VOLTAGE MODE CONTROL FOR BUCK CONVERTER

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ABSTRACT

This project is about the study, design and a practical implementation of voltage mode control of buck converter. Buck converter is a stepdown switch mode power supply where its output voltage is always less than the input voltage. UC3573 is used in this project as a PWM control IC where it provides pulse signal to the gate terminal of the MOSFET. The output voltage of buck converter is changed when there is changing in the input voltage and/or the load. To cater the problem, voltage mode control (VMC) scheme is applied in this project. This controller has a simple hardware implementation and flexibility. PSpice simulations are performed before hardware implementation. A prototype buck converter with voltage mode control is built on printed circuit board (PCB). The prototype buck converter maintains the output voltage when there is changing in the input voltage and/or the load.

ABSTRAK

Projek ini adalah mengenai reka bentuk dan pelaksanaan yang praktikal tentang kawalan mod voltan penukar buck. Penukar buck adalah bekalan kuasa mod suis stepdown di mana voltan keluaran adalah sentiasa kurang daripada voltan input. UC3573 digunakan dalam projek ini sebagai PWM kawalan IC di mana ia memberi isyarat denyut ke terminal get MOSFET. Voltan keluaran penukar buck berubah apabila terdapat perubahan dalam voltan input dan / atau beban. Untuk menampung masalah, kawalan mod voltan (VMC) skim digunakan dalam projek ini. Pengawal ini mempunyai pelaksanaan perkakasan yang mudah dan fleksibiliti. Simulasi Pspice dilakukan sebelum pelaksanaan perkakasan. Penukar buck prototaip dengan kawalan mod voltan yang dibina di atas papan litar bercetak (PCB). Prototaip penukar buck mengekalkan voltan output apabila terdapat perubahan dalam voltan input dan / atau beban.

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LIST OF ABBREVIATIONS

DC	Direct current
VMC	Voltage mode control
ESL	Effective Series Inductance
ESR	Equivalent series resistance
PWM	Pulse width modulator
PCB	Printed circuit board
CCM	Continuous current mode
IC	Integrated circuit
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
Vin	Input voltage
Vo	Output voltage
Vramp	Ramp voltage
Verror	Error voltage
Vswitch	Switch voltage
D	Duty cycle
Ts	Switching period
fs	Switching frequency

LIST OF SYMBOLS

%	Percentage
PCB	Printed Circuit Board
V	Volt
L	Inductor
C	Capacitor
R	Resistor
D	Duty Cycle
ΔV	Voltage Ripple
DC	Direct Current
f_S	Switching Frequency
i_L	Switch/Inductor Current
V_{ref}	Reference Voltage
ESR	Equivalent Series Resistance
PS	Power Supply
Po	Output Power
CCM	Continuous Conduction Mode

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CHAPTER 1

INTRODUCTION

1.1 Introduction

DC-DC converter is a power electronic circuit that changes one level of DC voltage to another level of DC voltage, normally with a regulated output. DC to DC converters are widely used in power supplies for electronic instruments and high power applications such as battery charging and dc motor driver. Basically, DC-DC converter is divided into two types of converter which are step-down converter that knows as buck converter and step-up converter also knows as boost converter. Meanwhile for the buck-boost converter, it can step-down or step-up the voltage, however the polarity for input and output voltage is opposite each other. For each type of DC-DC converter, it has its own properties including the steady state ratio between output voltage and input voltage, the input and output current, the frequency response of the duty cycle to output voltage transfer function and the character of the output voltage ripple.

To achieve design objectives for line and load regulation and dynamic response, an appropriate controller is applied to the DC-DC converter. The most common control scheme is voltage mode control (VMC) due to its most convenient method of controlling DC-DC converters. Buck converter works as a circuit to convert the unregulated dc voltage input, to a regulated output voltage where its output voltage is always less than the input voltage. However, the output voltage of buck converter is changed when there is a changing of the input voltage and/or the load. In designing DC-DC converter for the power converter, a tight output voltage regulation under different line and load conditions must be obtained in order to maintain the condition of the circuit.

1.2 Problem Statement

The main reason of studying and designing a buck converter power supply is to improve the efficiency of the desired output voltage and make all things about power supply become better since there are several problems that occur with the conventional power supply.

The common power supply usually lack of overall efficiency in maintaining desired output voltage. This is because most of the common designs uses linear regulator to control and supply power. Another drawback is the size of conventional power supply is bigger than switch-mode power supply. They are also quite difficult to be designed because it contains complicated integrated circuits (IC) and they also radiate more electromagnetic interference.

1.3 Objectives

The objectives of the project are:

i. To study the principle operation and characteristics of buck converter.
ii. To perform cicruit simulation using Pspice software.
iii. To develop a practical voltage mode control for buck converter based on simulation parameters and outcomes.

1.4 Scope of Project

The scopes of this project are as follows:

i. Design the closed-loop feedback of voltage mode control for buck converter.
ii. To apply Pspice simulation to obtain the satisfied results and develop hardware using PCB.

1.5 Thesis Outline

This thesis consists of five chapters. In Chapter 1, the explanation for the project will be given in a general term. The objectives of the project will be elaborated. It is followed by the scope of project.

In Chapter 2,describes the overview of the project elaborately. Explanation will be focused on thereotical and simulation design. Explanation will be based on theory and conceptual ideas. Some practical approach in this project will also be discussed.

In Chapter 3, hardware design is explained in detail under the methodology. All input parameters will be clearly stated. Each components used for this project will be discussed under this chapter.

In Chapter 4, the results for testing are discussed. The strengths and weakness of the voltage mode control for buck converter will be discussed.

Chapter 5 will be the conclusion of the project. The contents include the experience and the knowledge gained during accomplishing this project. Furthermore, a few recommendations will also be suggested. Improvement or future enhancement will be explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Switching Regulators in DC-DC Converters

Switching regulator is used widely in DC-DC conversion. It offer three main advantages compared to a traditional linear power supplies. First, switching efficiency can be much better than linear. Second, because less energy is lost in the transfer, smaller components and less thermal management are required [2]. Third, the energy stored by an inductor in a switching regulator can be transformed to output voltages that can be greater or smaller than the input. However, linear regulators provide lower noise and higher bandwidth; their simplicity can sometimes offer a less expensive solution. A switching regulator is a circuit that consists of power switch, an inductor, and a diode to transfer energy from input to output. It can be rearranged to form a step-down (buck), step-up (boost), or an inverter (flyback)[4]. The buck converter topology as shown in Figure 2.1 is used switching regulator as a switching power. In summary, because of its versatility, efficiency, size and cost, the switching regulator is preferred in most high power applications.

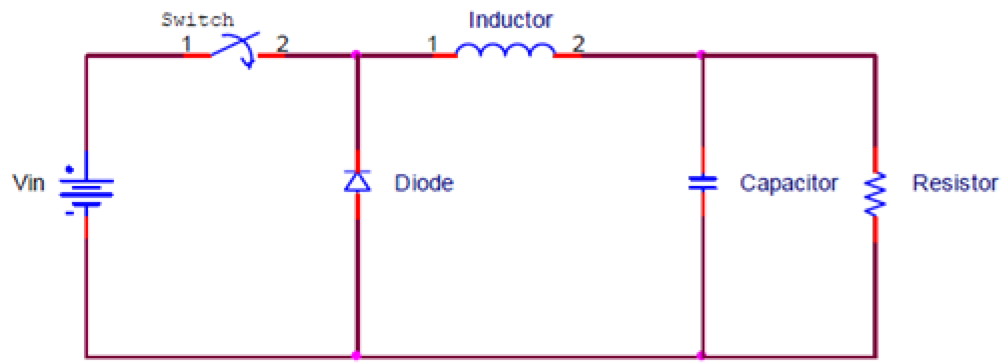

Figure 2.1: Buck Converter

2.2 The Buck Converter Topology

The buck converter or step-down switch mode power supplies can also known as a switch mode regulator. Popularity of a switch mode regulator is because of its fairly high efficiency and compact size and a switch mode regulator is used in place of a linear voltage regulator at relatively high output [5]. Linear voltage regulators tend to be inefficient. Since the power devices used in linear regulators have to fritter a fairly large amount of power, they have to be adequately cooled, by putting them on heat sinks and the heat is transferred from the heat sinks to the surrounding air either by natural convection or by forced-air cooling. Heat sinks and provision for cooling makes the regulator bulky and large. In applications where size and efficiency are critical, linear voltage regulators cannot be used.

The basic idea behind the buck converter is that by rapidly opening and closing the switch, short bursts of current are allowed to flow through the inductor to the load. Another feature to describe buck converter is the relationship between the dc input voltage Vin and the dc output voltage Vout [6]. The relationship is a simple function of the duty cycle of the switch. It is a simplest power stage topology that converts a higher input voltage to a lower output level. Figure 2.1 below show the basic buck converter circuit where Vs is input voltage, S is the swich, D is the diode, L is the inductor, C is the capacitor, RL is the load and Vo is output voltage.

Analysis of the buck converter begins by making these assumptions :

i. The circuit is operating in the steady state.

ii. The inductor current, iL is in continuous condition.

iii. The output voltage is held constant at voltage, Vo and the capacitor is very large.

iv. The switching period is T, meanwhile the switch's closed time is DT and open time is (1-T)DT.

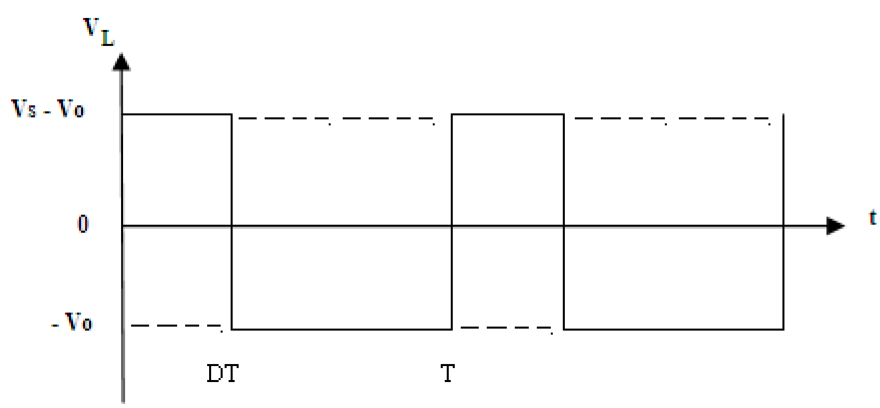

Figure 2.2 : Inductor's voltage waveform for Buck converter.[5]

When the switch closed,

$$(\Delta i_L)_{closed} = \left(\frac{Vs - Vo}{L}\right) DT \tag{2.1}$$

When the switch opened,

$$(\Delta i_L)_{opened} = -\left(\frac{Vo}{L}\right)(1\text{-}D)\, T \tag{2.2}$$

The net change in inductor current over one period is zero,

$$\therefore\ (\Delta i_L)_{closed} + (\Delta i_L)_{opened} = 0 \tag{2.3}$$

$$Vo = Vs\, D \tag{2.4}$$

Note that the average current must be the same as the average current in the load resistor. Thus, since the average capacitor current must be zero for steady- state operation:

$$I_L = I_R = \frac{Vo}{R} \tag{2.5}$$

The value (ΔiL) is referred to the (ΔiL) *opened* and the maximum value of the inductor current is

$$I\ max = I_L + \frac{\Delta iL}{2} = Vo\ \left[\frac{1}{R} - \frac{1-D}{2Lf}\right] \tag{2.6}$$

The minimum inductor current is,

$$I_{min} = I_L - \frac{\Delta iL}{2} = Vo \left[\frac{1}{R} + \frac{1-D}{2Lf} \right] \tag{2.7}$$

The voltage ripple is determined by,

$$\frac{\Delta Vo}{Vo} = \frac{1-D}{8LCf^2} \tag{2.8}$$

Figure 2.3 shows the inductor current waveform for the buck converter which is in continuous current mode. The value is always positive and greater than zero.

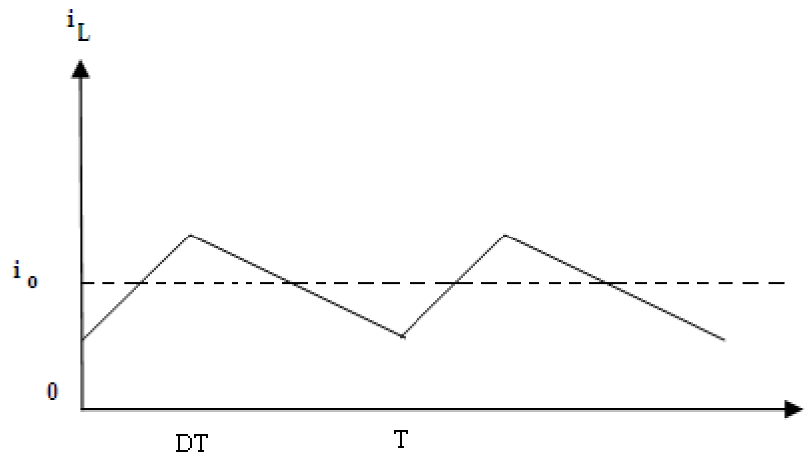

Figure 2.3 : Inductor’s current waveform for Buck converter.[5]

The average inductor current must be the same as the average current in the load resistor [2]. The capacitor current waveform was shown in figure 2.4.

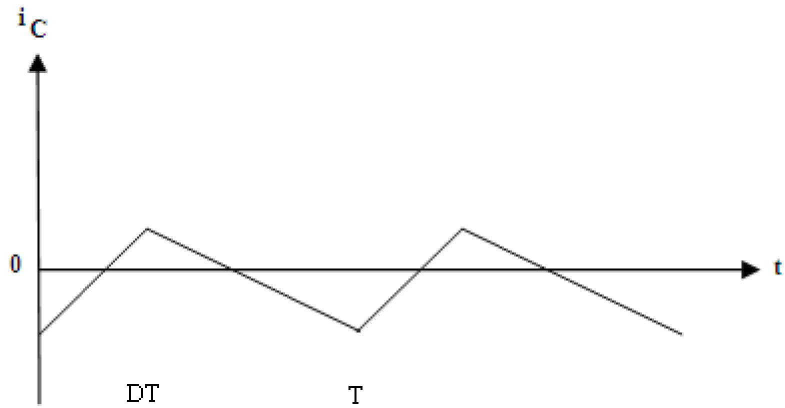

Figure 2.4 : Capacitor current waveform for Buck converter.[5]

2.3 Feedback and Control Circuitry Scheme

One of the key objectives in designing a controller for the power converter is to obtain tight output voltage regulation under varying load and input voltage condition. Feedback and control circuitry can be carefully nested around converter circuits to regulate the energy transfer and maintain a constant output within normal operating conditions. The implementation of feedback and control circuitry to the converter consists of two purposes which are to adjust the duty ratio to a required value in order to provide a fixed output and to ensure the stability where the power converter will return to the desired operating point after some disturbances are applied.

As shown in Figure 2.2, a power supply feedback loop can be interpreted in terms of small-signal linear equivalent gain blocks. The appended to certain gain blocks represents that the gain varies as a function of frequency. The open-loop gain, T, is defined as Equation 2.1 which is the total gain around the entire feedback loop:

$$T(s) = K_{EA} \cdot K_{MOD} \cdot K_{PWR} \cdot K_{LC} \cdot K_{FB} \quad (2.1)$$

Closed-loop gain, G, defines as Equation 2.2 where the output vs. control input relationship, with the loop closed:

$$G(s) = \frac{1}{K\ FB}\ \frac{T}{1+T} \quad (2.2)$$

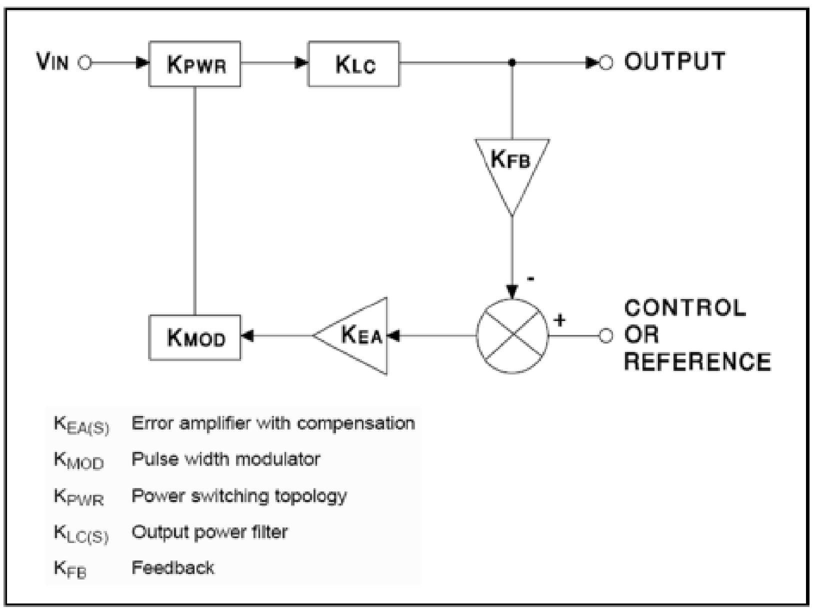

Figure 2.5 : Feedback Control Loop [6]

Open-loop gain T is normally very much greater than 1 when it is at low frequencies so that closed-loop gain G approaches the ideal 1/KFB. At higher frequencies, mostly because of the low-pass filter characteristic KLC(S), T will be decreased. The frequency where T has decreases to 1 (0dB) is indicated as the crossover frequency, fC. In a power supply voltage control loop, G(s) represents the power supply output vs. the reference voltage. KFB is normally a simple voltage divider. For example, if VREF is 2.5V, a 2:1 divider (KFB = 0.5, G = 2) as the results VOUT = 5Volts.

2.3.1 Voltage Mode Control

The key feature of this control is the existence of a feedback loop which keeps track of the output voltage variation and adjusts the duty cycle. Furthermore, in this control scheme, the difference between the output voltage vc, and a reference signal, vref, is processed by a compensation network which generates a control signal, vcon[1]. This control signal tells how the duty cycle has to be changed in order to give the best transient dynamics for the desired output. This control signal is compared with a periodic ramp signal, Vramp(t), to generate a pulse width modulated signal which drives the switch.

In the voltage mode control scheme, the converter output voltage is sensed and subtracted from an external reference voltage in an error amplifier. Then the error amplifier produces a control voltage that is compared to a constant amplitude saw tooth waveform. After that the comparator produces a PWM signal that is fed to drives of controllable switches in the dc – dc converter. Furthermore the frequency of the PWM signal is the same as the frequency of the saw tooth waveform. The advantage of this scheme is simple hardware implementation and flexibility[3].