TORQUE RIPPLE REDUCTION IN PROPORTIONAL INTEGRAL (PI) CONTROL OF DIRECT CURRENT (DC) MOTOR DRIVES

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"I/We hereby declare that I have read this project report and in my/our opinion this project report is sufficient in terms of scope and quality for the award of Degree of Bachelor in Electrical Engineering (Industry Power)"

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Date : MAY 2006

"I hereby declare that this project report is the result of my own work and all sources of references have been clearly acknowledged."

Signature : ....

Name : WAN ROBIAH BT WAN ISMAIL

Date : MAY 2006

To my beloved mother, father, sister and family and friends

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ABSTRACT

The used of DC motor these recent years has been increased due to the human needs that been applied to the robotic, machine and others. In this project, the classical technique control which is PI controller has been studied for servo application to drive the system or loads to control speed and torque. The main objective of this project is to reduce the torque ripple in DC motor drives by using unipolar switching scheme instead of bipolar switching scheme. Besides, this project objective is also to obtain good performances of the DC motor drives which are minimum of overshoot and fast transient response. To design this controller, the cascade control structure has been applied. In this report, the torque and speed control will be discussed. In the first stage, the PI controller is designed to get the proper value of gain K_p and K_i for speed and torque controller by using linear theory analysis. Then the PI values of the torque and speed will be evaluated under a large signal analysis using Simulink Matlab. Finally, the torque control to observe the torque ripple reduction using unipolar switching scheme of DC motor drives has been constructed and simulated using ORCAD PSPICE (the schematic circuit can be presented as practical experimental set-up).

ABSTRAK

Penggunaan motor berarus terus beberapa tahun kebelakangan ini semakin meningkat selaras dengan keperluan manusia yang mana diaplikasikan pada robot, mesin dan sebagainya. Dalam projek ini, teknik kawalan klasik iaitu pengawal PI telah dikaji untuk aplikasi servo, untuk memacu sistem atau beban bagi mengawal halaju dan arus. Objektif utama projek ini adalah untuk mengurangkan daya kilas arus atau gangguan daya kilas pada motor berarus terus dengan menggunakan kaedah pensuisan ekakutub selain daripada kaedah pensuisan dwikutub. Selain itu, objektif projek ini adalah untuk mendapatkan prestasi yang baik bagi motor berarus terus di mana dengan lajakan terlampau minimum kurang sensitif kepada kepelbagaian parameter. Juga, pengawal ini mempunyai sambutan dinamik yang baik seperti memberikan sambutan fana yang cepat dan lajakan terlampau yang minimum. Untuk mereka bentuk pengawal ini, struktur kawalan '*cascade*' digunakan. Dalam laporan ini, pengawalan arus dan halaju dibincangkan. Pada peringkat pertama, pengawal PI direka bentuk untuk mendapatkan nilai '*gain*' K_p dan K_i untuk pengawal halaju dan arus dengan menggunakan analisis teori linear. Selepas itu, nilai-nilai PI bagi arus dan halaju akan dinilai di bawah analisis pengisyarat besar menggunakan Matlab Simulink. Akhir sekali, pengawal arus untuk mengenalpasti pengurangan gangguan arus menggunakan pengsuisan ekakutub untuk motor arus terus dibentuk dan disimulasi menggunakan ORCAD PSPICE (skema litar boleh ewakili bentuk eksperimen atau litar sebenar).

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LIST OF SYMBOLS AND ABBREVIATIONS

DC	-	Direct current
AC	-	Alternated current
PI	-	Proportional-Integral
K_i	-	Integral gain of PI controller
K_p	-	Proportional gain of PI controller
PID	-	Proportional-Integral Derivative
PD	-	Proportional Derivative
PPU	-	Power-processing unit
Op-Amp	-	Operational amplifier
Φ_f	-	Field flux
T	-	Electromagnetic torque
k_t	-	Torque constant
i_a	-	Armature current
i_{ref}	-	Current reference
ω_m	-	Speed (rad/s)
e_a	-	Back emf
k_e	-	Back emf constant
P_e	-	Electrical power
P_m	-	Mechanical power
U_a	-	Armature voltage
R_a	-	Armature resistance
T_L	-	Load torque
J	-	Total moment inertia

B	-	Vicious friction
V_c	-	Control signal
V_{tri}	-	Triangular voltage
V_d	-	DC voltage
f_s	-	Switching frequency
PWM	-	Pulse Width Modulation
MOSFET	-	Metal-oxide-semiconductor field effect transistors
$R_{ds(on)}$	-	Resistance across the MOSFET (drain to the source) when Switch is turn on
J_1	-	Nominal inertia coefficient

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The purpose of this chapter is to review the background of DC motor theory that are essential to the understanding the electric drive. This chapter will explain the theory of PI controller and two other controllers in short. Besides, this chapter will also explain on the objectives and scopes of project and the methodology that have been using in this project.

1.2 Literature Review

Literature review is used as one of the method for the purpose of learning and to gain more knowledge in terms of project, designing the controller and circuit and also to understand in details on the problem of torque ripple in DC motor drives.

1.2.1 Background of DC Motor

Direct current (DC) motors have variable characteristics and are used extensively in variable-speed drives. DC motors can provide a high starting torque and it is also possible to obtain speed control over a wide range. The methods of speed control are normally simpler and less expensive than those of ac drives. DC motors play a significant role in modern industrial drives. Both series and separately excited DC motors are normally used in variable-speed drives, but in series motors are traditionally employed for traction applications. Due to commutators, DC motors are not suitable for very high speed applications and require more maintenance than do AC motors.

The direct current (DC) motor is one of the first machines devised to convert electrical power into mechanical power. Permanent magnet (PM) direct current converts electrical energy into mechanical energy through the interaction of two magnetic fields. One field is produced by a permanent magnet assembly; the other field is produced by an electrical current flowing in the motor windings. These two fields result in a torque which tends to rotate the rotor. As the rotor turns, the current in the windings is commutated to produce a continuous torque output. The stationary electromagnetic field of the motor can also be wire-wound like the armature (called a wound-field motor) or can be made up of permanent magnets (called a permanent magnet motor).

DC motor has been widely used in DC drive applications. Traditionally, DC motor drives have been used for speed and position control application. In the past few years, the use of AC motor servo drives in these applications is increasing. But for application where an extremely low maintenance is not required, DC drives continue to be used for some reason which it's low in cost and excellent drive performance. This drives usually been implicated in application of printer, robots, scanner and others. In conjunction with the highly demand for the drives in so many field of works and needs especially in engineering sectors, factory automation, and not forgotten our daily life, the motor accuracy and effectiveness have to be improved [1].

We cannot avoid of getting a few problems while using this DC motor drives. The objective of this project is to discuss the design of motor-drives controllers and reduce the torque ripple in motor drives operation. With the proper design of feedback controller, it is expected that the system is less sensitive to disturbances and changes in the system parameters and also reduce the ripple.

1.2.2 Proportional Integral (PI) Controller

PI controller consists of K_i and K_p gains. These controllers are placed at both speed and torque loop but with the different values. Gain K_p determines proportional gain of controller, while gain K_i determines the integral gain of controller [7][5]. It's also implemented in this transfer function to obtain zero steady state error, obtain a good dynamic response (i.e. fast transient responses with minimum overshoot), and make the system less sensitive to disturbances and changes in the system parameters.

PI controller is always been compared to PID and PD controller. PI controller is suited for dominant dead time (time constant > dead time) and PID controller is suited for dominant time constant and no noise from the transmitter. D is used when the loop has low noise and to increase the stability. If the loop is very noisy, D will increase the noise in high frequency and make the output jittery. D is not used on a pure dead time process. It will make the loop unstable. As long as there is some amount of lag or first order time constant in the process, D can help. D term is most often used on temperature loops. Most temperature loops can make use of derivative because they are low noise, are not pure dead time, and usually have two or more lags. Of course, there are exceptions, but that is a good rule of thumb [7].

1.2.3 Cascade Control Structure

The cascade control structure is commonly used for DC motor. It is because its flexibility. The cascade control structure is consisting of inner torque loop and outer speed loop. This cascade structure requires that the bandwidth (speed of response) increase towards the inner loop, with the torque loop being the fastest and the speed loop being slower [1]. This will be designed with the Matlab simulink. The Proportional Integral (PI) which is the controller is design to meet the objectives discussed above.

1.3 Project Objectives

The objectives of this project are as follows:

i. To reduce torque ripple which occurred in DC motor operation by using unipolar switching device;

ii. To analyze the effects of increasing switching frequency to the speed of the DC motor;

iii. To control the speed of DC motor using proportional integral (PI) controller;

iv. To obtain zero steady state error and a good dynamic response (i.e. fast transient responses with minimum overshoot).

v. To design a proper feedback controller to make the system insensitive to disturbances and changes in the system parameters;

Here are the steps to design the transfer function with good PI controller with the help of MATLAB based on linear control theory:

i. Get the model of DC motor and the whole system using MATLAB software (PI controller, Mechanical load, DC-DC converter and etc).

ii. The whole system will be simulated with large signal analysis to evaluate the controller.

iii. The simulink blocks have to be transfered to a circuit design using ORCAD PSPICE.

1.5 Project Methodology

The flow charts in Figure 1.1 shows the steps of progress to achieve the project objectives.

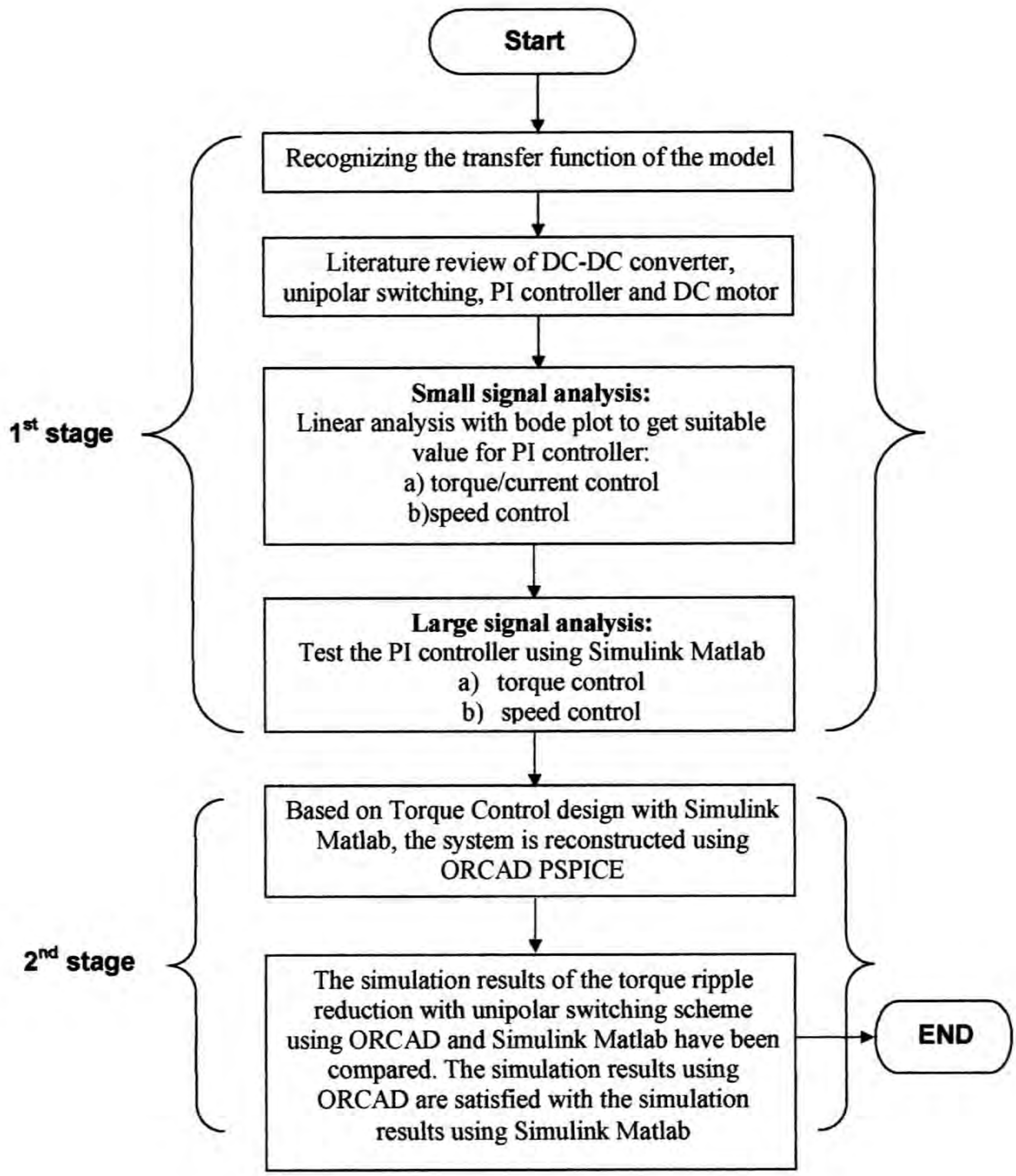

Figure 1.1 : Flow chart of project

1.6 Project Organisation

The rest of the project's chapter are organised are as follows:

Chapter 2 reviews the basic of DC motor theory along with the model of DC motor and its equivalent transfer function or equations. This chapter also explain the four-quadrant operation using DC-DC converter. Besides, it will also explain on how the bipolar switching scheme and unipolar switching scheme operates.

Chapter 3 reviews the cascade control structure design with PI controller to control motor and mathematical formulation of the control system requirements. Designing PI controller with small signal analysis and evaluate the overall system with the large signal.

Chapter 4 describes the simulation results for large signal torque loop that have been done by using Matlab software. Besides, this chapter will also describe the simulation results for the circuit that have been design by using ORCAD PSPICE. Here, it also compares the simulation results by using Matlab with ORCAD PSPICE to shows that the objectives have been achieved for torque loop.

Chapter 5 gives the conclusions and suggestions of the future works to the project.