Simulation of Real, Reactive Power and Regulation with UPFC

K. Manoz Kumar Reddy

Associate professor, Electrical and Electronics Department, Sri Aditya Engineering College, India

Abstract- The Unified Power Flow Controller (UPFC) is the most sophisticated and complex power electronic equipment that has emerged for the control and optimization of power flow and also to regulate the voltage in electrical power transmission system. This paper presents real, reactive power and voltage control through a transmission line by placing UPFC at the sending end using computer simulation. When no UPFC is installed, real and reactive power through the transmission line cannot be controlled. A control system which enables the UPFC to follow the changes in reference values like AC voltage, DC voltage and angle order of the series voltage source converter is simulated. In this control system, a generalized pulse width modulation technique is used to generate firing pulses for both the converters. Simulations were carried out using MATLAB and PSCAD software to check the performance of UPFC.

Index Terms- power flow controller (UPFC), real, reactive power and voltage 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 [1]. 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 UPFC is the most versatile and complex of 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. In this paper, a UPFC control system that includes both the shunt converter and the series inverter has been simulated. The performance of UPFC in real, reactive power flow and regulation of voltage has been evaluated.

The improvements in the field of power electronics have had major impact on the development of concept itself. A new generation of FACTS controllers has emerged with the improvement of Gate Turn-off (GTO) thyristor ratings (4500V to 6000V, 1000A to 6000A). These controllers are based on voltage source converters and include devices such as Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMS), Static Synchronous Series Compensators (SSSCs) and the Unified Power Flow Controllers (UPFCs).

II. OPERATING PRINCIPLE OF UPFC

The basic components of the UPFC are the two voltage source converters sharing a common dc storage capacitor, and connected to the power system through the coupling transformers. One converter is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer. A basic UPFC functional scheme is shown in Figure 1.

Figure 1: Basic functional scheme of UPFC

The series inverter is controlled to inject a symmetrical three phase voltage system, of controllable magnitude and phase angle in series with the line to control active and reactive Power flows on the transmission line [5]. So this inverter will exchange active and reactive power with the line. The reactive power is...
electronically provided by the series inverter and it is excited by dc link capacitor [6]. The shunt converter is operated in such a way as to demand this dc terminal power from the line keeping the voltage across the storage capacitor \( V_{dc} \) constant. So the net real power absorbed from the line by the UPFC is equal only to the losses of the converters and their transformers. The remaining capacity of the shunt converter can be used to exchange reactive power with the line so to provide the voltage regulation at the connection point.

The main function of UPFC is to inject an ac voltage with controllable magnitude and phase angle at the power frequency in series with the voltage and the transmission line via an insertion transformer [2]. This injected voltage is provided by the inverter (booster) which acts essentially as a synchronous AC voltage source. The real power exchanged between the line and the inverter is supplied by the exciter through the DC bus and is equal to the real power exchanged between the line and the exciter at the shunt terminal. By inserting a controllable AC voltage, the UPFC regulates the magnitude and phase angle of transmission line voltage at its series terminal to achieve a prescribed active power and reactive power in the line.

The two converters can work independently of each other by separating the dc side. So in that case, the shunt converter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power flows on the transmission line.

III. MATHEMATICAL MODEL OF UPFC

The basic model of UPFC and its operation can be represented as shown in Figure 2.

\[
P_i = P_b \leq P \leq P_r = \left(1.56 - 1.56 \times \cos \alpha + 0.25 \times \cos(\alpha - \alpha_b) + 0.02 \sin(\alpha - \alpha_b) - 0.138 \sin \alpha\right)
\]

The variation limits of \( \alpha_b \) and \( \alpha \) are according to the following to the following relation:

\[
0 \leq \alpha_b \leq 2\pi
\]
\[
0 \leq \alpha \leq 0.71 \text{ radians}
\]

IV. SIMULATION SETUP IN PSCAD

Figure 3 shows the simulation model including a power system with a transmission line. The UPFC installed near the sending end effectively controls the power flow from sending to receiving end.

Here \( V_s \) and \( V_r \) are assumed to be sending and receiving end voltages. This model is based on the assumption that sending end corresponds to a power plant while the receiving end to an electric power network. The receiving end voltage \( V_r \) being an infinite bus will not cause any phase angle change. The phase angle of \( V_s \) is adjusted according to the power demand for the power plant. A phase difference of \( 12^\circ \) sending and receiving end voltages is simulated.

The main circuit of the series device (SSSC) consists of a three phase PWM inverter, the ac terminals of which are connected in series to a transmission line through 3 single phase transformers. The shunt device (STATCOM) consists of a three phase PWM inverter, the ac terminals of which are connected in parallel with the transmission line via a three phase star delta transformer [3].

A. Control circuits

In this simulation, the shunt converter operates in automatic voltage control mode. Figure 4 shows the DC voltage control circuit for the shunt converter. DC link voltage is measured (VDCM) and compared with the reference value (VDCref), whose error is fed to the PI controller to generate the shift.

Similarly, AC voltage from the sending end bus feeding the shunt coupling transformer is measured in p.u(Vpum) and compared with the ac voltage set point (here 1.0 p.u), whose error is mi. Figure 5 shows the AC voltage control circuit for shunt converter. Two sets of signals, reference and triangular ones are needed, one set for turning on and the other for turning off the GTOs. The generated shift and \( mi \) signals are used to develop firing pulses for 6 GTOs in the inverter in PSCAD environment. A generalized sinusoidal pulse width modulation switching technique is used for pulse generation. HL logic is used to generate firing pulses.
In this case series inverter operates in the direct voltage injection mode. The series inverter simply injects voltage as per the theta order specified. Figure 6 shows the series inverter control circuit, which is an open loop phase angle controller, generates modulation index, \( m_i \) and shift. The \( m_i \) and shift are used to generate firing pulses.

![Series inverter open loop phase angle controller](image)

Figure 6: Series inverter open loop phase angle controller

V. SIMULATOR RESULTS

A transmission line of a simple power system with parameters as given in Table 1 is considered. UPFC is placed in series with the transmission line at the sending end. Voltage, active power, reactive power with UPFC and without UPFC are studied and compared. The power system studied is SMIB system. When the transmission line is without UPFC, the sending end and receiving end voltages are 1 p.u as shown in Figure 7(a). When UPFC is placed across the same transmission line, the voltage regulation is improved as per Figure 7(b).

![Sending and receiving end voltages](image)

Figure 7: Sending and receiving end voltages (a) Without UPFC (b) With UPFC

In this simulation, the theta order input to the series inverter control circuit is 5°. The series inverter injects voltage into the transmission line at point of connection. By varying the theta order input to the controller the phase and magnitude of series injected voltage can be varied. When the transmission line is without UPFC, the real and reactive power flow cannot be controlled [4]. Figure 8(a) shows the active power through the line without UPFC. Figure 8(b) shows the active power flow through the line which is controlled by UPFC. Transmission capability of existing transmission line is highly improved with the presence of UPFC. But the difference between the sending end real power and receiving end real power is high in the transmission line with UPFC. This is due to increase in transmission losses, which include losses in both converters and coupling transformers.

![Sending and receiving end active power](image)

Figure 8: Sending and receiving end active power (a) Without UPFC (b) With UPFC
The reactive power flow through the transmission line with and without UPFC is shown in Figure 9. The raise in transmission capability is noticed from the simulation results.

![Figure 9: Sending and receiving end reactive power](image)

(a) Without UPFC (b) With UPFC

The performance of the UPFC can be justified by its controller’s performance. AC voltage controller tracking its reference values is shown in Figure 7. Similarly DC voltage controller tracks its reference value, 46 KV as shown in Figure 10.

![Figure 10: DC link voltage in UPFC](image)

The series inverter injects voltage of variable magnitude and phase into the transmission line at the point of its connection, thereby controlling real and reactive power flow through the line. The active power through the line is supplied by SSSC active power. This real power obtained from the DC source connected to its DC terminals. The shunt converter provides the required power to the series inverter through the DC link active power [7].

### TABLE 1. SYSTEM PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line to line voltage</td>
<td>230 KV</td>
</tr>
</tbody>
</table>

### VI. CONCLUSION

In this PSCAD environment is used to simulate the model of UPFC connected to a three phase three wire transmission system. This paper presents control and performance of UPFC intended for installation on a transmission line. A control system is simulated with shunt converter in AC and DC voltage control mode and series inverter in open loop phase angle control mode. Simulation results show the effectiveness of UPFC in controlling real, reactive power and voltage through the line. Due to AC voltage controller, AC voltage regulation is improved. The DC voltage controller maintains the DC link voltage to the DC voltage set point 46 KV. This paper presents an improvement in the real and reactive power flow through the transmission line with UPFC when compared to the system without UPFC.

### REFERENCES


### AUTHORS

**First Author** – K. Manoz kumar reddy, Mtech, Associate professor, Sri Aditya Engineering College.
Email id - kmkreddy@gmail.com