



Multiple Control Functions of UPFC

K. Manoz kumar reddy

*Associate professor, Electrical and Electronics Department, Sriaditya engineeringcollege, India
kmkreddy@gmail.com*

Abstract—The most important function of unified power flow controller (UPFC) is its multiple control function. These control functions have been suggested to be implemented by multiple controllers. However study example presented in the paper demonstrate the existence of the dynamic interactions among different UPFC controllers namely power flow controller, AC voltage controller and DC voltage controller. Due to interactions it is demonstrated in the paper that there are cases where separately designed and individually implemented stable UPFC controllers may result in poor control performance and even the closed loop system instability when they are in joint operation. Hence it is suggested in this paper that the multiple functional UPFC is treated as a multi input and multi output (MIMO) control system such that a single multi variable controller can be designed for the UPFC to perform the multiple control functions, which takes full account of the control interactions in the MIMO UPFC system.

Keywords—unified power flow controller, multiple control function, power flow controller, AC voltage controller, DC voltage controller.

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 [1]. 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 [2].

The unified power flow controller was proposed to achieve the flexible AC transmission systems (FACTS) [3]. One of its important features is its multiple control function. For example, the series part of the UPFC can be equipped with power flow control function and the shunt part can operate for the AC voltage support. Further more, for the normal operation of UPFC the DC voltage across the link capacitor in the UPFC must be regulated by a DC voltage controller. Hence in a single multiple functional UPFC installed in a power system, there could be more than three control channels or control input-output pairs. If every UPFC control function is performed by a controller, there could be more than three controllers installed in the UPFC. If these UPFC controllers are designed separately in a sequence, in fact, the multiple functional UPFC is treated as single input single output (SISO) system then the dynamic interactions among various control channels are not considered. Hence from the point of

view of control system design, the control performance and the closed loop system stability cannot be guaranteed when these controllers are in joint operation as they are supposed to, even though a satisfactory control performance and the closed loop system stability have been obtained when each controller is designed individually [4].

In this paper, an example power system installed with a UPFC is presented, where the UPFC is assigned two control functions, power flow and AC voltage control. Three PI controllers, i.e. PI power flow controller, PI AC voltage controller and PI DC voltage controller, for the UPFC are designed separately in a sequence which ensures closed loop system stability and a satisfactory control performance. However, it is found that when these three PI controllers are in joint operation, poor control performance and even the closed loop system instability occurs. This indicates the existence of the dynamic interactions among the controllers, which has not been taken account of when the controllers are designed separately by treating the UPFC as a SISO control system.

In fact, from control theory, the UPFC installed in the example power system forms a three input and three output system where there are interactive dynamics among the three control channels or input-output pairs. Assignment of a controller for each control channel and the separate design of each controller, i.e. power flow, AC and DC voltage controller, assumes the complete dynamic decomposition of the system, which is not true. Therefore in this paper it is suggested that the multiple functional UPFC is handled as a MIMO control system to be assigned with a multivariable controller to fulfil the multiple control functions. In this paper, a multivariable PI controller is proposed for the UPFC in the example power

system to perform three control functions, power flow, AC and DC voltage control.

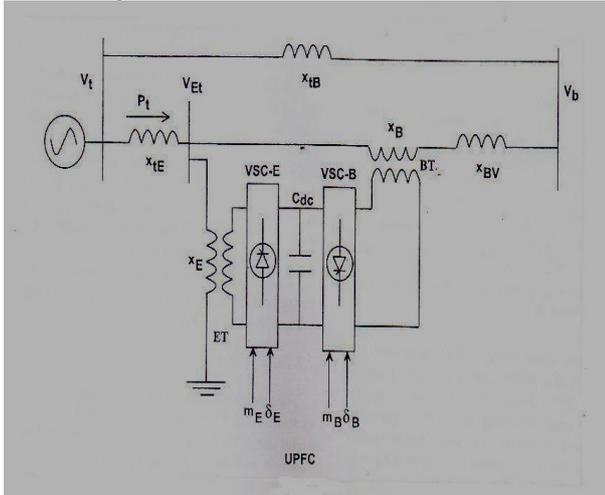


Fig. 1 A UPFC connected to SMIB system

II. MULTIPLE CONTROL FUNCTIONS OF UPFC

Fig. 1 is a single machine infinite bus power system installed with a UPFC. The UPFC consists of an excitation transformer (ET), a boosting transformer (BT), two three phase GTO based voltage source converters (VSCs) and a DC link capacitor. In Fig. 1, m_E , m_B and δ_E , δ_B are the amplitude modulation ratio and phase angle of the control signal of each VSC, respectively, which are the input control signals to the UPFC. The UPFC installation is for active power flow control on the transmission line and AC voltage support at the UPFC shunt busbar [5]. For the normal operation of the UPFC, the DC voltage across the DC link capacitor C_{DC} is V_{DC} , needs to be controlled by a DC voltage regulator such that active power exchange between the UPFC and the power system is zero at steady state operation, i.e. V_{DC} is maintained to be constant for the operation of VSCs. Therefore, there are total three control functions to be fulfilled, i.e. power flow control, AC voltage control and DC voltage control.

III. ARRANGEMENT OF UPFC CONTROLLERS

If a controller is assigned to each of these control functions, there are three UPFC controllers to be designed. This kind of arrangement can be shown by Fig. 2, where there are three control channels or input-output pairs: U_P-P_{tl} , $U_{AC}-V_{Et}$ and $U_{DC}-V_{DC}$. The linearised model of the power system plus the UPFC is

$$\dot{X} = AX + b_1 \Delta m_E + b_2 \Delta \delta_E + b_3 \Delta m_B + b_4 \Delta \delta_B$$

$$X = [\Delta \delta \ \Delta \omega \ \Delta E_q \ \Delta E_{fd} \ \Delta V_{DC}]^T$$

The output control signal of each UPFC controller, U_P , U_{AC} , and U_{DC} , in Fig. 2 is chosen among the control signals of

VSCs of the UPFC, Δm_E , $\Delta \delta_E$, Δm_B and $\Delta \delta_B$. To investigate the interactions among the UPFC controllers, in the following study case, for an example power system are to be presented. The configuration of the example power system is shown by Fig. 1 and its parameters are given in Appendix. All UPFC controllers take the proportional plus integral (PI) control law.

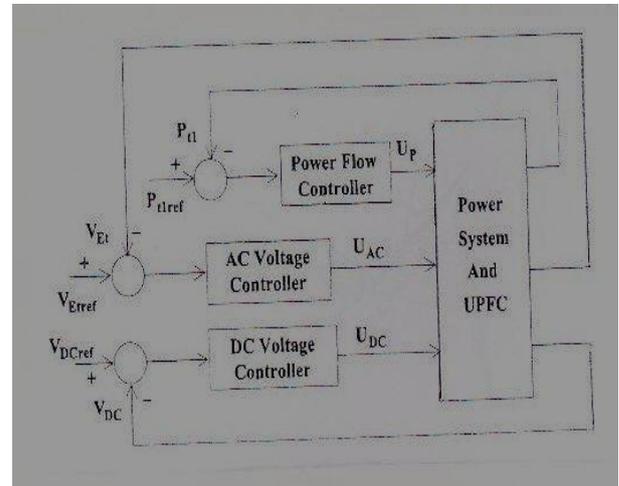


Fig. 2 A UPFC connected to power flow, AC and DC voltage controllers.

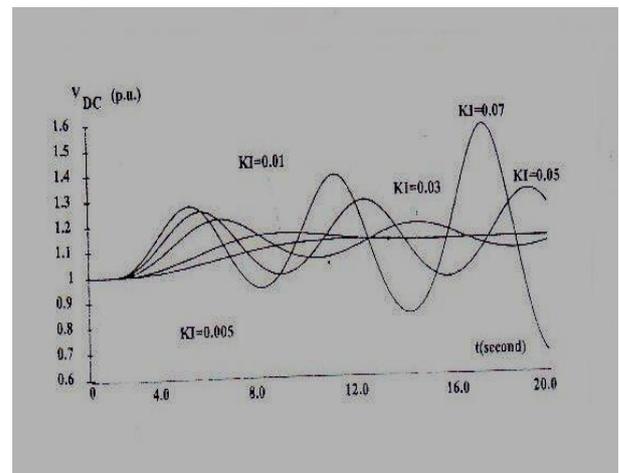


Fig. 3 Control performance of an I DC voltage controller with $U_{DC}=\delta_E$

IV. DESIGN OF UPFC DC VOLTAGE CONTROLLER

The objective of the UPFC DC voltage controller design is to have a constant DC voltage maintained across the capacitor in the UPFC [6]. The controller can be an I type controller or a PI type controller. For the UPFC control system design, this is the controller to be set firstly because the normal operation of UPFC relies on a constant DC voltage. However, it has been found that the parameter setting of the controller is difficult.

Fig. 3 shows the simulation results of assessing the control performance of an I DC voltage controller and Fig. 4 shows the results of that of a PI DC voltage controller when U_{DC} is chosen to be δ_E . In Figs. 3 and 4, K_P and K_I are the gain values of I or PI DC voltage controllers respectively. From Figs. 3 and 4, it can be seen that with the choice of $U_{DC}=\delta_E$, the best control performance is obtained by the PI DC voltage controller with $K_P=1.0$ and $K_I=3.0$. This PI parameter setting is used in the following study case for the DC voltage controller.

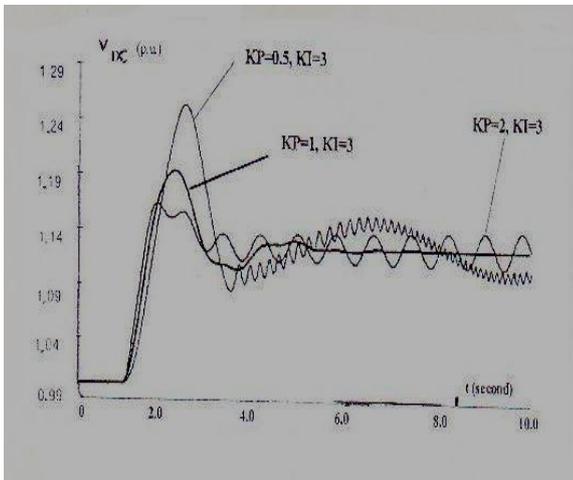


Fig. 4 Control performance of an I DC voltage controller with $U_{DC}=\delta_E$.

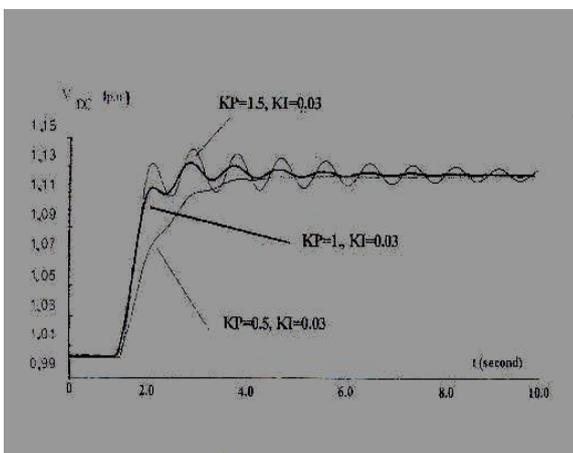


Fig. 5 Control performance of an I DC voltage controller with $U_{DC}=\delta_E$.

With the different choice of control input signal, the task of the design does not get easier as shown in Fig. 5, where the UPFC has a PI DC voltage controller with $U_{DC}=\delta_B$. The best control performance is obtained with $K_P=1.0$ and $K_I=0.03$ which is used in the following case study for DC voltage controller with $U_{DC}=\delta_B$.

V. CASE STUDY

The selection of the output control signal for each UPFC controller is: $U_P=m_B$, $U_{AC}=m_E$ and $U_{DC}=\delta_E$. The series part of the UPFC is equipped with power flow control function and the shunt part operates for the AC voltage support and DC voltage regulation of the link capacitor of the UPFC. Hence the UPFC controllers are

1) PI power flow controller:

$$m_B = (K_{pp} + K_{PI}/s)(P_{t1ref} - P_{t1})$$

2) PI DC voltage controller:

$$\delta_E = (K_{DCP} + K_{DCI}/s)(V_{DCref} - V_{DC})$$

3) PI AC voltage controller:

$$m_E = (K_{ACP} + K_{ACI}/s)(V_{Etrf} - V_{Et})$$

They are set separately by use of standard tuning method for PI controller design in SISO systems. The design is carried out in the following sequence

1) PI DC voltage controller is designed first with PI power flow controller and AC voltage controller being in open loop. The result of the parameter tuning is $K_{DCP}=1.0$, and $K_{DCI}=3.0$. Fig. 6 gives the results of nonlinear simulation to assess the controllers performance. In the simulation, the reference DC voltage, V_{DCref} is changed at 1.0 s of the simulation from 1.0 to 1.125 p.u. From Fig. 6, it can be seen that the closed loop system stability and satisfactory control performance is obtained.

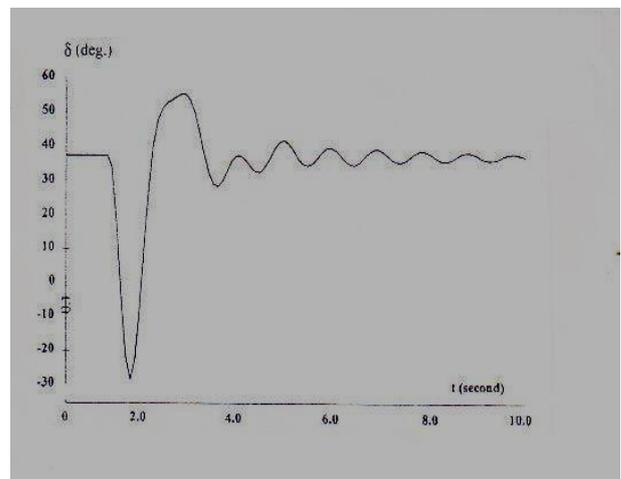


Fig. 6a Control performance of a PI DC voltage controller

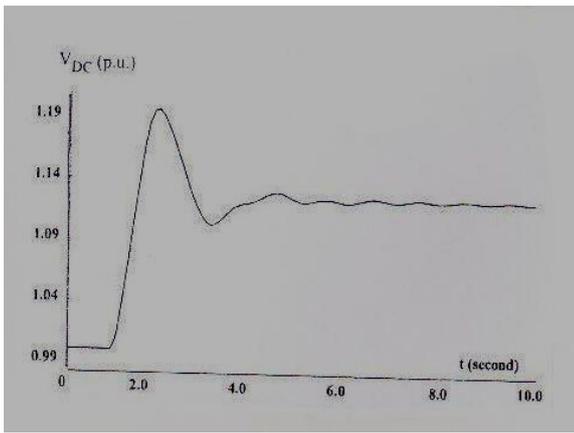


Fig. 6b Control performance of an PI DC voltage controller

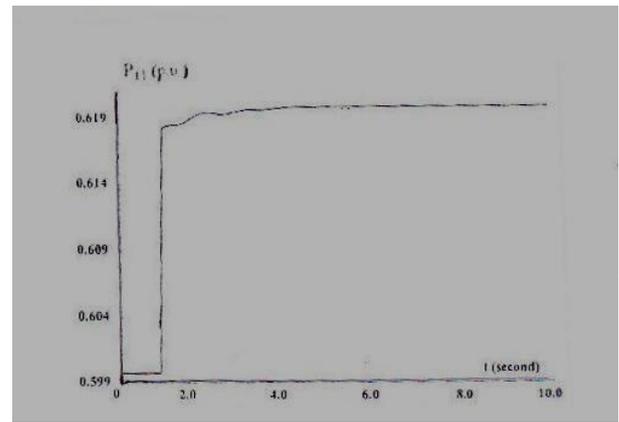


Fig. 7b Control performance of an PI power flow controller

2) After the PI DC voltage controller is installed, PI power flow controller and PI AC voltage controller are designed subsequently with the tuned parameters to be $K_{PP}=10.0$, $K_{PI}=10.0$ and $K_{ACP}=10.0$, $K_{ACI}=10.0$. In the design, the PI controllers set previously are close looped. However, the design is treated as to a SISO system without considering the dynamic interactions among the three control channels or input-output pairs. Figs. 7 and 8 present the results of non linear simulation to check the performance of controllers. In Fig. 7, the reference active power delivered along the transmission line, P_{T1ref} is increased at 1.0 s of the simulation from 0.6 to 0.62 p.u. In Fig. 8, the reference AC voltage, V_{E1ref} is changed at the 1.0 s of the simulation from 1.043 to 1.0 p.u. From Figs. 4 and 5, it can be seen that the closed loop system is stable and control performance for the power flow and AC voltage regulation is satisfactory.

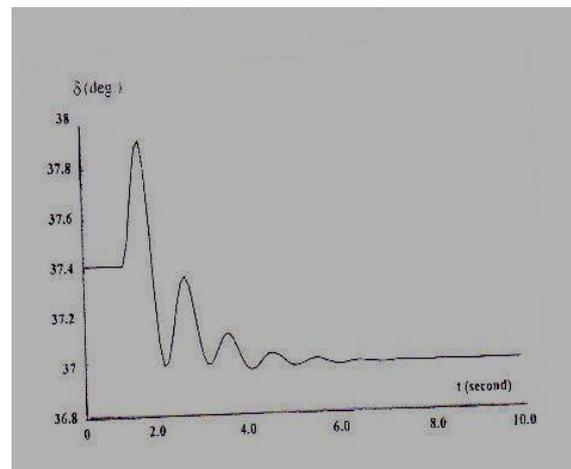


Fig. 8a Control performance of a PI AC voltage controller

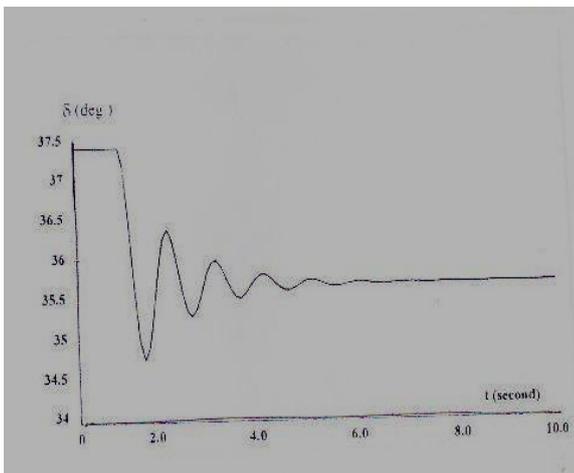


Fig. 7a Control performance of a PI power flow controller

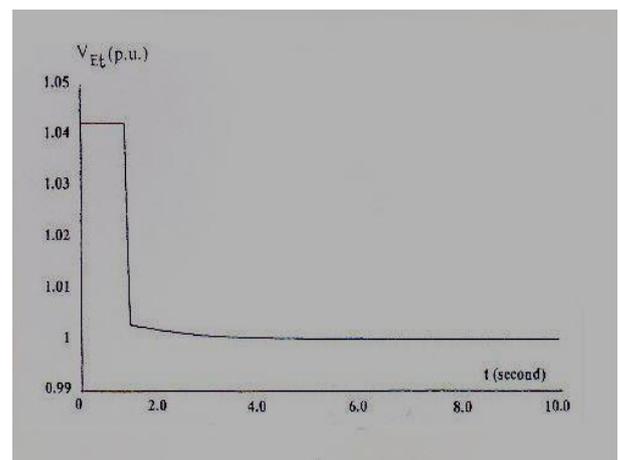


Fig. 8b Control performance of a PI power flow controller

3) Finally, the control performance of the PI DC voltage controller is re-examined with the power flow and AC voltage controller in joint operation. The results of non linear simulation are shown in Fig. 9. In the simulation the reference DC voltage, V_{DCref} is changed at 1.0 s of the simulation from 1.0 to 1.125 p.u. From Fig. 9, it can be seen that the closed loop system instability occurs, although the closed loop system was stable when the PI DC voltage controller is designed before the installation of power flow and AC voltage controller. This indicates the existence of the dynamic interactions between the DC voltage control channel and other two control channels, which were not considered at the first place when the PI DC voltage controller was designed. The dynamic interactions are negative in this case, which result in closed loop system instability.

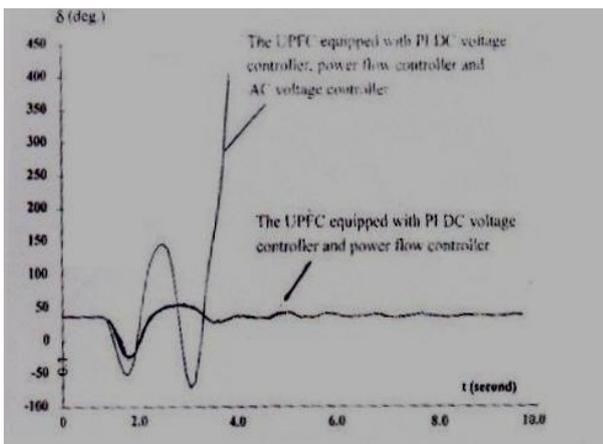


Fig. 9a Control performance of an PI DC voltage controller when it is in joint operation with other controllers

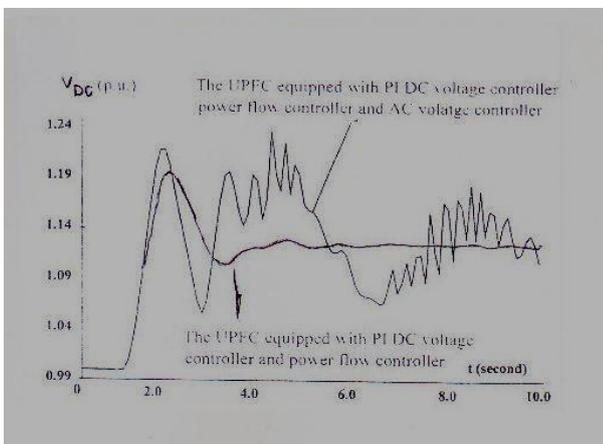


Fig. 9b Control performance of an PI DC voltage controller when it is in joint operation with other controllers

VI. CONCLUSIONS

In this paper multiple functional UPFC installed in a power system can have multiple controllers to perform multiple control functions. However, from the case study which is discussed, there exists dynamic interactions among various UPFC controllers. From the results of nonlinear simulation of the UPFC in the power system equipped with only the PI DC voltage controller and the power flow controller, it can be seen that the closed loop system stability is maintained with the joint operation of these controllers. Hence it can be concluded that the negative dynamic interaction responsible for closed loop system instability is between the PI DC and AC voltage controller. In this paper it is demonstrated that in fact, the multiple functional UPFC installed in the power system forms a MIMO control system. A single multivariable controller can be designed successfully for the UPFC to perform multiple control functions, such as power flow, AC and DC voltage controls.

VII. APPENDIX

The parameters of the example single machine infinite bus power system are $V_t=1.043$ p.u., $V_b=1.0$ p.u., $x_E=0.15$ p.u., $x_B=0.03$ p.u., $x_{tE}=0.3$ p.u., $x_{tB}=1.0$ p.u., $C_{dc}=1.0$ p.u., $x_{Bv}=0.27$ p.u.

REFERENCES

- [1] N.G.Hingorani, L.Gyugyi, "Understanding FACTS," *Concepts and Technology of Flexible AC Transmission Systems*. IEEE press, 2000.
- [2] L.gyugi, "A unified power flow concept for flexible AC transmission systems," *IEEE proc.c 139(4)1992*.
- [3] K.RPadiyar and K.uma rao, "Modelling and control of unified power flow controller for transient stability," *Electrical power and energy systems, vol 21 (1999) 1-11*.
- [4] A.W.Green, J.T.Boys, "Threephase voltage sourced reversible rectifiers," *IEEE proc.135(1988)362-370*.
- [5] K. Manoz kumar reddy, "simulation of unified power flow controller", *proceedings of National conference on recent trends in power systems and power electronics, (Feb 2012)148-151*.
- [6] S.Limyingcharoen, U.D.Annakkage, N.c.Pahalawatththa, "Effects of unified power flow controllers on transient stability," *IEEE proceedings, vol.145, part C, No2, March 1998, p.182-188*.