Control Strategy for Unified Power Flow Controller

Seelam Swarupa, and K. V. S. Ramachandra Murthy

Abstract: **In this thesis, a reactive power coordination controller has been implemented to limit excessive voltage excursions during reactive power transfers. The controller implemented coordinates Reactive Power flows. Response of Power System to Step Changes in Reactive Power Flow Reference has been examined in this Thesis. This Thesis reviews the methodology given in [1] and extends beyond its scope.**

The response of two bus system consisting of UPFC is studied with and without coordination controller. A two bus system is considered with 13.8 kV generator of 1000 MVA and step up transformer of 13.8 kV/230 kV, 1000 MVA. The step change in the reference reactive power of 50 MVAr to 225 MVAr has been introduced in the system and Peak over shoot in the reactive power oscillations have been observed with and without coordination controller of UPFC. Similar analysis is carried out on with 13.8kV/345 kV Transformer. It is observed that there is an improvement of 20% reduction in the peak overshoot of the reactive power oscillations. The modeling and analysis have been carried out in the MATLAB/SIMULINK environment.
Keywords : UPFC, Control Strategy, reactive power control.

I. INTRODUCTION

Power system in general are interconnected for economic, security and reliability reasons. Exchange of contracted amounts of real power has been in vogue for a long time for economic and security reasons. To control the real flow on tie lines connecting controls areas, power flow control equipment such as phase shifters are installed. They direct real power between control areas. The interchange of real power is usually done on hourly basis. On the other hand, reactive power flow control on tie lines is also very important. Reactive power flow control on transmission lines connecting different areas is necessary to regulate remote end voltages. Though local control actions within an area are the most effective during contingencies, occasions may arise when adjacent control areas may be called upon to provide reactive power to avoid low voltages and improve system security.

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Fixed series capacitors help in increasing stability limits in an interconnected power system. With transmission open access, each transmission system owning utility will increase their transmission capacity to attract more utilities to use its transmission facilities. Many existing power systems have already made the use of series compensation to increase their transmission capacity . By series compensation, the amount of reactive power consumed by the line is reduced hereby increasing the amount of reactive power transferred to the receiving end and improving the voltage profile at the receiving end. This is one of the secondary benefits of using series compensation. Under system disturbance conditions like three phase faults or line tripping, controllable series compensation helps in damping power system oscillations.

Excessive UPFC bus voltage excursions during reactive power transfers requiring reactive power coordination have been addressed in by Jayaram and Salama[1]. L. Gyugyi, proposed [2] the unified power flow controller (UPFC) which is able to control the reactive power flows at the sending- and the receiving-end of the transmission line. K. K Sen proposed [3] the theory and the modeling technique of a flexible alternating current transmission systems (FACTS) device, namely, unified power flow controller (UPFC) using an Electromagnetic Transients Program (EMTP) simulation package.

A collection of measured performance characteristics are presented [4] to illustrate the unique capabilities of the UPFC by Renz. P. K. Dash, proposed [5] the design of radial basis function neural network controllers (RBFNN) for UPFC to improve the transient stability performance of a power system. P.K Dash proposed [6] a simple hybrid fuzzy logic proportional plus conventional integral controller for FACTS devices in a multi-machine power system. Z. Huang, proposed [7] a new power frequency model for unified power flow controller (UPFC) is suggested with its DC link capacitor dynamics included. Y. Morioka, proposed [8] a unified power flow controller (UPFC) miniature model developed for performing system feasibility studies. Wang et. al. [9] proposed three types of FACTS-based stabilizers for a unified model of a multi-machine power system. Hingorani presented [10] the control mechanism of real and reactive power flow in transmission lines using FACTS controllers.

II. SHUNT CONVERTER CONTROL SYSTEM

Fig 1 shows the de-coupled control system for the shunt converter. The D-axis control system controls the dc link capacitor voltage and the Q-axis control system controls the UPFC bus voltage /shunt reactive power. The details of the de-coupled control system design can be found .The de-coupled control system has been designed based on linear control system techniques and it consists of an outer loop control system that sets the reference for the inner control system loop. The inner control system loop tracks the reference.

III. SERIES CONVERTER CONTROL SYSTEM

Fig. 2 shows the overall series converter control system. The transmission line real power flow is controlled by injecting a component of the series voltage in quadrature with the UPFC bus voltage . The transmission line reactive power is controlled by modulating the transmission line side bus voltage reference . The transmission line side bus voltage is controlled by injecting a component of the series voltage in-phase with the UPFC bus voltage.

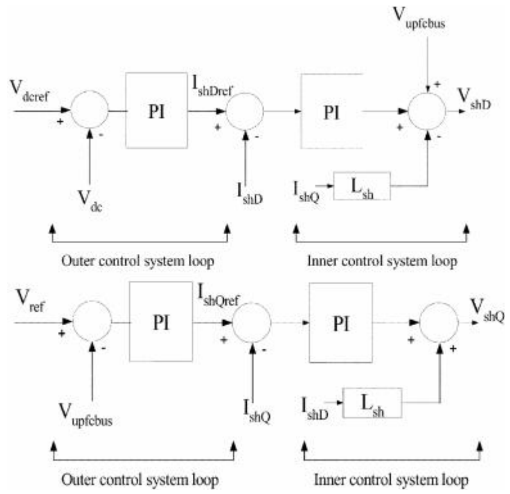

Fig. 1 De-Coupled D-Q axis Shunt Converter Control System.

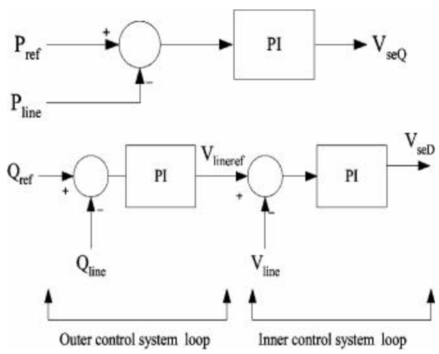

Fig. 2 Series Converter Real and Reactive Power Flow Control System.

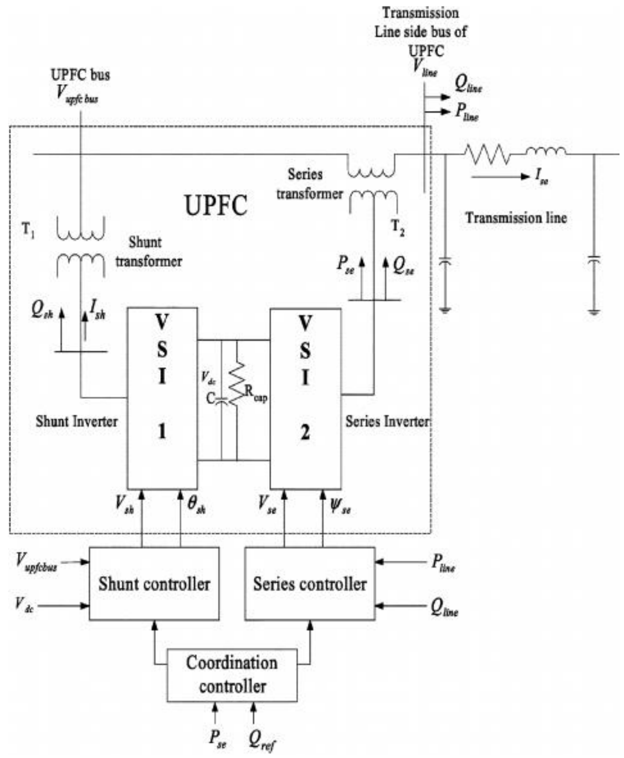

Fig. 3: UPFC Connected to a Transmission Line.

The in-phase component (VseD) of the series injected voltage which has the same phase as that of the UPFC bus voltage, has considerable effect on the transmission line reactive power (Qline) and the shunt converter reactive power (Qsh). Any increase/decrease in the transmission line reactive power (Qline) due to in-phase component (VseD) of the series injected voltage causes an equal increase/decrease in the shunt converter reactive power (Qsh). In short, increase/decrease in transmission line reactive power is supplied by the shunt converter. Increase/decrease in the transmission line reactive power also has considerable effect on the UPFC bus voltage. The mechanism by which the request for transmission line reactive power flow is supplied by the shunt converter is as follows. Increase in transmission line reactive power reference causes a decrease in UPFC bus voltage. Decrease in UPFC bus voltage is sensed by the shunt converter UPFC bus voltage controller which causes the shunt converter to increase its reactive power output to boost the voltage to its reference value.

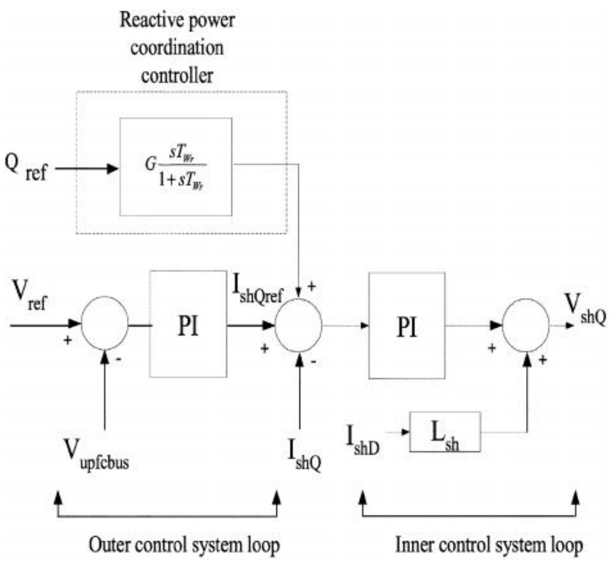

Fig. 4. Shunt Converter Q-Axis Controller with Reactive Power Coordination Controller.

The increase in shunt converter reactive power output is exactly equal to the increase requested by the transmission line reactive power flow controller (neglecting the series transformer T2 reactive power loss). Similarly, for a decrease in transmission line reactive power, the UPFC bus voltage increases momentarily. The increase in UPFC bus voltage causes the shunt converter to consume reactive power and bring the UPFC bus voltage back to its reference value. The decrease in the shunt converter reactive power is exactly equal to the decrease in transmission line reactive power flow (neglecting the reactive power absorbed by the series transformer T2).

In this process, the UPFC bus voltage experiences excessive voltage excursions. To reduce the UPFC bus voltage excursions, a reactive power flow coordination controller has been designed. The input to the reactive power coordination controller is the transmission line reactive power reference. Fig.4S shows the shunt converter Q-axis control system with the reactive power coordination controller.

The gain of the washout circuit has been chosen to be 1.0. This is because, any increase/decrease in the transmission line reactive power flow due to change in its reference is supplied by the shunt converter. The washout time constant is designed based on the response of the power system to step changes in transmission line reactive power flow without the reactive power coordination controller.

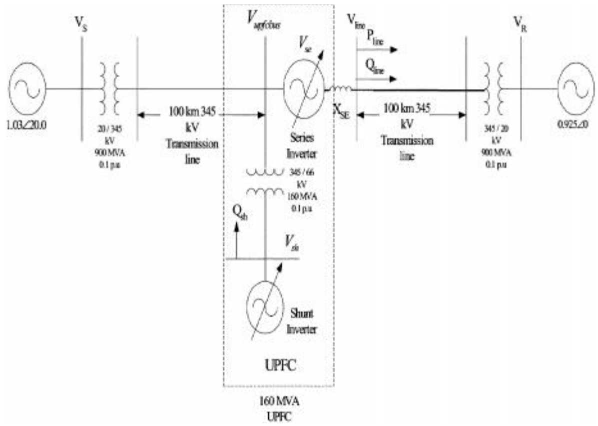

Fig. 5 Power system with UPFC.

IV. SIMULATION RESULTS

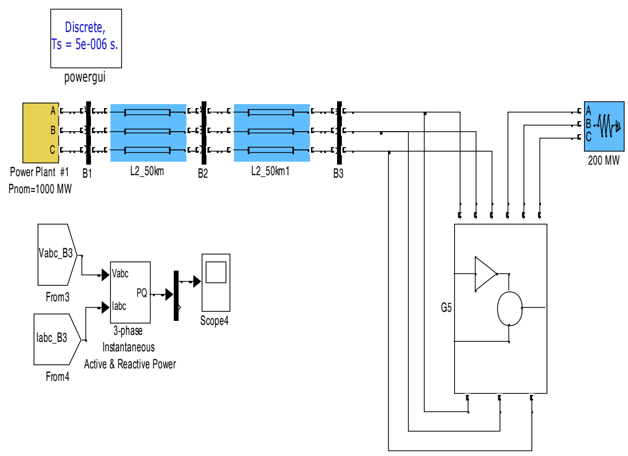

Fig. 6 Simulink Model of UPFC Connected Transmission Line

A. Response to Step Changes in Reactive Power Reference

A two machine power system with UPFC is shown in fig. 6 has been considered to study the response of the power system to step input changes in reactive power reference. The analysis is carried out on two different systems levels. One system is at 230 kV level and the other is at 345 kV.

Table 1 shows the reduction in peak overshoot of the reactive power oscillations on 230 kV system when it is subjected to a step change. Magnitude of step change is presented in column 3 and Peak over shoot without controller is presented in column 4 and over shoot with controller is presented in column 5.

System 1:
Generator ratings : 13.8 kV,1000MVA
Transformer ratings : 13.8 kV/230kV,1000MVA

$Q_{initial}$ (MVAr)	Q_{new} (MVAr)	Step Change MVAr	Over shoot (with out coordination controller)	Over shoot (with controller)
125	75	50	180	147
125	50	75	176	153
125	25	100	173	152
125	-25	150	166	151
125	-50	175	163	150
125	-100	225	164	148

Table 2 shows the reduction in peak overshoot of the reactive power oscillations on 345 kV system when it is subjected to a step change. Magnitude of step change is presented in column 3 and Peak over shoot without controller is presented in column 4 and over shoot with controller is presented in column 5.

System 2:
Generator: 13.8 kV,1000MVA
Transformer: 13.8 kV/345kV,1000MVA

$Q_{initial}$ (MVAr)	Q_{new} (MVAr)	Step Change MVAr	Over shoot (with out coordination controller)	Over shoot (with controller)
125	75	50	180	150
125	50	75	176	145

Fig 7 to 10 show the reduction in reactive power oscillations on 230 kV system. And Fig. 11 and 12show the reduction in reactive power oscillations on 345 kV system. Load considered in this work is 200 MW synchronous motor.

i) Results on 230 kV System :

Fig.7 shows the variation of reactive power from 125 MVAR to 75MVAR at 0.3 seconds and back to 125MVAR at 0.6 seconds. The peak over shoot without controller is observed to be 180 MVAR and with the coordination controller, it is observed to be 147 MVAR. Fig .8 shows the variation of reactive power with coordination controller.

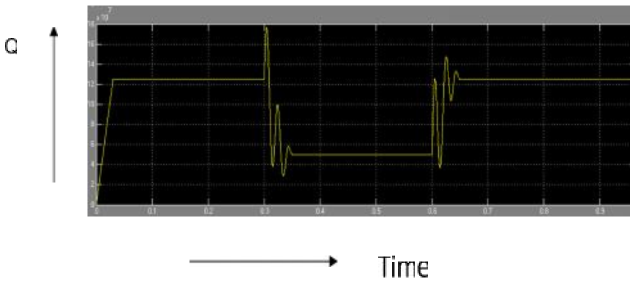

Fig. 7 Variation of Qline with step change of 50 MVAr without controller

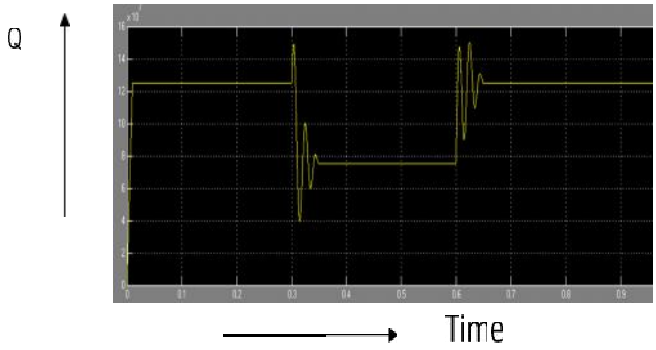

Fig 8 Variation of Qline with step change of 50 MVAr with controller

Fig. 9 shows the variation of reactive power from 125 MVAR to 25MVAR at 0.3 seconds and back to 125MVAR at 0.6 seconds. The peak over shoot without controller is observed to be 173 MVAR and with the coordination controller, it is observed to be 152MVAR. Fig. 10 shows the variation of reactive power with coordination controller.

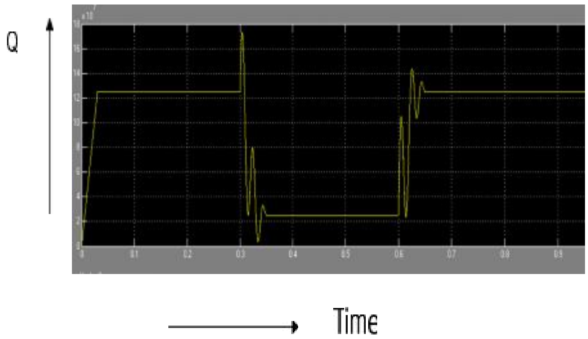

Fig. 9 Variation of Qline with step change of 100 MVAr without controller

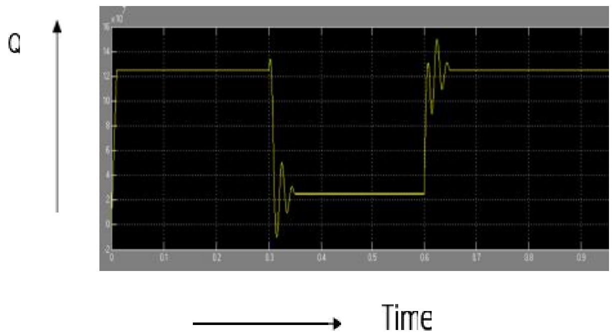

Fig 10 Variation of Qline with step change of 100 MVAr with controller

ii) Results on 345 kV System

Fig. 11 shows the variation of reactive power from 125 MVAR to 75MVAR at 0.3 seconds and back to 125MVAR at 0.6 seconds. The peak over shoot without controller is observed to be 180 MVAR and with the coordination controller, it is observed to be 150MVAR. Fig. 12 shows the variation of reactive power with coordination controller.

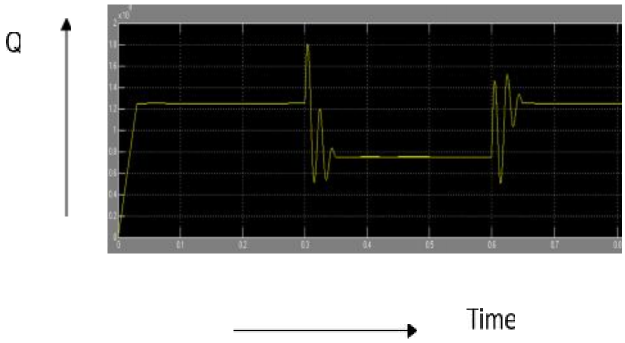

Fig. 11 Variation of Qline with Step Change of 50 MVAr without Controller

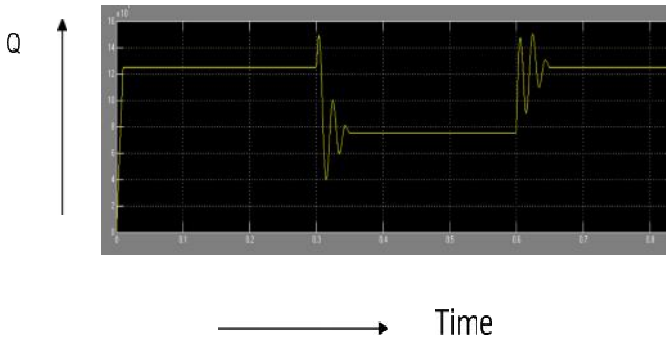

Fig. 12 Variation of Qline with Step Change of 50 MVAr with Controller

IV. CONCLUSION

This thesis has implemented a new real and reactive power coordination controller for a UPFC. The basic control strategy is such that the shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter controls the transmission line real and reactive power flow. The contributions of this work can be summarized as follows.

Response of Power System to Step Changes in Reactive Power Flow Reference has been examined in this Thesis. A two bus system is considered with 13.8 kV generator of 1000 MVA and step up transformer of 13.8 kV/345 kV, 1000 MVA. The step change in the reference reactive power of 50 MVAr to 225 MVAr has been introduced in the system and Peak over shoot in the reactive power oscillations have been observed without the controller and with the controller. It is observed that there is a 20% reduction in the peak overshoot by implementing the real and reactive power coordination controller. Also there is a improvement in raise time of 30 msec.

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