CHAPTER 6

CONCLUSIONS AND SCOPE FOR FUTURE WORK

This chapter aims at summarizing the work done in the thesis and highlighting the significant contributions of the thesis. The ambit of future work is also reviewed in the chapter.

6.1 SUMMARY OF THE PRESENT WORK

The main aim of the thesis is to investigate the impact of increased penetration of wind energy on the stability of power system. The following aspects are addressed in the thesis: (i) Analysis of the stability of power system with fixed speed and variable speed WECS, (ii) Coordinated controller design of variable speed WECS, (iii) Analysis with Type-2 wind turbines and (iv) validation of small signal stability analysis results using time domain study.

In Chapter 3 stability of a power system with PMSG based WECS is investigated. The importance of coordinated tuning of MSC and GSC controllers and its influence on system stability is showcased in this chapter. Three different approaches are considered for tuning of controller parameters. The objectives for the approaches are maximization of system damping, minimization of performance indices and both respectively. The co-ordinated tuning is posed as an optimization problem. First two approaches are solved by genetic algorithm. Multi-objective problem is formulated in third approach by determining the analytical relationship between objective functions and
controller parameters using RSM and then solved by NSGA II. From the investigations, the following conclusions are arrived at.

(1) The complexity in the program execution time is greatly reduced when RSM is applied for developing analytical relationship between controller variables and objectives.

(2) The time taken for approach 3 is very less compared to approach 2.

(3) Most of the performance indices out of eight taken are improved in the third approach and comparable with approach 2.

(4) Maximum damping obtained through third approach is comparable with approach 1.

(5) Eigen values closer to the origin in first approach are moving away from the origin when RSM+NSGA II is applied.

(6) RSM+NSGA II based tuning is perfectly tracking the reference voltages and speed compared to other two approaches for varying wind velocity profile.

(7) With RSM+NSGAI2 overshoot, undershoot and settling time of DC link capacitor voltage and grid voltage are better than other two approaches during load change and three phase fault.

Chapter 4 investigated the small stability of a multi-machine power system with large wind penetration. Studies are conducted connecting fixed
speed and variable speed WECS at different locations. The effect of supplanting conventional synchronous generation with distributed generation is studied by replacing the synchronous generators by equivalent wind farms. The movement of modes with wind velocity and number of wind turbines is studied. Controller parameters of variable speed WECS are varied and their impact on the system stability is examined. Moreover, the efficacy of the proposed controller design is tested on a multi-machine system.

From the investigations following conclusions are arrived:

1) The damping of SG modes increase with wind power penetration and the overall system stability is enhanced.

2) When a Type 2 wind farm is connected to the power system the oscillatory modes become real and power limitation is achieved at high wind speeds.

3) With increase in wind velocity, PMSG rotor mode and SG electrical modes damping increases and SG rotor mode damping ratio slightly decreases.

4) With fixed speed WECS the damping of SG modes shows a marked increase compared to variable speed WECS.

5) With PMSG based WECS the eigenvalues are influenced by controller parameters and are less sensitive to change in wind speed.

6) Coordinated tuning of MSC and GSC controllers employing RSM and NSGA II yields better results and plays a crucial role in enhancing system stability.
In Chapter 5 the small signal stability of Indian utility grid with fixed speed and partially variable speed wind farms is analyzed. Indian utility grid is a 156 bus system with 1608MW of conventional synchronous generation and 2857MW of distributed generation. Small signal stability of the system is analysed with Type-1 wind farms and a combination of Type-1 and Type-2 wind farms. The movement of eigenvalues at rated speed and above rated speed is studied. The results obtained are validated using time domain analysis. The transient stability of Indian utility grid when subjected to a three phase fault is also studied. From the analysis the following conclusions are arrived at

1) The IG electromechanical modes move towards the left half of the plane with increase in wind velocity enhancing the system stability.

2) At above rated wind speeds Type 2 wind farms enable power to be maintained at its rated value. At a wind speed of 21 m/s with Type-2 wind farms power obtained increases by 17.84%.

3) SG rotor mode damping improves significantly with Type-2 wind farms. Therefore Type 2 wind farms enhance the stability of power system.

4) When subjected to a three phase fault, voltage response of Type-2 wind farms reaches steady state at a faster rate than Type-1 wind farms due to the presence of rotor resistance controller.
6.2 SCOPE FOR FUTURE WORK

Since interest in predicting the response of wind turbines to grid faults is increasing and often addressed, it would be beneficial, to concentrate on the following issues in future research:

- In this thesis, an aggregate model is used for wind farm and this aggregate model does not include the tower shadow and wake effects. Analysis of grid connected WECS can be done including these effects.

- Analysis of grid connected variable speed WECS can be performed with non-linear controllers based MSC and GSC control.

- Analysis of grid connected WECS can be extended by including Type-3 wind turbines.

- Impact of replacing the aged fixed speed wind farms with variable speed wind farms in Indian utility system on power system stability is envisaged.

- The inclusion of the load characteristics and its time variation can be studied to analyse the dynamics of the power system operation. The interaction of the loads in addition to the wind power variation on the power system dynamic operation can lead to interesting results.

- Stochastic model can be considered for grid connected wind energy conversion system. Because random phenomena of
power system in terms of line fluctuations and load changes would force the system to leave its stable operating region.

- Uncertainties in the system load at wind generator bus can be modelled and dynamic models by capturing noise due to wind effects could be developed.

- Dynamic behaviour of double-output induction generator (DOIG) driven by wind turbine under wind speed variation and during and after grid faults, can be investigated. The damping methods can be tested to reduce high transient values of current and voltages at different parts of WECS.

- The changing nature of power system and their dynamic behaviours could be analysed to identify critical issues that limit the large scale integration of wind generators and FACTS devices.

- Modal analysis of grid connected DFIG can be performed to understand DFIG intrinsic dynamics completely which can be useful for control design and model justification.

- Comprehensive models of wind turbine can be used to analyse power and voltage fluctuations. The control scheme of the grid side converter can be supported with a voltage regulation loop to reduce flicker emission.