

Unified Power Flow Controller (FACTS Device): A Review

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ABSTRACT

In this study a comprehensive review on unified power flow controller, which is a FACTS device, is presents. The essential features of UPFC controller and mathematical & simulation model was discussed The opportunities arise through the ability of this controller to control the interrelated parameters including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillations at various frequencies below the rated frequency are addressed. By providing added flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating.

Key words: FACTS, UPFC, power flow control, power system stability, simulink etc.

I. INTRODUCTION

In recent years, greater demands have been placed on the transmission network, and these demands will continue to increase because of the increasing number of nonutility generators and heightened competition among utilities themselves. Increasing demand on transmission, absence of long-term planning and the need to provide open access to generating companies and customers all together have created tendencies toward less security and reduced quality of supply. The FACTS technology is essential to alleviate some but not all of these difficulties by enabling utilities to get the most service from their transmission facilities and enhance grid reliability.

On the other hand, as power transfer grow, the power system becomes increasingly more complex to operate and the system can become less secure for riding through the major outages. It may lead to large power flows with inadequate control, excessive reactive power in various parts of the system, large dynamic swings between different parts of the system and bottlenecks.

Due to increase in power demand modern power system networks are being operated under highly stressed conditions. This has resulted into the difficulty in meeting reactive power requirement, especially under contingencies and hence maintaining the bus voltage within acceptable limits [4]. Voltage instability in the system generally occurs in the form of a progressive decay in voltage magnitude at some of the buses .a possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other elements by their protective system

leading to cascaded outages and voltage collapse in the system [5,6].

In recent years, major changes have been introduced into the structure of electric power utilities all over the world. The reason for this was to improve efficiency in the operation of the power system by means of deregulating industry and opening it up to private competition. This is global trend and similar structural changes have occurred elsewhere in other industries, i.e. in the telecommunications and airlines transportation industries. The net effect of such changes will mean that the transmission, generation and distribution system must now adapt to a new set of rules Dictated by open market. Furthermore the adaptation to new generation patterns will also necessities adaptation and require increased flexibility and availability of the transmission system. The power industry has responded to these challenges with the technology of flexible AC transmission system or FACTS. This term may encompass a whole family of power electronic controllers, some of which may have achieved maturity within the industry whilst some others are yet in the design stage.

II. OVERVIEW

The Unified power flow controller (UPFC) concept was proposed by Gyugyi in 1991.in the late 1980s, the Electric Power research Institute (EPRI) formulated the Flexible AC transmission voltage and power flow and reduces dynamic disturbances. Usually the main purpose of FACTS **Transmission system limits:** Power flow over a transmission system is limited by some followings:

- System stability
- Loop flows
- Voltage limits
- Thermal limits of either lines or terminal equipment
- High short circuit level limits

Such transmission on power transfer are primarily due to the lack of high-speed control of inter related electrical parameters including voltage, current, impedance, phase angle, reactive and active power. FACTS controllers enhance the value of AC transmission assets by controlling any one or more of this parameter. Makombe and Jenkins experimentally proved that a UPFC can control the three control parameters either individually or in appropriate combinations at its series-connected output while maintaining reactive power support at its shunt-connected input device is to enhance the useable

transmission capacity of lines and control the power flow.

III. UNIFIED POWER FLOW CONTROLLER (UPFC)

As before told, UPFC concept was proposed by GyuGyi in 1991. The UPFC was devised for real time control and dynamic compensation of ac transmission systems. It provides multifunctional flexibility to solve many of the issues facing the power delivery industries. UPFC is able to control synchronic or individually all the parameters (i.e. voltage, phase angle, and impedance) affecting power flow in the power system network. Thus this unique capability is announced by the adjective “unified” [1].the main reason behind the wide spreads of UPFC are its ability to power flow bi-directionally maintaining well regulated DC voltage, workability in the wide range of operating conditions.

This is the second or latest generation of FACTS technology. This FACTs device combines the two features of two other FACTS devices STATCOM (static synchronous compensator) and SSSC (the static synchronous series compensator). Basically these devices are voltage source converters (VSC's) .the UPFC is a generally synchronous voltage source (SVS). The SVS usually exchange both reactive and real power with the transmission system. Frankly speaking an SVS is able to generate only reactive power exchanged; the real power must be supplied to it, or absorbed from it by a suitable power supply or link [1].

(a) VOLTAGE SOURCE CONVERTERS USED IN UPFC:

STATCOM:

A static synchronous generator operated as a shunt –connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. For the voltage-sourced converter, its ac output voltage is controlled such that it is just right for the required reactive current flow for any ac bus voltage dc capacitor voltage is automatically adjusted as require serving as a voltage source for the converter. STATCOM also designed to act as an active filter to absorb system harmonics. Figures shows the schematic diagram of STATCOM without energy storage system and with energy storage system

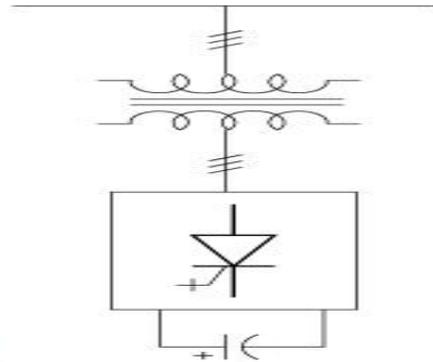


Fig1 shunt connected controller (STATCOM)

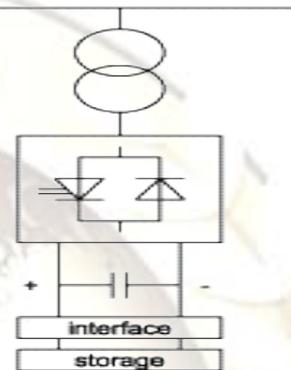


Fig2 STATCOM with storage i.e. battery energy storage system (BESS)

SSSC:

A Static synchronous series generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with and controlled independently of the line current for the purpose of increasing or decreasing overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation to increase or decrease momentarily the overall real voltage drop across the line.

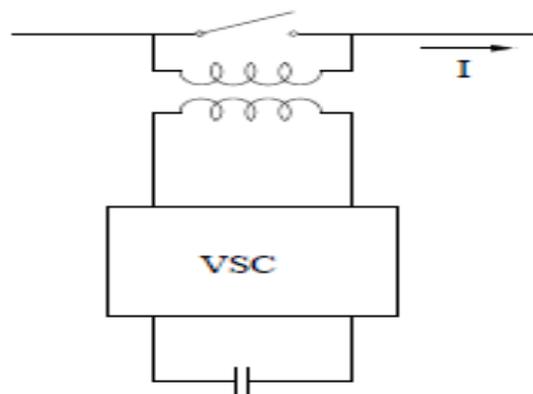


Fig3 Schematic of SSSC

(b) Basic principle of UPFC:

As in the figure show, UPFC consist of two back to back converters named VSC1 and VSC2, are operated from a DC link provided by a dc storage capacitor. These arrangements operate as an ideal ac to ac converter in which the real power can freely flow either in direction between the ac terminals of the two converts and each converter can independently generate or absorb reactive power as its own ac output terminal.

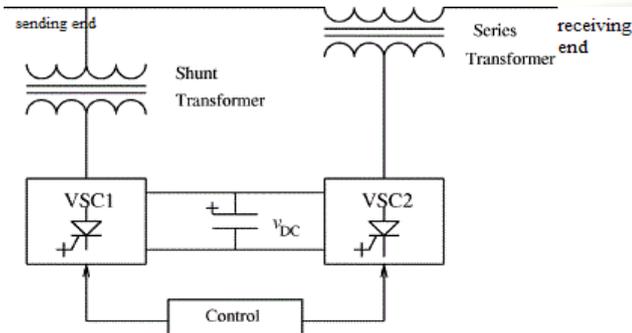


Fig 4 basic UPFC scheme

One VSC is connected to in shunt to the transmission line via a shunt transformer and other one is connected in series through a series transformer. The DC terminal of two VSCs is coupled and this creates a path for active power exchange between the converters. VSC provide the main function of UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an injection transformer. This injected voltage act as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive and active power exchange between it and the ac system. The reactive power exchanged at the dc terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted into dc power which appears at the dc link as a real power demand [1]. And VSC1 is to supply or absorb the real power demanded by converter2 at the common dc link to support real power exchange resulting from the series voltage injection. This dc link power demand of VSC2 is converted back to ac by VSC1 and coupled to the transmission line bus via shunt connected transformer. in addition, VSC1 can also generate or absorb controllable reactive power if it is required and thereby provide independent shunt reactive compensation for the line. Thus VSC1 can be operated at a unity power factor or to be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by VSC1. Obviously, there can be no reactive power flow through the UPFC dc link.

(c) Equivalent circuit of UPFC:

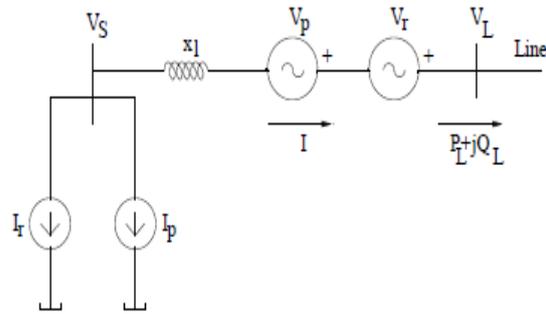


Fig 5 equivalent circuit of UPFC

The equivalent circuit of the UPFC is shown in Fig.5 The shunt converter draws both active (I_p) and reactive current (I_r). The active current (I_p) is not independent and is related to V_p by the relation in steady state.

$$V I_p = I V_p$$

The equivalent circuit of the UPFC can be viewed as a two port network. The shunt converter is connected at one port while the Series converter is connected in series with the line at the other port. The voltage at the latter port is denoted by V_L . If the series injected voltages, V_p and V_r are controlled to regulate the power and reactive power in the line; these quantities are conveniently measured at the line side port of the UPFC.

Since the voltage V_L is normally uncontrolled, the complex power $P_L + jQ_L$

Need not describe a circle for constant (magnitude) VC. Actually, it can be shown that $P_L + jQ_L$ describes an ellipse in the P-Q plane [17]. The complex power S_L is given by

$$S_L = P_L + jQ_L = I^* V_L$$

$$= \frac{V_L^* - V_R^*}{-jX_L} V_L$$

$$\text{Since } V_R = V_L - \frac{\delta}{2}$$

$$\hat{V}_L = \hat{V}_S + \hat{V}_C$$

$$= V \angle \frac{\delta}{2} + V_C \angle \beta$$

P_L and Q_L can be expressed as

$$P_L = P_0 + \frac{V V_C}{X_L} \sin\left(\frac{\delta}{2} + \beta\right)$$

$$Q_L = Q_0 + V \frac{V_C}{X_L} \frac{V V_C}{X_L} \cos\left(\frac{\delta}{2} + \beta\right) + 2 \frac{V V_C}{X_L} \cos\left(\frac{\delta}{2} - \beta\right)$$

$$\text{Since } P_0 = \frac{V^2}{X_L}, Q_0 = \frac{V^2}{X_L} (1 - \cos \delta)$$

$$\text{Defining } Q'_0 = Q_0 + \frac{V^2}{X_L}$$

$$(P_L - P_0)^2 (5 - 4 \cos \delta) + (Q_L - Q'_0)^2 - 4(P_L - P_0)(Q_L - Q'_0) \sin \delta$$

$$= \frac{V^2 V_C^2}{X_L} (2 \cos \delta - 1)^2$$

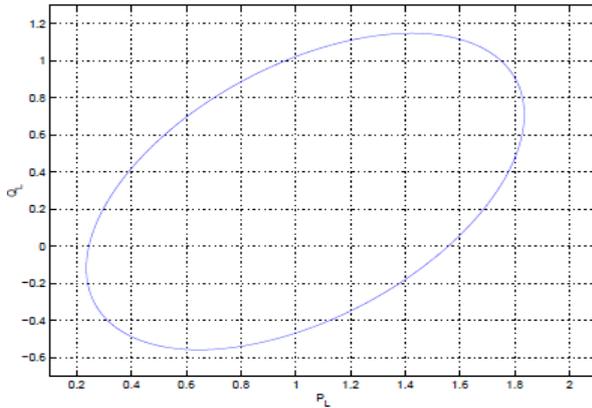


Fig 6 operating region in the $P_L - Q_L$ plane

The above is an equation for ellipse with the centre $(P_0, Q_0 + \frac{V^2}{X_L})$.

It is to be noted that I_r can be controlled to regulate the voltage V_S if it is not regulated by the generator connected at the sending end. Thus, three variables, V_S , P_L and Q_L can be regulated by controlling I_r ; V_C and β . It is assumed that there are no constraints imposed by the equipment ratings that will limit the control objectives.

(d) Control of UPFC

As the UPFC consists of two converters that are coupled on the DC side, the control of each converter is explained below:

Control of the Shunt Converter

Simulink model of shunt converter is shown in fig 12. The shunt converter draws a controlled current from the system. One component of this current is I_p which is automatically determined by the requirement to balance the real power supplied to the series converter through the DC link. This power balance is enforced by regulating the DC capacitor voltage by feedback control.

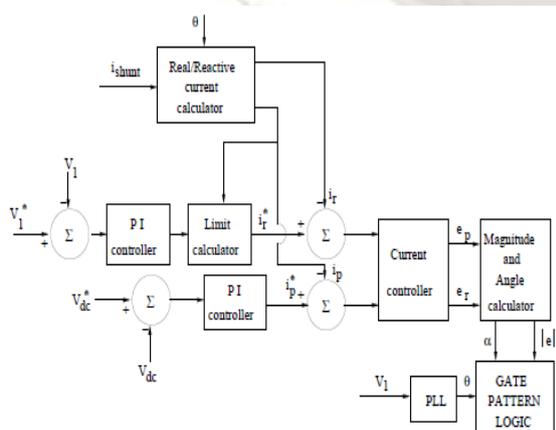


Fig 7 block diagram of shunt controller

The other component of the shunt converter current is the reactive current, I_r which can be controlled in a similar fashion as in a STATCOM. There are two operating (control) modes for a STATCOM or the shunt converter [17]. These are,

1. VAR control mode where the reactive current reference is determined by the inductive or capacitive VAR command. The feedback signals are obtained from current transformers (CT) typically located on the bushings of the coupling (step down) transformer.
2. Automatic voltage control mode where the reactive current reference is determined by the output of the feedback voltage controller which incorporates a droop characteristic (as in the case of a SVC or a STATCOM). The voltage feedback signals are obtained from potential transformers (PT) measuring the voltage V_1 at the substation feeding the coupling transformer.

Control of the series converter

Simulink model of series converter is shown in fig 11. In this control mode, the series injected voltage is determined by a vector control system to ensure the flow of the desired current (phasor) which is maintained even during system disturbances (unless the system control dictates the modulation of the power and reactive power).

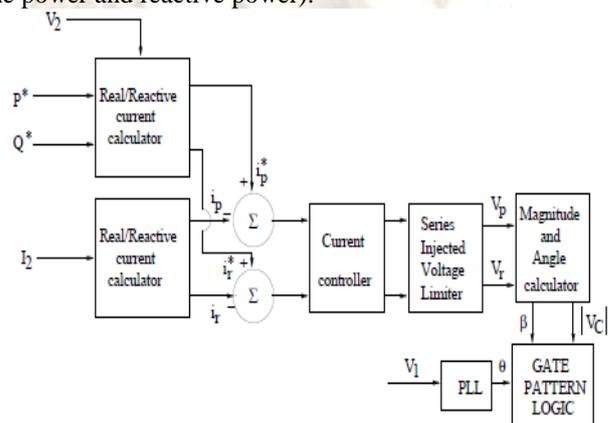


Fig 8 block diagram of series controller

Although the normal conditions dictate the regulation of the complex power flow in the line, the contingency conditions require the controller to contribute to system stability by damping power oscillations.

The different control modes for the series voltage are given :

1. Direct voltage injection mode where the converter simply generates a voltage phasor in response to the reference input. A special case is when the desired voltage is a reactive voltage in quadrature with the line current.
2. Phase Angle Shifter Emulation mode where the injected voltage V_C is phase shifted relative to

the voltage V_1 by an angle specified by the reference input.

- Line impedance emulation mode where the series injected voltage is controlled in proportion to the line current.
- Automatic power flow control mode where the reference inputs determine the required real power (P) and the reactive power (Q) at a specified location in the line.

(e) Simulink model of UPFC

There is simulink model of UPFC shows in figures which are described in Mat lab.

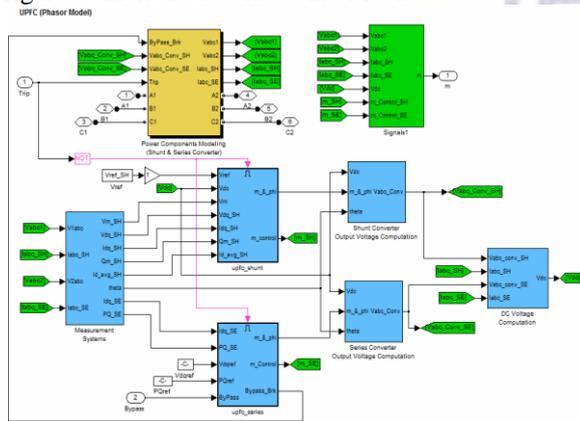


Fig 9 UPFC (phasor model)

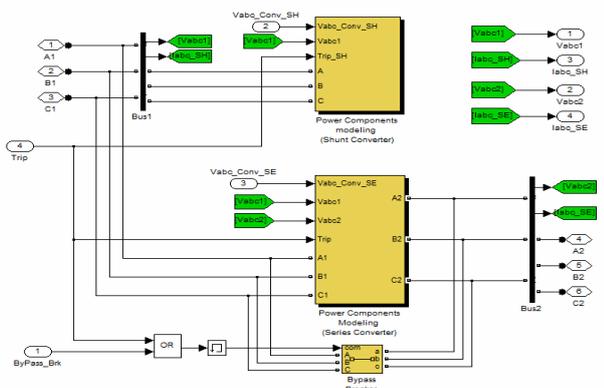


Fig 10 shunt and series converter model

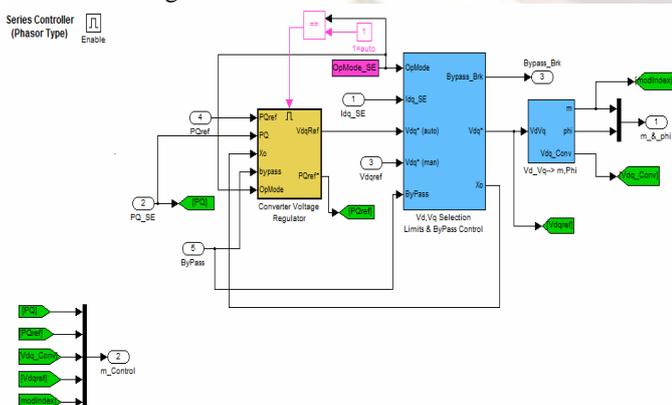


Fig 11 series controller (SSSC)

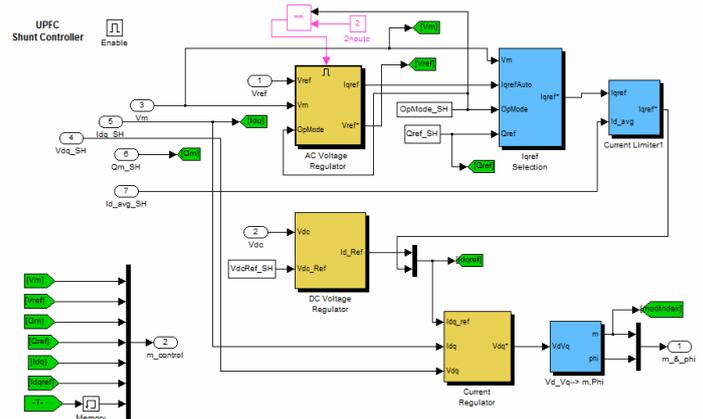


Fig12 shunt controller (STATCOM)

IV. CONCLUSION

In this study, a brief review of UPFC (FACTS), the essential features of UPFC controller and mathematical & simulation model was discussed. The potential to enhancement of power system stability was explained. In power system transmission, it is required to maintain the voltage magnitude, phase angle and line impedance. Consequently, to control power flow over designated transmission line and enhancement of power system stability FACTS devices are used in modern power system network. In this paper the role of UPFC device in power system and current status of electric power system network are addressed. Therefore, following results are found power flow control is achieved by using FACTS (UPFC) devices. Transient stability is improved and faster steady state is achieved. Hence congestion is less by improving transient stability.

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