



Faculty of Electrical Engineering

**DUTY CYCLE PREDICTION CONTROL TECHNIQUE FOR A DC-DC BUCK
CONVERTER BASED ON DOMINANT POLES LOCATION**

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Bachelor of Electrical Engineering (Control, Instrumentation & Automation)

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DECLARATION

I hereby, declared this report entitled “Duty Cycle Prediction Control Technique for A Dc-Dc Buck Converter Based on Dominant Poles Location” is the result of my own research except as cited in references.

Signature :

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and qualify for the award of the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation).

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Name of Supervisor :

Date :

ABSTRACT

The DC-DC converter is designed by controlling the input voltage using switch mode configuration to obtain a desired DC output voltage. DC-DC converter are divided into three types which are buck converter, boost converter and buck-boost converter. A feedback control strategy is needed to accomplish the DC-DC converter system to produce good transient response and zero steady-state error. The objective of this project is to do system modelling on DC-DC buck converter. Since the aim of this project is to achieve good transient response and zero steady-state error, a feedback controller which is modified PID controller is formulated in order to predict a duty cycle for DC-DC buck converter which called as Duty Cycle Prediction Control Technique. Finally, to analyse the transient response and steady-state error of the DC-DC buck converter. There are two methods to work on system with and without controller and for duty cycle prediction. The first method is by modeling the system and second method is by using real plant. For the first method, the modeling on DC-DC buck converter has been done to obtain the transfer function of plant system. The step response and root locus of the system with and without controller has been obtained by using coding in the MATLAB. Meanwhile, good transient response and zero steady-state error by Duty Cycle Prediction Control Technique has been verified by using MATLAB/Simulink. For the second method, there are three cases have been tested which were changes in reference voltage, load and input voltage on system with and without controller. A modified PID controller has been designed and constructed. The derivative time, derivative gain and gain value has been obtained by using root locus technique. The algorithm used in the duty cycle prediction has been derived by using the partial fraction method based on the dominant poles location. Eventually, the modified PID controller has been inserted into the system with controller and duty cycle prediction. From the result, the proposed idea, Duty Cycle Prediction Control Technique has been successfully perform the case change in reference voltage. It produced good transient response and zero steady-state error. Therefore this technique can be used as the new feedback control technique.

ABSTRAK

Penukar DC-DC direka dengan mengawal voltan input yang menggunakan konfigurasi suis mod untuk mendapatkan DC voltan output yang dikehendaki. Penukar DC-DC dibahagikan kepada tiga jenis iaitu penukar buck, penukar rangsangan dan penukar buck-boost. Satu strategi kawalan maklum balas yang diperlukan untuk mencapai sistem penukar DC-DC untuk menghasilkan sambutan fana baik dan kesilapan sifar keadaan mantap. Objektif projek ini adalah untuk membuat sistem model penukar DC-DC buck. Untuk mencapai sambutan fana baik dan kesilapan sifar keadaan mantap, pengawal maklum balas yang pengawal PID yang diubah suai dirumus untuk meramalkan kitar tugas untuk penukar DC-DC buck yang dipanggil sebagai Teknik Ramalan Duty Cycle. Akhir sekali, untuk menganalisis sambutan fana dan ralat kesilapan mantap penukar DC-DC buck. Terdapat dua kaedah untuk sistem dengan dan tanpa pengawal dan untuk ramalan prediction. Cara pertama adalah menggunakan sistem model. Cara kedua adalah menggunakan sistem sebenar. Bagi kaedah pertama, pemodelan pada penukar DC-DC buck telah dijalankan bagi mendapatkan fungsi pindah sistem sebenar. Sementara itu, sambutan fana dan ralat kesilapan mantap oleh Teknik Ramalan Duty Cycle telah disahkan dengan menggunakan MATLAB / Simulink. Bagi kaedah kedua, terdapat tiga kes telah diuji iaitu perubahan dalam voltan rujukan, beban dan voltan input pada sistem dengan dan tanpa pengawal. Sebuah pengawal PID diubahsuai telah direka dan dibina. Masa terbitan, keuntungan derivatif dan nilai keuntungan telah ditetapkan berdasarkan cara londar punca. Algoritma yang digunakan dalam ramalan kitar tugas telah diperolehi dengan menggunakan pecahan separa. Akhirnya, pengawal PID yang diubah suai telah dimasukkan ke dalam sistem dengan ramalan pengawal dan duti kitaran. Dari keputusan itu, idea yang dicadangkan, Teknik Ramalan Duty Cycle telah berjaya melaksanakan perubahan berlaku di voltan rujukan. Ia menghasilkan sambutan fana baik dan sifar keadaan mantap. Oleh itu, Teknik Ramalan Duty Cycle boleh digunakan sebagai teknik kawalan maklum balas yang baru.

DEDICATION

Dedicated to

my beloved father, Lau Ah Peng

my appreciated sibling, Lau Khai Shian and Karen Lau

*my special friend Ng Tiew Lye for giving me moral support, cooperation, encouragement
and also understanding*

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CHAPTER 1

INTRODUCTION

1.1 Introduction

DC-to-DC converter is an electronic circuit and it is able to convert direct current (DC) source from one voltage level to another. It is one of a type of electric power converter. The DC-DC converter is designed by controlling the input voltage using switch mode configuration to obtain a desired DC output voltage. One of the applications of DC-DC converter is found in batteries charging system. For instance, if there is no voltage control when a battery discharge will cause the battery decreases and may come out with a lot of problems. The most efficient way of regulating voltage is using a DC-DC converter.

DC-DC converter are divided into three types which are buck converter, boost converter and buck-boost converter. Basically the buck and boost types converter are used to increase or decrease the output voltage lower or higher than the input voltage, respectively. For a wider usage, buck-boost converter is introduced to function either as buck or boost converter. Buck converter is also called as step-down converter to step down input voltage to its output voltage. While boost converter is called as step-up converter which step up its input voltage to its output voltage.

A feedback control strategy is needed to accomplish the DC-DC converter system. Without a feedback control strategy, a steady-state error occurs at DC output voltage for the case step-change of load or voltage output. The most recognised control strategy is Proportional-Integral-Derivative (PID) and modified PID controller.

In this final year project, Duty Cycle Prediction Control Technique has been developed to obtain a controllable DC output voltage. MATLAB/Simulink is used to simulate it so that it can achieve a good transient response and zero steady-state error of DC output voltage. It has tested for transient case with changes in reference voltage.

1.2 Motivation

The function of DC-DC buck converter is to step down the input voltage to its output voltage. A modified PID controller has been designed to ensure a better output response and desired output voltage based on the requirement. In power electronics field, the DC-DC buck converter is preferably used because of its simplicity, low cost and high efficiency. DC-DC buck converter is always efficient (which often higher than 90%), it is useful for tasks like converting a computer's main large of the supply voltage (normally 12V) to lower voltages or reference voltages that needed by USB, RAM or CPU. Eventually the buck converter should be accomplished by controller to achieve better performance and the controller used is modified PID controller. Duty Cycle Prediction Control Technique is developed because it is simple and more autonomous.

1.3 Problem Statement

The buck converter should be accomplish by controller to regulate the voltage. Without a feedback control strategy, a steady-state error occurs at DC output voltage for the case change of load or voltage output.

Proportional-integral-derivative (PID) controller is always used in a lot of closed-loop control system. By tuning the parameters of PID controller for example proportional gain which is K_p , integral gain which is K_i and derivative gain which is K_d , linear or non-linear system can achieve satisfied performance. Practically, a normal PID control system will produce a set-point kick phenomenon [15]. Set-point kick phenomenon is somehow like the output signal come out with sharp points and this make the output signal is not smooth enough.

To overcome this problem, a modified PID is used. Basically, it can prevent the set-point kick phenomenon, this is because instead of putting PI-D or I-D and the derivative action in the forward path, it will be placed in a smaller loop around the plant. However, the modified PID is more complicated and its algorithms are too long and complex to run a system. Therefore, a modified PID controller is formulate in order to predict duty cycle for DC-DC buck converter. It is able to regulate the voltage in the system with the case changing reference voltage, load and input voltage to produce better performance somehow like eliminate the steady-state error.

1.4 Objectives

The objectives of this project are:

- i. To do system modeling on DC-DC buck converter
- ii. To formulate a modified PID controller in order to predict a duty cycle for DC-DC buck converter.
- iii. To analyse the performance of DC-DC buck converter.

1.5 Scope

- i. Literature on DC-DC converter
- ii. Literature on principle operation of DC-DC buck converter
- iii. Obtain a mathematical model of DC-DC buck converter
- iv. Design and simulate the PWM switching pattern of DC-DC buck converter
- v. By using system modelling method and real plant method on DC-DC buck converter by using real plant
- vi. Work on the system with and without controller and duty cycle prediction
- vii. Analyse the performance of DC-DC buck converter

1.6 Limitation of the Project

The modified PID controller also has its own limitation. It just can response to smaller changes in reference voltage, load and input voltage. Since there is only a year to carry out this project, there is limited time to do research on Duty Cycle Prediction Control Technique too. The load change and input voltage by using this technique do not have enough time to discuss. Therefore, a further research on modified PID controller should be carried out so that the controller is able to respond in bigger change in reference voltage, load and input voltage while further research on Duty Cycle Prediction Control Technique need to be carried out to develop load change and input voltage.

CHAPTER 2

LITERATURE REVIEW

2.1 DC-DC Converter

DC-to-DC converter is an electronic circuit and it is able to convert direct current (DC) source from one voltage level to another. It is one of a type of electric power converter. DC-DC converter are divided into buck converter, boost converter and buck-boost converter. The function of the DC-DC converter is that it uses switch-mode configuration to control the input voltage and finally obtain a desired DC output voltage.

2.1.1 Uses of DC-DC Converter

DC to DC converters are normally applied in the portable electronic devices which uses batteries for example mobile phone or laptop computers. When the stored energy in the battery drained, the battery voltage declines. Therefore, switched DC to DC converters are used to increase voltage from a partially lowered battery voltage. Basically it prevents the use of multiple batteries and saves space. From the study, DC to DC converter circuits are able to regulate the output voltage for instance, high-efficiency LED power source it regulates the current through the LED, and it use as a simple charging pump which can increase the output voltage by double or triple it. In addition to this, photovoltaic systems also utilized this kind of converter to maximize the energy obtained.

2.1.2 PWM DC-DC Converters

Due to the research of Mor Mordechai Peretz, and Shmuel (Sam) Ben-Yaakov, they proposed on time-domain design of digital compensators for PWM DC-DC converters. This paper presented the development of digital controller of PWM DC-DC converters with a time-domain design method. The concept is applied to fit a digital PID model to the desired response. Furthermore, in the time domain and diversion errors from the continuous to

discrete domain is accomplished by the method of proposed controller design. The study was to explore PID model controller to control the closed-loop performance that obtained from a system and the stability boundaries of the proposed time-domain controller design method[1].

2.2 Principle Operation of DC-DC Buck Converter

Mahesh Gowda N M, Yadu Kiran and Dr. S.S Parthasarthy proposed the principle of operation of a buck converter. When the MOSFET is ON, the input voltage is used in inversion through the diode. The diode should remain OFF if the MOSFET stays ON. The ON state of MOSFET means the diode is in OFF state. When the MOSFET turned ON, inductor current will build up. At the moment when MOSFET is OFF, inductor current has a finite value which is the peak value of the output current when it is in the primary chopper cycle. When the MOSFET OFF, this peak current occurs instantly. To prevent the unexpectedly drop of inductor current to zero, inductance will present. This voltage makes the diode turn into forward-biased and causes the current move along to continue and decay exponentially. Without the voltage source, the flow of current is called "Free-Wheeling", yet due to the energy stored in the inductor. The diode is to allow the free-wheeling path when MOSFET when it is OFF. The diode will thus turns ON when the MOSFET becomes off because of the presence of an energy stored inductor. The difference between successive cycles becomes negligibly small after few cycles. Thus he circuit conditions have reached steady state[2].

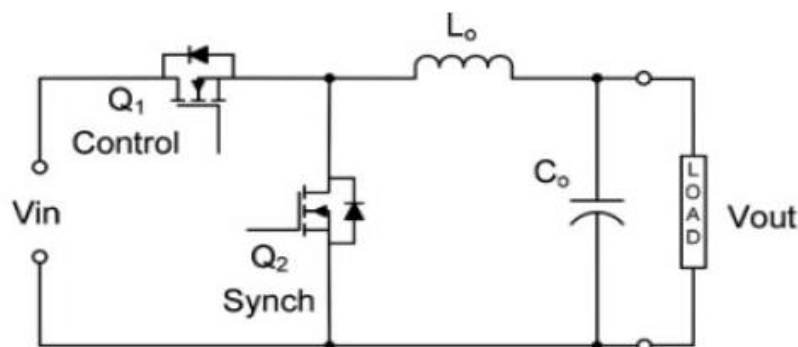


Figure 2.1: The Schematic Circuit Diagram of DC-DC Buck Converter

Figure above shows the schematic circuit diagram of a DC-DC buck converter. The diagram shows it is a simple circuit including two MOSFETs, an inductor, a capacitor, a resistor as load are used.

2.3 Modelling on DC-DC Buck Converter

Due to the research of Jose M. Sosa, P.R. Martinez-Rodriguez, G. Escobar, J.C. Nava-Cruz, and c.A. Limones-P Ozos proposed on the controller for a reduced output current ripple DC-DC buck converter. This paper presented without switching devices, the modelling of a DC-DC buck converter with lower output ripple can be successfully achieved. Sensitive loads for example the application in LED or high accuracy tools are needed for low output ripple. The function of buck converter is maintained and the output current and voltage ripples are extremely lower. In order to mitigate resonant behaviours, active damping must be provided. According to this, the regulation on output voltage and active damping can be achieved when the model-based controller proposed[3]. A fundamental component of this suggested controller has an estimation plan when changing of power under an intent output voltage[3]. Few simulations are developed to analyse the performance of closed-loop system[3].

Due to the research of Mahesh Gowda N M, Yadu Kiran and Dr. S.S Parthasarthy, they proposed on a mathematical model of a Buck Converter for simulation using Simulink. They explained the superior rise time, settling time and peak overshoot can be obtained by using MATLAB's tuning tools to obtain. In order to allow the application of the controller tuning tools gave by MATLAB, the system's transfer function is also discussed [2]. The paper mentioned that the default PID block is free to substitute with their own algorithms.

Due to the research of H. Abaali, he proposed on DC-DC buck converter with the design modelling control and simulation of. The buck converter is broadly used DC-DC converter topology[4]. This work proposes, using the current-mode control and method of state-space averaging to do the modelling of DC-DC buck converter. The operating point changes analysed the effectiveness of the suggested model and the control loop[4]. From this research, its effectiveness of the linear model of DC-DC buck converter was proved by using simulation results.

2.4 Proportional–Integral–Derivative Controller (PID Controller)

A proportional-integral-derivative controller (PID controller) is a generic feedback control mechanism that commonly used in industrial control systems. This is because it can mend the error between a measured process variable with a desired set point. After that a corrective action will be done to make the process become better. The PID controller calculation (algorithm) includes Proportional, the Integral and Derivative values. Proportional value will determine the reaction of current error, the integral value will determine the reaction of total errors while the derivative value will determine the reaction of rate at which the changing error occurred. The specific process requirements can be achieved by "tuning" the three values in the PID controller.

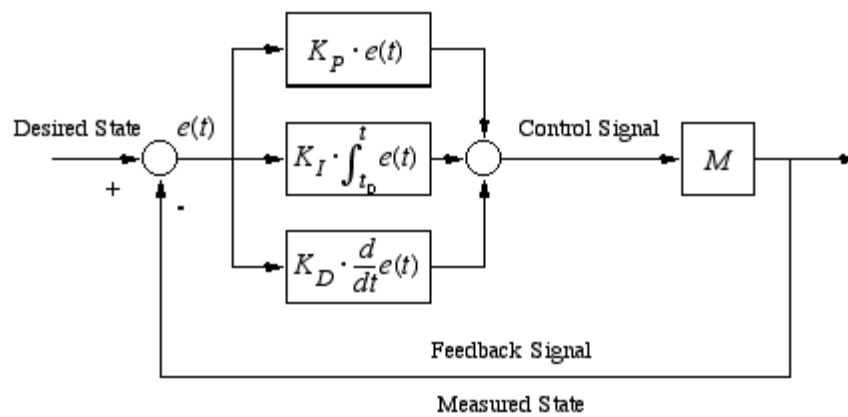


Figure 2.2: The PID Controller

Figure above shows the diagram of PID controller. The diagram shows the sum of proportional band or gain, integral gain or reset and derivative gain or rate.

2.4.1 Digital PID Controller

Due to the research of Chao-Ying Wang, Yang-Chieh Ou, Chih-Feng Wu and Muh-Tian Shiue, they proposed a PID controller design for voltage DC-DC buck converter[5]. DC-DC buck converter's phase margin is improved by the digital PID[5]. The behaviour model showed for the DC-DC buck converter of voltage-mode with ADC, digital PID controller and digital pulse width modulator (DPWM) based on the data of voltage error between input voltage and reference voltage is worked to analyse the responses by utilizing MATLAB Simulink[5].

2.4.2 Single-input fuzzy PID (SIF-PID) controller

Due to the research of Yubo Yuan, Changyuan Chang, Zhiqi Zhou, Xiaomin Huang and Yang Xu, they proposed designation of a single-input fuzzy PID controller for DC-DC buck converter based on the genetic optimization scheme. To enhance the performance of converter, a SIF-PID controller is designed. The three parameters of PID controller will alterate the fuzzy logic controller[6]. To decrease the computational burden, parallel diagonal lines in rule table can determine one-dimension rule vectors regarding the incline λ of the. To improve the coefficient λ , the genetic calculation is implied. This happen to make sure the simpler rule vectors and the first rule table are proportional regarding to control performance [6]. Simulation results presented the benefit of the controller mentioned.

Due to the research of Changyuan Chang, Yubo Yuan, Tianlin Jiang and Zhongjie Zhou, they proposed on the DC–DC buck converters used the field programmable gate array usage of a single-input fuzzy proportional–integral–derivative controller. This paper exhibited the outline and the DC–DC buck converters related with the field programmable gate array usage of a single-input fuzzy (SIF) proportional–integral–derivative (PID) control plot[7]. The amount of fuzzy rules being reduced. This minimizes SIF logic. Formation of The double-input rule table and TOEPLITZ structure formation is showed by analysing the system response curve[6]. The PID parameters regulated by the fuzzy logic controller based on the conditions of the power converters. Subsequently, the SIF-PID controller is like DIF-PID controller and it is better than the routine PID controller in terms of the control performance [7]. The simulation and experimental results has been validated with proposed controller.

2.4.3 PID Controller Tuning

Due to the research of Santanu Kapat, Member, and Philip T. Krein and Grainger, they proposed tuning on PID controller in a DC-DC converter. It is a method to reduce transient recovery time. This tuning concept will create high performance of PID controller. For large signal, minimum time transient recuperation can be performed by utilising a suitable auto-tuning principle. To deal with the ideal tuning principle, the geometric way is used[8]. The proposed principle is completed the estimation minimum time transient recuperation was shown in the large-signal transient. Meanwhile, a standard tuning rule can show the gains in

small-signal transient[8]. Prototype of a buck converter is tested and the scheme mentioned is implemented.

Due to the research of Subhash Chander, Pramod Agarwal and Indra Gupta, they proposed on discrete and auto-tuned PID controller for DC-DC converter for rapid transient response. This paper enhanced discrete auto-tuning PID scheme for DC-DC converters where expected huge load changes or rapid response time. The calculation created at here is to tune discrete PID controller and get its parameters. To enhance its performance, it is connected to synchronous buck converter [9]. Based on the current process, the controller parameters are constantly modified to improve the transient response and rise time of the converter. Non-linear parameters is created when a synchronous buck converter is composed[9]. The effects of non-linear for example quantization, S/H, delay, and saturation are considered. Simulation results presented the effectiveness of the developed algorithms.

2.4.4 Sliding Mode PID Control

Due to the research of Khalifa Al-Hosani, Andrey Malinin and Vadim I. Utkin, they proposed on sliding mode PID control of buck converters. The objective of the controller designed is to control a DC-DC buck converter to track a desired set point voltage[10]. The intricacy of this controller emerges from the fact that the main information accessible to the controller is the deliberate error[10]. The buck converter inductance and capacitance are unknown.

Due to the research of Muhammad Attique Qamar, Jin Feng, Abbad Ur Rehman and Abid Raza, they proposed on discrete time sliding mode control of DC-DC buck converter. Two special systems are introduced by using the Discrete Time Sliding Mode Control[11]. To develop discrete time controller, emulation design approach and approximate discrete time equal system model is used. The comparison of the performance between emulation design and approximate equivalent system model for DC-DC buck converter is made[11]. The approximate equivalent model is a chattering-free control, indicates robustness to uncertainties and gives quick dynamic response.

2.4.5 Frequency Domain Based Controller

Due to the research of Husan Ali, Xiancheng Zheng, Xiaohua Wu, Shahbaz Khan and Dawar Awan, they proposed on frequency domain based controller design for DC-DC buck converter. With collection on a suitable control technique for stability improvement, extensively analysing on switched-mode DC-DC converters needed to be done for modelling and analysis[12]. Stability is very important in the design of all types of controllers, it can be achieved by correct value loop gain design for the closed loop system. From this research, frequency domain performance is able to measure the stability and behaviour of the converter. The gain margin and phase margin of the system is judged to analyse the stability of a system. The DC-DC converter has investigate three linear control[12]. Basically, poles and zeros should be placed at suitable locations and this is a basic technique utilizing in passive circuit components[12]. Measuring step response and the overshoot, rise time and settling time are evaluated by the time domain [12]. The simulation of the system is done by using MATLAB.

2.5 Modified PID Controller

The modified PID controllers used to stabilise the unstable plant. Basically, the P-parameters, I-parameters and D-parameters are independent with each other. Its function is to improve the characteristic and response of the system.

2.5.1 Modification and Application of Auto-tuning PID Controller

Due to the research of Nedjeljko Perić, Ivan Branica, Ivan Petrović, they presented a modified auto-tuning algorithm of the PID controller. The purpose of it is to apply in the larger class of the process. The description of the algorithms' functioning is to do modification. The suggested algorithm is applied in the programmable logic controller (PLC) Siemens SIMATIC S7-300. The suggested algorithms ensure good robustness properties and the results is shown in simulation[13].

2.5.2 A Modified Design of PID Controller of DC Motor Drives Using Particle Swarm Optimization PSO

Due to the research of Adel A. A. El-Gammal, Adel A. El-Samahy, they proposed a new particle swarm optimization technique to adjust the gain so that it can give the minimum integral error, settling time and overshoot. By using selected weighting factors, this new