Chapter 6

Conclusion

6.1 Conclusion

Wind energy is considered one of the reliable renewable energy sources. The share of wind energy with respect to total installed energy capacity is increasing worldwide. The Doubly Fed Induction Generator (DFIG) based on wind turbine with variable-speed control scheme is the most popular wind energy generator in the wind energy industry. This machine can be operated either in stand-alone mode or grid connected.
A thorough understanding of the modeling, and control, as well as the steady state analysis of this machine in both operation modes is necessary to achieve the required voltage and frequency in case of stand-alone, and to optimally extract the energy from the wind in case of grid connected and accurately predicts its performance.

Krause's model for the induction machine in d-q synchronously rotating reference frame is revised. Simulation and hand calculations indicate complete similarity.

Stand-alone DFIG is studied in both uncontrolled and controlled operation. In the uncontrolled operation mode, the study revealed that achieving fixed stator voltage and/or frequency is impossible. Therefore, introducing the controlled mode is a must. The system studied was formed from a controlled rectifier and a dc filter linked with a six pulse 180^{o} inverter. The study indicated that a fixed stator voltage of 380-V and fixed frequency of 50-Hz was achieved. Comparison between simulation and experimental results shows a good agreement between them. The study, also, revealed that although the stator voltage is kept constant at 380-V, its wave form is not a pure sinusoidal. The stator voltage total harmonic distortion is found to be 19.6 %. To improve the stator voltage waveform an inverter controlled by space vector pulse width modulation technique was introduced.

Space-vector controlled DFIG in the stand-alone mode is presented. Using such technique, the stator voltage total harmonic was improved to 8%. A further study, when introducing third harmonic elimination using passive filter indicated a considerable reduction in total harmonic distortion to only 2.2%. Also, in this chapter, another study was considered. Self-excitation was introduced to the system. The system consists of an uncontrolled rectifier and a dc filter with a capacitor of 1000-μF that is initially charged to 500-V. The system was successfully simulated, which indicates the possibility of self-excited operation.

The study of a DFIG when connected to a utility grid was introduced. The study includes variable speed operation for below and above synchronous speed. The system was simulated successfully. An assumed required active and reactive power was the target. An open-loop calculation, based on the required active and reactive power was introduced to the simulation. A decoupled active and reactive power control was achieved. The maximum percentage error between required and calculated power is less than 7%. This error is acceptable since it is an open loop system and the rotor voltage magnitude and angle were calculated from an approximate equivalent circuit without considering the

magnetic circuit saturation effect. The developed controller achieves the objective of controlling both active and reactive power under different speed pattern operation.

The effect of wind speed variation on both active and reactive output power supplied from the DFIG to the grid was studied. A sudden change in the wind speed was assumed. The change includes a speed variation from sub-synchronous to super-synchronous speed. It should be noted that, the change in wind speed from sub-synchronous speed to super-synchronous speed changes the magnitude, the angle and the sequence of the rotor voltage to keep the active and reactive power constant. The study revealed that the phase sequence reverses for super-synchronous speed.

6.2 Future work

There are some interesting points that can be considered as a future work, such as:

- Considering a closed loop system for grid connected DFIG to improve the accuracy.
- Using different control strategies to minimize the harmonics injected to the power network.
- Study various control techniques to achieve maximum power capture for DFIG in wind turbine system.