Comparative analysis of distribution network performance improvement with TCSC and UPFC devices

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Abstract—

In an A.C Transmission system power flow can be controlled by injecting a compensating voltage in series with the line. Thyristor Controlled series compensator(TCSC) are utilized as a conventional means for the purpose while Unified power flow controller (UPFC)is the latest converter based devices employing fast power electronic equipments. This paper utilizes the steady state model of Thyristor controlled series capacitor and a unified power flow controller for series voltage compensation, and evaluating their range of power flow control for simple network. The models are incorporated into the existing Newton Raphson load flow algorithm. The iterative equations of the Newton Raphson load flow algorithm are modified by the device parameters and the combined set of power flow equations and UPFC or the TCSC control equations are solved for convergence of the formula. Matlab codes are utilized for the implementation of the two devices in the Newton-Raphson algorithm. Power flow control ranges are evaluated for few IEEE bus systems and standard 5 bus system. Results are reported and studies are presented to illustrate and compare the effectiveness of the UPFC and TCSC.

Index Terms--Control Strategy, Converters,Matlab, Newton Raphson algorithm, Power flow, TCSC, UPFC.

I. INTRODUCTION

OWING to the higher industrial demands and deregulation of the power supply industry the transmission facilities are being overused. This provides the momentum for exploring new ways of maximizing the power transfers of existing transmission facilities while, at the same time, maintaining acceptable levels of network reliability and stability. This scenario makes necessary the development of high performance control of the power network. Recent advancement in power electronics has proven to satisfy this need by introducing the concept of flexible AC transmission system (FACTS). The FACTS controllers are used in regulating the power flows, transmission voltages and mitigate the dynamic disturbance.

Since its inception the FACTS devices has developed in steps, the first generation being mechanically controlled capacitors and inductors. The second generation of FACTS devices replaced the mechanical switches by the thyristor valve control. This gave a marked improvement in the speed and the enhancement in concept to mitigate the disturbances. The third generation exploited the concept of converter based devices. These devices provide multidimensional control of the power system parameters [7], [8]. Power flow in a transmission line can be controlled by regulating the voltage at the two ends of the line, the phase angle or the reactance of the line. Thyristor controlled series compensators works on the principal of regulating the voltage of the transmission line by injecting voltage employing capacitor or inductor. Converter based Unified power flow controller regulates the output voltage of the converter to control the power flow [7]-[9]. In order to fully investigate the impact of these devices on power system effectively, it is essential to formulate their correct and appropriate model. Generally there are three types of model of FACTS devices available in the literature.(i) Steady state model for system study state evaluation.(ii)Electromagnetic model for detailed equipment level investigation.(iii) Dynamic models for stability studies.

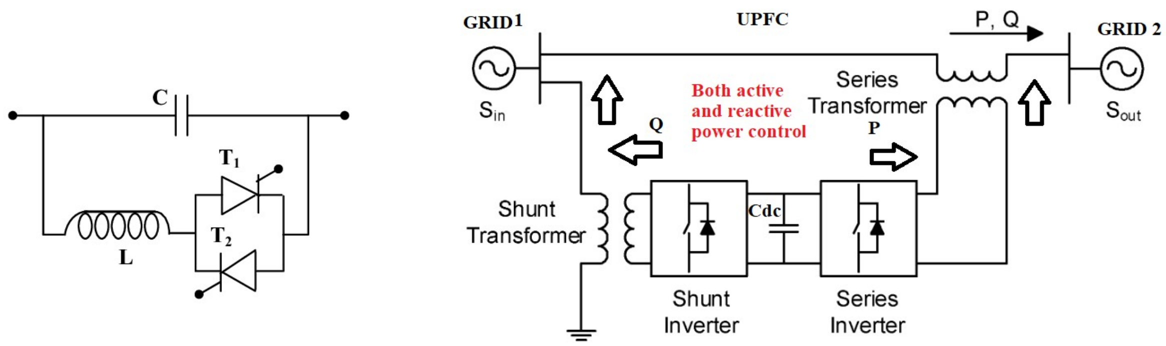

Figure 1: TCSC and UPFC structure

This paper deals with the steady state models of UPFC [2]-[5] and TCSC [6] which can be incorporated in Newton Raphson load flow algorithm. According to connection FACTS devices are divided into four type i.e. series controller, shunt controller, combination of series-shunt controller and combination of series-series controller. (FACTS) controllers should be fixed at appropriate locations in the power system. Flexible AC Transmission Systems (FACTS) technology helps utilities in reducing transmission overcrowding and in utilizing more efficiently the existing transmission system without compromising the reliability and safety of the system. Apart from steady state flow control their quick response offers high potential for stability of power system and its enhancement. The benefits of employing FACTS are many: (a) Increasing the power transfer capability of existing transmission systems, (b) Directly controlling real and reactive power flow, (c) Provide fast dynamic reactive power support and voltage control, (d) Improving system stability, (e) Reduce financial costs and environmental impact by possible deferral of new transmission lines[6-7]. In this paper among various FACTS controller series controller i.e. thyristor controlled series capacitor (TCSC) and combination of series and shunt controller i.e. Unified power flow controller (UPFC) are considered.

II. TCSC CONFIGURATION

TCSC has been used for many years to control power flow [10]. The basic configuration of TCSC is shown in Fig. 1. TCSC consists of three main components; bypass inductor (L), capacitor banks (C), and two antiparallel Thyristor T1 and T2. The TCSC reactance can be adjusted according to the firing angle (α) of the Thyristor to control the active power flow of the connected line. However, this device can be represented as a variable reactance (X_{TCSC}) as shown in Fig. 2.

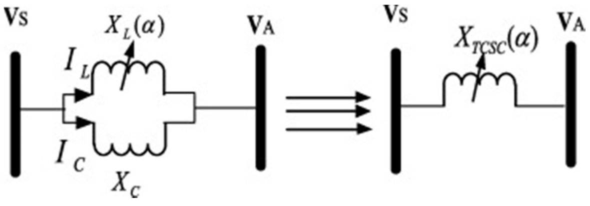

Fig. 2. TCSC equivalent circuit.

The TCSC reactance is calculated as follows:

$$X_{TCSC} = X_C // X_L(\alpha) = \frac{X_C X_L(\alpha)}{X_C + X_L(\alpha)}$$

where

$$X_L(\alpha) = X_{Lmax}\left[\frac{\pi}{\pi - 2\alpha - sin(2\alpha)}\right]$$

$$X_{Lmax} = L.\omega$$

$$X_C = \frac{1}{C.\omega}$$

The final X_{TCSC} can be calculated using (5).

$$X_{TCSC} = \frac{X_C . X_{Lmax}\left[\frac{\pi}{\pi - 2\alpha - sin(2\alpha)}\right]}{X_C + X_{Lmax}\left[\frac{\pi}{\pi - 2\alpha - sin(2\alpha)}\right]}$$

The relation between the X_{TCSC} and α can be drawn as given in Fig. 3. This curve is divided into capacitive, inductive, and resonance regions.

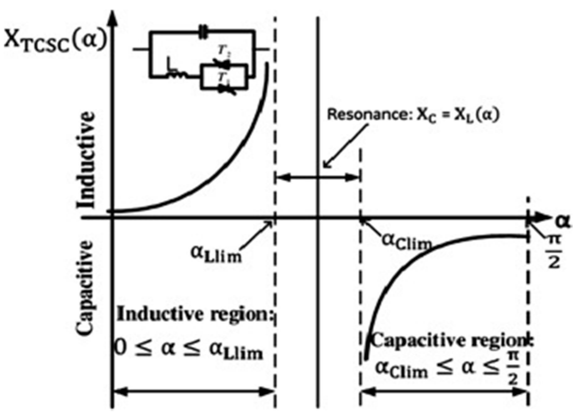

Fig. 3. X_{TCSC} characteristic curve.

The proposed TCSC model is based on the power injection approach. The total number of buses for the system is increased according to the TCSC number, where, one reference bus should be added for each TCSC. Fig 3 illustrates the TCSC implementation between sending bus S and receiving bus R, where bus A is the auxiliary bus (reference bus). This device is used to adjust the active power between sending and receiving buses to equal the specified value, P^{SP}. However, this device can be modeled simply as two loads injected at sending and auxiliary buses as shown in Fig. 4. The active power of these loads is fixed at the specified value SP while the reactive powers are calculated by applying Kirchhoff's Current Law (KCL) at sending and auxiliary buses.

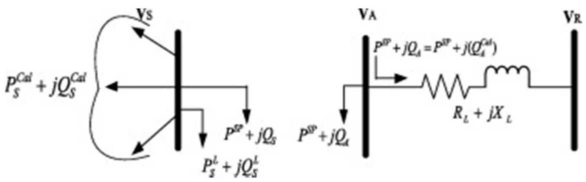

Fig. 4. Simple TCSC Model.

III. UPFC CONFIGURATION

Unified Power Flow Controller (UPFC) is a Flexible AC Transmission System (FACTS) based real and reactive power compensating device. It is a flexible device compared to three-phase controlled bridges. A UPFC is a combination of series and shunts connected Voltage source Converters connected back to back in other means we can also call it a combination of Static Compensators (STATCOM) and Static Series Synchronous Compensators (SSSC) linked via DC bus (DC link voltage). It provides active and reactive power control for a transmission line.

Purpose of Unified Power Flow Controller

UPFC FACTS devices boost power flow regulation through series and shunt connected back-to-back with each other. A DC capacitor bank between the converter can store energy for compensation. The main purpose of UPFC are listed here:

1. Control of line reactive and active power.
2. Enhances Power system capacity.
3. Limits transitory disturbances.
4. Upgrade synchronous rotor angle stability.
5. Strengthens system against low-frequency damping oscillations.
6. Protects the transmission line during any faults or disturbances, i.e., UPFC disconnects during any fault.
7. Subdue power system oscillations.

UPFC consists of a shunt-connected voltage source converter VSC-1 coupled with the transmission line via a coupling transformer and a series connected voltage source converter VSC-2 connected via a series transformer. Both converters are connected back to back and coupled through DC capacitor banks.

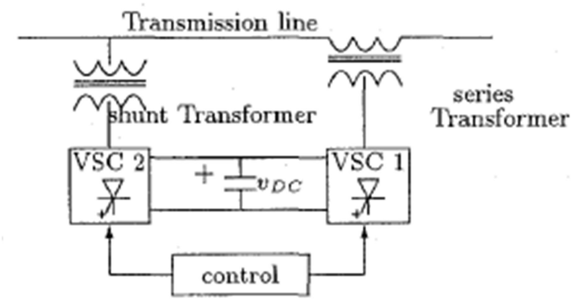

Fig.5 : Structure of UPFC

The shunt and series connected converters provide active and reactive power compensation for the connected transmission line. The series connected VSC-1 exchange both reactive and real power by controlling the injected voltage between V_{pq}– $V_{pq,max}$, and phase angle between 0-360^0.
While the shunt converter VSC-2 compensates for the real power demand by supplying from the transmission line to the VSC-1. VSC-2 also maintains constant voltage at the DC terminals. The DC capacitor banks help for the absorption and generation of actual power through energy storage. Overall the net real power drawn from the power system equalizes with the losses imposed in the two converters.

Operational constraints of UPFC

- The magnitude of the series voltage injected into the transmission line.
- Compensating line current constraints.
- Rating of shunt connected converter.
- Power transfer limits of the UPFC to the transmission line
- Actual power transfer capacity between series and shunt-connected converters.

Simulink model of shunt converter is shown in fig 6. The shunt converter draws a controlled current from the system. One component of this current is Ip 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.

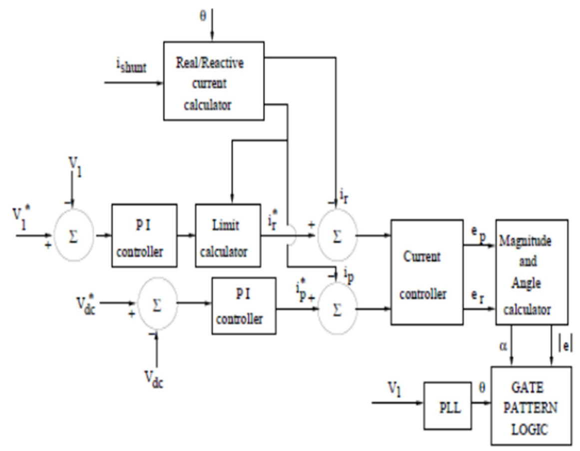

Fig 6: block diagram of shunt controller

The other component of the shunt converter current is the reactive current, Ir 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 V1 at the substation feeding the coupling transformer.

Simulink model of series converter is shown in fig 7. 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).

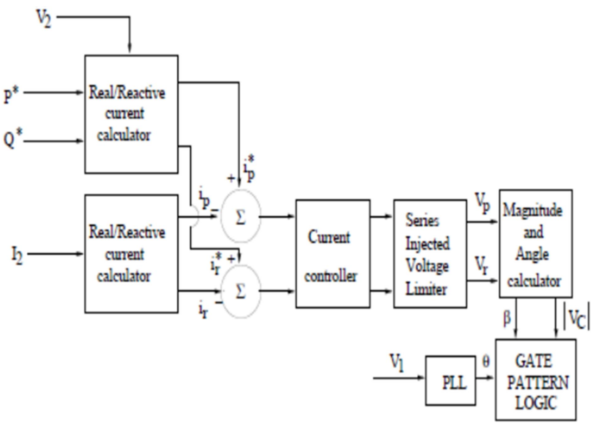

Fig 7: block diagram of series controller

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 is phase shifted relative to the voltage by an angle specified by the reference input.

3. Line impedance emulation mode where the series injected voltage is controlled in proportion to the line current.

4. 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.

IV. SIMULINK RESULTS

A. TCSC Compensation System

The MATLAB/SIMULINK model for a TCSC compensated system is shown below,

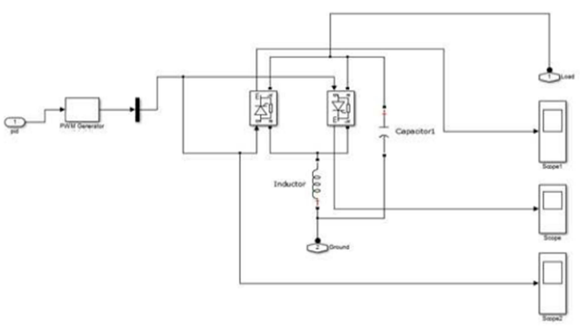

Fig. 8: Simulink Model of TCSC

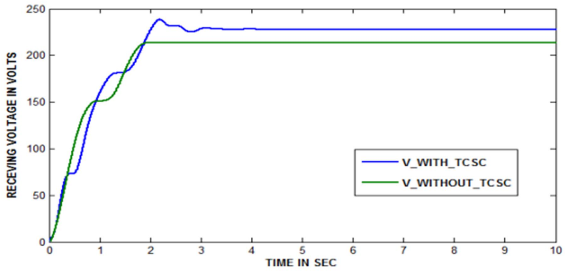

Fig. 9: Response of receving end voltage with and without compensation

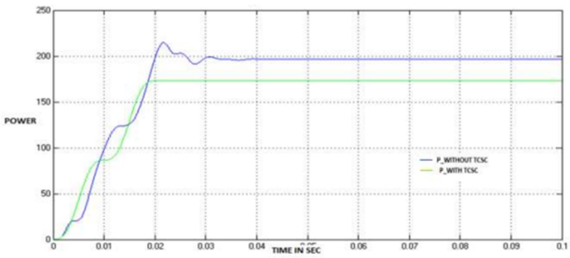

Fig. 10: Response of receving end power with and without TCSC compensation

B. UPFC Compensation System

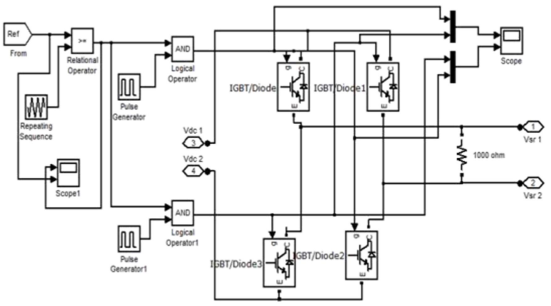

Fig. 11: UPFC Controller Simulink Model

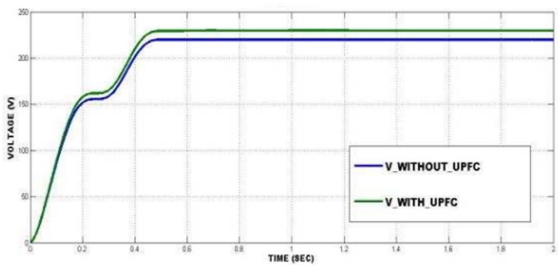

Fig. 12: Response of receving end voltage with and without compensation

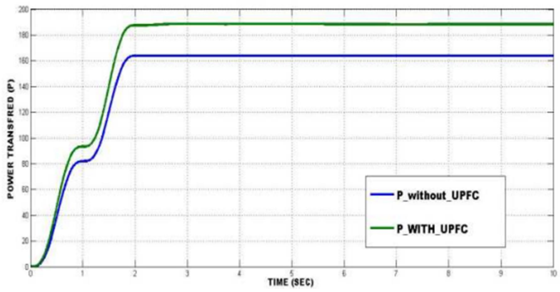

Fig. 13: Response of receving end powerwith and without UPFC compensation

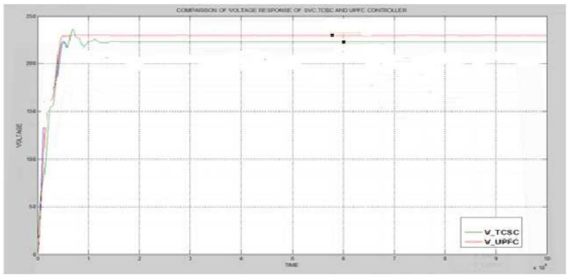

Fig. 14: Comparison of receving end voltage with TCSC andUPFC compensation

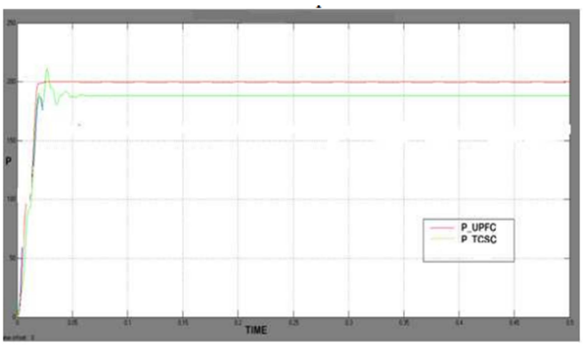

Fig. 15: Comparison of receving end power with TCSC andUPFC compensation

V. CONCLUSION

It is seen from the above simulation results that both the Voltage profiles and Power Flow are improved with all the compensating devices, but maximum real and reactive power compensation is obtained with the introduction of UPFC in the system. UPFC offers superior performance in improvement of voltage stability margin and better voltage profiles compared to TCSC because , as the UPFC is a combination of series- shunt controller compensation devices in which shunt part inject the reactive power at the point of connection in transmission line. Also series part maintains the voltage by injecting AC voltage in transmission line directly. The settling time of UPFC is very less than TCSC. From simulation graph we can also concluded that UPFC gives significant improvement in transient stability and steady state stability than TCSC Controller for particular 300km long transmission line prototype system.

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