DESIGN A SWITCH MODE POWER SUPPLY USING DISCONTINUOUS MODE OF BUCK-BOOST TOPOLOGY

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MEI 2007

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"I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronic and Drive)"

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This report is submitted in partial fulfillment of the requirements for the Bachelor of Electrical Engineering (Power Electronic and Drive)

FACULTY OF ELECTRICAL ENGINEERING
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APRIL 2007

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"I here by declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references."

Signature :..

Name : MARSHALL LANGI TANYIT NASIP

Date : 16 APRIL 2007

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DEDICATION

To my beloved family, girlfriend and friends.

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ABSTRACT

Switch Mode Power Supply (SMPS) is a common product used in the electronic industries. This project is about the switching mode power supply using discontinuous mode buck-boost converter topology. Basically, SMPS design is a very interesting to learn, where the switching and duty cycle can determine the output of it result. SMPS is also a common item that can be found in the electronic market. Mostly all the electronic gadget is accompany with an SMPS. This is where show that the SMPS have gap differences with the linear power supply. For example: Laptop, hand phone charger, computer and many more. As the electronic industries grower larger in Malaysia, it is a suitable the project to be done during the PSM 1. In the future may be the SMPS size and efficiencies will incredibly increase. In this project we need to design a buck –boost converter that able to make the result of step up and step down voltage of 12V to 5V and 24V. From here we need to determine each of the components that will effect the whole circuit duty cycle, and to make sure the circuit always in discontinuous mode.

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ABSTRAK

"Switch Mode Power Supply (SMPS)" merupakan satu komponen yang biasa digunakan dalam bidag industri elektronik pada masa kini. Projek ini mengisahkan tentang penggunaan teori "buck-boost" dalam SMPS. Di sini teknik sius dalam satu kitaran adalah amat dititik beratkan, kerana ia dapat menentukkan hasil yang dikelurkan daripada SMPS. Selain itu, penggunaan SMPS juga boleh didapati di mana-mana saja pada zaman sekarang. Iaitu penggunaannya yang semakin meluas dalam barang-barang elektronik jika hendak dibandingkan dengan "linear power supply". Contohnya: : "Laptop", pengecas telefon bimbit, komputer dan sebagainya. Disebabkan perkembangan dalam sector industri elektronik yang semakin pesat di Malaysia, adalah begitu sesuainya projek ini dilaksanakan semasa projek sarjana muda. Pada masa akan datang, adalah tidak hairanlah jika saiz dan efisiensinya boleh diperkembangkan lagi. Dalam PSM ini saya perlu menghasilkan sebual "buck-boost converter" yang berkeupayaan untuk menaikkan voltan dan sertan menurunkan voltan berpenca daripada 12V kepada 5V dan 24V sebagai keputusannya. Saya juga harus memastikan bahawa kesemua komponent yang digunakan dapat membantu dalam menjayakan projek ini.

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LIST OF ABBREVIATION

PSM	-	Projek Sarjana Muda
PWM	-	Pulse Width Modulated
SMPS	-	Switch Mode Power Supply
V_{in}	-	Input Voltage
V_{out}	-	Output Voltage
R_{load}	-	Load Resistance
f	-	Frequency
r	-	Voltage Ripple
I_{out}	-	Output Current
T	-	Period
D	-	Duty Cycle
$I_{L_{MAX}}$	-	Maximum Inductor Current
C	-	Capacitor
L	-	Inductor

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CHAPTER 1

INTRODUCTION

1.1 Project Objective

These are my project objective during my PSM:

i. To design high efficiencies Switch Mode Power Supply (SMPS) using a discontinuous mood of Buck-Boost topology.

ii. To increase a 12Vdc to 5Vdc and 24Vdc.

iii. To provide a compatible calculation to each component in this SMPS.

iv. Enable the capability to knowing the different parameters in the simulation and hand calculation for this SMPS.

1.2 Project Scope

These are the scope which I will be cover during PSM:

i. To fully understand the selected topology before starting the project.

ii. Find the related reference to help the progress in understand the topology

iii. Design the compatible calculation for all the components in this related topology.

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iv. Doing simulations until find the satisfied result and answer for the SMPS.

1.3 Problem Statement

During this project, there are few problem will occur, which we must take note that the MOSFET are being use will create a high voltage ripple. Beside that detecting the error and to refine this problem will take some of our time to producing a better result during the simulation. By selecting a wrong type of diode also will greatly effect the circuit operation, while doing the simulation we are advice using an ideal diode.

While attempting to get the final result, the PWM unable to give a desire duty cycle which lead to the failure of boost up 12V to 24V. At here understand of choosing a correct PWM design will show the different in attempting the desire result.

1.4 Methodology

Achieving the objective of this project and answering the problematic as mentioned in the previous chapter, the following methodology are going to be carried out in this project:

1. Process of studies (literature study);

2. Process analysis; and

3. Process evaluation (adjustment).

Literature studies are done for the purpose of learning about the operation characteristics and also the function of each part of the circuit. In the literature study, determination will be done by understanding the problem statement based on the project objectives.

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CHAPTER 2

LITERATURE REVIEW

2.1 Project Background

This project summary is about designing a switch mode power supply using a discontinuous buck-boost converter topology. By using this type of converter topology I need to decrease and increase a 12V voltage to 5V and 24V voltage. At here we need to take note of the important threat about the duty cycles for the get drive to provide approximates pulse towards the MOSFET switching. Besides that, calculation of inductor and capacitor will also play the important role to determine the correct output. Without the correct component apply towards this project will lead to a failure in the hardware implementation.

2.2 Theory

2.2.1 Theory of DC-DC Converter

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries. Such electronic devices often contain several sub circuits which each require unique voltage levels different from those supplied by the battery additionally, the battery voltage declines as its stored power is drained. DC to DC converters offer a method of generating multiple controlled voltages from a single variable battery voltage, thereby saving space instead of using multiple batteries to supply different parts of the device.

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Electronic switch-mode DC to DC converters are available to convert one DC voltage level to another. These circuits, very similar to a switched-mode power supply, generally perform the conversion by applying a DC voltage across an inductor or transformer for a period of time which causes current to flow through it and store energy magnetically, then switching this voltage off and causing the stored energy to be transferred to the voltage output in a controlled manner. By adjusting the ratio of on/off time, the output voltage can be regulated even as the current demand changes. This conversion method is more power efficient than linear voltage conversion which must dissipate unwanted power. This efficiency is beneficial to increasing the running time of battery operated devices. A drawback to switching converters is the electronic noise they generate at high frequencies, which must sometimes be filtered.

Isolated DC-DC converters convert a DC input power source to a DC output power while maintaining isolation between the input and the output, generally allowing differences in the input-output ground potentials in the range of hundreds or thousands of volts. They can be an exception to the definition of DC-DC converters in that their output voltage is often the same as the input voltage.

A current-output DC-DC converter accepts a DC power input, and produces as its output a constant current, while the output voltage depends on the impedance of the load. The various topologies of the DC to DC converter are shown in Table 2.1:

Table 2.1: Comparison for DC-DC Converter Capabilities.

TOPOLOGY	POWER RANGE (W)	Vin RANGE	IN/OUT ISOLATION	TYPICAL EFFICIENCY (%)	RELATIF PART COST
BUCK	0-1000	5-40	NO	78	1.0
BOOST	0-150	5-40	NO	80	1.0
BUCK-BOOST	0-150	5-40	NO	80	1.0
IT FORWARD	0-150	5-500	YES	78	1.4

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FLYBACK	0-150	5-500	YES	80	1.2
PUSH-PULL	100-1000	50-1000	YES	75	2.0
HALF-BRIDGE	100-500	50-1000	YES	75	2.2
FULL-BRIDGE	400-2000+	50-1000	YES	73	2.5

2.2.2 Theory of Buck-Boost Toppology

The buck-boost converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is a switch mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. Also, the polarity of the output voltage is opposite the input voltage.

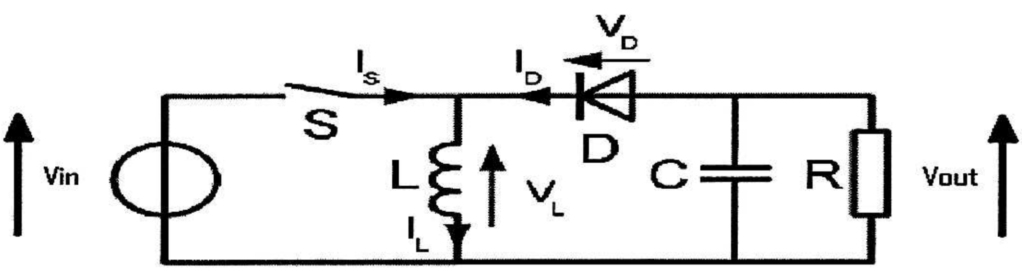

Figure 2.1: Basic diagram of buck boost topology.

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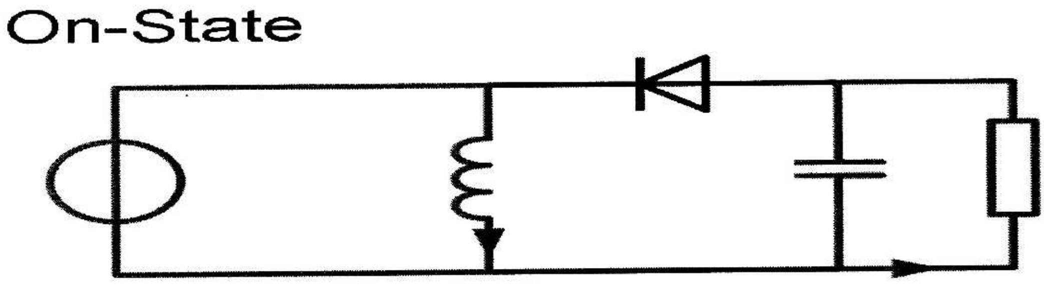

Figure 2.2: Basic diagram of buck boost topology during On-State.

While in the On-state, the input voltage source is directly connected to the inductor (L). This will result an accumulating energy in L. In this stage, the capacitor supplies energy to the output load.

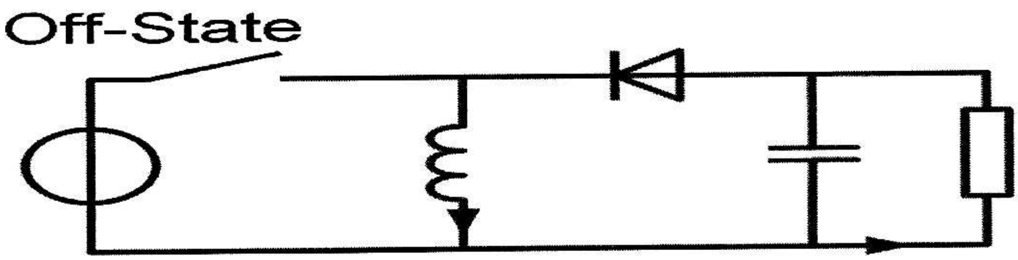

Figure 2.3: Basic diagram of buck boost topology during Off-State.

While in the Off-state, the inductor is connected to the output load and capacitor, so energy is transferred from L to C and R.

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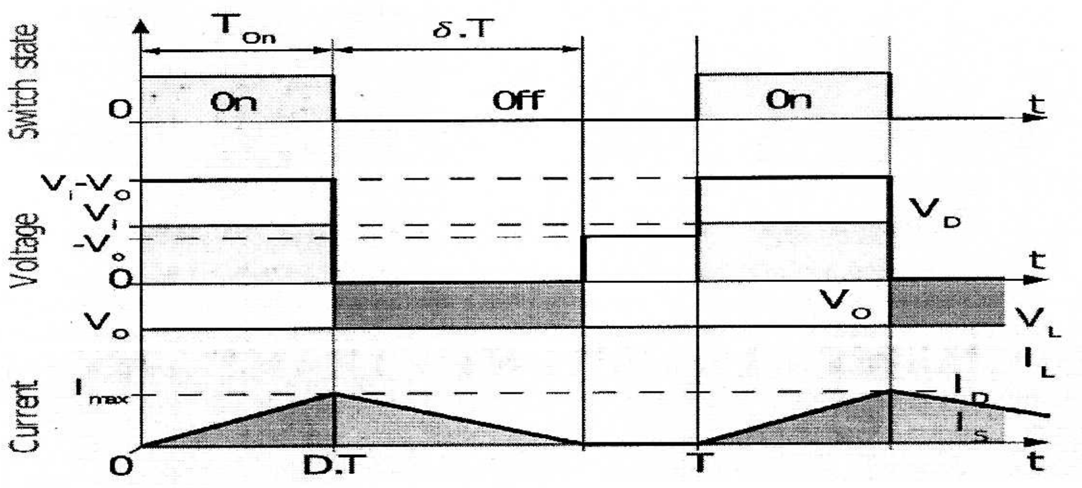

Figure 2.4: Expected result for buck-boost discontinuous mode graph.

In discontinuous mode, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle. Although slight, the difference has a strong effect on the output voltage equation if compare to continuous mode. The values are calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{MAX}}$ (at t=D.T) is

$$I_{L_{MAX}} = \frac{V_{in}.D.T}{L} \tag{2.1}$$

During the off-period, I_L falls to zero after δ.T:

$$I_{L_{MAX}} + \frac{-V_{in}.D.T}{L} = 0 \tag{2.2}$$

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Using the two previous equations, δ is:

$$\delta = \frac{V_{in}.D}{V_{out}} \tag{2.3}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on circuit diagram, the diode current is equal to the inductor current during the off-state. Therefore, the output current can be written as:

$$I_{out} = \frac{I_{L_{MAX}}}{2}.\delta \tag{2.4}$$

Therefore, the output voltage gain can be written as:

$$\frac{V_{out}}{V_{in}} = \frac{V_{in}.D^2.T}{2L.I_{out}} \tag{2.5}$$

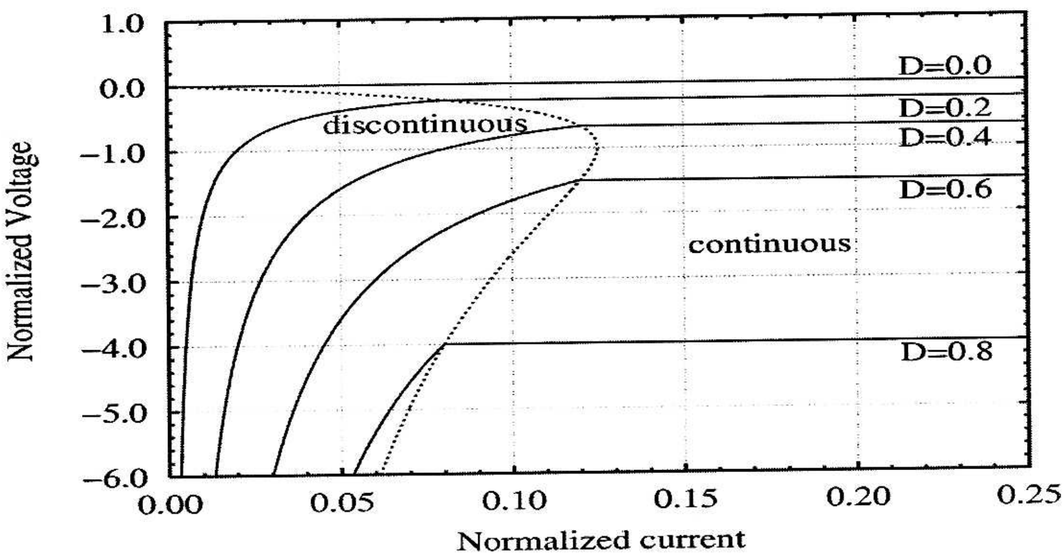

Figure 2.5: Differences in duty cycle for the buck boost topology.

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2.2.3 Component Selection

As we know, every component selection is very important to determine the outcome of buck-boost converter. The electrical requirements and applied stresses are given for each power stage component. The completed power supply, made up of a power stage and a control circuit, usually must meet a set of minimum performance requirements. This set of requirements is usually referred to as the power supply specification. Many times, the power supply specification determines individual component requirements.

2.2.3.1 Switching

In switching power supply power stages, the function of the power switch is to control the flow of energy from the input power source to the output voltage. In a buck-boost power stage, the power switch connects the input to the inductor when the switch is turned on and disconnects when the switch is off. The power switch must conduct the current in the output inductor while on and block the difference between the input voltage and output voltage when off. Also, the power switch must change from one state to the other quickly in order to avoid excessive power dissipation during the switching transition. The type of power switch considered in this report is a power MOSFET. Other power devices are available but in most instances, the MOSFET is the best choice in terms of cost and performance. The two types of MOSFET available for use are the n-channel and the p-channel. P-channel MOSFET is popular for use in buck-boost power stages because driving the gate is simpler than the gate drive required for an n-channel MOSFET.

2.2.3.2 Capacitance

In switching power supply power stages, the output capacitance stores energy in the electric field due to the voltage applied. Thus, qualitatively, the function of a capacitor is

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to attempt to maintain a constant voltage. The value of output capacitance of a buck-boost power stage is generally selected to limit output voltage ripple to the level required by the specification. The series impedance of the capacitor and the power stage output current determine the output voltage ripple. The three elements of the capacitor that contribute to its impedance (and output voltage ripple) are equivalent series resistance (ESR), equivalent series inductance (ESL), and capacitance(C).The following gives guidelines for output capacitor selection.

In discontinuous inductor current mode operation, to determine the amount of capacitance needed, the following equation is used, assuming all the output voltage ripple is due to the capacitor's capacitance.

$$C \geq \frac{I_{MAX} \times (1 - \sqrt{\frac{2 \times L}{R \times T_S}}}{f \times V_{OUT}} \qquad (2.6)$$

However, in many practical designs, to get the required ESR, a capacitor with much more capacitance than is needed must be selected. Beside that, assuming there is enough capacitance such that the ripple due to the capacitance can be ignored, the ESR needed to limit the ripple to output voltage as simply:

$$ESR \leq \frac{V_{OUT}}{I_L} \qquad (2.7)$$

Ripple current flowing through a capacitor's ESR causes power dissipation in the capacitor. This power dissipation causes a temperature increase internal to the capacitor. Excessive temperature can seriously shorten the expected life of a capacitor. Capacitors have rippled current ratings that are dependent on ambient temperature and should not be exceeded.

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2.2.3.3 Inductance

In switching power supply power stages, the function of inductors is to store energy. The energy is stored in their magnetic field due to the current flowing. Thus, qualitatively, the function of an inductor is usually to attempt to maintain a constant current or equivalently to limit the rate of change of current flow. The value of output inductance of a buck-boost power stage is generally selected to limit the peak-to-peak ripple current flowing in it. In doing so, the power stage's mode of operation, continuous or discontinuous, is determined. The inductor ripple current is directly proportional to the applied voltage and the time that the voltage is applied, and it is inversely proportional to its inductance.

In addition to the inductance, other important factors to be considered when selecting the inductor are its maximum dc or peak current and maximum operating frequency. Using the inductor within its dc current rating is important to insure that it does not overheat or saturate. Operating the inductor at less than its maximum frequency rating insures that the maximum core loss is not exceeded, resulting in overheating or saturation. Current flowing through an inductor causes power dissipation due to the inductor's dc resistance; this power dissipation is easily calculated. Power is also dissipated in the inductor's core due to the flux swing. Occasionally, the inductor's maximum operating frequency and applied volt-seconds ratings give the guidance regarding core loss. The power dissipation causes a temperature increase in the inductor. Excessive temperature can cause degradation in the insulation of the winding and cause increased core loss. Care should be exercised to insure all the inductor's maximum ratings are not exceeded. The inductor power losses are given:

$$P_L = (I_L) \times R_{winding} + P_{CORE} \qquad (2.8)$$

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