DESIGN AND DEVELOPMENT OF CURRENT MODE AC/DC SWITCHING POWER SUPPY

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Bachelor of Electrical Engineering
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"I hereby declare that I have read through this report entitle "Design and Development of Current Mode AC/DC Switching Power Supply" 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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A report submitted in partial fulfillment of the requirements for the degree of Electrical Engineering (Power Electronic and Drive)

Faculty of Electrical Engineering

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2012

I declare that this report entitle “Design and Development of Current Mode AC/DC Switching Power Supply” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………………………….

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~To my beloved mother and father~

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ABSTACT

Nowadays, power electronics plays a very meaningful role in many branches and sectors such as industrial, household applications and etc. The implementation of converters used in very wide function such as power supply, control systems and etc. Flyback converter is used widely and comprehensively in power supplies for modern equipment such as notebooks, printers, computer's monitors and also in household appliance due to its compactness and cost effectiveness. Basically, in general AC/DC adapter or power supply has evolved around the flyback topology especially for the low output voltage power supply. Therefore, for flyback converter to achieve the desired systems performance, optimization issues for the design requirement in next generation of portable electronics systems such as efficiency, cost and size need to be highlighted. This power supply is designed using current mode control of switching power supply by implementing flyback topology. The single stage AC/DC current-mode controlled flyback converter is designed with the present of optocoupler feedback implementing from the output voltage of the power supply. This power supply has been implemented well and the results shown that the output voltage of the power supply is maintained at desired value with the variation of input voltage.

ABSTRAK

Pada masa kini, elektronik kuasa memainkan peranan yang amat bermakna dalam banyak cawangan dan sektor seperti perindustrian, aplikasi rumah dan sebagainya. Penggunaan pengubah elektronik kuasa digunakan dalam fungsi yang sangat luas seperti bekalan kuasa, sistem kawalan dan sebagainya. Pengubah "*flyback*" digunakan dengan secara meluas dan menyeluruh dalam sektor bekalan kuasa untuk peralatan moden seperti komputer riba, pencetak, monitor komputer dan juga di dalam perkakas isi rumah kerana kecil dari segi saiz dan keberkesanan kosnya. Pada asasnya, penyuai arus ulang-alik/arus terus atau bekalan kuasa telah berkembang sekitar topologi "*flyback*" terutamanya bagi bekalan kuasa voltan keluar yang rendah. Oleh itu, bagi penukar "*flyback*" untuk mencapai prestasi sistem yang diingini, isu-isu pengoptimuman untuk keperluan reka bentuk dalam generasi akan datang sistem elektronik mudah alih seperti kecekapan, kos dan saiz perlu diketengahkan. Bekalan kuasa ini direka menggunakan kawalan mod semasa pengsuisan bekalan kuasa dengan melaksanakan topologi "*flyback".* Satu peringkat semasa penyuai arus ulang-alik/arus terus dengan mod kawalan penukar "*flyback*" direka dengan kehadir optocoupler yang menghantar maklum balas daripada voltan keluaran bekalan kuasa.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

AC	–	Alternating Current
DC	–	Direct Current
k_{cu}	–	Copper Fill Factor
μ_e	–	Effective Relative Permeability of Compound Core
DCM	–	Discontinuous Current Mode
PWM	–	Pulse Width Modulator
l_e	–	Effective Length
i_m	–	Magnetizing Current

CHAPTER 1

INTRODUCTION

1.1 Project Background

Nowadays, the new era of power systems have emerged and been broadly applied which provide power supply to different kind of loads, which is important to the coexistence of different voltage levels in the same system. Current mode switching power supply is one of the most popular types of power supply that can provide a steady, accurate and constant output source according to the loads requirements.

AC/DC current-mode switching power supply that implementing in flyback converter is widely used in off line power supplies for modern office equipments such as laptops, printers, and etc, this due to its high power density and high efficiency as well as cost effectiveness, compactness, and light weight [1]. The main use of these power systems is to regulate output voltage and current according to the loads specifications.

The switching power supplies have progressively replaced the linear power supplies in most application of power supplies [4]. Despite, it can achieve a large power density and high efficiency, high cost is still a main problem for not being broadly utilized [4]. Therefore, production cost of a switching power converter is one of the main factors in power supplies industry. Hence, simplicity is the most important criterion in order to choose a suitable power supply topology.

In flyback converter application, a peak current-mode control is usually used by implementing error amplifier configured to work with an optocoupler which then provides and isolated control signal feedback to the current-mode control stage [8]. The regulated output voltage then can be controlled by comparing the output signal and reference signal and change the duty cycle of gate signal accordingly if any error detected.

1.2 Problem Statement

The increasing of the acquisition price of the power supply adapter and the difficulties in getting the right kind of adapter according to the system requirement drives to create new structures of static converter by using flyback topology. The flyback topology is used because it is one of the simplest topology with the lowest component in it power circuit that can leads to reduce its overall manufacturing cost and light weight.

Regarding to the power supply adapter in the markets, the most significant trends in it design requirements are related to input output voltages, power ratings, constant power loads, power factor correction and etc. Therefore, to satisfy all the requirements needed by a certain loads such as adapter for electrical appliances leads to produce and improve a new AC/DC power supply based on the switching-mode control that can steadily maintain the output voltage following variation of the load.

1.2 Objectives

The main purpose of this project is to create and produce a current-mode AC/DC switching power supply. The project is aimed to meet the following objectives:

1) To design and development of Current Mode AC/DC switching power supply using flyback topology.
2) To design and produce a flyback transformer.
3) Propose a draft of AC/DC converter that can be applied for specific purposes such as power supply adapter (electrical appliances).

1.4 Project Scope

The project scopes as below:

1) The designed converter is based on the 18V and 100W output requirement.
2) Current mode switching power supply with output voltage feedback and implementing an optocoupler, which provides an isolated control signal to a current-mode control stage.
3) Current mode AC/DC power supply designed to operate in discontinuous current mode (DCM) state and using single switching metal–oxide semiconductor field-effect transistor (MOSFET).

CHAPTER 2

LITERATURE REVIEW

2.1 Switching Mode Power Supply

2.1.1 Introduction

Currently, the switching mode power supplies have been becoming more and more popular compared to the linear power supplies [1]. It is widely used in electric systems such as computers, televisions, electrical parts, etc. Switching mode power supply is a part where its use is very important, followed by the difficulties that have to go through to produce it. Basically, it is a part that provides power supply to the load from the mains power supply according to the criteria required by the load. This is to ensure that the criteria required by the load in accordance to the supplied feeding it.

Even though the switching mode power supply technology was previously well known, it started being widely used as a replacement to linear power supply only in the early 1960s when suitable semiconductors with reasonable performance and cost became available [2].

AC/DC switched mode power supply is used to convert the AC supply input voltage to a DC voltage. Basically the process is to convert the unregulated input AC voltage to regulated DC voltage by using the process of smoothing, clamping, rectification and filtration. The input voltage is first rectified by using the combination of diodes, normally by h-bridge diode, and then the rectified voltage is filtered with the input capacitor. The rectified dc voltage across the capacitor is then fed to a dc-to-dc converter.

Regarding to efficiency and effectiveness, switching mode power supply has been created by using relatively low-loss components such as diodes, capacitors, switches, transformers and inductors and in the same time minimizes the use of lossy components such as resistors. The primary objective of this system is to control the switches so that the desired voltage and current supplied to the load are obtained.

2.1.2 Basic Concept of Switching-Mode Power Supply

Basically, the main concept of switching mode power supply is by the understanding the power conversion of a certain voltage denoted by V_{ON} is applied during the switch turn-on time denoted by t_{ON} . Hence, by the same concept, a certain voltage denoted by V_{OFF}will automatically get during the switch turn-off time denoted by t_{OFF} [1]. With the same analysis in both side time interval t_{ON} and t_{OFF}, it leads to linear current segments. Therefore, a steady-state in switching power conversion can be defined as:

$$\Delta P_{IN} = \Delta P_{OUT} \tag{2.1}$$

This equality implies that the power at the end of the given switching cycle returns to the exact instantaneous value that it had at the start of the same cycle, every cycle [1]. Therefore, the entire current (and voltage) pattern becomes repetitive, and the operation is in that sense 'steady' [2]. Thus it basically means:

$$V_{on} \times t_{ON} = V_{OFF} \times t_{OFF} \tag{2.2}$$

Where the product of the applied voltage and the time duration of switching cycle it is applied for is called Voltseconds Laws [1].

2.2 Flyback Converter Topologies

2.2.1 Introduction

Due to the its high efficiency, high power density, the switching power supply such as flyback converter is becoming more popular over the linear power supply. Due to the highly development in semiconductor technology, the development trend to obtained compact size, high efficiency, light weight for a power converter can be easily reached [4].

The flyback form is the basis of most low power off-line converter. However, it is often underestimated due to its complexity [1]. By some points, the flyback converter can play important roles in reducing some disadvantages of linear power supply and gradually replaced the linear converter in most application of power supplies [4].

2.2.2 The Fundamental of Flyback Converter

Among the currently-existing transformer-coupled switching-mode converters, the flyback converter is the simplest topology, since no choke is required, only one power switch is used and the high-frequency power transformer with unfiled windings is employed [5]. Basically a basic flyback converter consists of a transformer, power diode, switching-MOSFET, and a PWM controller as shows in Figure 2.1 [4].

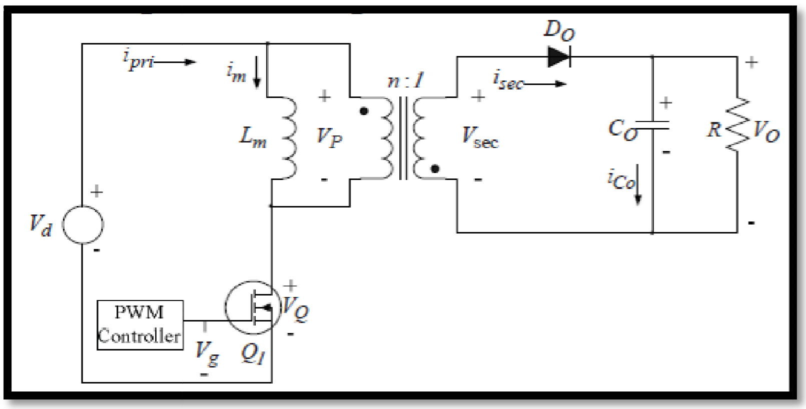

Figure 2.1: The Flyback Converter

The fundamental of flyback converter can be described as same as isolated buck boost converter. By using the equivalent model of buck boost model, the flyback converter design can be simplified by including the magnetizing inductance L_m, into the buck boost converter analysis. By referring to the figure 1, the symbol of transformer is used to represent the two-winding of inductor that often also called as flyback transformer [4]. The flyback transformer in the flyback converter acted as coupling inductor for energy conversion but not for voltage transform [4] as conventional transformer.

In the equivalent buck boost models, the voltage across the primary winding scales according to the ratio $^{n_s}/_{n_p}$ to become the voltage across the secondary winding [1]. To get the voltage in secondary winding due to the primary winding, the voltage in secondary winding need to multiple by the ratio of $^{n_s}/_{n_p}$ as it scales on to the primary winding side.

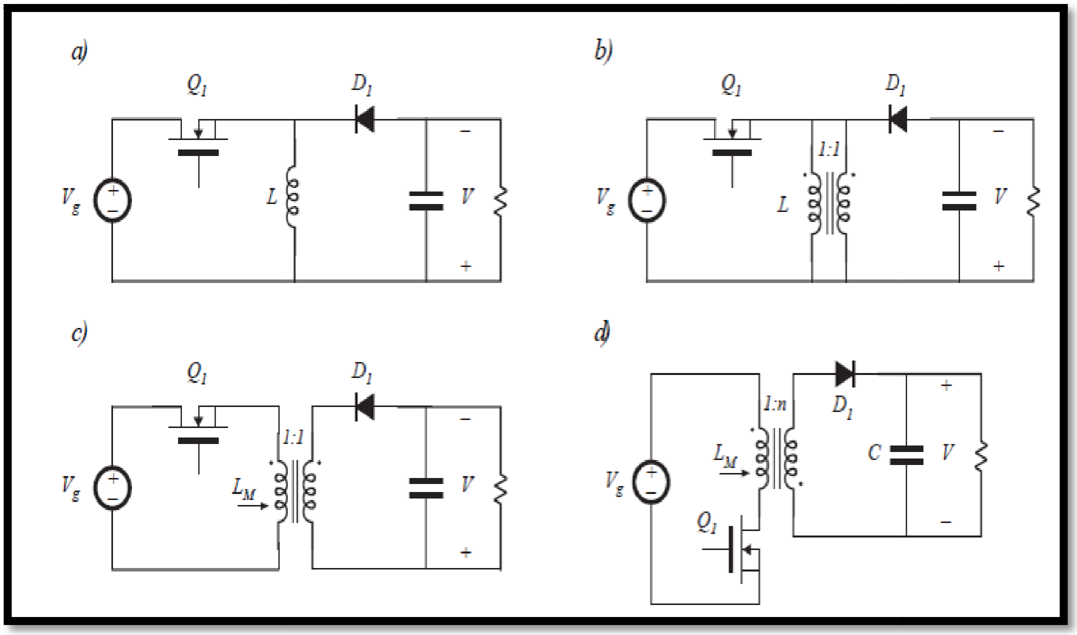

Figure 2.2: Flyback Converter with equivalent Buck-boost model

By understanding that the V_o is the voltage across the secondary winding when switch is turn-on, we can get a reflected voltage, designated V_{OR} on the primary side. Means that, $V_{OR} = V_o \times {}^{n_p}/_{n_s}$ and in the same time $V_{INR} = V_{IN} \times {}^{n_S}/_{n_P}$ by transformer scaling rule [1].

The rest of the calculation derivation is given as follows:

1) The peak of the primary side current, I_{PK} :

$$I_{PK} = I_{PKS} \times {}^{n_s}/_{n_p} \tag{2.3}$$

2) The load current reflected to the primary output current, I_{OR}:

$$I_{OR} = I_O \times {}^{n_s}/_{n_p} \tag{2.4}$$

3) If losses are ignored,

$$P_{IN} = V_{IN}I_{IN} = P_O = V_O I_O = V_{OR}I_{OR} \tag{2.5}$$

4) The duty cycle for flyback converter, D:

$$D = \frac{V_{OR}}{V_{IN}+V_{OR}} \equiv \frac{V_O}{V_{INR}+V_O} \tag{2.6}$$

5) If it is included with the switch and diode drops, the duty cycle for flyback converter, D:

$$D = \frac{V_{OR} + V_{DR}}{V_{IN} + V_{OR} + V_{SW} + V_{DR}} \equiv \frac{V_O + V_D}{V_{INR} + V_O + V_{SWR} + V_D} \qquad (2.7)$$

2.2.3 Operating Modes of Flyback Converter Topology

In the flyback converter topology, there are two distinctly different operating modes, which are the discontinuous operating modes and the continuous operating modes. The waveform, performance, and the transfer functions are quite different for two modes [2]. The main parameters that determine the mode of operation of flyback converter topology are the value of load current and primary inductance [2].

In this project, the discontinuous mode operation is used. In this operating mode, during the switch turn-on, a fixed voltage across the primary winding and current in winding will ramp up linearly at the rate of $\frac{dI}{dt} = (V_{DC} - 1)/L_p$ where L_p is the primary magnetizing inductance [2].

When the switch in off state, the current operates in reverse polarity on all winding and this condition usually called "flyback action". The current start to ramp down until zero before the next cycle of switch (next switch turn-on), all the energy stored in primary winding has been delivered to the load and the system is said to be operating in the discontinuous mode [2].

2.2.4 Flyback Converter disadvantages:

Despite many advantages in flyback converter, it has a certain drawbacks that lead to it disadvantages. The two main disadvantages of flyback converter are the large output voltages spikes, large output filter capacitor ad high ripple current requirement.

2.2.4.1 Large Output Voltage Spikes

In most cases in flyback topology, output voltages are much lower than input voltage, resulting in a large $\frac{N_P}{N_S}$ ratio and leads to large secondary current [2]. During the turn-off state, the secondary current start to flow into the output capacitor C_O and it's equivalent series resistor R_{esr} and leads to a large, thin output voltage spike, $I_P(\frac{N_P}{N_S})R_{esr}$ [2]. Usually, to overcome the problem, a small LC filter is added after the main output capacitor, C_O in flyback converter.

2.2.4.2 Large Output Filter Capacitor and High Ripple Current Requirement

Frequently, a filter capacitor for flyback converter is much larger than a filter capacitor in forward converter. A larger capacitor is necessary because it schemes be able to delivers supplies current to the load during the MOSFET on state [2].

On the other hand, output current ripple play important rule in determines the final choices of filter capacitor. Eventually, it may be the ripple current rating of the capacitor selected initially on the basis of the output ripple voltage specification [2]. If the selected output capacitor produce a predefined ripple current rating, a larger output capacitor must be chosen.

2.3 Controller Design Relations and Modeling of Flyback Converter

Among the currently-existing DC/DC converter, the flyback converter is the simplest topology, since there is no choke required, only one power switch is used and the high-frequency power transformer with unifilar windings is employed [5]. Furthermore, the switching mode flyback converter can manage a wide-range of output voltage and can obtain multiple output voltage with minimum losses compared to others converter [5].

The key design of the converter is subject to the store and release of magnetic energy [4]. By switching the MOSFET on and off alternatively, the energy conversion of a flyback converter can be done. Referring to the discontinuous mode operation, the L_m stored energy in the MOSFET during turn-on intervals, and then the energy is released to the load during the turn-off interval.