“ I hereby declare that I have read this fully report entitled “*Modified PID Controller for DC-DC Buck Converter using Voltage Based PWM*” and found that it has comply the partial fulfilment for awarding the *Bachelor of Electrical Engineering (Power Electronic and Drives*)”

Signature : ………………………………………………………………………..

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Signature : ………………………………………………………………………………

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Date :

MODIFIED PID CONTROLLER FOR DC-DC BUCK CONVERTER

USING VOLTAGE BASED PWM

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

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ABSTRACT

The usage of power electronic converters have been used widely since the invention of the devices. The main purpose includes converting electrical energy from one form into another form. Buck converter is one of the typical power electronic converters that changes the unregulated voltage into a regulated voltage, and provides different voltage level at its output. Operation of buck converter alone shows overshoot at the first moment of its start up. Thus, a control method is proposed so that the performance of the buck converter can be enhanced and the overshoot can be eliminated, as well as improving other significance characteristic, taking into account internal and external disturbances that might occur. A modified PID controller is proposed to control the buck converter output voltage. In this research, the main objective is to compare the system's responses between the conventional PID, PI and the proposed modified PID controller. With that, conventional PID method is applied first to compare the characteristic given by the buck converter using conventional and modified controller. The tuning method used is the zero-pole placement in the root locus method. The method is chosen after the mathematical model of the buck converter, the output voltage in transfer function managed to be derived. The result shows that regardless of being regarded as conventional, buck converter achieves its optimum performance with the normal PID as its controller. In conclusion, from the comparative analysis, conventional PID is more suitable to be the controller for buck converter operation as compared to others.

ABSTRAK

Penggunaan kuasa penukar elektronik telah digunakan secara meluas sejak ciptaan peranti. Tujuan utama termasuk menukarkan tenaga elektrik dari satu bentuk ke bentuk yang lain. Penukar buck adalah salah satu penukar kuasa elektronik biasa yang mengubah voltan yang tidak terkawal ke dalam voltan yang dikawal selia, dan menyediakan tahap voltan yang berbeza pada keluarannya. Namun, terdapat voltan pada paras berlebihan jika penukar buck beroperasi tanpa kawalan. Oleh itu, kaedah kawalan adalah dicadangkan supaya prestasi penukar buck boleh dipertingkatkan dan terlajak boleh dihapuskan, di samping meningkatkan kepentingan lain ciri-ciri, dengan mengambil kira dalaman dan gangguan luaran yang mungkin berlaku. Pengawal PID diubahsuai adalah dicadangkan untuk mengawal voltan output penukar buck. Dalam kajian ini, objektif utama adalah untuk membandingkan jawapan sistem antara konvensional PID, PI dan pengawal PID diubahsuai yang dicadangkan. Dengan itu, kaedah konvensional PID digunakan pertama untuk membandingkan ciri-ciri yang diberikan oleh penukar buck dengan menggunakan pengawal konvensional dan diubahsuai. Kaedah penalaan digunakan adalah penempatan sifar tiang dalam kaedah londar punca. Kaedah ini dipilih selepas model matematik penukar buck, voltan output dalam rangkap pindah berjaya diperolehi. Hasil kajian menunjukkan bahawa tidak kira dianggap sebagai konvensional, buck converter mencapai prestasi optimum dengan PID normal sebagai pengawalnya. Kesimpulannya, daripada analisis perbandingan, PID konvensional adalah lebih sesuai untuk menjadi pengawal untuk operasi buck converter berbanding dengan orang lain.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

NOMENCLATURE

IEEE	-	Institute of Electrical and Electronic Engineers
MATLAB	-	Matrix Laboratory
PD	-	Proportional-Derivative
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
PWM	-	Pulse Width Modulation

CHAPTER 1

INTRODUCTION

1.1 Research Background

The general purpose of power electronic converter is converting electrical energy from one form into another. The main aim includes enabling the electrical energy to reach the load in top efficiency. Besides, the usage of power electronic aids in reducing the size of the device to convert these energy, thus cutting the implementation cost. In this project, the power electronic device that has been used is a dc to dc converter. Dc to dc converter includes:

i. Buck
ii. Boost
iii. Buck-boost

Buck converter has been chosen to be used for this project. The buck converter converts an unregulated dc input into a controlled dc output within desired voltage value. Buck converter is also known as the step down converter. This is due to its circuit characteristic of steeping down the unregulated input voltage into a smaller output voltage. In this project, the buck will step down the input voltage 9 V_{dc} to 5 V_{dc} using switching frequency of 50kHz. The buck converter circuit is connected together with a controller in order to control the behaviours of the system in linear. This system is regarded as a close loop system with feedback. MATLAB Simulink software has been used to run all the simulations.

This project involves of mathematical modelling, simulation and analysis on stability and comparison.

1.2 Problem Statement

The output voltage (V_o) of buck alone is undeniably stable. Nevertheless, within seconds of the operation of the buck converter, the voltage value shows overshoot and a steady-state error. Moreover, other criteria that must be concerned includes the rise time and settling time in order to obtain the desired output in its peak efficiency. Let alone a dc-dc buck converter operates without a specific controller, the rise time is too long before it reaches the steady-state condition. The overshoot is high and the settling time is high due to the output oscillation that is too long. As for the steady-state error, sometimes the output of the buck converter alone does not reach the desired value that has been calculated mathematically.

1.3 Objectives

1.3.1 To propose a modified PID as a feedback control system to address issues of step-changes in reference and load for dc-dc buck converter

1.3.2 To compare the system's responses between the conventional PID, PI and the proposed modified PID controller

1.4 Scopes of Project

1.4.1 Literature review on dc-dc converters, PWM switching and feedback controllers

1.4.2 Obtain a mathematical model of dc-dc buck converter

1.4.3 Design and simulate the PWM switching pattern of dc-dc buck converter

1.4.4 Design and simulate the conventional PID, PI and the modified PID controllers

1.4.5 Analyse and compare the results of conventional PID, PI and modified PID controllers

1.5 Report Outline

The contents of the report is classified as follows:

Chapter 1 describes the overview of the entire project, research background, problem statement, objectives, scope and the expected outcome of the project.

Chapter 2 elaborates the literature review related to the project. This includes study of dc-dc converter, controllers, tuning method and limitations in tuning. Each of the facts and analysis is described based on comprehensive study in reference to various reliable materials and previous researches. The information collected includes from IEEE journals, articles, books and technical papers.

Chapter 3 explains the methodology of the project and covers the methods and procedures that have been used in carrying out the entire project. In this chapter, the Gantt Chart for the whole 2 semesters of duration that the project has been carried out is explained briefly.

Chapter 4 highlights the results obtained from all the simulations. Analysis for open-loop buck converter system, closed-loop system using conventional and modified PID are made. Also, the comparative analysis to justify the controller that suits best to enhance the performance of buck converter optimally. Discussions and deep analysis are done and noted.

Chapter 5 concludes the study achievement and proposed some recommendations for future references.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and basic principles

2.1.1 DC-DC Converter

In order to step down a voltage from one value to another, a transformer can always be used. But, a buck converter is more suitable to be used because of the ability of switching converter to provide isolation of noise, power bus regulation and so on. A dc-dc converter may change the voltage level into desired value depending on the value of resistance, inductance and capacitance in the circuit. Meaning, the desired voltage level can be obtained by manipulating the value of those criteria stated. In this project, the operation of the system need to be fully analysed.

2.1.2 PWM and Switching

In designing a buck converter, Pulse Width Modulation (PWM) plays an important role. Adjustment of output voltage cab be achieved by varying the duty cycle of the switch using PWM. Duty cycle is the ratio in a period in which power semiconductor is kept ON to the cycle period. Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is used for various purposes, which includes measurement, communications, power control and even conversion. Typically, an IC is necessary in order to control PWM for output regulation. The power supplied to the load is controlled via the transistor switch. For a power output above 50W, it is highly recommendable to use Power MOSFET instead of BJT. Therefore, selecting the transistor must be made wisely, considering all factors including ability to withstand the voltage spikes produced by the inductor and rapid switching times.

2.1.3 Feedback Control Systems

A feedback control system can be described as a system that retains a specified relationship between the output and reference input using comparison and use the differences as a mean of control method. For instance, a temperature control system in a room. The actual room temperature is measured and then compared with the reference temperature (desired temperature). Then, the thermostat switch between cooling or heating equipment on and off so that the temperature in the room reach its desired level, in spite of the outside conditions.

2.1.4 Closed-Loop Control System

Feedback control systems are often referred to as closed-loop control systems. The terms feedback control and closed-loop control are used interchangeably because of their significance. In a closed-loop system the actuating error signal, which is the difference between the input signal and the feedback signal (which may be the output signal itself or a function of the output signal and its derivatives and/or integrals), is fed to the controller so as to reduce the error and bring the output of the system to a desired value. The term closed-loop control always implies the use of feedback control action in order to reduce system error.

2.1.5 Open-Loop Control System

Open-loop control system can be interpreted as a system where the output is not subjected into any control method. In other words, the output value is not measured for comparison with any reference input or fed back in an open-loop control system. Washing machine can be a perfect example to elaborate open-loop control system. It involves soaking, washing and rinsing. All the operations are based on time. Hence, it is clear that the machine does not measure the output signal, which is, the cleanliness of the clothes.

Since in any open-loop control system the output is not compared with the reference input, to each reference input there corresponds a fixed operating conditions.

Hence, the accuracy of the system depends on calibration. However, in case any undesired noise or disturbance occur, an open-loop system will fail to perform its desired task. Practically, the open-loop system is highly recommendable when the relationship between the input and output are known and when there are no presence of internal or external disturbances. Clearly, such systems are not feedback control systems. Note that any control system that operates on a time basis is open loop.

2.1.6 Closed-Loop versus Open-Loop Control Systems

An advantage of the closed-loop control system is the fact that the use of feedback makes the system response relatively insensitive to external disturbances and internal variations in system parameters. It is thus possible to use relatively inaccurate and inexpensive components to obtain the accurate control of a given plant, whereas doing so is impossible in the open-loop case.

Taking stability as the point of view, it is easier to create an open-loop control system. This is due to system stability is not a major problem in an open-loop system. Meanwhile, it is a major problem in a closed-loop control system, which may tend to overcorrect errors and thereby can cause oscillations of constant or changing amplitudes.

It should be highlighted that, it is encouraged for systems in which the inputs are known early and in which there are no disturbances to use open-loop control. In a case where unpredictable disturbances or unpredictable variations in a certain system component might occur, then closed-loop control system is highly recommended to be implemented. Note that the output power rating partially determines the cost, weight and size of a control system. Closed-loop system that have been implemented in the same corresponding plant as open-loop system requires more components and thus, the closed-loop control system is basically higher in cost and power. As long as it is applicable onto the system, open-loop control system shall be used. A good open-loop and closed-loop controls combination will result in a reduction in cost as well as satisfactory performance of the system.

2.1.7 Proportional Integral Derivatives

A proportional-integral-derivative controller (PID controller) is a comprehensive control loop feedback mechanism widely used in industrial control systems. The operation of PID controller can be deemed simple yet powerful. First, the desired set point must be given. It will adjust the error between the measured process variable and the desired set point by calculating them and provides adjustment or corrective action. There are three separate parameters in the PID controller algorithm. Those are the Proportional, Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The process is then adjusted via a control element subjected to all those three total summation such as the position of a control valve or the power supply of a heating element. An accurate desired output responses that meets the process requirement can be achieved by properly 'tune' the three constants in the PID controller algorithm. PID controller can always be changed into a PI or PD controller, depending on the parameters of the PID algorithm used. Meaning, for a PI controller, proportional and integral terms are used with the absence of derivative value. PD controller is simply a PID without the integral value. Note that the PID stated is the conventional type, meaning, the architecture of all three algorithm parameters is shown as Figure 2.1. A modified PID is simply a PID controller with a modification in the architecture of the parameters.

2.1.7.1 Proportional term

The proportional term provides changes to the output that is proportional based on the error value. Proportional gain, Kp will be multiplied with the error so that the proportional response can be modified.

The proportional term is given by:

$$P_{out} = K_p e(t) \tag{2.1}$$

Where

- P_{out}: Proportional output
- K_p: Proportional Gain, a tuning parameter
- e: Error = SP – PV
- t: Time or instantaneous time (the present)
-

For a given change in error, a high proportional gain results in a large change in the output. However, if the proportional gain is too high, the system itself may become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. Meaning, extremely small proportional gain will not provide desired control action as it may be too small when responding to system disturbances.

In the absence of disturbances pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady-state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

2.1.7.2 Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i.

The integral term is given by:

$$I_{out} = K_i \int_0^t e(\tau)d\tau \qquad (2.2)$$

Where

- I_{out}: Integral output
- K_e: Integral Gain, a tuning parameter
- e: Error = SP − PV
- τ: Time in the past contributing to the integral response

The integral term speed up the movement of the process towards set point and eliminates the residual steady-state error that occurs with a proportional only controller. Meaning, in the case of buck converter, the integral term enables the output response to reach its rise time and settling time faster. But, since the integral term is responding to accumulated errors from the past, it can cause the present value to overshoot the set point value (cross over the set point and then create a deviation in the other direction). Section loop tuning further elaborates integral gain tuning and controller stability.

2.1.7.3 Derivative term

The derivative gain, K_d is defined as the magnitude of the contribution of the derivative term to the overall control action. The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d.

The derivative term is given by:

$$D_{out} = K_d \frac{de}{dt} \qquad (2.3)$$

Where

- D_{out}: Derivative output
- K_d: Derivative Gain, a tuning parameter
- e: Error = SP − PV
- t: Time or instantaneous time (the present)

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise in the signal and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

Figure 2.1 shows the implementation of a PID controller on a certain plant. The proportional, integral and derivatives terms are summed up together to feed the plant, based on the calculated error gained from the feedback.

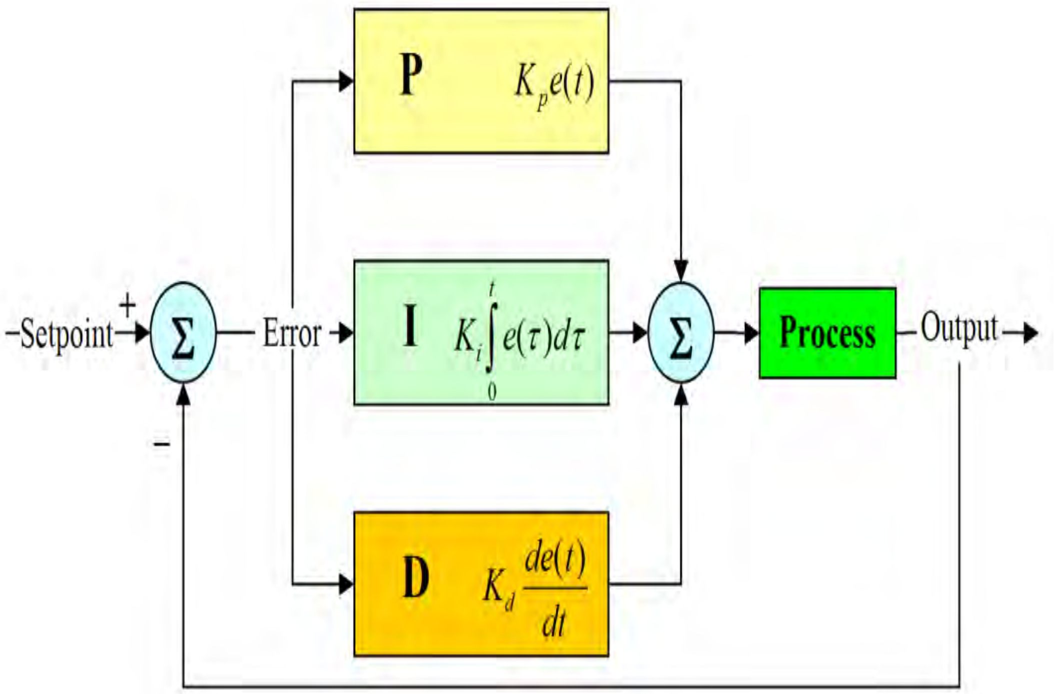

Figure 2.1: PID Controller Block Diagram

2.1.8 Tuning Method

Controller tuning is a very important step in a closed-loop control systems. In case of PID controller, all the proportional, integral and derivative gains parameters need to be choose wisely or else, the overall process might become unstable and further damages the system itself. To tune a control loop means to adjust all the controls parameters as stated, which are proportional, integral and derivative values accurately so that the desired control response can be obtained.

There are several indicators that need to be fulfilled before attempting to tune a controller. As for PID, these include overshoot, rise time, settling time and others. For example, in case a process with an overshoot would harm the entire device, then eliminating the overshoot comes as a priority and hence, the gains need to be adjusted accordingly. Another example might be process to minimize energy expended in reaching a new set point. In general, stability of response (the reverse of instability) is required and the process must not oscillate for any combination of process conditions and set points.

Some processes have a degree of non-linearity and so parameters that work well at full-load conditions do not work when the process is starting up from no-load. This section describes some traditional manual methods for loop tuning.

There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, and then choosing P, I, and D based on the dynamic model parameters. Poor tuning leads to unsatisfactory controller performance. Over the years, several tuning methods have been proposed; among the more prominent ones are the Ziegler-Nichols, Pole-placement and Frequency Response methods.

2.1.8.1 Ziegler-Nichols method

Even though the PID controller has been reportedly used in industry since the early 1900's, a systematic tuning strategy, was only proposed in the 1940's. The Ziegler-Nichols is the earliest tuning method introduced for the controller. Ziegler and Nichols suggested rules for tuning PID controllers (meaning to set values Kp, Ti and Td) based on experimental step responses or based on the value of K that results in marginal stability when only proportional control action is used. Ziegler-Nichols rules, which are briefly presented in the following, are useful when mathematical models of plants are not known. (These rules can, of course, be applied to the design of systems with known mathematical models.) Such rules suggest a set of values of K, Ti and Td, that will give a stable operation of the system. However, the resulting system may exhibit a large maximum overshoot in the step response, which is unacceptable. In such a case we need series of fine running until an acceptable result is obtained. In fact, the Ziegler-Nichols tuning rules give an educated guess for the parameter values and provide a starting point for fine tuning rather than giving the final settings for K Ti and Td in a single shot.

2.1.8.2 Pole-Placement Method

The pole-placement method has been used mostly for a low order system, i.e. system with two order or below. The approach is to adopt a general second-order model as in equation below and to specify a desired damping ratio, ς and natural frequency, ω for the system

$$s^2 + (2\varsigma\omega)\mathrm{s} + \omega^2 = 0 \tag{2.4}$$

Its K_p and K_i values with the specified damping ratio and natural frequency can be obtained by comparing equation above with the characteristics equation of the closed-loop system transfer function. For example, consider the first system with a transfer function of

$$G_{plant}(\mathrm{s}) = \frac{K}{1+sT} \tag{2.5}$$