UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

IMPROVED DTC USING OPTIMAL SWITCHING STRATEGY FOR DUAL-OPEN END WINDING INDUCTION MOTOR

LEE KAH WAI

Bachelor of Electrical Engineering with Honours

IMRPOVED DTC USING OPTIMAL SWITCHING STRATEGY FOR DUAL-OPEN END WINDING INDUCTION MOTOR

LEE KAH WAI

A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declare that this thesis entitled "Improved DTC using Optimal Switching Strategy for Dual-Open End Winding Induction Motor is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
Name	:	LEE KAH WAI
Date	:	

APPROVAL

I hereby declare that I have checked this report entitled "Improved DTC using Optimal Switching Strategy for Dual-Open End Winding Induction Motor" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature	:	....
Supervisor Name	:	....
Date	:	....

DEDICATIONS

To my beloved mother and father

For giving the support in all perspective

To my respectful supervisor,Dr. Auzani Bin Jidin

For giving the endless support, guidance and teaching

To my respectful Guider, Madam Siti Azura Binti Tarusan

For helping in clearing my confusion

My friends

For their moral support and encouragement through my journey of education

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In the end, not to forget the one and only one who give me all their support in the journey of my study, my parents. Their support either in mental or financial is a great help for me to strengthen my will in continue this tough journey.

ABSTRACT

Direct Torque Control (DTC) of induction machine has received wide acceptance in many adjustable speed drive applications due to its simplicity and high-performance torque control. However, the DTC using conventional design poses two major problems such as high switching frequency and larger torque ripple. These problems are due to inappropriate voltage vectors which are selected among a limited number of voltage vectors available. The proposed research aims to formulate an optimal switching strategy for dual-open end winding induction motor. By using dual inverters, it provides greater number of voltage vectors which can offer more options to select the most appropriate voltage vectors. By selecting the suitable voltage vectors, it allowed the motor to produce minimum torque slope but enough to reach the required demand. To achieve this result, the proposed method does not require speed information, PI controller, frame transformation, space vector modulator, reference voltage estimator and machine parameters. The improvements obtained are minimizing the switching frequency with reducing the losses and torque ripple reduction.

ABSTRAK

Kawalan dayakilas langsung (DTC) untuk motor aruhan telah mendapatkan penerimaan yang luas dalam kebanyakkan aplikasi pemacu pelarasan laju atas sebab reka bentuk ia ringkas dan mempunyai prestasi yang agak tinggi. Walau bagaimanapun, DTC yang menggunakan reka betuk yang biasa menimbulkan dua masalah, iaitu riak dayakilas yang besar dan frekuensi pensuisan yang tinggi. Masalah-masalah tersebut ditimbulkan kerana ketidak sesuaian vektor voltan terpilih antara vektor voltan yang terhad. Kajian yang dicadangkan bertujuan untuk memformulasi sebuah strategi pensuisan yang optimal bagi dual-open end winding motor aruhan dengan memakai dua inverter. Dwi inverter ini akan memberikan lebih banyak pilihan dalam vektor voltan dan mendapatkan vektor voltan yang sesuai untuk situasi motor yang berbeza. Dengan memilih vektor voltan yang sesuai, ia dibenarkan motor untuk menghasilkan cerun minimum tork tapi cukup untuk mencapai permintaan diperlukan. Untuk mencapai keputusan ini, kaedah yang dicadangkan memerlukan kelajuan maklumat, PI pengawal, rangka transformasi, space vektor modulator, rujukan voltan estimator dan parameter mesin. Penambahbaikan yang terdapat daripada kajian yang dicadangkan adalah dapat meminimumkan frekuensi pensuisan yang dijangka akan mengurangkan kehilangan kuasa dan pengurangan riak bagi dayakilas.

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LIST OF SYMBOLS AND ABBREVIATIONS

d,q	Direct and quadrature of the stationary reference frame
d^r, q^r	Real and imaginary of the rotor
i_s, i_r	Stator and rotor current space vector in stationary reference frame
R_s, R_r	Stator and rotor resistance
L_s	Stator self-inductance
L_r	Rotor self-inductance
L_m	Mutual inductance
$\bar{\varphi}_s, \bar{\varphi}_r$	Stator and rotor flux linkage space vector in reference frame
i_{rd}, i_{rq}	d and q components of the rotor current in stationary reference frame
i_{sd}, i_{sq}	d and q components of the stator current in stationary reference frame
v_{sd}, v_{sq}	d and q axis of the stator voltage in stationary reference frame
$\varphi_{sd}, \varphi_{sq}$	d and q components of the stator flux in stationary reference frame
$\bar{v}_s$	Voltage vector
n	Number of phase
i_a, i_b, i_c	Phase current of a, b, c
L	Self-inductance
T_e	Electromagnetic torque
${T_e}^*$	Reference torque
ϵ_T	Output torque error
σ_T	Output torque status

θ_r	Angle with respect to rotor axis
θ_s	Angle with respect to stator axis
δ_{sr}	Different angle between stator flux linkage and rotor flux linkage
V_{DC}	DC link voltage
${S_a}^+, {S_b}^+, {S_c}^+$	Switching states of IGBTs
P	Number of pole pair
θ_{sec}	Angle of sector definition
ω_r	Rotor electrical speed in rad/s
ϵ_φ	Output flux error
${\varphi_s}^*$	Reference of flux
φ_s	Flux estimate
σ_φ	Output flux status
σ	Total flux leakage factor
DTC	Direct Torque Control
IM	Induction Motor
VSI	Voltage Source Inverter
FOC	Field Oriented Control
DT	Sampling period
AC	Alternating Current
DC	Direct Current
SVM	Space Vector Modulator
UB	Upper Band
LB	Lower Band
IGBT	Insulated Gate Bipolar Transistor

i_{sq}^{e} , i_{sd}^{e}	Current from the excitation frame
CSFTC	Constant Switching Frequency Torque Controller
PI	Proportional Integral
$\bar{\iota}_s$	Current vector

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CHAPPTER 1

INTRODUCTION

1.1 Research Background

Direct torque control (DTC) and Field Oriented Control (FOC) were introduced by Takahashi and Noguchi and Siemens' F. Blaschke in 1980. Both methods utilized the AC motor drives. DC motor drives was widely used in many industrial applications due to their structure and fast torque dynamic control. But due to its construction of brushed DC motor, the DC motor required regular maintenance such as replacing the carbon brush and it can't operate in high speeds. Slowly AC motor drive become the top choice of many industrial applications due to its low maintenance, high efficiency and tolerate in very high speeds demand.

The first method introduced, Field Oriented Control (FOC), this method is based on two mathematical transformation introduced by Clark and Park. Clark and Park transformation are used in high performance drive or vector control which involved magnet machines. With these the torque and flux will then can be control by using the generated current component, i_{sq}^{e} and i_{sd}^{e} in the reference frame. To use FOC method it required the frame transformer, the speed data and current controller to control the torque and flux. Besides, FOC needed a frame transformation to convert the produced current from the excitation frame (i_{sq}^{e} and i_{sd}^{e}) to the stationary reference frame. To convert, it required a complex mathematical calculation and varies sensors. Further detail will be discuss in chapter II.

Later then the Direct Torque Control (DTC) method was introduced. Even though the FOC method provide more advantages most of the companies are then slowly shift from FOC to DTC method. The DTC requires lesser sensitivity on parameter variation to estimate the control parameters. On the other hand, DTC eliminated the use of frame transformation which involved in complex mathematical calculation. Besides using the sensor in DTC, it utilizes the hysteresis controller and a single PI controller to regulate the speed. To establish a fast-instantaneous torque and flux control, a decouple structure is employed and with the present of three-level and two-level hysteresis the torque and flux can be controlled even better.

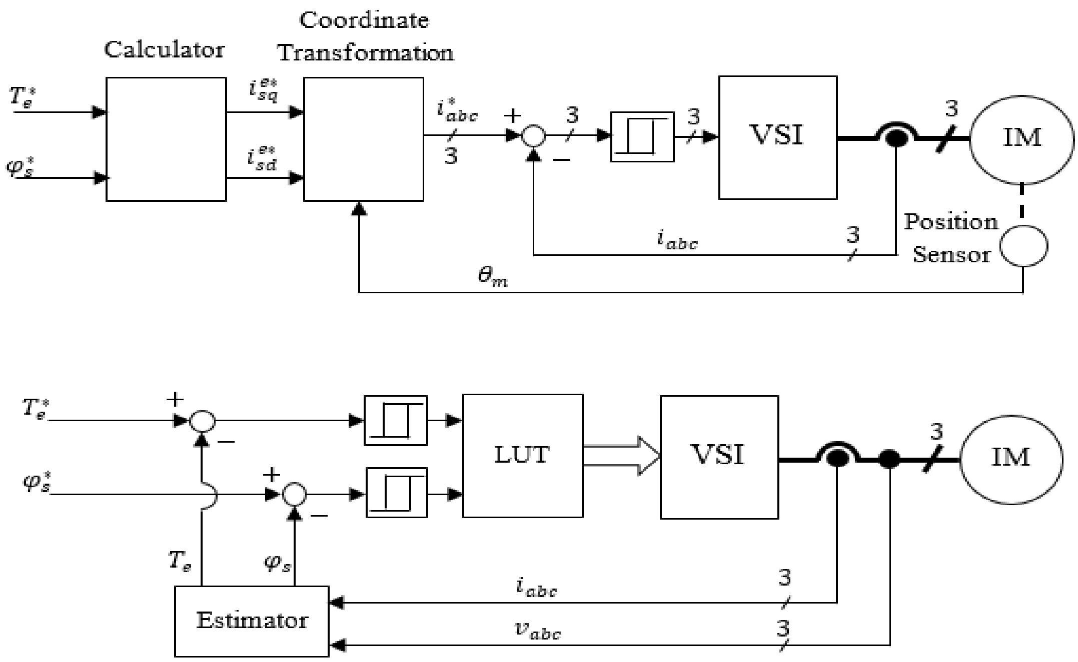

Figure 1: FOC and DTC structure

Although DTC provides varies of benefits compared to FOC but there is one major drawback of DTC, large torque ripple and variable switching frequencies. There are many modifications been proposed from many areas to minimize the torque ripple and the problem in switching frequencies. Among all the modification proposed, the Space Vector Modulation (SVM) has gained the interest of the public and widely acceptance due to its offer great reduction of torque ripple and a constant switching frequency. Even though this modification, SVM, offered a great improve to DTC but at the same time it increases the complexity and leads to the inaccurate of the performance in control as well as the dynamic torque control.

1.2 Problem statement

With the comparison between DTC and FOC, it clearly shows that the DTC provides more advantages over FOC. Although the DTC offers these advantages and a simple control structure with fast dynamic control but with the use of hysteresis controller come with a next problem, namely large torque ripple and variable inverter switching frequencies. These problems are due to the digital implementation of hysteresis controllers which with a low sampling time. As the sampling time was small it tends to create delay and resulted in torque overshoot the upper band or the lower band of the hysteresis. In the other way it means the torque error are not within the restricted bandwidth of the hysteresis controller. As the torque error are not accurate it will then affect the selections of the voltage vector. The incorrect selection of voltage vector causes the large torque ripples.

Due to the torque slope behaviour, it leads to high switching frequencies as well as the switching losses and hence reduces the efficiency of the inverter. As the power loss emitted in the form on heat, through time the switching devices will degrade and in the end to malfunction.

1.3 Objectives of Research

The objective of this thesis is to reduce the torque ripple and the switching frequencies by implementing dual-inverters for open-end windings induction machine.

1.4 Scopes of Work

The scopes of work for this study are:

- Improve the DTC performances by selecting the most suitable voltage vector.
- To formulate the optimal switching strategy by using a look-up table and modification of torque error status.
- To verify the improvements with simulations and experimentations.

1.5 Research Methodology

A study on the various switching strategies in DTC was carried out in order to understand the how to reduce the torque ripple and maintain a constant switching frequency.

Based on the study, voltage vectors method was the most popular and interested by the public. By selecting the appropriate voltage vector based on the torque error for different speed operation it will certainly help in reducing the torque ripple as well as the switching frequencies. After the justification of torque error, the voltage vector will then be selected by referring to the look-up table.

To obtain constant switching frequencies, the hysteresis controller was then replaced by the constant switching frequency torque controller (CSFTC) to eliminate

the use of PI controller. With CSFTC the major problem in DTC structure can be minimize without changing the entire original DTC structure.

1.6 Thesis Contributions

The research work gave the contribution as follow:

- The torque ripple and switching frequency can be reduce with the appropriate selection of voltage vector.
- The comparison between torque error status and flux error produced by hysteresis controller was made to remain the simple structure of the original DTC design. By then, the use of speed sensor and complex calculation can be eliminated.
- Increase the control bandwidth of DTC by replacing the hysteresis controller with CSFTC and eliminated the use of PI controller.

1.7 Thesis Outline

In this thesis the chapters are:

- Chapter 2 provides an overview of Direct Torque Control structure of induction machine. The parts used in DTC and the mathematical formula were discussed. The basic principle of DTC and the major problems will to be discussed.
- Chapter 3 will explain the detail of methods used to formulate an optimal switching strategy of DTC using dual-inverter for open-end windings induction machine.