INTRODUCTION.

I.1 - Historical review.

The history of electrical motors goes back as far as 1820, when Hans Christian Oersted discovered the magnetic effect of an electric current. One year later, Michael Faraday discovered the electromagnetic rotation and built the first primitive D.C. motor. Faraday went on to discover electromagnetic induction in 1831, but it was not until 1883 that Tesla invented the A.C asynchronous motor [MAR 1].

Currently, the main types of electric motors are still the same, DC, AC asynchronous and synchronous, all based on Oersted, Faraday and Tesla's theories developed and discovered more than a hundred years ago.

Since its invention, the AC asynchronous motor, also named induction motor, has become the most widespread electrical motor in use today.
At present, 67% of all the electrical energy generated in the UK is converted to mechanical energy for utilisation. In Europe the electrical drives business is worth approximately $1.0 Billion/ Annum.
These facts are due to the induction motors advantages over the rest of motors. The main advantage is that induction motors do not require an electrical connection between stationary and rotating parts of the motor. Therefore, they do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors. Induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less prove to any failure at high speeds. Furthermore, the motor can work in explosive environments because no sparks are produced.
Taking into account all the advantages outlined above, induction motors must be considered the perfect electrical to mechanical energy converter. However, mechanical energy is more than often required at variable speeds, where the speed control system is not a trivial matter.

The only effective way of producing an infinitely variable induction motor speed drive is to supply the induction motor with three phase voltages of variable frequency and variable amplitude. A variable frequency is required because the rotor speed depends on the speed of the rotating magnetic field provided by the stator. A variable voltage is required because the motor impedance reduces at low frequencies and consequently the current has to be limited by means of reducing the supply voltages [VAS 1] [MOH 1].

Before the days of power electronics, a limited speed control of induction motor was achieved by switching the three-stator windings from delta connection to star connection, allowing the voltage at the motor windings to be reduced. Induction motors are also available with more than three stator windings to allow a change of the number of pole pairs. However, a motor with several windings is more expensive because more than three connections to the motor are needed and only certain discrete speeds are available. Another alternative method of speed control can be realised by means of a wound rotor induction motor, where the rotor winding ends are brought out to slip rings. However, this method obviously removes most of the advantages of induction motors and it also introduces additional losses. By connecting resistors or reactances in series with the stator windings of the induction motors, poor performance is achieved.

At that time the above described methods were the only ones available to control the speed of induction motors, whereas infinitely variable speed drives with good performances for DC motors already existed. These drives not only permitted the operation in four quadrants but also covered a wide power range. Moreover, they had a good efficiency, and with a suitable control even a good dynamic response. However, its main drawback was the compulsory requirement of brushes [MAR 1] [MOH 1].

With the enormous advances made in semiconductor technology during the last 20 years, the required conditions for developing a proper induction motor drive are present. These conditions can be divided mainly in two groups:

- The decreasing cost and improved performance in power electronic switching devices.
- The possibility of implementing complex algorithms in the new microprocessors.

However, one precondition had to be made, which was the development of suitable methods to control the speed of induction motors, because in contrast to its mechanical simplicity their complexity regarding their mathematical structure (multivariable and non-linear) is not a trivial matter.

It is in this field, that considerable research effort is devoted. The aim being to find even simpler methods of speed control for induction machines. One method, which is popular at the moment, is Direct Torque Control [VAS 2].

Historically, several general controllers has been developed:

- Scalar controllers: Despite the fact that "Voltage-Frequency" (V/f) is the simplest controller, it is the most widespread, being in the majority of the industrial applications. It is known as a scalar control and acts by imposing a constant relation between voltage and frequency. The structure is very simple and it is normally used without speed feedback. However, this controller doesn't achieve a good accuracy in both speed and torque responses, mainly due to the fact that the stator flux and the torque are not directly controlled. Even though, as long as the parameters are identified, the accuracy in the speed can be 2% (except in a very low speed), and the dynamic response can be approximately around 50ms [LEO 1] [LUD 2].

- Vector Controllers: In these types of controllers, there are control loops for controlling both the torque and the flux [BOS 1]. The most widespread controllers of this type are the ones that use vector transform such as either Park or Ku. Its accuracy can reach values such as 0.5% regarding the speed and 2% regarding the torque, even when at stand still. The main disadvantages are the huge computational capability required and the compulsory good identification of the motor parameters [ROM 1] .
- Field Acceleration method: This method is based on maintaining the amplitude and the phase of the stator current constant, whilst avoiding electromagnetic transients. Therefore, the equations used can be simplified saving the vector transformation, which occurs in vector controllers. This technique has achieved some computational reduction, thus overcoming the main problem with vector controllers and allowing this method to become an important alternative to vector controllers [BED 5] [ROM 1] [YAM 1].

Direct Torque Control (DTC) has emerged over the last decade to become one possible alternative to the well-known Vector Control of Induction Machines. Its main characteristic is the good performance, obtaining results as good as the classical vector control but with several advantages based on its simpler structure and control diagram.

DTC is said to be one of the future ways of controlling the induction machine in four quadrants [LUD 1] [VAS 2]. In DTC it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state. This method still requires further research in order to improve the motor's performance, as well as achieve a better behaviour regarding environmental compatibility (Electro Magnetic Interference and energy), that is desired nowadays for all industrial applications.

DTC main features are as follows:

- Direct control of flux and torque.
- Indirect control of stator currents and voltages.
- Approximately sinusoidal stator fluxes and stator currents.
- High dynamic performance even at stand still.

The main advantages of DTC are:

- Absence of co-ordinate transform.
- Absence of voltage modulator block, as well as other controllers such as PID for motor flux and torque.
- Minimal torque response time, even better than the vector controllers.

However, some disadvantages are also present such as:

- Possible problems during starting.
- Requirement of torque and flux estimators, implying the consequent parameters identification.
- Inherent torque and stator flux ripple.

I.2 - Structure of the thesis.

The work presented in this thesis is organised in six main chapters. Theses six chapters are structured as follows.

Chapter 1 is entitled " Induction Motor Model. Generalities.". It introduces a mathematical model of cage rotor induction motors. Different ways of implementing these models are presented as well as some simulations corroborating its validity. It must be said that all simulations are obtained from MATLAB/Simulink. The elements of space phasor notation are also introduced and used to develop a compact notation.

Chapter 2 is entitled " Direct Torque Control. Principles and Generalities.". It is devoted to introduce different Direct Torque Control (DTC) strategies. However, firstly it is summarised different induction motor controllers, such as the very well known vector control and "V/f". Once DTC is placed in this general classification, it is fully and deeply described. Finally, different methods for improving the main DTC drawbacks are introduced and studied. These methods are classified as follows:

- Different look up tables.
- Predictive methods.
- Fuzzy logic based systems.

Moreover, a method for regulating the stator flux to its optimum value it is presented.

Chapter 3 is entitled " Fuzzy Direct Torque Control". It covers a full and deep description of a Fuzzy Logic Direct Torque Controller (FLDTC) which improves its performance. At the end of the chapter simulated results are presented, which compare the classical DTC with FLDTC.

Chapter 4 is entitled " Design of Experimental Induction Motor Drive System". This chapter describes the designed workbench drive. Real simulations of DTC and FLDTC are presented taking into account all the non ideal behaviour and delays of the real drive. A way to overcome the mentioned limitations is presented.

Chapter 5 is named " Experimental Results". This chapter is focused on the real implementation of the classical DTC and FLDTC. Experimental results corroborate the correct behaviour of both controllers. An experimental comparison between both controllers is shown. Obviously, all experimental results obtained are from the workbench described in chapter 4.

In Chapter 6, entitled "Conclusions", all achievements are summarised and appropriate conclusions are drawn.

Finally, all PC/DSP programs used in the real implementation are listed in the appendixes. Rules used in the Fuzzy Controllers are also listed. Also, some pictures of the workbench are shown in the appendixes.

I.3 - Aims of the thesis.

The present thesis deals with the development of a Fuzzy Logic Direct Torque Controller that has improved performance compared to the classical DTC system. The main improvement has been the torque ripple reduction. Also, a stator flux optimum controller allows the FLDTC to consume the right energy from the mains, keeping the power consumption to a minimum, when again compared to the classical DTC system.

This new FLDTC system is firstly designed and proved by means of simulations. Later in the thesis, experimental implementation is discussed and the results are presented.

Therefore, the development of this novel induction motor controller can be separated into the following steps:

- Point out the DTC disadvantages. Study the possible ways to overcome them, choosing the best one (Fuzzy Logic).
- Develop and mathematically describe the chosen Fuzzy Logic system. Corroboration of its proper performance by means of simulation.
- Development of a suitable "research workbench drive". Implementation of the FLDTC to prove its proper functionality.