Improved performance by the impact of unified power flow controller on transmission system

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Abstract - The two main objectives of FACTS are to increase the transmission capacity and control power flow over designated transmission routes. Representative of the last generation of FACTS devices is the Unified Power Flow Controller (UPFC). The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle). The UPFC is the most different and complex power electronic equipment for optimal power flow control in electrical power transmission system. In this paper the study of UPFC with its various modes of operation is understood. Second, the operation of control system used in its converters is also studied. Finally by the help of modeling of a power system in MATLAB/SIMULINK, and by installing UPFC in transmission link, its use as power flow controller and voltage injection is seen. In this paper we see how the UPFC increases the transmission capacity and reduce the power congestion in the transmission line.

Keywords- FACTS, UPFC, Voltage Source Converter, power flow control

I. INTRODUCTION

With increasing demand of electric power, the existing transmission networks even in the developed countries are found to be weak which results in a poor quality of unreliable supply. In order to expand or enhance the power transfer capability of existing transmission network the concepts of FACTS (Flexible AC transmission system) is developed by the Electric Power Research Institute (EPRI) in the late 1980s. The main objective of FACTS devices is to replace the existing slow acting mechanical controls required to react to the changing system conditions by rather fast acting electronic controls. FACTS means alternating current transmissions systems incorporating power electronic based and other static controllers to enhance controllability and increase power transfer capability.

FACTS controllers may be series, shunt or combination of both. Shunt controllers inject current into the system and may be variable impedance or variable source or both for ex: Static Synchronous Compensator (STATCOM), static var compensator (SVC) etc. Series controllers inject voltage in series with the line for ex: Static Synchronous Series Compensator (SSSC), Thyristor controlled Series Capacitor (TCSC), Thyristor switched series Capacitor (TSSC), Thyristor Controlled Series Reactor (TCSR), Thyristor Switched Series Reactor (TSSR). A combination of static synchronous compensator (STATCOM) and static series compensator (SSSC) which are coupled via a common dc link to allow bidirectional flow of real power between series o/p terminals of SSSC and shunt o/p terminals of STATCOM is called UPFC (unified Power Flow Controller).

The unified power flow controller (UPFC) is one of the most widely used FACTS controllers and its main function is to control the voltage, phase angle and impedance of the power system thereby modulating the line reactance and controlling the power flow in the transmission line.The UPFC is the most versatile and complex of all the FACTS devices, combining the features of the STATCOM and SSSC. The UPFC can provide simultaneous control of all basic power system parameters, ie, transmission voltage, impedance and phase angle. It is recognized as the most sophisticated power flow controller currently, and probably the most expensive one.

II. **UPFC** OPERATION AND CONTROL

The basic components of the UPFC are two voltage source inverters (VSIs) connected by a common dc storage capacitor which is connected to the power system through a coupling transformers. One (VSIs) is connected in shunt to the transmission system through a shunt transformer, while the other (VSIs) is connected in series to the transmission line through a series transformer. A basic UPFC functional scheme is shown in fig.1. Three phase system voltage of controllable magnitude and phase angle (Vc) are inserted in series with the line to control active and reactive power flows in the transmission line. So, this inverter will exchange active and reactive power within the line. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor (Vdc) constant. So, the net real power absorbed from the line by the UPFC is equal to the only losses of the inverters and the transformers.

The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point .The two VSI‟s can work independently from each other by separating the dc side. So in that case, the shunt inverter is operating as a (STATCOM) that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. The series inverter is operating as (SSSC) that generates or absorbs reactive power to regulate the current flowing in the transmission line and hence regulate the power flows in the transmission line.

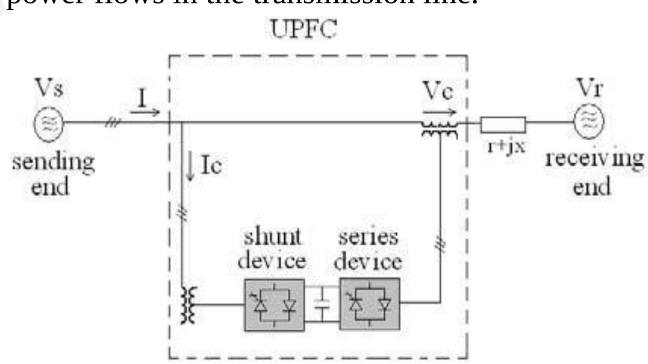


Figure 1: UPFC Link in Transmission Line

The UPFC has many possible operating modes.

VAR Control Mode: The reference input is an inductive or capacitive VAR request. The shunt inverter control translates the var reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage, Vdc, is also required.

Automatic Voltage Control Mode: The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer. The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways.

Direct Voltage Injection Mode: The reference inputs are directly the magnitude and phase angle of the series voltage.

Phase Angle Shifter Emulation Mode: The reference input is phase displacement between the sending end voltage and the receiving end voltage.

Line Impedance Emulation Mode: The reference input is an impedance value to insert in series with the line impedance.

Automatic Power Flow Control Mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

In order to understand the UPFC Control System the phasor diagram in the figure 2and figure3 given below is system.

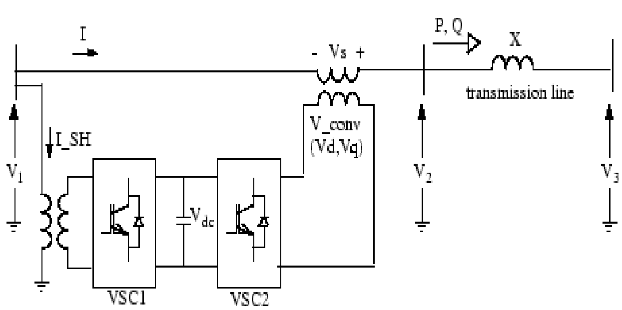


Figure2: Single-line Diagram of a UPFC

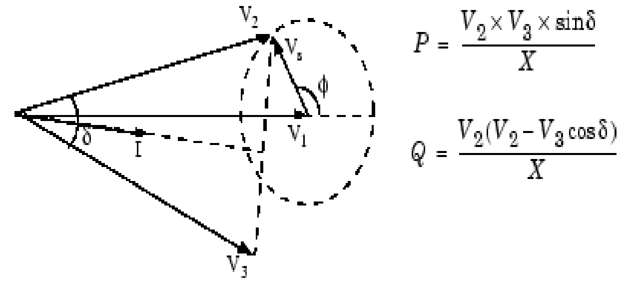


Figure3: Phasor Diagram of Voltages and Currents

This FACTS topology provides much more flexibility than the SSSC for controlling the line active and reactive power because active power can now be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with respect to line current. If the magnitude of injected voltage Vs is kept constant and if its phase angle with respect to V1 is varied from 0 to 360 degrees, the locu described by the end of vector V2 (V2=V1+Vs) is a circle as shown on the phasor diagram. As is varying, the phase shift δ between voltages V2 and V3 at the two line ends also varies. It follows that both the active power P and the reactive power Q transmitted at one line end can be controlled.The shunt converter operates as a STATCOM. In summary, the shunt converter controls the AC voltage at its terminals and the voltage of the DC bus. It uses a dual voltage regulation loop: an inner current control loop and an outer loop regulating AC and DC voltages. Control of the series branch is different from the SSSC. In a SSSC the two degrees of freedom of the series converter are used to control the DC voltage and the reactive power. In case of a

UPFC the two degrees of freedom are used to control the active power and the reactive power.

III. UPFC Modeling

The two modes i.e. the power flow control and the voltage injection mode are simulated in SIMULINK to see the effect of UPFC on a power system. The figure 5 below illustrates the steady-state and dynamic performance of a unified power flow controller (UPFC) used to relieve power congestion in a transmission system. The load flow analysis and the single line diagram simulation are done on power flow simulator. This software helps to calculate the power flow, the voltage at each bus and the cost effectiveness of the system.

A. Explanation of Single Line Diagram

A UPFC is used to control the power flow in a 500 kV /230 kV transmission systems. The system, connected in a loop configuration, consists essentially of five buses (B1 to B5) interconnected through three transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kV, 15000 MVA equivalent and to a 200 MW load connected at bus B3. Each plant model includes a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1200 MW generation capacity of power plant #2 is exported to the 500 kV equivalents through two 400 MVA transformers connected between buses B4 and B5. The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500 kV bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based, converters (one shunt converter and one series converter interconnected through a DC bus). The two voltage source inverter connected by a capacitor charged to a DC voltage realize the UPFC the converter number one which is a shunt converter draws real power from the source and exchange it (minus the losses) to the series converter the power balance between the shunt and series converter is maintained to keep the voltage across the DC link capacitor constant. The single line diagram is implemented on MATLAB/ SIMULINK. The series converter is rated 100MVA with a maximum voltage injection of 0.1pu the shunt converter is also rated 100MVA the shunt converter is operated in voltage control mode and the series converter is operated in power flow control mode.The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87kV) in series with line L2.

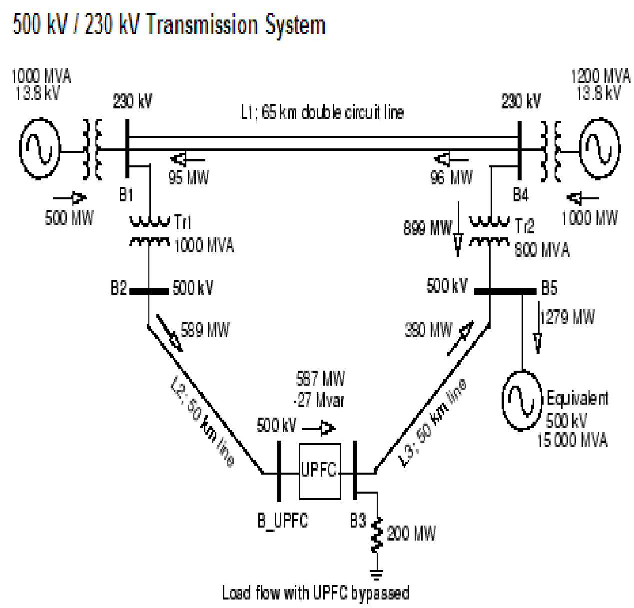


Figure 4: Description of 500kV/230kV Transmission system

B. Model Block

The single line diagram illustrated in Figure 4 is implemented on MATLAB SIMULINK to check the validity of the UPFC controller. The Model of UPFC will generate two kinds of results. First is based upon the simulations at power flow control mode and second on voltage injection Mode. The important keys to note in the block diagram are,

1. Use of Bypass breaker – Used to connect or disconnect UPFC Block from Power System.
2. The reference power inputs [P Qref] – Reference for power flow control
3. The reference voltage Vdref – Reference for voltage injection
4. Power flow analysis at load flow indicated by arrows –UPFC

C. Power Flow Control with the UPFC

Parameters of the UPFC are given in the dialog box. In the Power data parameters that the series converter is rated 100 MVA with a maximum voltage injection of 0.1 pu. The shunt converter is also rated 100 MVA. Also, in the control parameters, that the shunt converter is in Voltage regulation mode and that the series converter is in Power flow control mode. The UPFC reference active and reactive powers are set in the magenta blocks labeled Pref(pu) and Qref(pu). Initially the Bypass breaker is closed and the resulting natural power flow at bus B3 is 587 MW and -27 Mvar. The Pref block is programmed with an initial active power of 5.87 pu corresponding to the natural power flow. Then, at t=10s, Pref is increased by 1 pu (100 MW), from 5.87 pu to 6.87 pu, while Qref is kept constant at -0.27 pu.

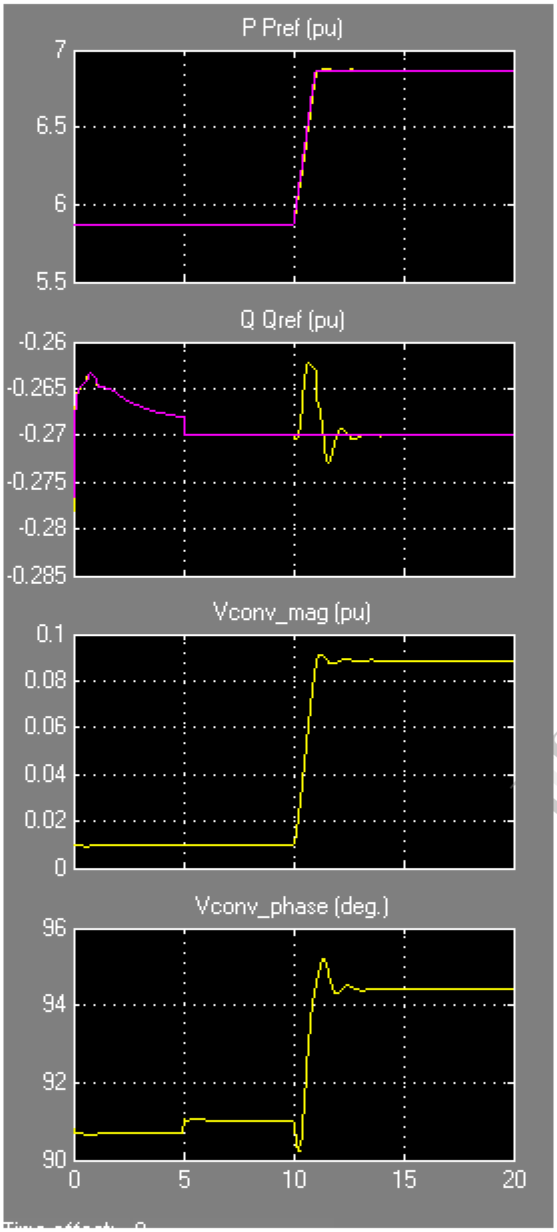
D. Voltage injection

In the UPFC dialog box Control parameters (series converter) are seen. The mode of operation is now Manual Voltage injection. In this control mode the voltage generated by the series inverter is controlled by two external signals Vd, Vq multiplexed at the Vdqref input and generated in the Vdqref magenta block. For the first five seconds the Bypass breaker stays closed, so that the PQ trajectory stays at the (-27Mvar, 587 MW) point. Then when the breaker opens, the magnitude of the injected series voltage is ramped, from 0.0094 to 0.1 pu. At 10 s, the angle of the injected voltage starts varying at a rate of 45 deg/s.

IV. SIMULATIONS

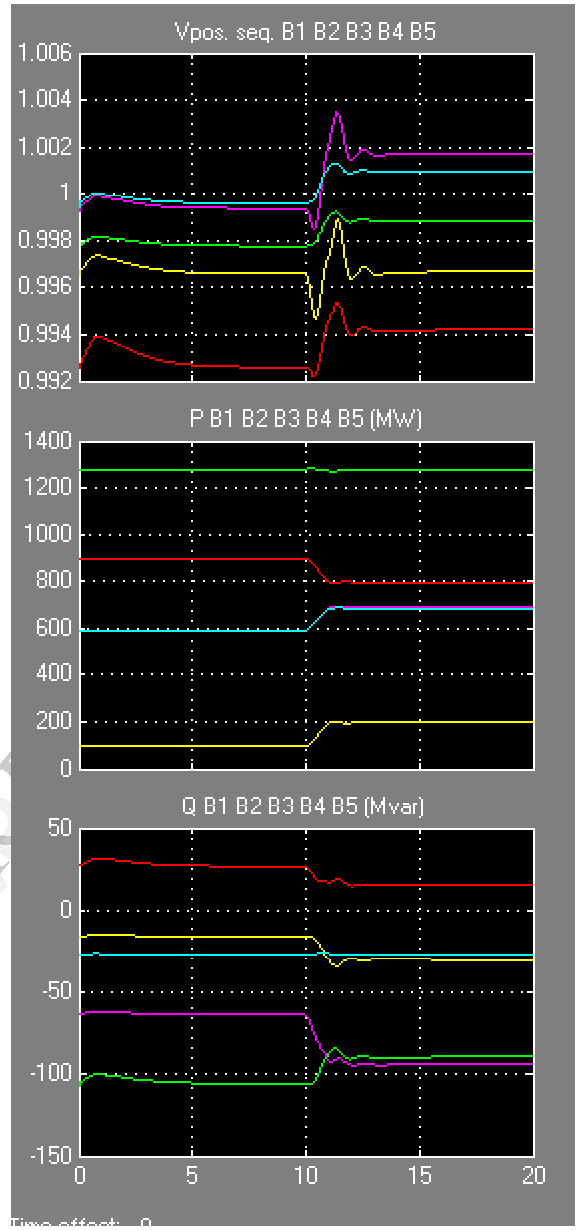
a. Power flow control with UPFC

Note: X-axis indicates time (t sec)



b. VPQ lines with UPFC

Note -X-axis indicates time in sec.
Graph1:series injected voltage in per unit.
Graph2:real power flow in transmission line.
Graph3:reactive power flow in transmission line.



V. RESULTS

The results are in compliance with the UPFC characteristics. The net reference real power output of the UPFC increased by 100 MW when the breaker opened. The increase in the real power led to decrease in congestion on bus 5. This can be seen by the power variation at every bus in the graphs given above. Relating to the reactive power, when the breaker opened the oscillations of reactive power was finished and reactive power was then constant at -27MVAr.

VI. CONCLUSION

UPFC is able to modify the voltage magnitude, phase angle and line impedance of the transmission system. In this paper the, MATLAB/SIMULINK is used to simulate the model of UPFC connected to a 3 phase transmission system. This paper presents the control & performance of the UPFC used for power quality improvement. The real and reactive powers increase with the increase in angle of injection. Simulation results show the effectiveness of UPFC to control the real and reactive powers. It is found that there is an improvement in the real and reactive powers through the transmission line when UPFC is introduced.

Therefore, to control the power from one end to another end, this concept of power flow control and voltage injection is applied. Modeling the system and studying the results have given an indication that UPFC are very useful when it comes to organize and maintain power system.

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