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SPEED AND TORQUE CONTROLS OF BRUSHLESS DC MOTOR

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SPEED AND TORQUE CONTROLS OF BRUSHLESS DIRECT CURRENT MOTOR

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Power Electronic and Drives)

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APPROVAL

"I hereby declare that I have read through this report entitle
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and found that it has comply the partial fulfilment for awarding the degree of
Bachelor of Electrical Engineering (Power Electronic and Drives)".

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Date : 18 JUNE 2014

DECLARATION

I declare that this report entitle "SPEED AND TORQUE CONTROLS OF BRUSHLESS DIRECT CURRENT MOTOR" 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.

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ABSTRACT

This project presents the Speed and Torque Controls of Brushless Direct Current (BLDC) motor. Due to the drawbacks of conventional Direct Current (DC) machines which are Brush Direct Current (BDC) motor, the use of BLDC motor is proposed because of its advantageous compared to BDC motor. Even if compared to other machines in industrial, BLDC motor still possessed better performances in term of its control simplicity, high torque density, and lower maintenance. The proposed Speed and Torque Controls is implemented by restrain the current and torque within predefined band gap and also closed loop speed controller by varying the Proportional (Kp) and Integral (Ki) gains. By applying this concept, it required one current loop for the hysteresis to take place but the benefit of this method is that it can force the torque ripple to shut within the band gap. Next, the dynamic response of the Torque Hysteresis Control for BLDC scheme is modelled by proportional integral speed controller. A proper selection of Kp and Ki gains will determine the dynamic response of BLDC drive. Thus, in order to realize the project, a simulation were carried out using MATLAB/SIMULINK and sim-power system blockset simulation. Then, for the experimental, the control system was using the dSPACE in the iDRIVE driver kit. Lastly, based on the results obtained, it is proven that this scheme has good controlling mechanism and suitable for BLDC motor drive. Besides, the implementation of both PI controller and Torque Hysteresis Controller also gives excellent performance for the BLDC motor.

ABSTRAK

Projek ini membentangkan tentang Kawalan Kelajuan dan Tork untuk Motor Arus Terus Tanpa Berus (ATTB). Oleh kerana kelemahan Mesin Arus Terus konvensional iaitu Motor Berus Arus Terus (BAT), penggunaan motor ATTB adalah dicadangkan kerana ia lebih berfaedah jika dibandingkan dengan motor BAT. Malah jika dibandingkan dengan mesin lain dalam industri, motor ATTB masih memiliki prestasi yang lebih baik dari segi kesederhanaan kawalan, ketumpatan tork yang tinggi, dan penyelenggaraan yang lebih rendah. Skim Kelajuan dan Kawalan Tork yang dicadangkan adalah dengan melaksanakan dengan kekangan arus dan tork dalam jurang jalur yang telah ditetapkan dan juga mengawal pusingan kelajuan tertutup dengan mengubah pekali Berkadar (kp) dan pekali Penting (Ki). Dengan menggunakan konsep ini, ia memerlukan satu pusingan arus tertutup bagi histeresis berlaku tetapi kebaikan kaedah ini ialah ia boleh memaksa riak tork untuk menutup jurang dalam band ini. Seterusnya, tindak balas dinamik Tork Kawalan Histeresis untuk skim ATTB dimodelkan oleh pengawal kelajuan penting berkadar. Pilihan pekali Kp dan Ki yang betul akan menentukan tindak balas yang dinamik dalam memacu motor ATTB. Oleh itu, untuk merealisasikan projek ini, simulasi dilaksanakan dengan menggunakan MATLAB/ SIMULINK dan sistem simulasi blok SIM/POWER. Kemudian, bagi eksperimen pula, sistem kawalan adalah menggunakan dSPACE dalam pemandu kit iDrive. Akhir sekali, berdasarkan kepada keputusan yang diperolehi, telah terbukti bahawa skim ini mempunyai mekanisme kawalan yang baik dan sesuai untuk memacu motor ATTB. Selain itu, pelaksanaan kedua-dua pengawal PI dan Tork Histeresis juga memberikan prestasi yang sangat baik untuk motor ATTB itu.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

For decades, Direct Current (DC) motors served in many applications. It is due to the simplicity of its construction, controlling mechanism, and can produce superior dynamic performance. Despite of that, the construction of DC motor that equipped with brushes and commutator can cause some limitations. Furthermore, due to the existence of the brushes and commutator, it requires regular maintenance, cannot operated at very high speed, and usually reduce the life expectancy of Brushed DC (BDC) motor. Thus, the Brushless DC (BLDC) motor were developed to overcome deficiency of the Brushed DC motors.

However, Brushless DC (BLDC) motor requires proper controller as it uses electronic commutator for its operation. Thus, this report is about the research on Speed and Torque Controls that will be used to control the motor. The project has started with simulation profile for the control scheme in FYP 1 and experimental of the algorithm using dSPACE in FYP 2. Next, both simulation and experiment results have been compared to verify its significant.

1.2 Project Motivation

DC motors were known for their efficiency and reliable characteristics that are suitable for many applications. Unlike AC motors, DC motors able to operate at a fixed speed for a fixed voltage. Yet, one of the conventional DC motors is Brushed DC motor have many drawbacks on its mechanical compartments. It requires both brushed and commutator for its operation where its limit the capabilities of the motor. Thus, the BLDC motors is proposed to overcome the drawbacks of conventional dc machines.

From the reviewed methodology of the controlling mechanism, it is showed that the conventional method needs many improvement in order to improve the speed control performance of the BLDC machines to its fullest. Compared to the previous control algorithms, the proposed Speed and Torque Controls is chosen as it gives better controlling mechanism on the speed, phase currents and torque of the BLDC motors by varying Kp and Ki of PI speed controller. Besides, amongst the conventional methods are voltage control and PWM control which has its own characteristics. However, both of it gives a very high current overshoot when operating the machines. Thus, Torque Hysteresis Controller is introduce due to its advantages which is it able to handle the drawbacks because the method has inherent over-current protection that is always being monitored. Furthermore, the dynamic response of the BLDC provided by proportional integral speed controller gives the fullest operating condition of the machines.

1.3 Objectives

The objectives of this project are:

i. To model and simulate the Speed and Torque Controls of BLDC motor using MATLAB/SIMULINK.

ii. To verify the Speed and Torque Controls of BLDC motor via simulation and experimentation.

1.4 Scope Of Project

The main scope of this project is to control Speed and Torque for BLDC motor using PI speed controller and Torque Hysteresis Controller respectively. This project is proposed to improved the speed performance by selecting appropriate values of Kp and Ki gains. Besides, it is important to develop the model of BLDC motor for further understanding. Next, for the final stage of the project, the simulation model of Speed and Torque Controls for BLDC motor using MATLAB/SIMULINK must be analyse and compared with experimental result to verify the efficiency of the scheme. The experiment was conducted using iDRIVE controller that equipped with dSPACE, Voltage Source Inverter (VSI), Gate Driver, Decoder, and Current Transducer.

1.5 Report Outlines

Chapter 1 is mainly about defining the objectives and scope of the project. All the consideration have been taken into account to ensure the project achieved the objectives. The project background and motivational project also been discussed in this chapter. This is the most important part to ensure that the vision of the project is clearly understood.

In chapter 2, a brief literature review has been done to study the theoretical views of the machines used and all the related previous works. Besides, the construction and operation of the BLDC motor also been analysed. Lastly, all the conventional control techniques has been study to ensure a better understanding on the executed project.

Next, for chapter 3, the methodology of the project were clearly discussed. This is to make sure that the process of conducting the project are in the right track and follow the order. The process includes determining the switching state for the inverter and decoding Hall Effect signals scheme. Besides, the tests such as the torque test also have been done to the real motor to evaluate the capabilities of the motor.

Generally, chapter 4 is related about the discussion on the obtained result. Results from the simulation and experiment were analyse to observe its performance. The characteristic of the results will indicates either it has obtained the desired output of the proposed control scheme.

In chapter 5, the findings and outputs of the project have been concluded. This is important to analyse and verified either the proposed project achieve its target. Besides, the recommendations for better control scheme also been proposed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is generally about to study and analyse the related information and previous works on the related topics. It is compulsory to fully understand the theoretical and concepts of both BLDC motor and drives to ensure that the project can accomplished and meet the objectives.

2.2 Basic Topologies

2.2.1 Construction of BLDC Motor

A BLDC motor is constructed with two main parts that is a permanent magnet rotor and wire wound stator poles[1]. This construction distinguishes between BLDC and BDC motor where BDC motor constructed such that its stator generates a stationary magnetic field that surround the wired wound rotor. Magnetic steel sheets is preferred to construct the stator magnetic circuit. The stator phase windings are normally wound as one coil on the magnetic pole or can even be inserted in the slots[2]. Since this motor is implement partially both conventional ac and dc machines, it cannot be classified to either one of it even though it is powered by a direct current(DC)[3]. Next, BLDC motors may have any number of phase windings but generally it were designed in single phase , two phase, and three phase configurations. However, three phase configuration motors connected in star connection are the most popular and widely used due to its efficiency and low torque ripple. Theoretically, the higher the number of phase windings will improve the electromagnetic torque quality but infinite number of phase windings is not appropriate in practice[2].

As mentioned, BLDC motors did not consists of commutator and brushed as BDC motors to operate. This motor requires controller that is an electronic commutation in order for it to supply commutated current to the motor windings synchronized to the rotor position[4]. As the magnetic field at the stator will change due to the current polarity changes in the slots windings. Thus, the current polarity must change accordance to the rotor magnetic field which requires the rotor position to be traced[3]. In order to specify the rotor position, a feedback position sensor is readily mounted or embedded in the BLDC motor that is known as Hall Effect sensor. Hall sensor used to detect the rotor position in order to determine which stator winding that will be energized in proper sequence[1]. The cross section of BLDC motor with respect to the embedded Hall Effect sensor.

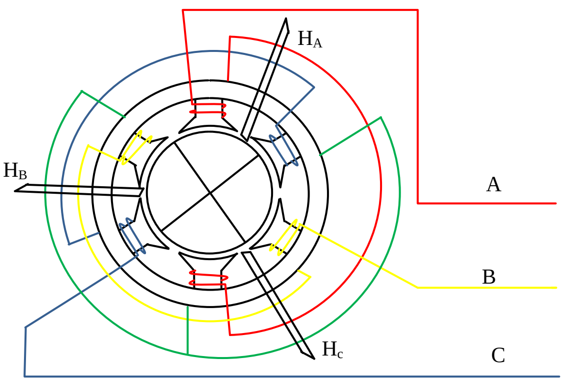

Figure 2. 1 : Cross section of BLDC motor with respect to Hall Effect Sensor

2.2.2 Operation Of BLDC Motor

The BLDC motor is constructed by a three phase star connection windings and ungrounded neutral point[5]. However, it operated as if it is designed in two phase connection. Depending on rotor position, only two of the inverter legs will be energised at particular time[6]. Where, the third leg is kept inactive at the same time. Each sequence shown in Figure 2.3 rotates at 60 electrical degrees. One full 360 degree rotation six step voltage source inverter need 6 sequence with only one current path for each sequences[7]. In Figure 2.2 below shows the correlative of back emf, phase currents, and Hall effect signals relatively.

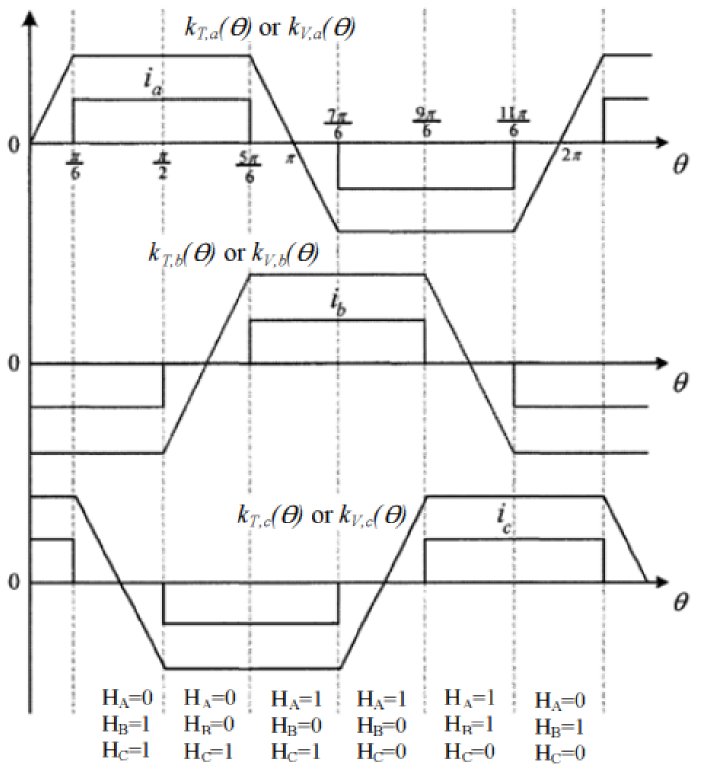

Figure 2. 2 : Ideal back-emf's, phase currents, and Hall Effect signals

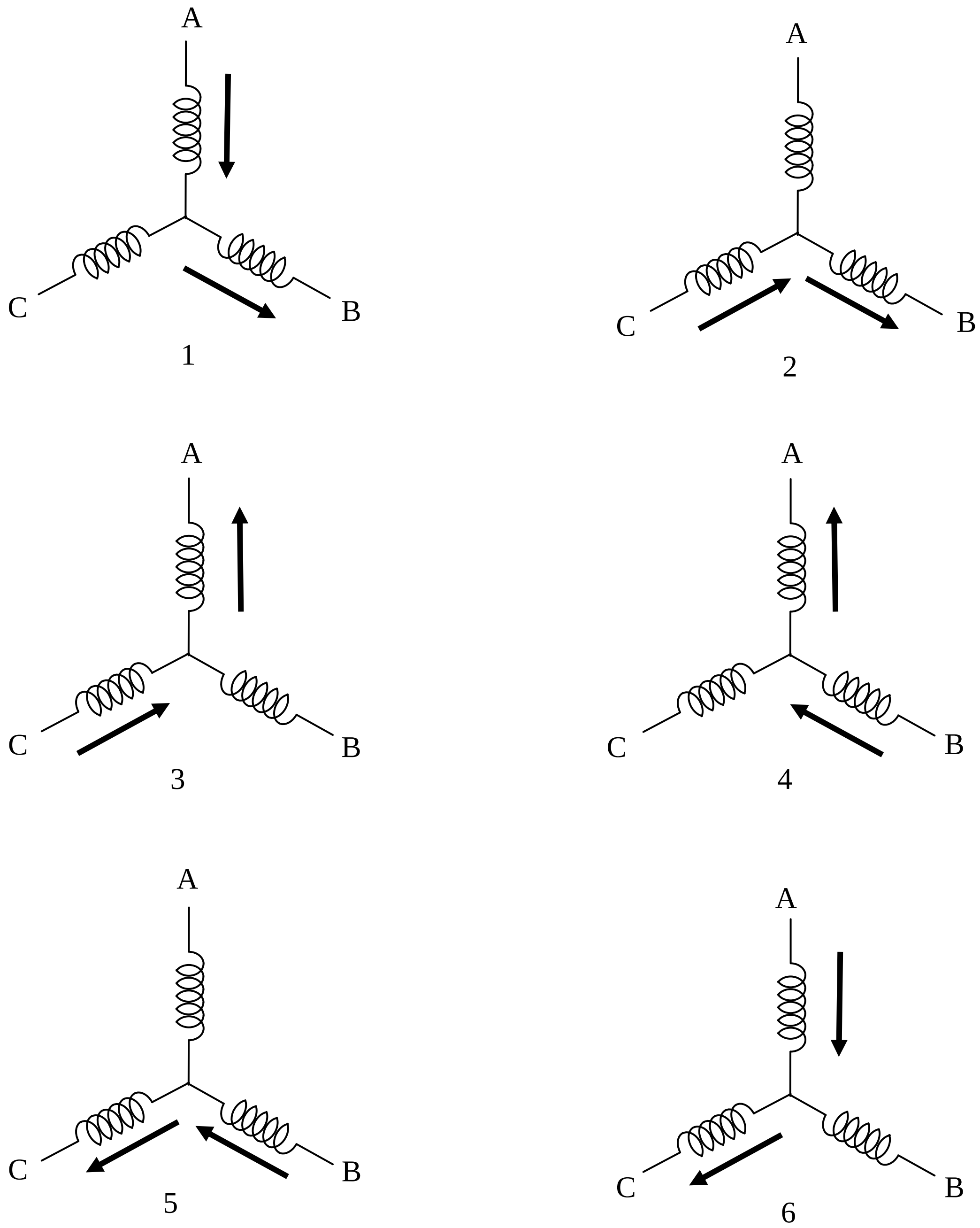

Figure 2. 3 : Winding energizing sequence

2.2.3 Stator Winding Variants

2.2.3.1 Trapezoidal Motors

As the name indicate, the trapezoidal motor produce a back Electro Motive Force(EMF) in trapezoidal shape. In addition, due the trapezoidal shape of the induced back EMF in the stator winding, its phases needs to be supplied with quasi-square currents for ripple-free torque operation. Even though the torque output produce by sinusoidal motors smoother than a trapezoidal motor, but it can gives higher efficiency, torque output is constant and proportional to currents amplitude, simple and lower cost. It also has been chosen as the motor that to be used in the project.

2.2.3.2 Sinusoidal Motors

Whereas for sinusoidal motors, it requires sinusoidal phase current for ripple-free torque operation as it generates sinusoidal shaped of the back EMF. Despite of its smooth torque output, it comes with several drawbacks because requires complex software and hardware compare to trapezoidal motors. Besides, the rotor position should be detected at every time instant, thus it should be equipped with high resolution position sensor.

2.2.4 Hall Effect Sensors

Hall effect sensor is a magnetic field sensor that capable to be implement as principle component in lots of other types of sensing devices such as current, pressure, and position. In the utilization of BLDC motors, Hall effect sensor that generally used are position sensor type. To ensure that the BLDC motors rotate smoothly, the energized stator windings should be in the right order. Thus, the embedded Hall Effect sensor in the stator act as the detector to determine the rotor and sector on which the rotor is presently located position during the motor operation. A three bit code is generated by the sensor with the values ranging from 1 to

6 respectively[8]. The produced code value is then gives information on which winding should be energize for the next sequences.

Mostly, in each of BLDC motors are mounted with three Hall sensors in the stator at the non-driving end of the motor. The sensors are placed with equal distance from one another by 60 electrical degrees to ensure that each sensors output is aligned with either one of the electromagnetic circuit[8]. A digital high level for the first 180 electrical degrees of electrical rotation will be produce while the rest of 180 electrical degrees will outputs a low level[8]. This digital levels are generate by each of the sensor elements. The Hall sensor will interpreted either high or low signal each time when the rotor magnetic poles pass near the sensors. Thus, this process will show either North or South pole that is passing close to the sensors.

However, the signals that are either low or high must be decoded to respected signals as shown in Table 2.1. Only then, the decoded signals can generate the reference current that will be used for the control scheme.

Table 2. 1 : Hall Effect decoded signals

Hall Effect Signals			Decoded Signals		
H_A	H_B	H_C	H_A'	H_B'	H_C'
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

2.3 Related Previous Work

2.3.1 Topologies Of Control Strategy For BLDC Motor

This section will discussed about the schemes that applicable for BLDC machine. All the concepts and operation works being compared to each other for better understanding on controlling BLDC motor.

2.3.1.1 Voltage Control

Voltage control strategy implement the theory that speed of BLDC motor is directly proportional to the voltage applied to the motor terminals[3]. The speed of the BLDC motors are achieved by varying the voltage source that supplied to the motor. As the higher the voltage source, the faster the speed of the motor. This control strategy did not consist any current control loop, hence there are no current sensors used in the drive. Besides, this strategy is less cost compared to pulsed power stage which is the PWM. However, a linear power stage gives out high losses at high current and low voltage.

2.3.1.2 PWM Control

Pulse Width Modulation(PWM) applied the concepts of controlling the average output voltage from a fixed input voltage[3]. The theoretically of PWM control can be explained clearly by the concepts of basic switch mode dc to dc converter. Where, the average voltage depends on the switching at the converter. PWM can be classified into either variable or constant switching time period based on the switching nature. If the switching time period is constant, it indicates the constant frequency PWM control. Otherwise, it is known as variable frequency PWM control when the switching time period is can be varied. By having a constant frequency in the PWM control, the filtering process much easier as the harmonics are produced in multiples at the switching frequency. Differ from variable switching frequency where it is completely difficult to filter the harmonics under any circumstances.

However, in practice, the load will be resistive-inductive. As any case, when the current passing the inductors, it is forced toward zero in a short time, inductive load may damage the switches and resulting very high voltage spikes[3]. Thus, it needs a diode labelled as free wheeling diode to eliminate the high voltage spikes by allowing the current to naturally go down towards zero. This add the drawbacks of the PWM.

PWM approaches in producing signals are by comparing the voltage control with a sawtooth carrier signal. The switching signal describes as follow:

$$\text{Switching signal} = \begin{cases} Vcontrol > Sawtooth\ signal & , switch\ turned\ on. \\ Vcontrol < Sawtooth\ signal & , switch\ turned\ off. \end{cases}$$

2.3.1.3 Torque Hysteresis Control

In Torque Hysteresis Control (THC) strategy, there will be one current control loop for the structure. The control scheme implement inner current control loop by using DC link current[6]. Two of the three phase currents were measured and then fed to the DC link current. By doing this, the reference currents can be generated. However, it is important to ensure that the sum of phase currents is zero to enable this concept being used. This method suits the BLDC motor because it is designed with three phase star connection with an ungrounded neutral point. Using this scheme, an efficient and high torque dynamic response of the electric machines can be achieved. Besides, the advantage of using this technique is that from the phase currents, the torque were directly determined[1]. The production of DC link current and torque are given as in equation 2.1 and equation 2.2 respectively.

$$I_{ref} = \frac{T_{ref}}{k_t} \tag{2.1}$$

$$T_{e,total} = T_{e,a} + T_{e,b} + T_{e,c} = k_{t,a} i_a + k_{t,b} i_b + k_{t,c} i_c \tag{2.2}$$