CHAPTER 7

CONCLUSIONS AND FUTURE WORKS

7.1 Introduction

This chapter presents the summary of this dissertation. The work that has been done in each chapter, the main contributions and also future works are presented in this chapter.

7.2 Conclusions

The chapter 3 of this dissertation presents the full order model of the Nine-Phase IPM machine in different stator connection. The modeling method used in this chapter is capable of predicting all details of the machine behavior. The first configuration is a single-star nine-phase IPM and it is simulated using all details of the machine geometry, including the full order functions of the turn and winding functions of the machine stator and the full order functions of the permanent magnet blocks and the airgap function. After generating the inductances of the machine, they are transformed to the rotor reference frame using the nine by nine transformation matrix to get the different components of the inductances. The generated inductances are used along with the permanent magnet flux linkages to model the machine. The model is simulated using MATLAB Simulink and the simulation results are presented.

The same method of the modelling was performed for symmetrical and asymmetrical triple-star nine-phase IPM machines. In this modellings, the full order functions of the turn and winding functions and the airgap functions are used to generate the inductances of the machine. After the inductances are generated they are transformed to the rotor reference frame. The resulting inductances in the rotor reference frame are used in the machine model to generate the model of

The machine. Both of the models are simulated using MATLAB Simulink and the simulation results are presented.

In the chapters 4 the average model of the symmetrical and asymmetrical triple-star nine-phase IPM are derived. The modelling method in this chapter, is based on the Fourier series of the machine parameters. The Fourier series of the machine windings and the airgap function are used to obtain the Fourier series of the machine inductances and finally the inductances are transformed to the rotor reference frame to be used in the machine model. The models are simulated using MATLAB Simulink and the simulation results are presented. After generating the models, they are transformed to a new reference frame in which the couplings between the machines are removed and the machine model is simplified. The simplified model is suitable for designing the drives without dealing with the couplings between the machine sets. The new transformation matrixes and the decoupled models are presented in this chapter.

Also in the chapter 4 an asymmetrical six-phase double-star IPM machine is modeled using the Fourier series of the machine parameters. After modelling the machine, the model is transformed to the rotor reference frame to show the coupling terms between the axis of the machine. After generating the machine model, the model is transformed to a new reference frame in which the coupling terms between the machines are zero. The decoupled model is an effective tool to design the drive. The new transformation matrixes are presented in this chapter.

In the chapter 5 a sensorless drive is designed for the single-star nine-phase IPM machine. The procedure starts with modelling of the nine-phase converter. In this modelling the converter model is derived using the switching function and the model is transformed to the synchronous reference frame.

The design of the machine drive is done based on the minimum copper loss strategy. Based on this strategy and using Lagrange method, the copper loss is minimized while the machine is satisfying the load torque constraint. Using this method, the relationship between the q and d axis currents is derived.

The current regulators are also designed in this chapter for the machine axis in the rotor reference frame. The current regulators are designed based on the dynamic equations of the voltages of the machine axis.

The new position estimation method is also presented in this chapter along with the high frequency analyses. The essential signal processing method and the observer are also designed and presented. The designed drive and estimator are simulated with the full order model of the machine and the simulation results are presented. Finally using Tustin approximation, the drive is discretized and implemented in the prototype. The simulation results for constant volt/Hz and vector control drive are verified by the experimental results. The main contribution of this chapter is to get the positions from the non-torque producing channels so the machine does not generate any extra torque pulsations.

In the chapter 6 a sensor less drive is designed for the symmetrical triple-star nine-phase machine. After modelling the triple-star nine phase converter, the machine drive is designed using the average model of the machine which includes the coupling between the machine sets. The designed drive shows many complexities in the controller due to the couplings of the machines.

To remove the complexities, the decoupled model that was generated in the chapter 4 is used to design the drive. The drive is designed based on the minimum copper loss strategy and it has six current controller loops which are operating on the torque producing and non-torque producing channels of the machine. The reference currents of the torque producing channels are generated from the speed controller loop and minimum copper loss strategy. Also the reference of the non-torque producing channels is kept zero and the current regulators are designed based on the dynamic equations of the machine voltages.

To implement the drive, the rotor position is also needed. The rotor position of this controller is estimated using the high frequency injection in the fifth sequence channel of the stationary reference frame. The high frequency analyses are presented in this chapter and the essential signal processing methods are proposed. The designed drive and the estimator are simulated along with the full order model of chapter 3. After that, the designed drive and the estimator are discretized and translated to C++ language and the DSP-PFGA is programmed using that. Finally, the simulation is run for several speed profiles and the simulation results are verified using experimental results.

7.3 Future Works

The below suggestions are made for the future work of this dissertation.

- Sensorless Drive of Asymmetrical Triple-Star Nine-Phase IPM Machine.

A sensor less drive can be designed for the asymmetrical triple star machine presented in chapter 3. The drive can be designed using the decouple model generated in the chapter 4 and a sensor less method for rotor position estimation can be presented for the designed drive. The different channels of the machine can be analyzed to find a proper channel for injecting the high frequency signals.

- Position Estimation Using the High Frequency Currents Due to the PWM Signals.

One way to avoid the high frequency torque pulsations is to use the high frequency components of the currents generated by the PWM signals. The PWM signals can interact with the machine saliency and generate the position dependent currents. The signals can be extracted from the high frequency currents and be used in the position estimation procedure. This method will need more accurate prototype to be able to extract the rotor information from signals with lower signal to noise ratio.

- Adaptive Controller Design Using Variable Inductances.

As it can be seen from the FEMM results of chapter 3 the machine inductances in the rotor reference frame are not fixed. Their magnitudes of the inductances can vary be changing of the stator current. The machine controller can be an adaptive one that adapts the variations of the inductances. There are two different ways for implementing the adaptive controller. The first way is to design estimators to estimate the q and d axis inductances online and update the controller for each point of the operation.

The second strategy is to generate lookup tables for the inductances based on the FEMM results of chapter 3. In this strategy for each current magnitude, there will be corresponding inductances that are saved in the controller memory. Therefore, the software can refer to the table and find the closest q and d inductances to the real ones and update the controller. The same methods can also be applied to the rotor flux linkage to adapt the real time flux linkage of the rotor permanent magnet block that may vary with the temperature or saturation of the machine.

- Compensation of the Position Estimation Error.

From the results of the chapters 5 and 6, it can be seen that the estimated position has a short time delay compared to the actual rotor angle. This delay is mostly caused by the natural delay of the low pass filters that are used in the signal processing method of position estimation.

The delay can be compensated using proper compensation methods that can be applied to the low pass filters.