CHAPTER – 5

CO-ORDINATED EXCITATION AND UPFC CONTROL FOR TRANSIENT STABILITY ENHANCEMENT

5.1 Introduction:

Power systems are large complex systems exposed to wide range of operating conditions. Such a complex system demands large variety of controllers for satisfactory operations under various modes of operating conditions. However, as these controllers are usually designed for specific jobs, a co-ordination among them is necessary so that one controller does not affect adversely the performance of other controllers. Moreover, a proper co-ordination between different controllers can enhance the overall performance. Along with other FACTS devices UPFC is going to play very important role in power system operation and control in near future. It has been shown [14,15] that the UPFC is a very effective device for dynamic power flow control in a transmission system. the control range and speed provided by UPFC is not achievable with other devices. UPFC is the only device that can simultaneously or independently control all the three parameters (voltage, phase angle and impedance) that regulate the power flow through a transmission line. A UPFC can be used to control both real and reactive power flows of the transmission system simultaneously and independently. Thus it can be a very useful tool for power flow control as well as transient stability enhancement. Studies on the application of UPFC for transient stability enhancement have already been reported [16 – 23]. While most of these studies are concerned about the prospect of only UPFC for transient stability improvement and related methodologies, ref. [22] considers the problem of co-ordinated excitation and UPFC control. However, authors there [22] have done their studies on SMIB system. So many questions still remain unanswered regarding the co-ordinated control in multimachine power system. In this chapter a study has been done on co-ordinated control of UPFC along with the excitation controller proposed in the earlier chapters.

5.2 UPFC Control:

The UPFC can be controlled in a variety of ways to meet different objectives. In the present work, the control strategy is developed to faulfil the requirements for transient stability enhancement. In ref.[22] the authors have reported an interesting method, but their method is not suitable when PWM control of the converters are considered. In PWM control, the controller regulates the modulation index m and phase angle θ of the converter a.c. side voltages. The control blocks for the shunt and series converters of PWM controlled UPFC have been shown in chapter – 2 (Fig.2.6 and 2.7). the controllers are standard PI controllers, though in this problem only integral control has been considered. In the shunt branch control arrangement m_{sh}, the modulation index of the shunt converter is regulated to control the voltage of the a.c. bus to which the UPFC shunt branch is connected. In the present problem, the a.c. bus voltage is maintained at 1.0 p.u. because maintaining the voltage can aid to the transient stability of a power system. to achieve the above objective a constant reference voltage, $V_{ac\ ref}$ is applied. θ_{sh} is regulated to maintain constant d.c. voltage, which is achieved by maintaining a constant desired d.c. voltage reference, $V_{dc\ ref}$. Regarding the control of series branch, it is well known that modulation of active power flow through the transmission line can enhance transient stability and damping of power oscillations, while the reactive power flow does not contribute much to these factors. The magnitude of the series injected voltage of the UPFC mainly contributes to the reactive flow, while the phase of angle of it dominantly contributes to the active power flow. The reactive power flow is maintained at its pre-fault value by maintaining a constant Q_{ref} equal to the pre-fault value and regulating m_{se} accordingly through the integral controller. Active power flow through the line is controlled by suitably modulating the P_{ref} and, thereby, regulating θ_{se} through the integrator block associated with it. P_{ref} is modulated according to the following law:

$$P_{ref} = K_1\,\theta_{se} + K_2\,\omega_L$$

where ω_L is the local frequency at the UPFC location.

5.3 The Study System:

The example power system considered for simulation studies to illustrate the performance of the excitation and UPFC co-ordinated control is shown in Fig.5.1. The system is identical to that considered in Chapter – 4 (Fig.4.1) with only exception that a UPFC is now installed midway between the line connecting X_{T1} and X_{T2} as shown in Fig.5.1.

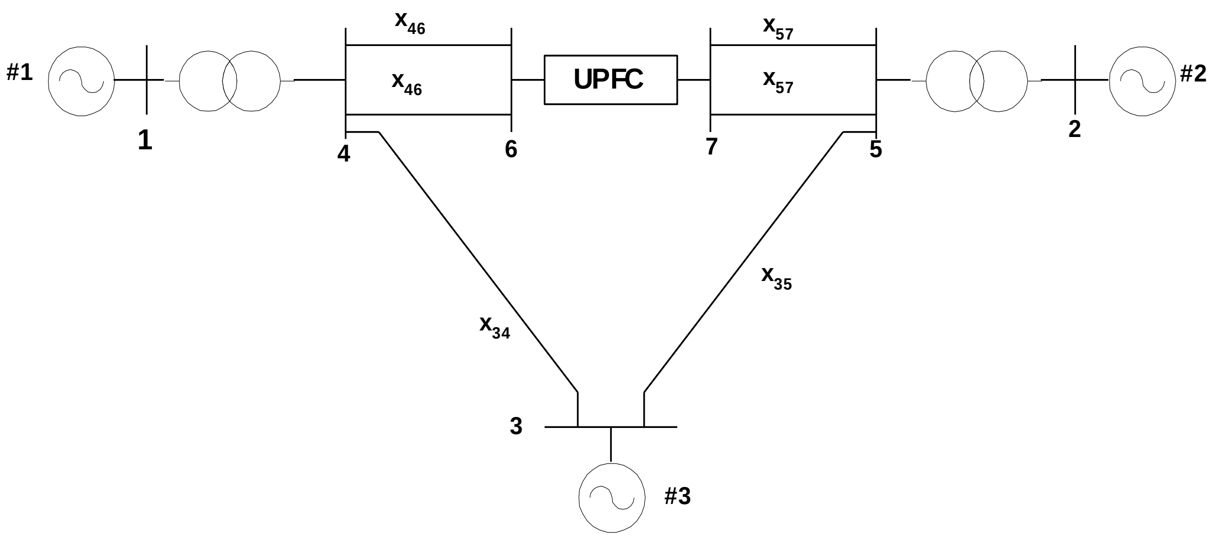

Fig.5.1: The Example Power System

All the system parameters are identical to those of the system of Fig.4.1 with only the following additions and modifications:

$$x_{46} = x_{57} = 0.5 \text{ p.u.}$$

the UPFC parameters:

$V_{dcref} = 31.113\text{kV}, \quad C = 5500\mu\text{F}.$

$R_{sh} = R_{se} = X_{sh} = X_{se} = 0$

$\max |V_{se}| \leq 0.2$ p.u.

$\max |V_{sh}| \leq 0.2$ p.u.

$0 \leq \theta_{se} \leq 360^o$

$0 \leq \theta_{sh} \leq 360^o$

$K_{I\,DC} = K_{I\,AC} = K_{IP} = K_{IR} = 1.0$

The fault considered in the simulation is a symmetrical 3-phase short circuit on one of the transmission lines x_{46}. λ is the fraction of the faulted line to the left of the fault as considered in the previous chapters.

Fault sequences considered are as follows:

Fault Sequence – I:

Stage 1: The system is in pre-fault steady-state.
Stage 2: A fault occurs at $t = t_o$
Stage 3 : The fault is removed by opening the faulted line at $t = t_1$
Stage 4 : The system is in a post-fault state.

Fault Sequence – II:

Stage 1: The system is in pre-fault steady-state.
Stage 2: A fault occurs at $t = t_o$
Stage 3 : The fault is removed by opening the faulted line at $t = t_1$
Stage 4 : The transmission line is restored with the fault cleared at $t = t_2$
Stage 5: The system is in a post-fault state.

Pre-fault operating point considered:

$\delta_{10} = 64.17^o$, $P_{m10} = 0.6$ p.u. ; $V_{t1} = 1.0$ p.u.
$\delta_{20} = 63.025$, $P_{m20} = 0.55$ p.u. ; $V_{t2} = 1.0$ p.u.

The simulation results are given in the next section.

5.4 Simulation Results:

Fig.5.2(a) to 5.2(e) show the simulation results for co-ordinated excitation and UPFC control. From Fig.5.2(a) it can be seen that for a fault very close to X_{T1} excitation control alone can not maintain the stability of generator #1. When co-ordinated control is applied, generator #1 remains stable for the same fault and the post-fault oscillations are reasonably damped (Fig.5.2(b)), Fig.5.2(c) and 5.2(d) show the result for a different fault location and fault clearing time. Fig. 5.2(e) shows the result when reclosing takes place following the removal of fault. In all cases it can be found that the co-ordinated excitation and UPFC control is very effective in enhancing transient stability and damping post-fault oscillations. UPFC control, when co-ordinated with the proposed excitation control, can further enhance the performance of a power system as far as transient stability is concerned.

Fig.5.2(a): Power angle response

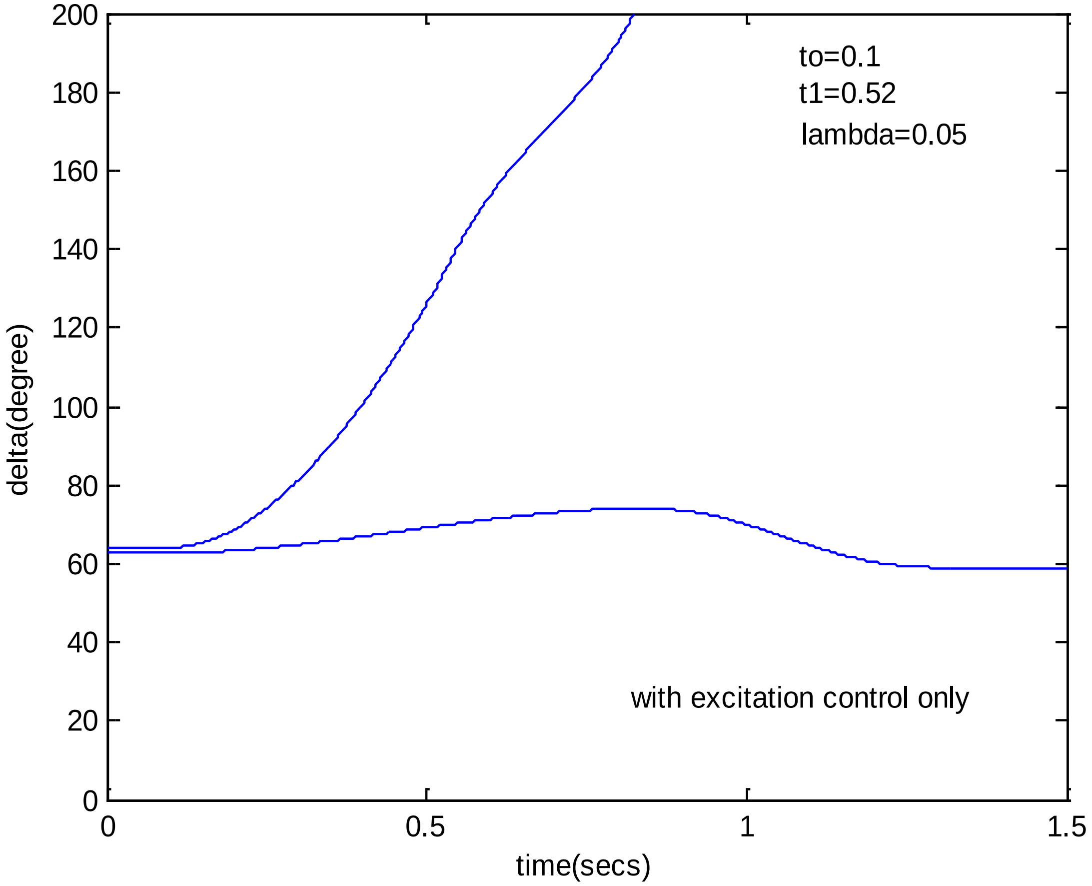

Fig.5.2(b): Power angle response

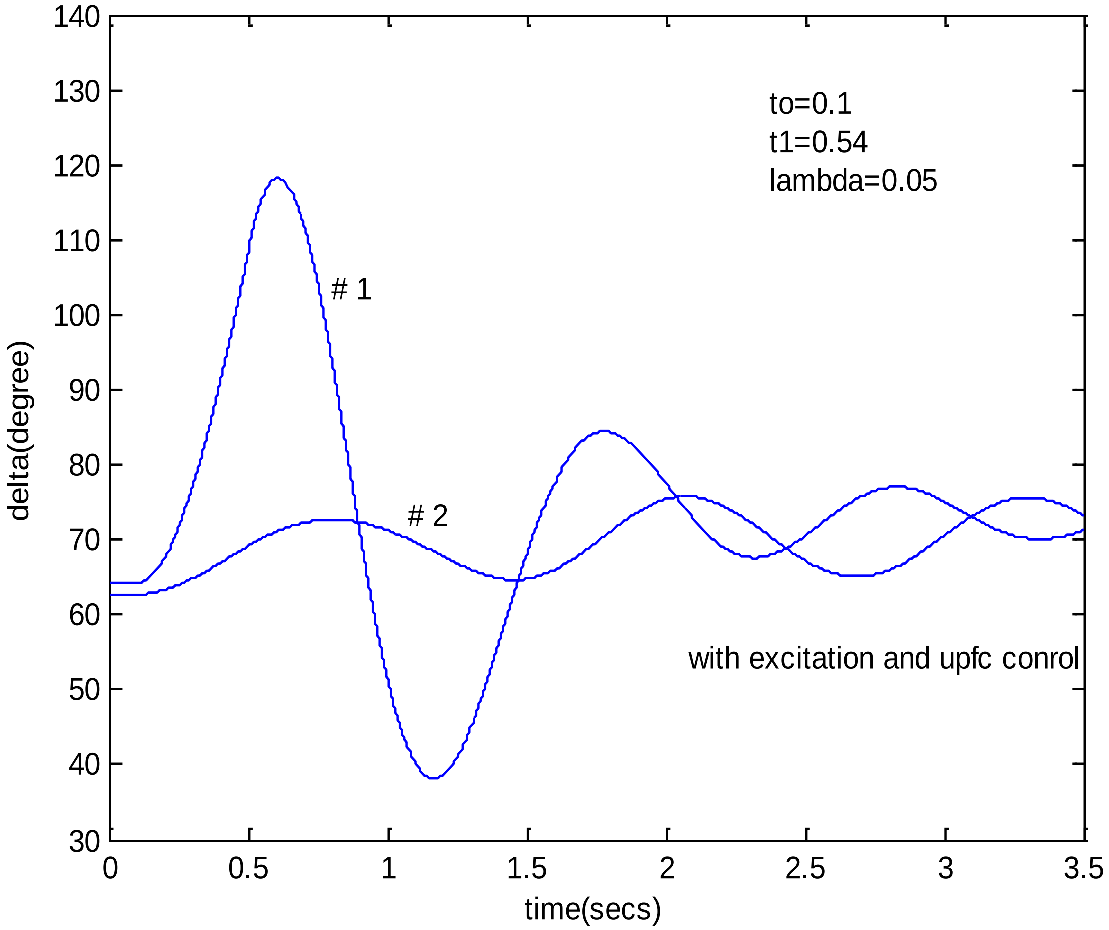

Fig.5.2(c): Power angle response

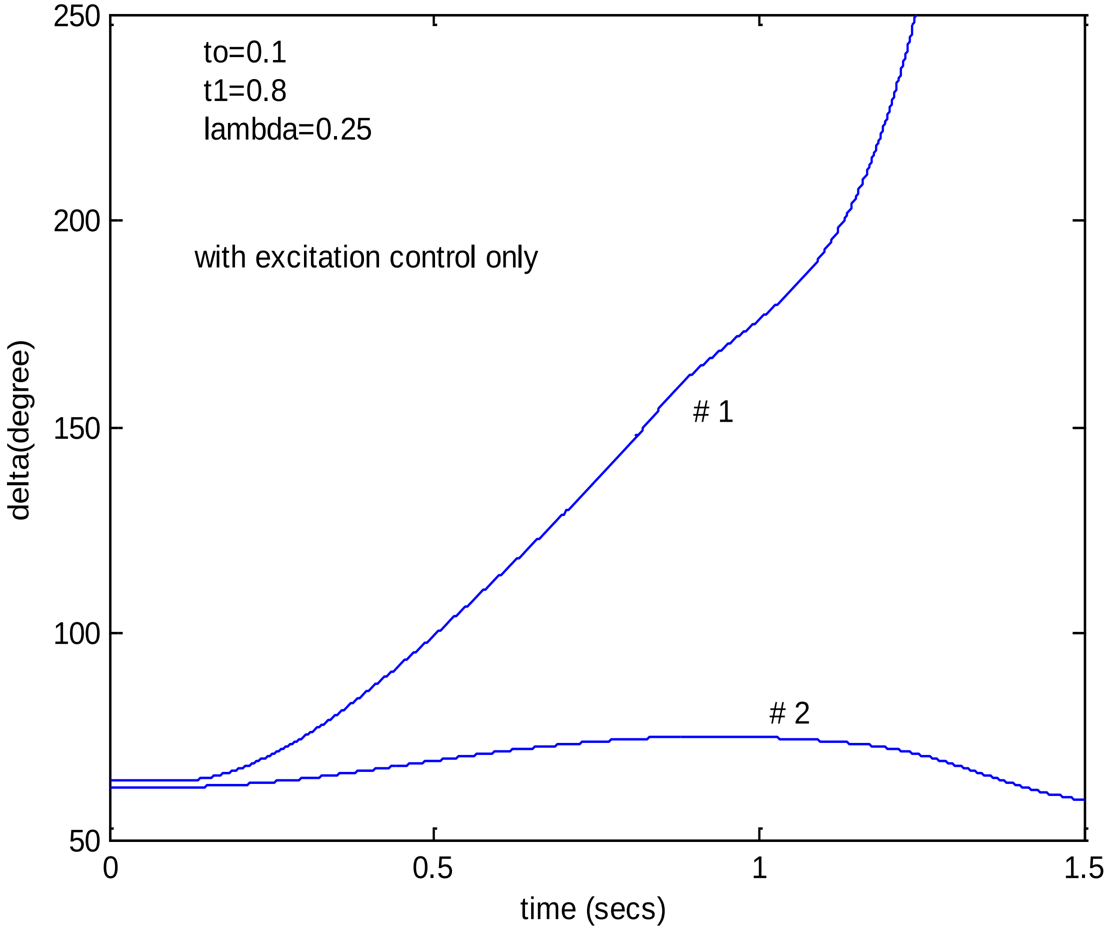

Fig.5.2(d): power angle response

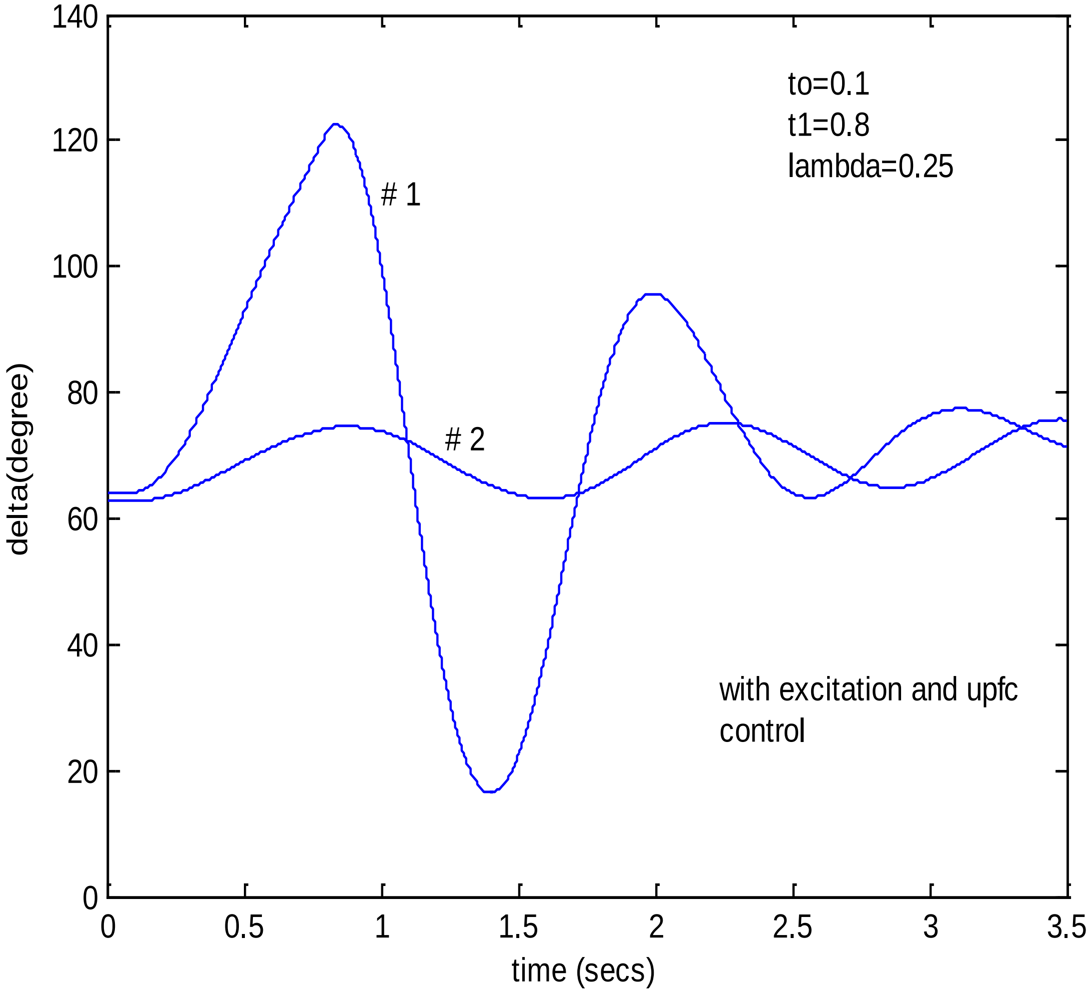

Fig.5.2(e): Power angle response