CHAPTER 6.
CONCLUSIONS. FURTHER WORK.

6.1 - Conclusions.

6.1.1 - Direct Torque Control.

Direct Torque Control is supposed to be one of the best controllers for driving any induction motor. Its main principles have been introduced and deeply explained. It is also demonstrated in this thesis that the method of DTC also allows the independent and decoupled control of motor torque and motor stator flux.

Two different estimators for the stator flux and torque have been fully developed.

It is also apparent from the investigation reported that DTC strategy is simpler to implement than the flux vector control method because voltage modulators, and co-ordinate transformations are not required. Although, it introduces some disadvantages, being the torque ripple one of the worst.

Four different methods for improving the classical DTC, which is the aim of the thesis, have been studied and deeply discussed:

- The first method is the search of a better look up table. After the research done in this field, it can be concluded that by means of changing the table can not be remarkably improved the DTC performance. However, some little improvements can be achieved. Many conclusions have been obtained in this study, being the fundamental ideas for the development of the most suitable Fuzzy Logic Controller.
- The second method is the predictive one. It implies, not only the usage of Space Vector Modulation, but also the calculation of the proper voltage reference. It has been concluded that it is too complicated regarding its real implementation because of its calculus, eliminating one of the DTC advantages, which is its simplicity.
- The application of the Fuzzy Logic for implementing a simple modulation between the selected active state and a null one, is the third method. It can be concluded that this method is very promising. Therefore, the present thesis has been focused on that.
- Finally, the fourth method is the regulation of the stator flux reference value. This method can be applied in any motor drive. Not only it reduces the torque ripple improving the motor performance, but also reduces the power reactive consumption taken from the mains supply. Therefore, this method will be further considered.

6.1.2 - Fuzzy Logic Direct Torque Control.

After all the research done, this thesis is focused on introducing a modulation in the DTC. A Fuzzy Logic Controller is in charge of controlling this modulation between the selected active state and a null one. Therefore, it has been suggested and deeply described the Fuzzy Logic Controller, which together with the DTC will create the Fuzzy Logic DTC. The FLC designed is adaptive, improving even further the whole FLDTC. It has been deeply described and justified its way of working, making emphasis on the fact that not only its inputs had to be the torque errors and flux locus, but also the motor operating point. Moreover, the idea that this fuzzy controller has to be adaptive has been taken into account.

Simulation results show the validity of the FLDTC method not only achieving a considerable reduction in torque ripple, but also reducing the energy consumption taken from the mains supply.

Moreover, the simulations correspond to two different motors being proved the validity of the FLDTC for any motor.

Firstly, all simulations have been obtained for an ideal generic plant, with sampling time equal to 100μs and no delays. Once the experimental workbench was set up, its particular parameters of sampling time and delay had been taken into account adapting the FLC. New simulated results with the real plant have been obtained and presented, proving the adaptation of the FLC to any plant, maintaining its good performance.

6.1.3 - Experimental motor drive system.

It has been set up versatile experimental equipment based on two processors, a PC and a DSP. Its main characteristics are as follows:

- The DSP is based in the ISA PC bus, being a good architecture to avoid any electro magnetic interference.
- Both processors can work independently. Therefore the system allows the parallel processing. This parallel architecture has the following advantages:
  - It is a high computational capability system. DSP boards can be added, working all them in parallel.
  - This architecture is currently quite common in industrial applications, giving the possibility of testing the future real prototypes.
- Communication between both processors is achieved easily through the Dual Port RAM. Both processors can access this memory simultaneously, without interrupting the other.
- Its program process can be modular, allowing the addition of new algorithms without changing the other ones. It allows the possibility of an easy experimentation of new algorithms.
- The DSP can be easily programmed in both C language and assembler. Assembler has been used in the critical real time tasks. All PC tasks have been programmed in C language, due to the fact that they are not critical regarding the execution time.

- All experimental results are based in ASCII files, allowing the exportation to any computer or workstation.

6.1.4 - Real implementation.

Experimental results, which match perfectly with the real simulations, have been obtained showing the validity of the entire research. Therefore, the idea of reducing the torque ripple, which is supposed to be one of the disadvantages of the classical DTC, by means of a fuzzy logic modulation, has been experimentally corroborated.

The experimental results are divided into two groups. The first group shows the proper behaviour of the classical DTC and FLDTC. In these graphics, it has been shown the evolution of all magnitudes, even with a resolution equal to the sampling time (166μs). Using the second group of experimental results, it has been done the comparison between the classical DTC and the FLDTC for different motor working points. It has been proved how the torque ripple is much lower in the FLDTC than in the classical DTC for any working points.

Moreover, the adaptation of the ideal FLC not only to any motor but also to the limitations of the real system has been corroborated.

6.2 - Further work.

All further work is summarised schematically in the following ideas:

- Developments of new fuzzy controllers to achieve better performance. This new fuzzy controller should, at least, take into account the following ideas:
  - Develop a completely auto adaptive controller.
  - The controller must be adaptive to any motor.
  - Try to overcome the electrical noises, which appears in any power drive.
- Study the torque ripple reduction not only with fuzzy modulators but also with multilevel converters.
- Find optimum controllers, not only for torque ripple reductions, but also for reducing EMI and for increasing energy savings form the mains.
- Quantify the real savings of reactive power obtained from the optimised stator flux reference value.
- Sensorless FLDTC implementation, just sensing two currents and the DC voltage and by means of either Kalman filter techniques or observers.
- Study and apply different FLDTCs, not only to induction motors as it has been done in the present thesis, but also to any electrical motor.