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Real and Reactive Power Coordination for a Unified Power Flow Controller

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Abstract: This project proposes a new real and reactive power coordination for a unified power flow controller (UPFC). The basic control for the UPFC is such that the series converter of the UPFC controls the transmission line real/reactive power flow and the shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the real power demand of the series converter is supplied by the shunt converter of the UPFC. To avoid instability/loss of DC link capacitor voltage during transient conditions, a new real power coordination has been designed. The need for reactive power coordination controller for UPFC arises from the fact that excessive bus voltage (the bus to which the shunt converter is connected) excursions occur during reactive power transfers. A new reactive power coordination controller has been designed to limit excessive voltage excursions during reactive power transfers. MATLAB simulation results have been presented to show the improvement in the performance of the UPFC control with the proposed real power and reactive power coordination controller.

Key words: FACTS % Unified power flow controller (UPFC) % Coordination controller

INTRODUCTION

What is most interesting for transmission planners is that FACTS technology opens up new opportunities for controlling power and enhancing the usable capability of the present transmission system. The opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, phase angle and damping of oscillations at various frequencies below the rated frequency. These constraints cannot be overcome otherwise, while maintaining the required system stability, by mechanical means without lowering the usable transmission capability. By providing added flexibility, FACTS controllers can enable in a line to carry power closer to its thermal rating. Mechanical switching needs to be supplemented by rapid response power electronics. Static VAR compensators control only one of the three important parameters (voltage, impedance, phase angle) determining the power flow in the AC power systems viz. the amplitude of voltage at selected terminals of the transmission line. It has long been realized that an all solid-state or advanced, static VAR compensator, which is true equivalent of ideal synchronous condenser, is technically feasible with the use of gate turn-off (GTO) thyristors. The UPFC is a recently introduced FACTS controller which has the capability to control all the four transmission parameters. The UPFC not only performs the functions of the STATCON, TCSC and the phase angle regulator but also provides additional flexibility by combining some of the functions of these controllers.

Unified Power Flow Controller: UPFC is the most comprehensive multivariable flexible ac transmission system (FACT) controller. Simultaneous control of multiple power system variables with UPFC posses enormous difficulties. In addition, the complexity of the UPFC control variables interacts with each other. UPFC which consists of a series and shunt converter connected by a common dc link capacitor can simultaneously perform the function of transmission line real/reactive power flow control in addition to UPFC bus voltage/shunt reactive power control. The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The interaction between the series injected voltage and the transmission line current

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leads to real and reactive power exchange between the series converter and the power system. Under steady state conditions, the real power demand of the series converter is supplied by the shunt converter. But during transient conditions, the series converter real power demand is supplied by the dc link capacitor. If the information regarding the series converter real demand is not conveyed to the shunt converter control system, it could lead to collapse of the dc link capacitor voltage and subsequent removal of UPFC from operation. In this case, the series converter provides the shunt converter control system an equivalent shunt converter real power reference that includes the error due to change in dc link capacitor voltage and the series converter real power demand. The control system designed for the shunt converter in causes excessive delay in relaying the series converter real power demand information to the shunt converter. This could lead to improper coordination of the overall UPFC control system and subsequent collapse of dc link capacitor voltage under transient conditions. In this project, a new real power coordination controller has been developed to avoid instability/excessive loss of dc link capacitor voltage during transient conditions. In contrast to real power coordination between the series and shunt converter control system, the control of transmission line reactive power flow leads to excessive voltage excursions of the UPFC bus voltage during reactive power transfers. This is due to the fact that any change in transmission line reactive power flow achieved by adjusting the magnitude/phase angle of the series injected voltage of the UPFC is actually supplied by the shunt converter. The excessive voltage excursions of the UPFC bus voltage is due to absence of reactive power coordination between the series and shunt converter control system. A new reactive power coordination controller between the series and the shunt converter control system has been designed to reduce UPFC bus voltage excursions during reactive power transfers.

Control Strategy for Upfc

Shunt Converter Control Strategy: The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. In this case, the shunt converter voltage is decomposed into two components. One component is in-phase and the other in quadrature with UPFC bus voltage. De-coupled control system has been employed to achieve simultaneous control of the UPFC bus voltage and the dc link capacitor voltage [1].

Series Converter Control Strategy: The series converter of the UPFC provides simultaneous control of real and reactive power flow in the transmission line. To do so, the series converter injected voltage is decomposed into two components. One component of the series injected voltage is in quadrature and the other in-phase with the UPFC bus voltage. The quadrature injected component controls the transmission line real power. This strategy is similar to that of a phase shifter. The in-phase component controls the transmission line reactive power flow. This is similar to that of a tap changer.

Basic Control System

Shunt Converter Control System: Figure 1. shows the de-coupled control system for the shunt controverter. The Daxis control system controls the dc link capacitor voltage (Vdc) and the Q-axis control system controls the UPFC bus voltage (Vupfcbus)/shunt reactive power. The decoupled control system design has been designed based on linear control system techniques and it consists of an outer loop controls system that sets the reference for the inner control system loop. The inner control system loop tracks the reference.

Series Converter Control System: Figure 2. shows the overall series converter control control system. The transmission line real power flow (Pline) is controlled by injecting a component of the series voltage in quadrature with the UPFC bus voltage (VseQ). The transmission line reactive power (Qline) is controlled by modulating the transmission line side bus voltage reference (Vlineref). The transmission line side bus voltage is controlled by injecting a component of the series voltage in-phase with the UPFC bus voltage (VseD).

Real and Reactive Power Coordination Controller

Real Power Coordination Controller: To understand the design of a real power coordination controller for a UPFC,consider a UPFC connected to a transmission line as shown in Fig. 1. The interaction between the series injected voltage (Vse) and the transmission line(Ise) leads to exchange of real power (Pse) between the series converter and the transmission line. The real power demand of the series converter (Pse) causes the dc link capacitor voltage (Vdc) to either increase or decrease depending on the direction of the real power flow the series converter. This decrease/increase in dc link capacitor voltage (Vdc) is sensed by the shunt converter controller that controls the dc link capacitor link capacitor

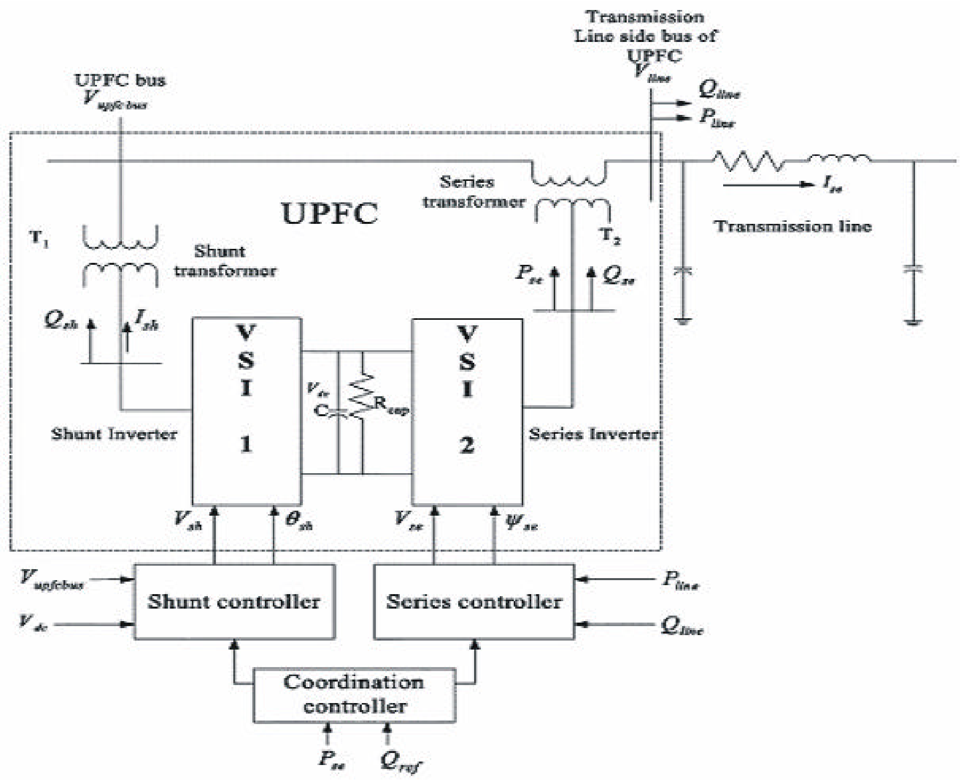


Fig. 1: UPFC connected to a transmission line

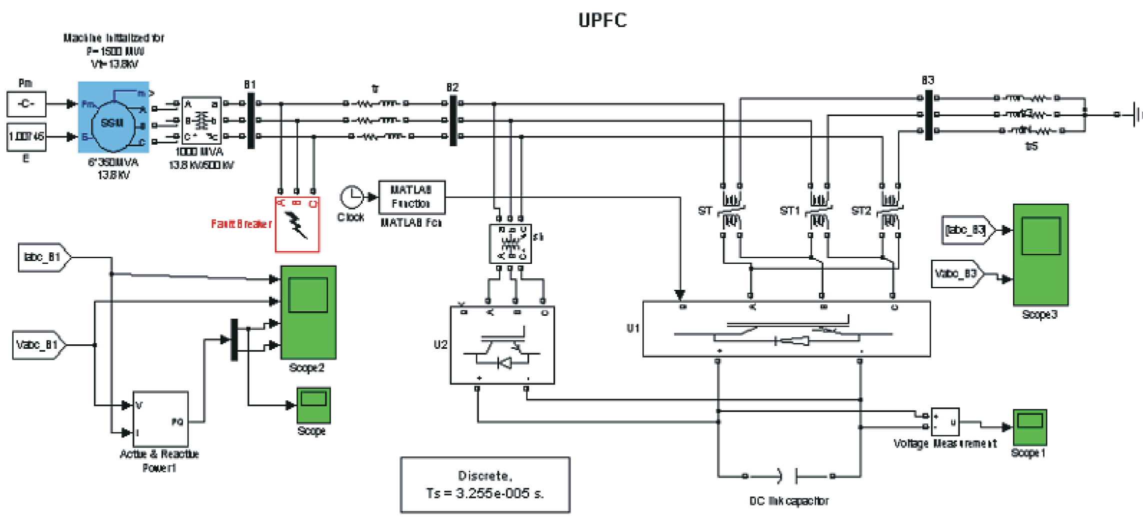
voltage (Vdc) and acts to increase/decrease the shunt converter real power flow to bring the dc link capacitor voltage(Vdc) back to its scheduled value.Alternatively, the real power demand of the series converter is recognized by the dc link capacitor voltage (Vdc).Thus, the shunt and the series converter operation are in way separated from each other [2]. To provide for proper coordination between the shunt and the series converter control system, a feed back from the series converter is provided to the shunt converter control system. The feedback signal used is the real power demand of the series converter (Pse). The real power demand of the series converter (Pse) is converter into an equivalent D-axis current for the shunt converter (iDse). By doing so, the shunt converter responds immediately to a change in its D-axis current and supplies the necessary series converter real power demand. The equivalent Daxis current (iDse) is an additional input to the D-axis shunt converter control system as shown Fig. 4. Equivation (1) shows the relationship between the series converter real power demand (Pse) and the shunt converter D-axis current (iDse).

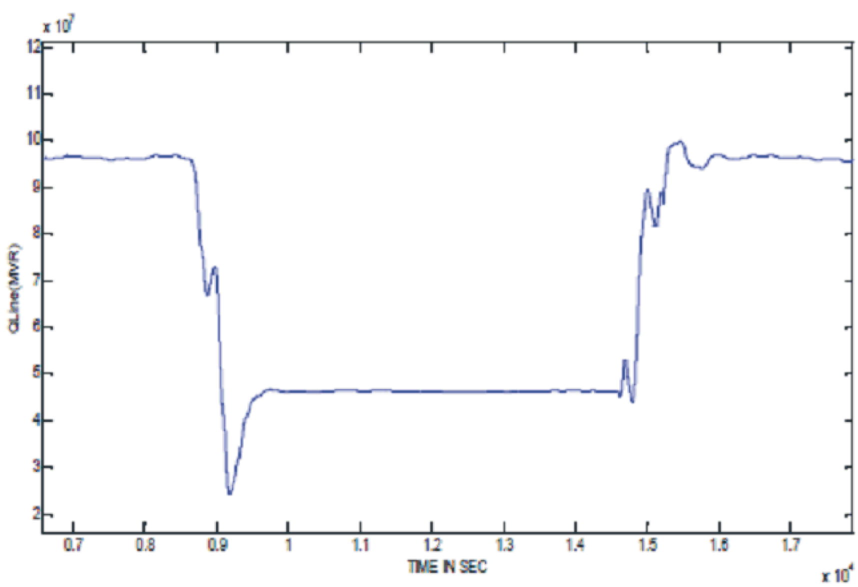
$$i_{Dse} = P_{se} / |V_{upfc\ bus}|$$

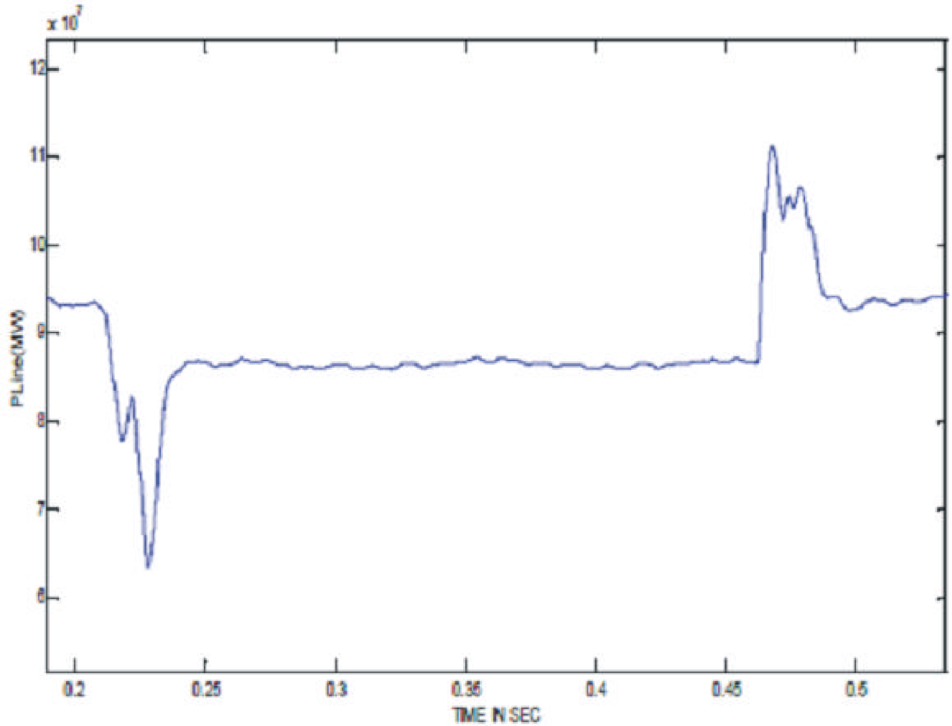
The real power demand of the series converter Pse is the real part of product of the series converter injected voltage Vse and the transmission line current Ise. Vupfc bus, iDse represents the voltage of the bus to which the shunt converter is connected and the equivalent additional D-axis current that should flow through the shunt converter to supply the real power demand of the series converter. As shown in Fig. 4, the equivalent D-axis additional current signal (iDse) is fed to the inner control system, thereby increasing the effectiveness of the coordination controller. Further, the inner control system loops are fast acting PI controllers and ensure fast supply of the series converter real power demand (Pse) by the shunt converter [3].

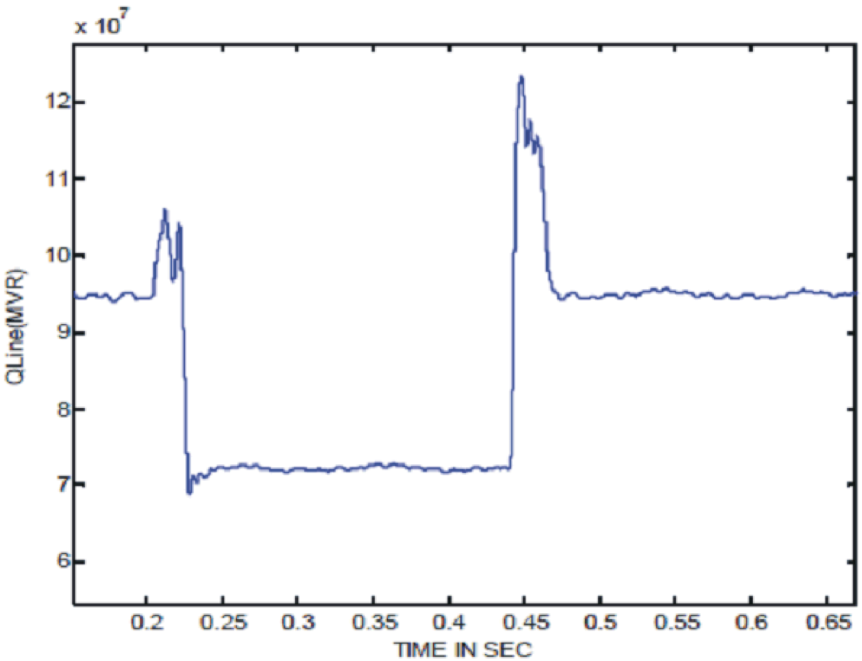
Reactive Power Coordination Controller: The in-phase component (VseD) of the series injected voltage which has the same phase as that of the UPFC bus voltage, has considerable effect on the transmission line reactive power (Qline) and the shunt converter reactive power (Qsh). Any increase/decrease in 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 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. 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. The increase in shunt converter reactive power output is exactly equal to the increase requested by the transmission line reactive power flow controller. 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 to its reference value [4]. The decrease in the shunt converter reactive power is exactly equal to the decrease in transmission line reactive power flow. In this process, the UPFC bus voltage experiences excessive voltage excursions. To reduce the UPFC bus voltage excursions, a reactive power coordination controller has been designed. The input to the reactive power coordination controller is the transmission line reactive power references. Fig. 5 shows the shunt converter Q-axis control system with reactive power coordination controller.

Simulation Diagram and Results









CONCLUSION

This paper has discussed 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 [5]. The contributions of this work can be summarized as follows. Two important coordination problems have been addressed in this paper related to UPFC control. One, the problem of real power coordination between the series and the shunt converter control system. Second, the problem of excessive UPFC bus voltage excursions during reactive power transfers requiring reactive power coordination. Inclusion of the real power coordination controller in the UPFC control system avoids excessive dc link capacitor voltage excursions and improves its recovery during transient conditions.MATLAB simulations have been conducted to verify the improvement in dc link voltage excursions during transient conditions. Inclusion of reactive power coordination controller helps in significantly reducing UPFC bus voltage excursions during reactive power transfers.

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