CHAPTER 6

CONCLUSION

6.1 INTRODUCTION

This chapter presents the significant contributions made during the course of the research work and proposes a few suggestions for future work. Before proceeding with the review of the work done, the objectives of this thesis stated earlier are recalled.

1. To investigate the damping capabilities of series and shunt connected FACTS controllers in a single machine infinite bus system and to develop an optimization model to tune the parameters of FACTS based damping controllers for enhancement of small signal stability.

2. To investigate the damping capabilities of series and shunt connected FACTS controllers in a multimachine power system through and to develop an optimal tuning method to tune the parameters of FACTS based damping controllers to damp out inter area and local modes.

3. To investigate the impact of FACTS controllers on the small signal stability of multi machine power system with grid connected wind farms having doubly fed induction generators.

4. To investigate the rotor speed stability of doubly fed induction generator following large disturbances.
6.2 REVIEW OF THE WORK DONE

This thesis has investigated the damping capabilities of different types of shunt and series FACTS controllers in enhancing the small signal stability of the power system.

A single machine infinite bus (SMIB) system was chosen for carrying out detailed investigations on different FACTS based stabilizers. A generalized small signal stability model based on current injections of FACTS devices is developed for the SMIB system. The series FACTS devices (TCSC, SSSC) are represented as single current injection in either node of a transmission line. If the device is a shunt connected device (SVC, STATCOM) then the injections are confined only to one node. UPFC is represented as two current injections in one node and one current injection in the other node.

The current injections due to the FACTS devices are expressed in the individual machine d-q coordinates and linearized around an operating state. The resulting linearized current expressions are substituted in the state equations of synchronous machine to get the state space model.

A nonlinear parameter constrained optimization model is developed to tune the parameters of the damping controller of FACTS devices to enhance the damping ratio of the critical electromechanical mode. The damping ratio of the critical electromechanical mode is expressed as function of the damping controller parameters \((K_{\text{stab}}, T_1)\) of the FACTS device. This relation is obtained by using the concept of induced torque coefficient. The optimization problem is formulated to maximize the damping ratio of the critical electromechanical mode subject to the parameter constraints. Sequential Quadratic Programming algorithm is employed iteratively until the objective function (damping ratio) is maximized. The parameters so obtained
by maximizing the damping ratio of the critical electromechanical mode are the optimal gain and time constant of the damping controller.

The robustness of the designed damping controllers are confirmed by conducting eigenvalue analysis with increased system loading by 20%. Among shunt devices STATCOM enhances the damping ratio of the electromechanical mode effectively compared to SVC. Among series devices SSSC is superior compared to TCSC in enhancing the small signal stability. It is observed that the system is small signal stable with UPFC in the network with a damping ratio of 0.4. The robustness of the FACTS stabilizers are confirmed by running transient stability simulations. It is observed that the rotor angle oscillations settle down quickly with UPFC in the network.

The tuning methodology adopted for the SMIB system is extended to the multimachine power system to optimize the gain and time constant of the damping controller. This section has developed a multimachine small signal stability model using FACTS devices. The effectiveness of FACTS controllers in damping both interarea and local oscillations is investigated using a two-area 4-machine power system. It is observed that the inter area mode is most critical mode and the FACTS stabilizers are designed to damp out this mode. The induced torque coefficient is computed for machine $G_3$ in the two area system. The damping ratio of this critical inter-area mode is expressed as function of the stabilizer parameters.

It is observed that among SVC and STATCOM, STATCOM enhances the damping ratio of the local modes and inter-area modes effectively. Among series FACTS devices TCSC and SSSC, SSSC is very effective in enhancing the damping ratio of the critical interarea mode. The damping ratio of the electro mechanical mode increases to 0.2966 with UPFC in the line.
The effectiveness of the proposed optimization model is tested also on 10 machines, 39 bus New England system which has multiple critical modes. It is observed that the optimally designed controllers lead to a stable system.

The impact of grid connected wind driven doubly fed induction generators on the small signal stability of the multimachine power system has been investigated. The gain and time constant of the FACTS damping controllers are tuned using constrained optimization model developed for maximizing the damping ratio of critical electro mechanical mode.

It is observed that on interconnecting the induction generator to the power grid the damping ratio of the swing mode become weak which causes small signal instability in the multimachine power system. This section has developed a multimachine small signal stability model for eigenvalue analysis with doubly fed induction generators.

From the results it is observed that among series connected FACTS devices SSSC increases the damping ratio of the electro mechanical mode significantly compared to TCSC. Among shunt connected devices STATCOM is the preferable choice for enhancing the small signal stability of the power system with windfarm. The damping ratio of the system is high with UPFC in the line.

The impact of DFIG based windfarm following a large disturbance in also studied with the impact of FACTS devices. Following a large disturbance in the network the rotor speed of the doubly fed induction generator reaches a post fault value far away from its steady state prefault value. The rotor speed stability of induction generator is analyzed by simulating a self clearing three phase fault in the grid windfarm line with the impact of FACTS stabilizers.
From the transient simulation results we conclude that among shunt connected FACTS controllers the STATCOM provides better damping to the rotor speed oscillations compared to that of the SVC. Among series connected FACTS controllers the UPFC damps both rotor angle oscillations of synchronous generators and rotor speed oscillations of induction generator very effectively.

6.3 **SCOPE FOR FUTURE WORK**

In future it is expected that more and more FACTS Controllers will continue to be employed for power flow and system voltage control.

Hence the following research works are expected to have considerable significance

- Coordinated tuning of multiple FACTS Controllers in the network for enhancement of power system damping.

- The interaction effects of multiple FACTS controllers on the small signal stability of power systems without and with wind farms need to be addressed.