HIGH PERFORMANCE ADAPTIVE PID CONTROLLER FOR BRUSHLESS DC MOTOR

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Electronics Engineering)

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ABSTRACT

Year of empirical research and efforts brought the world into its current position with modern technical amenities. The Brush Less Direct Current (BLDC) motor for the electric propulsion system is one of the innovations in this modern era. Nowadays, the BLDC motor drives are getting used in all types of automation system, electric vehicles, robotics, drones and in various industrial applications. The PID, FPA, PI, fuzzy logic, adaptive, QFT and PWM are the popular types of a control methods for the BLDC motor system and all of these control methods have their own distinctive functionality. But all the controllers suffer with the BLDC motors for its nonlinear behaviour, parameter variation in load unsettle influences and parametric varieties with high speed or variable speed configuration. To increase BLDC motor control performance a fast, rugged and quick adaptable controller is required. The controller needs to be tested and less rippled than the existing controller. The proposed adaptive PID controller have combined strength of PID-autotuner controller and PID controller for a BLDC motor control system. The PID-autotuner provides the adaptability for self-adjusting the parameters for nonlinearities, load performance and speed variation through steady response and performance accuracy based on frequency-response estimation process. Whether the fast responsive and rugged PID controller is to minimize the PID-autotuner's slow performance. The combined effect of both controllers, correcting each other by automatically readjusting the parameters for better afford. To verify the performance, MATLAB simulation platform has been used and a benchmark BLDC motor system was developed based on a specific BLDC motor system parameter. For performance comparison the PID and FPA speed controller was developed from reference papers, because of several review papers were mentioned the better performance of them. A brief comparison has been made with the Adaptive-PID controller and targeted PID & FPA controller benchmarking. Where, the proposed controller gave less ripple, less overshoot (>1%) and good load performance then PID and FPA controllers in load variation and different speed condition. The contribution of this research is to design an Adaptive PID controller for BLDC motor system, to increase the adaptable and reliably through performance compare to FPA and PID controller.

خلاصة البحث

سنوات من البحث التجريبي والجهود أوصلت العالم إلى وضعه الحالي مع وسائل الراحة التقنية الحديثة. ويعدّ محرك عديم الفرشاة ذو التيار المستمر BLDC المستخدم في نظام الدفع الكهربائي أحد ابتكارات العصر الحديث. وفي الوقت الحاضر، تستخدم وحدة التحكم بمحركات BLDC في جميع أنواع أنظمة التشغيل الآلي، والمركبات الكهربائية، والروبوتات، والطائرات المسيرة، وفي التطبيقات الصناعية المختلفة. ومن الأنواع الشائعة للمتحكمات في محرك BLDC: PID، و FPA، و PI، و FPA وPI، والمنطق الضبابي، والتحكم التكيفي، و QFT، و PWM. وهذه المتحكمات لها وظائفها المميزة، ولكن جميع المتحكمات تعاني مع محركات BLDC بسبب سلوكها غير الخطي، ولتغير المعلمة في تأثيرات الحمل غير المستقرة والتشكيلات المعلمية في حالة السرعة العالية أو المتغيرة. ولتحسين أداء التحكم في محرك BLDC، يلزم وحدة تحكم سريعة وقوية وقابلة للتكيف. كما يجب اختبار وحدة التحكم بحيث تكون نتائجها أقل تموجاً من المتحكمات الحالية. لذلك، فإنّ متحكم PID التكيفي المقترح يجمع بين متحكم PID-autotuner ومتحكم PID لنظام التحكم في محرك BLDC. حيث يوفر PID-autotuner القدرة على التكيف من أجل الضبط الذاتي للمعلمات بالنسبة للاخطية ولأداء الحمل ولتغيّر السرعة، من خلال الاستجابة الثابتة ودقة الأداء بناء على عملية تقدير الاستجابة الترددية. بينما متحكم PID القوي سريع الاستجابة هو للحد من بطء أداء PID-autotuner. إن التأثير الناتج عن الجمع بين المتحكمين يؤدي إلى أن يصحح أحدهما الآخر من خلال إعادة ضبط المعلمات تلقائيًا من أجل تحمل أفضل. وللتحقق من أداء المتحكم المقترح في هذه الأطروحة، استخدم برنامج المحاكاة MATLAB لتطوير نظام محرك BLDC معياري بناءً على معلمة نظام محرك BLDC محدد. ولمقارنة الأداء، تم تطوير متحكمي سرعة: PID، و FPA من أبحاث سابقة لأفضلية أدائهما كما بيّنت العديد من أبحاث المراجعة. ثم أجريت مقارنة موجزة بين متحكم PID التكيفي ومتحكمي PID و FPA المعياريين، حيث أعطى المتحكم المقترح تموّجاً أقل، وتجاوزاً أقل (%1>)، وأداء حمل أفضل من متحكمي PID و FPA في حال تغير الحمل وفي ظروف السرعة المختلفة. إنّ مساهمة هذا البحث هي في تصميم متحكم PID تكيفي لنظام محرك BLDC لزيادة القدرة على التكيف والموثوقية من خلال الأداء، مقارنة بمتحكمي FPA و PID.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Electronics Engineering.)

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DECLARATION

I hereby declare that this thesis is the result of my investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

μC	Microcontroller
ADC	Analog-to-Digital Converter
APID	Adaptive Proportional-Integral- Derivative
BEMF	Back Electro-Motive Force
BLAC	Brushless AC
BLDC	Brushless DC
CPU	Central Processing Unit
DAVETM	Digital Application Virtual Engineer
DC	Direct Current
DSP	Digital Signal Processing
DTC	Direct torque control
EMF	Electro-Motive Force
FFT	Fast Fourier transform
FOC	Field Oriented Control
GPIO	General Purpose Input/Output
GPT	General Purpose Timer
HW	Hardware
IDE	Integrated Design Environment
IGBT	Insulated Gate Bipolar Transistor

IGCT	Integrated Gate Commutated Thyristor
ITC	Interrupt Controller
LED	Light-Emitting Diode
MAC	Multiply-Accumulate unit
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
PEC	Peripheral Event Controller
PI	Proportional-Integral
PID	Proportional-Integral- Derivative
PIDC	Proportional-Integral-Derivative Controller
PMSM	Permanent Magnet Synchronous Motor
PWM	Pulse-Width Modulation
PMBDCM	Permanent Magnet Brushless Direct Current Motor
QFT	Quantitative Feedback Theory
RPM	Revolutions Per Minute
SMO	Sliding Mode Observer
SRM	Switched Reluctance Motor
USB	Universal Serial Bus
ZCP	Zero-Crossing Point

LIST OF SYMBOLS

λ	Control parameter
ε	EMF induced (V)
φ	Flux (Wb
B	Magnetic flex density (Wb/ m^2)
B_s	Stator magnetic flux density (Wb/ m^2)
H	Magnetic field strength (A/m)
T	Torque (N.m)
φ_l	Flux linkage (Wb(.turn))
μ_o	Permeability of free space (H/m)
μ_r	Permeability of material relative to free space (H/m)
λ_s	Stator flux linkage (Wb(.turn))
α	Alfa Constant
β	Bita
ε	Epsilon
θ_e	Electrical angle (rad)
θ_m	Mechanical angle (rad)
θ_r	Rotor angle (rad)
λp	Variable control parameter for 1st logistic chaotic maps
μq	Variable control parameter for 2nd logistic chaotic maps

dq	d-q coordinates
αβ	αβ coordinates
=	Equality
≤≤	Less than or equal to
≥≥	Greater than or equal to
+	Plus
-	Minus
η	Neu
Φ	Flux
θ	Theta
ζ	Jetta
μ	Mu
τ	Taw (used for angel)

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The modern era is the era of the industrial revolution which started with the invention of motors. With time, several types of motors were invented and can be classified into two main categories: AC motors and DC motors. There exists a set of DC motors which can be seen in various applications. However, in general, in industrial use, two types of DC motors are used. The electrical energy produces the magnetic flux in the first type through the field coil of the static pole structure, and the permanent magnet provides the required flux in the second type, which is not the situation for the wire-wound field poles. The Brushless DC (BLDC) motors are generally synchronous motors with a back EMF waveform trapezoidal structure. A Brushless Dc motor does not need a brush for switching but commutes the electronic process. Current revelations show that high-performance BLDC motor technology is generally used in the worldwide industrial applications and electric vehicles system because of good performance. A basic control system is shown in Figure 1.1 for the BLDC motors.

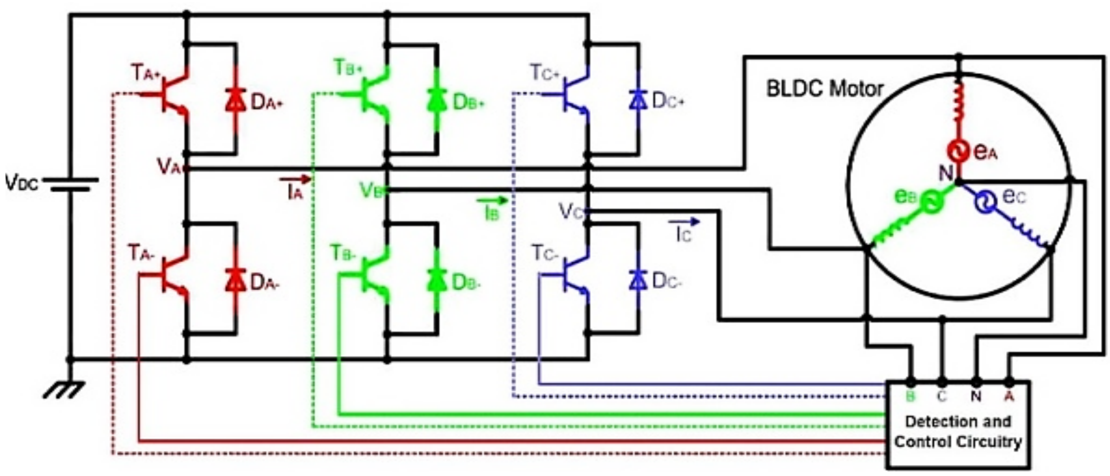

Figure 1.1 Block diagram for BLDC motors control system (Nick Davis, 2017)

The BLDC drive designs in operation require a complex procedure, such as the monitor, plot structure control, reproduction, and adjustment parameters, etc. For the BLDC motor speed control plan which requires a control drive, different current control systems have been proposed (Mukherjee, A. 2018). It may be that the adaptive PID control is quick, reliable, simple modifying and of high, unwavering quality. In customary adaptive PID control, the conventional speed control system is used. Highly nonlinear stages, parameter fluctuation and vulnerability of the mathematical model of the system are featuring the most modern techniques. The tuning of the PID control parameters is the problem and of low vigour, which makes it difficult to obtain the ideal status in the actual production conditions (Kapil, G. 2016). The parameters for tuning PID control are not quite so easy. It would have been challenging to achieve the best position in the areas studied. This study suggested a PID customizable controller by adjusting some improvements which could increase the control speed of BLDC motors if understood appropriately. Function and mathematical development also needed for better implementation of adaptive PID controller system. At the same time, K_P, K_i and K_d for the PID controller are subject to a series of rules. The modified controller will be restructured to any adjustment element by using the present principles (Salleh, Z. 2016). The present research work aims to highlight the adaptive feedback from fast tuning resulting from of the proposed modified adaptive PID controller that provides for a BLDC motor torque, speed control and constant movement of motors throughout load changes. The simulation and the results highlighted the importance of an adaptive PID controller with a better control efficiency than both the PID, Fuzzy, PI and FPA speed controllers.

1.2 STATEMENT OF THE PROBLEM

A BLDC motor requires controller to achieve sufficient torque and speed for maximum efficiency. In the case of BLDC motor speed is controlled by different types of controller through zero crossing of phase synchronization process or using different types of sensors. Although in low speed of BLDC motor, usually all controllers perform well for its magnetic configuration and simplicity of usage. But, in high speed and variable speed condition, these controllers' also present difficulties of several control intricacy, for example, nonlinearity, load unsettling influences and parametric varieties. To achieve better performance in high speed and variable speed condition, the controller must be rugged, adaptive and fast response for better synchronisation where, combined controller may be a good option.

For a controller, driving a BLDC motors is hard due to unpredictable power rating behaviour depending on load and withstanding of the permanent magnet in speed. In this situation adaptability is highly important for a controller to drive BLDC motor, but, sudden load change produce instability in high speed. Again, in high-speed mode fast response controllers give more overshoot than usual. Therefore, a combined performance of Adaptive controller and fast response PID controller is the best option.

High-efficiency BLDC motors are complex in design, which means they are heavy power consuming and expensive in terms of cost. They require more safety and efficient power management. Thus, Simulating a BLDC motor with several controller is an easiest way and cost effective solution for performance testing.

1.3 SCOPE OF RESEARCH

This study aims to build up an Adaptive PID controller to control BLDC motors. The Adaptive PID controller ought to be able to expand BLDC motors' effectiveness, speed and decrease reaction time and few more. Our controller structure rationale was to contract the controller for the genuine plant or business reason and deal with the incorporated controller for better execution in future. A mathematical model has been developed for adaptive PID controller, the model includes BLDC permanent magnet motors, sensor, power source and reference. Based on the proposed mathematical model, a schematic design has been developed and optimized by using MATLAB/ Simulink software. The simulated results of the experiment were evaluated by comparing with the benchmarks.

1.4 RESEARCH OBJECTIVES

The aimed of the study to achieve the following objectives:

- To develop an adaptive PID controller model for BLDC motor.
- To design less ripple controller using MATLAB-Simulink
- To evaluate the performance of the controller in case of speed, torque, voltage for benchmarking.

1.5 RESEARCH METHODOLOGY

The main aim of this research is to design and developed an Adaptive PID controller for BLDC motors. The results of improved torque and speed have been shown by simulation, analysis, discussion. Also, the implementation of the device, based on the simulation and the analysis, was done. After testing and implementation, the verification process started. The simulated experimental results were compared with the benchmark as follows:

- Modelling the brushless DC motor based on characteristic
- A mathematical model has been developed for adaptive PID controller, the model includes BLDC permanent magnet motor, sensor, drive circuit, and references.
- Based on the proposed mathematical model has been developed by using MATLAB/ Simulink.
- The simulated experimental results will be evaluated by comparing with the benchmark.

1.6 SUMMARY

This part has demonstrated and discussed the foundation of the investigation of the proposed controller framework for the BLDC motors. To accomplish the goal of this depiction of a general controller automation framework has been developed for an individual controller. Similarly, an investigation of the presentation the Adaptive PID controller was done. Moreover, the announcement of the issue was discussed, as the investigation is to find the availability and application for adaptive PID controller to control BLDC motors speed. This additional section gives an ordinary mind-opening thought for the controller technique in a similar stage. The necessity of the investigation which was pursued by highlighting the way to control the factory efficiently with the combined control if there should be an incident of the single controller technique.

1.7 THESIS ORGANIZATION

This part (Chapter 2) discusses the literature review part of the theses while (Chapter 3) contains the technique of the research methodology and examination. Chapter 4 shows the outcomes and the discussions which are dependent on the approach proposed in this research. Chapter 5 abridges the result of the exploration and finish up the discoveries.