# CHAPTER 7

## SUMMARY AND CONCLUSIONS

This thesis presents the mathematical modelling, technological methodologies and algorithmic approaches to design a reliable controller for DFIG driven by variable speed wind turbine appropriately. The DFIG control parameters are very much necessary to be optimized to enhance the performance of the WECs for reliable operation of the interconnected composite power system. In previous research, the conventional techniques have improved the control parameters however; the research work presented in this thesis proposes to design a reliable controller for DFIG driven by variable wind turbine to improve its transient performance with, rise time, settling time, and peak overshoot by using optimization and soft computational evolutionary techniques. The Static output feedback (SOF), Particle swarm optimization (PSO), Bacterial forging optimization (BFO), Firefly algorithm (FFA) along with Differential evolution algorithm (DE) and Genetic Algorithm (GA) in conjunction with their fitness functions have been described in detail. These evolutionary techniques have several advantages over the conventional methods like use of objective function no other auxiliary functions, irrespective to the type of parameters, avoid local optimization solutions, probabilistic nature and provide solution for any number of dimensions. A sixth order transfer function of DFIG model as a plant transfer function is used for performance improvement of the DFIG based wind turbine scheme. At last, the Reliability of DFIG based variable speed wind turbine, its performance enhancement analysis and Markov process based component reliability have described in details. In order to technological aspects of controller design for performance enhancement of DFIG based WECS under wide range of created scenarios and situations, the thesis work is concluded as follows.

In chapter 1, the idea of the current research work and historical development of the wind power generation technology have been presented in a chronological behaviour. The fundamental concepts of the DFIG based WECS with its possible present and future applications along with its major salient features have illustrated in details. The study starts with describing widespread perception on wind energy and commonly used a generator in wind conversion. Then it presents additional particulars on DFIGs active modes and utilization. It is followed by DFIG control methods in addition to overviews of different engaged electrical and mechanical controlling methods. Based on the review DFIG has compensation regarding electrical, mechanical as well as economic views. DFIG has the main promising prospect for WECS in power generation to harmonize the conventional systems. Finally, this chapter concludes with the motivation, research objectives, and organization of thesis.

In chapter 2, the mathematical modelling and controller design for DFIG driven by variable speed wind turbine by using SOF method is depicted in details. The mathematical model of the DFIG, its converters, their controllers and LMI approach have discussed appropriately. The obtained results are compared with the supervisory controller techniques for performance improvement of the DFIG based wind turbine scheme. The supervisory PID controller even though improves the system response in compare to the open loop system, however, the number of oscillations is not removed entirely. The PI controller designed using SOF technique not only improves the system response but in addition to reducing the percentage overshoot to zero. The PI controller using SOF technique shows that the system settles down in smaller time as in the case when supervisory PID controller used. In this chapter it has been seen that the settling time is reduced next to three percent approximately as well as the percentage overshoot reduces to zero when PI controller using SOF method is used in comparison to the supervisory PID controller. Hence, it is concluded that the SOF control technique provides suitable option for design of a reliable controller to be implemented in the DFIG based WECs.

In chapter 3, the controller design for DFIG driven by a variable speed wind turbine employing particle swarm optimization procedure and its fitness functions are described appropriately. The responses of the DFIG system regarding terminal voltage, current, active-reactive power and DC-Link voltage along with generator speed have slightly improved with PSO based controller. Finally, the obtained output is equated with a standard technique for performance improvement of the DFIG based wind energy conversion system. However obtained results show that the system using PSO based controller settles down in less time than the supervisory based PID controller. The comparisons between PSO based controller and the supervisory PID controller precisely has been described. It is concluded that the settling time is reduced next to 12 percent approximately along with the percentage overshoot; rise time, peak time, etc. are reduced to zero using proposed method. Ultimately, it is concluded that the PSO control technique provides a different alternative approach to design a reliable and adequate controller for implementation in the DFIG based wind energy conversion systems.

In chapter 4, the bio-inspired technique is applied to design a controller for doubly fed induction generator based variable speed wind turbine scheme. This methodology is based on exploiting the two efficient swarm intelligence based evolutionary soft computational method, i.e., Particle Swarm Optimization (PSO) and Bacterial Foraging Optimization (BFO) to design the controller for low damping plant of the DFIG. Wind energy impression and DFIG based WT component with operating principle as well as the equivalent circuit model of the DFIG, have been discussed appropriately. The controller design for DFIG based WECS using PSO and BFO technique along with its fitness functions are described in detail. The responses of the DFIG system regarding terminal voltage, current, active-reactive power and DC-Link voltage along with generator speed have slightly improved with PSO based controller in comparison with BFO based controller. Finally, the obtained output is corresponded with a benchmark procedure for performance enhancement of the DFIG based wind energy conversion system. Whenever comparison between PSO based controller and the BFO based PID controller are described precisely, it is accomplished that the settling time is reduced next to 62 percent approximately and the percentage overshoot, rise time, peak time, etc. are reduced to zero using proposed method. Finally, it is concluded that the PSO control technique make available an additional alternative to design a reliable and satisfactory controller for implementation in the DFIG based wind energy conversion systems.

The chapter 5 proposes the design of a PID controller for DFIG base WT to improve its transient performance such as rise time, settling time and peak overshoot by using two evolutionary techniques such as Firefly algorithm (FFA) and Differential evolution algorithm (DE) along with Genetic Algorithm(GA). These evolutionary techniques have several advantages over conventional methods like use of objective function no other auxiliary functions, irrespective to the type of parameters, avoid local optimization solutions, probabilistic nature and provide solution for any number of dimensions. In this practice, a sixth order transfer function of DFIG model as a plant transfer function is used. The controller design for DFIG based WECS using FFA, DEO and GAO technique along with its fitness functions are described in detail. The responses of the DFIG system concerning terminal voltage, current, active-reactive power and DC-Link voltage along with generator speed have slightly improved with FFA based controller in comparison with DEO& GAO based controller. At last, the obtained output is equated with a usual technique for performance enhancement of the DFIG based wind energy conversion system. In this chapter, the results of both evolutionary algorithms have compared and concluded that FFA based controller has better option for DFIG based wind turbine scheme. At last, it is clear that the DE-based PID controller improves the system responses as compared with the open loop control system; however, the FFA-based designed controller enhances the system response and also reduces the percentage overshoot equal to zero. The obtained results show that the system using FFA- based controller settles down in less time than the GA, DE-based PID controller scheme.  It is concluded that the settling time is reduced and the percentage overshoots are reduced to zero using the proposed method. Finally, it is summarized that the FFA- control technique provides another suitable option to design a reliable and adequate controller for implementation in the DFIG based variable speed wind turbine system.

In chapter 6, an on-off control scheme is used for MPPT and anticipated to control the rotor side converter of DFIG based wind turbine associated to the grid. It is trying to keep the torque within the optimal value at which the maximum power is obtained. The grid side converter is controlled in such a way to assure a smooth DC voltage as well as ensure sinusoidal current on the network. Finally the Reliability of DFIG based WT, its performance analysis and component reliability using Markov process have described appropriately. A concept of MPPT has been proposed to achieve the goal of tracking maximum power at a given wind velocity. To perform the MPPT from the wind system, the MPPT block in coordination with the rotor control block acts to maintain the torque to the value that is optimum for extracting the maximum power output from it. The energy conversion device which is used in wind turbine systems is DFIG; therefore, the DFIG is modeled as an energy conversion device. The modeling included the verification of developed model with that of the generator present in the library of the MATLAB / Simulink. The obtained results are better than of the model available in the MATLAB library. Further, the modeled generator has incorporated with rotor side converters and controllers to achieve a DFIG. The results obtained showed that the system could perform well at average wind speeds while the results are inconsistent with that of expected values at lower and higher wind speeds. Hence at average wind speed, the rotor side controller changes such that to alter the torque to the optimal value generated by the MPPT controller. The stationary Markov process is used to compute the reliability of the whole DFIG based WT scheme with subsystems. The proposed model is flexible since the failure rate and the mean time to repair rate can be calculated for different operational conditions and specifications based on DFIG technology.

**7.1 The Scope for Further Studies**

This thesis attempts to categorize and truncate research in wind energy extraction using DFIG, mainly controller systems, sound effects and highlighted evolution points. On the other hand, DFIGs have lots of benefits, and their competitive compensation makes them the preferred alternative for WECS which can associate with large power networks, but they infrequently used as stand-alone systems. Nevertheless, there are perceptible researchers, which were carried out on a small or isolated system using DFIGs but such application is rare due to control and power electronic system complication. Even though DFIG control methods and systems have been approximately for so long, this area is still fashionable among the researchers, and advanced control schemes still proposed as electrical otherwise mechanical controllers. Whereas, these methods cover both mechanical and electrical scopes; predominantly came into electrical categories. The parameters tuning problem of the designed PID controller for DFIG based Wind

Turbine system has been efficiently solved in this thesis by using meta-heuristic based algorithms. The processes have been examined and obtained results are attractive. When compared to conventional method, Evolutionary Algorithm results have superior for the DFIG based wind turbine system performance in term of time domain specifications. The performance of system for different evolutionary technique is different but not so much. The results or performances are so much depend on the parameter choose so change in these parameter will be depicted in the results also, and also this meta-heuristic based tuning use evolutionary techniques which are based on hit and trial and convergence of the solution so sometimes solution may stuck into a local solution which is not optimal, so definitely the new variant of these techniques will improve the solution and avoid drawbacks of previous variants of these techniques.

Finally, it is summarized and concluded that the proposed algorithms can be used as efficient alternatives to conventional tuning methods. The wind energy market is rocketing high at present. A lot of research and developmental works have been going on in the field of wind energy to find the optimal ways to harness the available power. A concept of MPPT has been proposed to achieve the goal of tracking maximum power at a given wind velocity. To perform the MPPT from the wind system, the MPPT block in coordination with the rotor control block acts to maintain the torque to the value that is optimum for extracting the maximum power output from it. The energy conversion device which is used in wind turbine systems is DFIG; therefore, a DFIG is modelled as an energy conversion device. The recent methodology for reliability analysis of the DFIG is described in this thesis. The stationary Markov process is used to compute the reliability of the whole DFIG based WT scheme with related subsystems. The proposed model is flexible since the failure rate and the mean time to repair rate can be calculated for different operational conditions and specifications based on DFIG technology.

**7.2 Scope of future work**

1. The validation of the proposed controller on the real system / model remains a topic for future study.

2. The transient analysis of the system under faults has not been considered and can be taken up as a separate study.

3. The advanced control schemes still proposed for electrical and mechanical controllers.

4. The used parameters in this research work are not so much engineered; in coming future there may be more suitable and experienced parameters to be used.

5. Different variant of the differential evolution algorithm have derived in this thesis, they will improve the results in coming future.

*The author feels that the carried out research work in this thesis would certainly help and motivate the readers and future researchers to provide a suitable guideline in field of the controller design of DFIG for WECS by using different optimization schemes.*