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PROJECT REPORT

FINAL PROJECT REPORT (FYP II)

IMPLEMENTATION OF DIRECT TORQUE CONTROL OF INDUCTION MACHINES UTILIZING ezDSP F28335 AND FPGA

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IMPLEMENTATION OF DIRECT TORQUE CONTROL OF INDUCTION MACHINES UTILIZING ezDSP F28335 AND FPGA

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A report submitted in partial fulfillment of the requirements for the degree of bachelor of power electronics and drives

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JUNE 2013

I declare that this report entitle **"Implementation of Direct Torque Control of Induction Machines Utilizing ezdsp F28335 and FPGA"** is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………..…..……

Name : Muhd Khairi Bin Abd Rahim

Date : ……………………………..……………………………...

Special dedication to my beloved Daddy and Mummy

Abdul Rahim Bin Ismail

&

Che Asiah Binti Saad

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, Most Merciful, Blessing and prayers be upon the Prophet Muhammad S.A.W, a member of the holy family and friends he is elected. Alhamdulillah, grateful to Allah S.W.T for give me a chance to complete this proposal entitled Implementation of Direct Torque Control of Induction Machines Utilizing ezdsp F28335 and FPGA. First of all I would like to express my sincere gratitude and appreciation to Universiti Teknikal Malaysia Melaka which give me opportunity in gaining knowledge and soft skills. The special thanks to Dr. Auzani Bin Jidin for his valuable guidance supervision, knowledge and funding for this Final Year Project. The support and supervision under him was truly help in my progress in this final year project.

Thus, with this occasion I would like to express my gratitude to many people who contributed to this final year project. Especially to the other students under the same supervision such as Zharif Rifqi, Wan Ahmas, Luqman and other on their help with opinion and knowledge in order to achieve the target for this final year project. Thousands of appreciation and thanks to anyone whom involved either directly or indirectly helped me in this project.

Last but not least, privileges of appreciation and affection direct to my parent for their support and encouraging me to never give up in completing this final year project.

ABSTRAK

Tesis ini membentangkan tentang perlaksanaan kawalan daya kilas langsung mesin induksi menggunakan ezdsp f28335 dan FPGA. Disebabkan sturukturnya yang ringkas dan pretasi kawalan daya kilas yang tinggi, ianya sangat dikenali serta diterima dalam kawalan motor di dalam banyak applikasi industri. Walaubagaimanapon, kawalan daya kilas langsung mempunyai beberapa masalah seperti riak daya kilas yang besar, frekuensi pensuisan yang berubah-ubah disebabkan oleh kawalan histeresis dan penghayutan integrasi dalam menganggar fluk yang disebabkan oleh penggunaan pengkamiran asli. Sasaran kajian projek ini adalah untuk mengurangkan permasalahan supaya pretasi tinggi kawalan daya daya kilas dapat dicapai. Bagi mengurangkan riak daya kilas, adalah perlu untuk mengurangkan beban dalam melaksanakan algoritma kawalan daya kilas dengan menggunakan ezdsp F28335 and FPGA. Pengagihkan sebahagian tugasan algoritma kawalan daya kilas kepada FPGA dapat membantu ezdsp dalam mencapai frekuensi persempelan maksima iaitu 20KHz. Tambahan lagi, algoritma DTC didalam ezdsp di laksanakan menggunakan pendekatan IQ-math yang menjamin pengurang masa dalam pengiraan dan pengurangan ralat pengiraan. Dengan melakukan ini, secara tidak lansung jalur lebar histeresis dan riak daya kilas dapat dikurangkan seperti operasi histeresis dalam analog. Masalah kedua dapat diselesaikan dengan menggunakan penapis pelepasan rendah dalam pengamiran penganggaran fluk. Blok IQ-math digunakan bagi memperbaiki penganggaran fluk dengan frekuensi potongan yang ditetapkan pada 5 rad/s. Hasil penambahbaikkan pretasi DTC akan dikenal pasti melalui keputusan simulasi dan eksperiment.

ABSTRACT

This thesis presents the implementation of Direct Torque Control (DTC) of induction machine utilizing ezdsp F28335 and FPGA. It is well-known that the DTC method has widely been acceptance for advanced motor control in many industrial applications due to its simplicity and high-torque control performance. However, the DTC has some major problems which are larger torque ripples, variable switching frequency due to the hysteresis controllers and initial and drift problem in estimating the flux because of the use of pure integrator. The research project aims to minimize the problems so that the high DTC performance can be achieved. To minimize the torque ripple, it is necessary to reduce the computational burden in executing the DTC algorithm by applying two digital controllers, i.e. ezdsp F28335 and FPGA. By distributing some tasks of DTC algorithm to be executed on the FPGA, the ezdsp manages to perform the sampling frequency at 20 kHz. Moreover, the DTC algorithm executed in ezdsp was based on the optimal IQ-Math calculation approach that guarantees lesser calculation times required with minimized calculation error. By doing like this, the bandwidth of hysteresis as well as torque ripple can be reduced as the hysteresis operation similar to the analogue one. On the other hands, the second problem can be solved by applying a low pass filter in the integration of flux estimator. The IQ-math blocks were used to construct the improved estimator with a cut-off frequency is set at 5 rad/s. The improvements of DTC performance were verified through simulation and experimental results.

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LIST OF SYMBOLS AND ABBREVIATIONS

VSD	-	Variable speed drive
FOC	-	Field Orientation Control
SVM	-	Space vector modulation
CPLD	-	Complex Programming Logic Device
VHDL	-	VHSIC Hardware Description Language
FPGA	-	Field-Programmable-Gate-Array
DC	-	Direct Current
AC	-	Alternating Current
DTC	-	Direct Torque Control
IGBT	-	Insulation Gate Bipolar Transistor
VSI	-	Voltage Source Inverter
DT	-	Sampling time
DSP	-	Digital Signal Processor
FYP	-	Final Year Project
Q	-	Quotient
I	-	Integer
FFT	-	Fast Fourier Transformation
GPIO	-	General Purpose input / output
DAC	-	Digital to Analog Converter
ADC	-	Analog to Digital Converter
V_s^g	-	Stator voltage space vectors in general reference frame
R_s, R_r	-	Stator and rotor resistance
i_s^g, i_r^g	-	Stator and rotor current space vectors in general reference frame
φ_s^g, φ_r^g	-	Stator and rotor flux linkage space vectors in general reference frames

ω_g	-	Motor angular speed
ω_r	-	Rotor electrical speed in rad/s
S_a, S_b, S_c	-	Switching states
$\varphi_{sd}, \varphi_{sq}$	-	d and q-axis component of stator flux in stationary reference frame
V_{sd}, V_{sq}	-	d and q-axis component of the stator voltage in stationary reference frame
i_{sd}, i_{sq}	-	d and q-axis components of the stator current in stationary reference frame
V_{DC}	-	DC link voltage
i_a, i_b, i_c	-	Phase current
φ_s	-	Estimated stator flux linkage
V_s	-	Stator voltage space vector in stationary reference frame
ω_e	-	Synchronous angular frequency
ω_c	-	Cut-off frequency

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CHAPTER 1

BACKGROUND OF THE RESEARCH PROJECT

1.1 Motivation of the Research

The DTC method has become an attraction to many researchers for developing advanced motor control due to its simplicity and fast torque dynamic response. It also has gained widely acceptance in industrial applications as the well-known high inverter technology company refer to as ABB Company has already begun its research in DTC since 1988 and began to market in year 1996 [1].

In recent years, it can be noticed that the DTC technology has replaced gradually the Field Oriented Control (FOC) method in many electric drive applications. This mainly due to the fact that the DTC has simpler structure compared to the FOC that requires a current controller, frame transformer, speed sensor and knowledge of machine parameters. Without the requirement of speed sensor and knowledge of machine parameters, these make sense that the DTC is normally known as sensor less and robust control in controlling the flux as well as electromagnetic torque.

The main benefit of doing this research project is that to gain valuable experience in identifying problems, troubleshooting any malfunction circuitry, selecting available proposed technique to minimize the problems of the DTC drive. It is emphasized that the realization of basic DTC drive through simulation and experimentation is significant, before further improvements can be done to have excellent DTC technology drive systems.

1.2 Problem statements

Despite its simplicity, the DTC has some major drawbacks such as larger torque ripples and variable switching frequency and initial and drift problems in estimating the flux. The output torque ripple cannot be restricted within the hysteresis band at the limited or lower sampling frequency. The problem becomes worst if too small bandwidth is chosen, and this will give high potential of incident of torque ripple to overshoot exceeds to the upper band to select the reversed voltage vector. Hence, it causes larger torque ripple. Another problem associated in hysteresis operation is the unpredictable switching frequency since the slope of torque during increasing and decreasing varies to the operating conditions.

The second problem is commonly occurred in flux estimator which is implemented using a voltage model or pure integrator. The problem becomes worst if the DC offset introduced in current measurement is higher and resolution of Analog-to-Digital converter is smaller. It should be noted that the problem in estimating the flux consequently causes error in calculating the torque that deteriorates the entire DTC performances.

1.3 Variations of DTC Improvements

1.3.1 Review of Motor Drives

In the past few years before, the DC motor was wide used in industrial as VSD due to its simplicity and ability to easily control the speed and torque as desired without need advanced electronic device. But, this DC motor need to use together with DC drives (scalar control), then the fast speed response and good torque with high accuracy will easily to achieve. However, the major drawback of DC drives where it's reduced reliability of DC motor, DC motor costly to purchased, need encoder for feedback, doesn't run at high speed and high maintenance. This problem can be avoid by replacing the DC motor with induction motor which low cost, low maintenance, simple in design and robust. The introducing of AC variable speed drives (vector control) technology was driver part of AC motor almost excellent as DC motor performance. In addition, in the last three decade the AC drives gradual replacing the DC motor in industrial application. This happen due to the development of modern semiconductor devices such as Digital Signal Processor (DSP) and power Insulated Gate Bipolar Transistor (IGBT) [3]. There was two voltage vector names that common heard such as Field Oriented Control (FOC) and Direct Torque Control (DTC). Nowadays, the DTC gained a lot of attraction in industrial due to fast response, good dynamic performance, simple structure and easy realizing digitalize [4 - 6].

1.3.2 The structure of DTC

The new control strategies of direct torque control (DTC) are presented by I.Takashashi and T.Noguchi in 1986 [3]. This both persons were propose circle flux trajectory and hexagon flux trajectory. In addition, a de-coupled control of stator flux and torque is providing fast dynamic response. Basically, the DTC consist a pair of hysteresis comparator, torque and flux estimator, look-up table and 3-phase voltage source inverter (VSI). The torque and stator flux is controlled by 3-level and 2-level hysteresis comparators, respectively. In order to satisfy the demand from both controllers, the appropriate voltage vectors from the look-up table are selected either to increase or decrease torque and flux [7]. The high performance of DTC can be achieve by having accurate estimation of flux and torque. Other else, we also should know that the switching frequency of VSI is contributed by hysteresis comparator. It already been highlighted in [2] that the operating condition such as rotor speed, stator and rotor fluxes and DC link voltage change also will varies the switching frequency.

1.3.3 The Major Drawback of DTC

Although the DTC structure was simplest than FOC, there still have two major drawback in DTC which come from hysteresis comparators such as high torque ripple and variable inverter switching. The torque ripple was large especially in low speed region which happen due to excessive inverter switching at any region [8]. However, this torque ripple can be minimized by reducing the bandwidth of hysteresis comparators. For make sure this technique successfully reducing torque ripple, we must have enough sampling time (DT). Otherwise, the incident of overshoot problem will happen due to selection of reverse voltage vector. The torque slope depends on the stator and rotor fluxes, motor speed and stator voltage [8]. We can summarize that torque slope was varies with speed of motor. Due to the variation of torque slope, the inverter switching frequency also varies at the same time. In the other words, the inverter switching frequency is unpredictable when we consider other operation condition. Referring to [8], a constant inverter switching frequency can be achieved by change the amplitude of hysteresis band based on operating condition. The bandwidth of hysteresis is changed by the PI controllers which get feedback from pulse counter which come from hysteresis comparator. These methods are applied for the both torque and flux hysteresis controller. However, there was another better method proposed by [9] which can improve both drawback of conventional DTC, respectively. The method been proposed was replacing the switching table of DTC with space vector modulator (SVM) also known as SVM-based DTC. By using this method, we can achieve a constant inverter switching frequency and the reduction of torque and speed ripple. The advantages of this method where it didn't need any reducing of sampling time (DT) in order to increase inverter switching frequency.

1.3.4 Implementation Utilizing Digital Controller

There was a method that been discuss in section 1.3.3 which can be used to reducing torque ripple by increasing the switching frequency while in the same time maintain it switching frequency (SVM-based DTC). However, in order to obtain small torque ripple, it will need fast processor when the implementation of SVM-based DTC is utilizing digital controller [10][11]. If we remember, there was another method to reducing torque ripple through reduction of hysteresis bandwidth, but it will required sufficient sampling time (DT) from digital controller (DSP/FPGA). Now days, the implementation of DTC algorithm utilizing DSP, CMOS, ASIC's and FPGA was a common thing in technology. Referring in [12], it had been mention which there was some part in DTC algorithm need flexibility and velocity for other parts. This flexibility can be achieved by using Digital Signal Processors (DSP). For the velocity, we can achieve it by using field-programmable-gate-arrays (FPGA). Already been reported which implementation using one device either by FPGA or DSP was not optimal. This was not optimal due to some part in DTC algorithm needed velocity and flexibility for other parts. The authors in [12] have explained that FPGA doesn't have suitable flexibility which needed to tune the DTC algorithm depending on the induction machine. In addition, the DTC algorithm needs speed for efficiencies, but the DSP performance was dependent on the number of computation. So when the number of computation requirement was high, then we needed to adopt FPGA. Other else, we should realize that DSP code was slower than FPGA implementation, but DSP offering flexibility. In the FPGA implementation, each elementary function of DTC such as torque and flux estimator algorithm, hysteresis comparator and look-up table is described in VHDL code at the hardware. This VHDL codes will be complied into FPGA. In [12], it's mentioned the advantages utilizing FPGA, which it will provide velocity for each elementary function. By measuring the performance of DTC utilizing FPGA, we can compute the size which required from each elementary function. We can summarize by using FPGA we will get a better performance compared to DSP implementation. Furthermore, FPGA also give best theoretical architecture from viewpoint of speed. There also not easy for debugging around the FPGA.

1.4 Objectives of the Research Project

The three main objectives of the research project are given as follows;

i) To model and simulate the DTC of induction machine using MATLAB-Simulink, specifically using IQ-Math blocks.

ii.) To achieve high sampling frequency of ezdsp F28335 by reducing the execution of DTC tasks, (i.e. computational burden. Some tasks were distributed and to be performed by FPGA. It is believed that the reduction of torque ripple can be achieved if the execution of ezdsp can perform at higher rate of sampling).

iii.) To improve the estimation of flux by applying a low pass filter in the integrator. (Thus, the initial and drift problem can be minimized and hence provide satisfactory calculation accuracy).

1.5 Scopes of Research Project

There were a few scopes that are underlined in order to put a clear boundary, so the final year project have a limitation and constrain for makes sure our project achievable and realistic. Firstly, to studies the principle of DTC operation and the variations of DTC improvement through reading several technical papers. Secondly, was to model and simulate the DTC of induction machine using MATLAB-Simulink and Quartus Softwares. Thirdly, are to realize the DTC algorithm utilizing ezdsp F28335 and FPGA. Lastly, in order to verify the improvement of DTC performances via experiment results.

1.6 Research Methodology

1.6.1 Collection of information on DTC

The source of the information about DTC was referred from the thesis of DTC research and book (example: - Modern Power Electronics and AC Drive, K. Bose). Other else, the information of DTC also been taken from electronic media such as IEEE portal and other external source from internet. All the information that already been collected normally focus on the mathematical modeling of induction machine, the basic principles of DTC and major problems in hysteresis based DTC.

1.6.2 Analyze the information

From the information that already been collected, this information now will be analysis for understanding the theoretical of DTC. The main focuses on the analysis was already been mentioned in the section of collection the information on DTC. But in this section, will be analyzing more details on the project main focus: -