active power compensating into power system effectively [12]

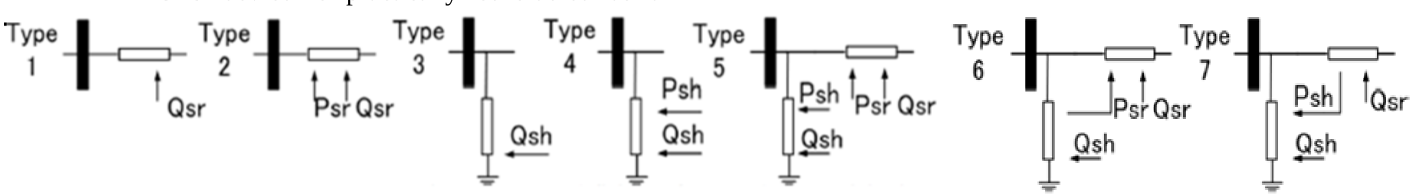


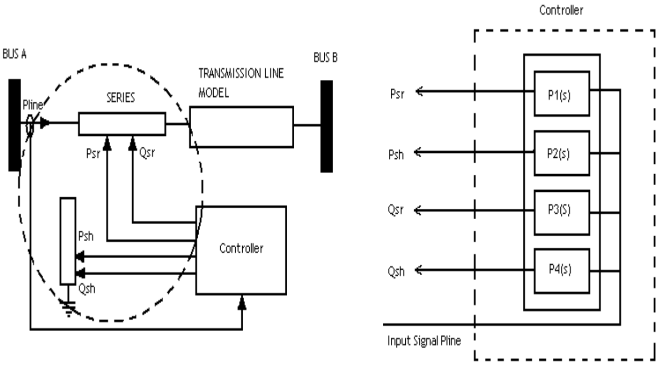
Fig.7 Power controlled function and power system connecting configuration

TYPE	Psr	Psh	Qsr	Qsh
1	X	X	0	X
2	0	X	0	X
3	X	X	X	0
4	X	0	X	0
5	0	0	0	0
6	0*	0	0	0
7	0	0*	0	0

Table 1 Power command signals type coding controlled

Note:

x = switch off
o = switch on
o*=switch on with condition respected to the definition



VI. CONTROL METHODOLOGY

Fig.8 Control Strategy

A. Control Scheme

Facilitation of FACTS device in this paper is to stabilize power system oscillations; therefore, voltage regulation has been ignored by assuming that the generators' automatic voltage regulator [4] provides sufficient voltage regulation and also consideration in small signal disturbance. Input signal detected for power system stabilizing FACTS has been introduced with local active power flow in which FACTS model installed place operating (Pline) that it is easy to measure and have good observability.

VII. FACTS APPLICATIONS IN POWER SYSTEMS

The application of FACTS controllers in power system can obtain, on a case-by-case basis, one or more of the following benefits. The contributions of each FACTS controller are:

- Control of power flow.
- Increase the loading capability of lines
- Improve transient stability limit during contingencies.
- Reduce the short-circuit power level
- Compensate reactive power
- Improve dynamic voltage stability
- Control loop power flow
- Damp power oscillation
- Mitigate voltage unbalance due to single-phase loads

V. CONCLUSION

Finally, an introduction to the basic circuits of several FACTS controllers was provided with a focus on their system performance characteristics. The FACTS controllers clearly enhance power system performance, improve quality of supply and also provide an optimal utilization of the existing resources. It has been concluded that none of the existing FACTS devices namely, TCSC provide reactive power control on transmission lines. In this respect, UPFC has the advantage over TCSC and phase shifter that it can control not only real power but also reactive power flow on transmission lines simultaneously Future systems can be expected to operate at higher stress levels so the FACTS could provide means to control and alleviate stress. All these will hasten the broad application of the FACTS concepts and the achievement of its ultimate goal, the higher utilization of electric power systems.

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