“ I hereby declare that I have read this fully report entitled “*Study of ZVS Bidirectional DC-DC Converter*” and found that it has comply the partial fulfilment for awarding the *Bachelor of Electrical Engineering (Power Electronic and Drives)*”

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**STUDY OF ZVS BIDIRECTIONAL DC-DC CONVERTER**

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

**Faculty of Electrical Engineering**
**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**JUNE 2015**

I declare that this report entitled "*Study of ZVS Bidirectional DC-DC Converter*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and not concurrently submitted in candidature of any other degree.

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Date : 1st JUNE 2015

# STUDY OF ZVS BIDIRECTIONAL DC-DC CONVERTER

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**ABSTRACT**

Power electronics converters are equipment that implemented with switching devices which turn on and off while the power will be converted from one form to another. It operates with high switching frequencies in order to reduce size of the converters transformers, capacitors and inductors. However, in high switching frequencies operation, it increases the amount of power that is lost due to switching losses. Thus, it will reduces the power converter efficiency. These switching losses are caused by the overlap of switch current and switch voltage during a switching transition. If voltage across or the current flowing through switch is zero during a switching transition, then there is no overlap of switch voltage and switch current, therefore, no switching losses occurs. Zero Voltage Switching (ZVS) is one of the techniques to reduce the problem. This also referred as soft switching techniques in the power electronics. The development of high power isolated bidirectional DC-DC converters with the half bridge topology has become an urgent topic because of the requirements of the hybrid vehicle applications and battery based energy storage systems. This half bridge has an advantages of simple circuit with no total device rating (TDR) penalty, simple control with high efficiency, and it is a soft switching implementation without additional devices compared to the traditional bidirectional DC-DC converters for the similar applications.

# ABSTRAK

Penukar elektronik kuasa dilaksanakan dengan peranti (alat) yang akan menghidupkan dan mematikan manakala kuasa pula ditukar dari satu bentuk ke bentuk yang lain. Ia beroperasi dengan frekuensi pensuisan yang tinggi untuk mengurangkan saiz penukar induktor, transformer dan kapasitor. Walaubagaimanapun, ia meningkatkan jumlah kuasa yang hilang dan mengurangkan kuasa kecekapan penukar. Kerugian beralih disebabkan oleh pertindihan suis voltan dan suis arus semasa peralihan pensuisan. Oleh itu, sama ada voltan atau arus yang mengalir melalui suis adalah sifar semasa peralihan pensuisan. Maka tidak ada pertindihan suis voltan dan suis arus seperti dalam teori, tidak ada kerugian pensuisan. *Zero Voltage Switching* (ZVS) merupakan salah satu teknik untuk memastikan perkara ini berlaku. Pembangunan berkuasa tinggi terpencil dwiarah DC-DC penukar telah menjadi satu topik penting kerana keperluan aplikasi kenderaan sel bahan api dan sistem penyimpanan tenaga bateri berasaskan sistem ini. ZVS baru ini digunakan dengan dwiarah DC-DC penukar iaitu topologi baru dengan kelebihan litar sederhana tanpa jumlah kedudukan peranti (TDR) penalti, kawalan mudah dengan kecekapan tinggi, dan ia adalah pelaksanaan pensuisan lancar tanpa peranti tambahan berbanding dengan tradisional jambatan penuh dan separuh dwiarah penukar DC-DC bagi aplikasi yang sama.

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## LIST OF ABBREVIATION

| | |
|---|---|
| ZVS | Zero Voltage Switching |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| BJT | Bipolar Junction Transistor |
| PWM | Pulse Width Modulation |
| DC | Direct Current |
| AC | Alternating Current |
| DUT | Device Under Test |
| IGBT | Insulated Gate Bipolar Transistor |
| ZCS | Zero Current Switching |
| EMI | Electromagnetic Interference |
| TDR | Total Device Rating |

# CHAPTER 1

# INTRODUCTION

## 1.1. BACKGROUND

Power electronic circuits that convert a direct current (DC) voltage to a different direct current (DC) voltage level which often providing a regulated output is known as DC-DC converters. Nowadays almost all electronic devices contain several mini-circuits that on each of it have its own voltage level requirement different from their battery supply, which sometimes needs a higher and sometimes needs a lower voltage in order to operate. Nowadays in DC-DC Converter application, most of it using the voltage control method in order to turn ON and turn OFF the switching device.

This project focused on analyzing a bidirectional DC-DC converter which using the isolated half bridge topology. In order to simulate the losses using these zero voltage switching bidirectional converter, it will used MATLAB simulation. The data performance will be analyzed and verified by comparing the data from the simulation.

## 1.2. PROBLEM STATEMENT

Recently, the requirements of battery based energy storage systems and fuel cell vehicle applications has make the development of high power isolated bidirectional DC-DC converters become an urgent topic. However, almost all of the bidirectional DC-DC converters still have some critical problems such as high current stress, low voltage conversion ratio, low efficiency, poor performance and unreasonable control strategy. This new ZVS bidirectional DC-DC converters technique was designed to overcome that problem that it is more reliable, high efficiency and simple control.

## 1.3. OBJECTIVES

The objectives of this project are list as follows:

i. To analyze the effect of the hard switching and zero voltage switching in a power devices (IGBT/MOSFET)
ii. To study the behavior of ZVS bidirectional DC-DC Converter circuit

## 1.4. SCOPE

The scope of project is to study on the bidirectional DC-DC Converter in achieving zero voltage switching (ZVS) by using the technique of the soft switching. In addition, some matters that were used include the development of the half bridge topology of the bidirectional DC-DC Converter with certain load.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

A literature review is a grouping of content that means to review critical purposes of current learning including the substantive findings with the theoretical and methodological contributions to each of particular topic. Likewise, a literature review could be defined as a review of an abstract fulfillment. This chapter will explain briefly about the fundamental of ZVS bidirectional DC-DC converter design. The introduction of the hard switching and soft switching will also be explained. In addition, this chapter also gives information regarding the basic DC-DC converter design and the snubber technique operation.

## 2.2 POWER CONVERTER (DC-DC CONVERTER)

Power electronic circuits that convert electrical energy from one type to another form is known as power converter. In power electronic circuit, a converter is an intermediate device between source and load. There are various types converter in these electrical engineering field, which are DC-DC converter, AC-AC converter, DC-AC converter and AC-DC converter [1]. The function of the DC-DC converter is same as the function of transformer. This is because DC-DC function used to convert from one level of current value or voltage value to another level either step up or step down voltage value which is same as the transformer function. In addition, power converter circuits have the options in controlling the output voltage normally. For the linear voltage regulators circuit, it is normally control by transistor. Figure 2.1 shows the basic circuit of the linear regulator on how it is used. However, in power converter circuit, it also have a device to control the circuit which is normally used such as BJT and MOSFET. Therefore, the controller of the circuit or the switching is the main component in order to operate the power converter. Figure 2.2 show the basic switching converter. The comparison between a basic switching converter and a linear voltage regulator shows that basic switching converter is better than linear voltage regulator [1]. This is because it can increase the efficiency of the circuit.

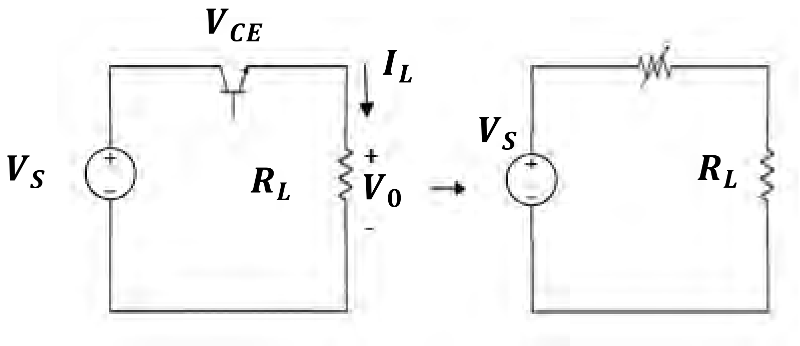


**Figure 2.1 :** Basic circuit of linear regulator [1]

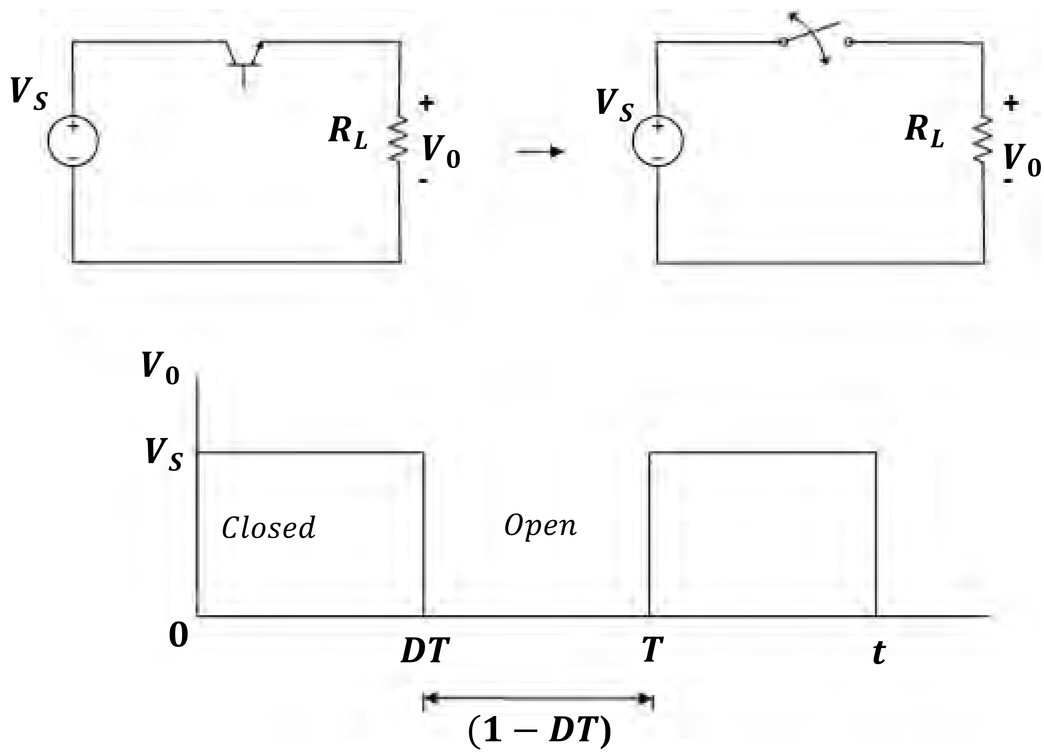


**Figure 2.2 :** Basic switching converter [1]

## 2.3 BUCK CONVERTER

Buck converter or well known as the step down DC-DC converter is a converter that step down voltage and step up current. Figure 2.3 below shows an example of an ideal buck converter circuit. The average output of this circuit is less than the voltage of DC input. By controlling the switch duty cycle, it will controls the output voltage. When the switch is closed, current will start to increase, and makes the inductor to produce an opposing voltage across its terminals in response to the changing current. This voltage drop react the voltage source and therefore it will reduce the voltage across the load.

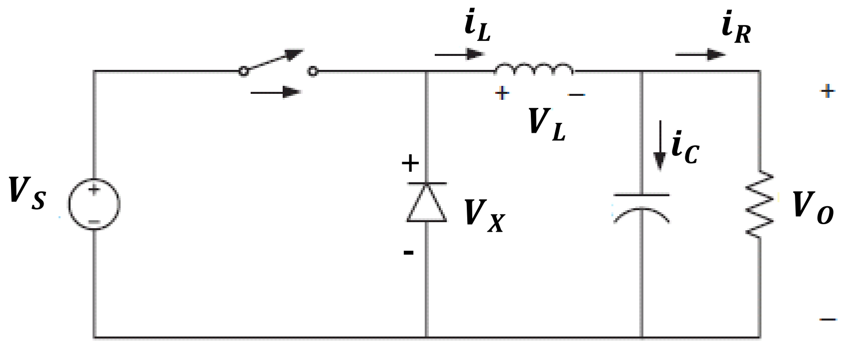


**Figure 2.3 :** Buck converter circuit [1]

## 2.4 BOOST CONVERTER

Step up DC-DC converter or a boost converter is another switching converter that operates by periodically opening and a closing electric switch. The output voltage that seems to be larger than the input voltage makes it to be known as the boost converter. Figure 2.4 below shows an example of an ideal circuit of a boost converter. For the main operation of the boost converter, the inductor in the input circuit resists sudden variations in the input current. When the switch is turned OFF the inductor stores energy in the form of a magnetic energy and discharges it when the switch is closed. In addition, the capacitor at the output circuit is assumed to be large enough whereby the time constant of the RC circuit in output stage is high.

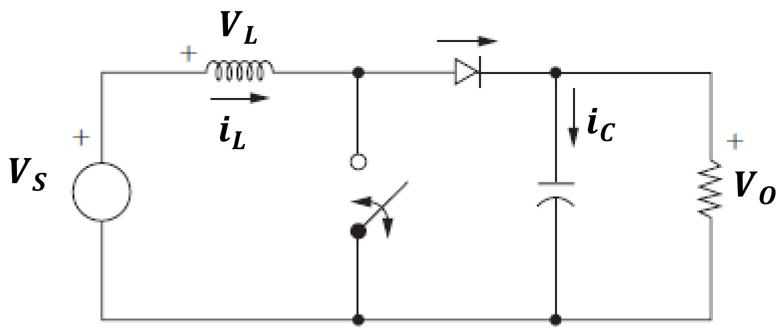


**Figure 2.4 :** Boost converter circuit [1]

### 2.5 BUCK BOOST CONVERTER

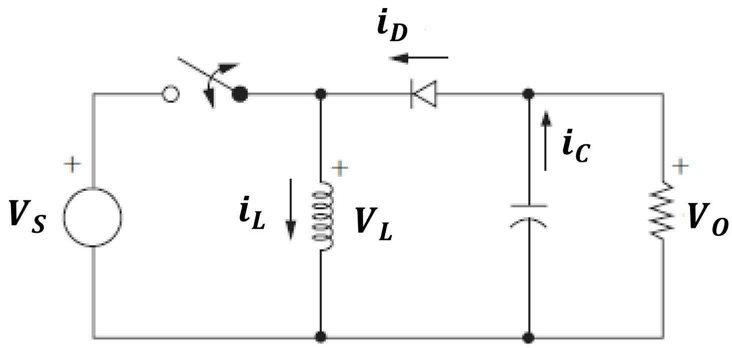


**Figure 2.5 :** Buck boost converter circuit [1]

A buck boost converter is a combination of a buck converter topology and a boost topology in cascade. The output voltage of this DC-DC type converter can be either higher or lower than the input voltage. Figure 2.4 above shows an example of an ideal buck-boost converter. The output to input conversion ratio is also a product of ratios in buck converter and the boost converter. Then the output voltage is controlled by controlling the switch-duty cycle. Therefore, the ratio of output voltage to input voltage is given by equation (1.1) below:

$$\frac{V_o}{V_{in}} = D.\frac{1}{1-D} = \frac{I_{in}}{I_o} \qquad (1.1)$$

Where, $V_o$ and $V_{in}$ are the output and input voltages, respectively. The term $I_{in}$ and $I_o$ are the output and input currents, respectively. The term $D$ is the duty ratio and defined as the ratio of the on time of the switch to the total switching period. This shows the output to be higher or lower than the input voltage, based on the duty ratio, $D$.

## 2.6 BIDIRECTIONAL DC-DC CONVERTER

### 2.6.1 Introduction

Recently, the bidirectional DC-DC converter application are widely used by implementing it for various type of power related systems, which includes renewable energy system, hybrid vehicle and also applied in battery chargers. The special things about these bidirectional DC–DC converters are its own ability to transfer the power between two dc sources in either direction. The special things about this application is it can improve the efficiency, reduce the cost, and improves the performance of the system. Figure 2.6 below shows the energy regenerative system for bidirectional DC-DC converter.

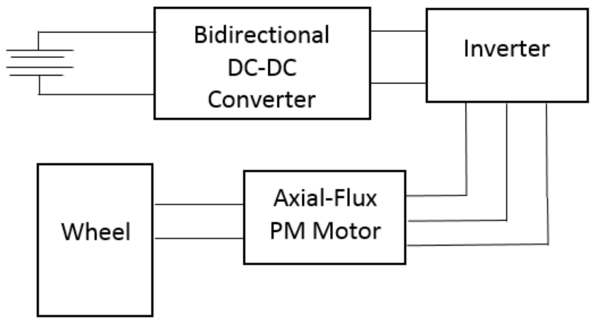


**Figure 2.6 :** Bidirectional DC-DC converter in energy regenerative system

In electrical vehicle application, bidirectional DC-DC converter is required to draw power from the auxiliary battery to boost the high-voltage bus during vehicle starting, accelerate and hill climbing [6]. It is used to achieve power transfer between two dc power sources in either direction, with its ability to reverse the direction of the current flow, and thereby power.

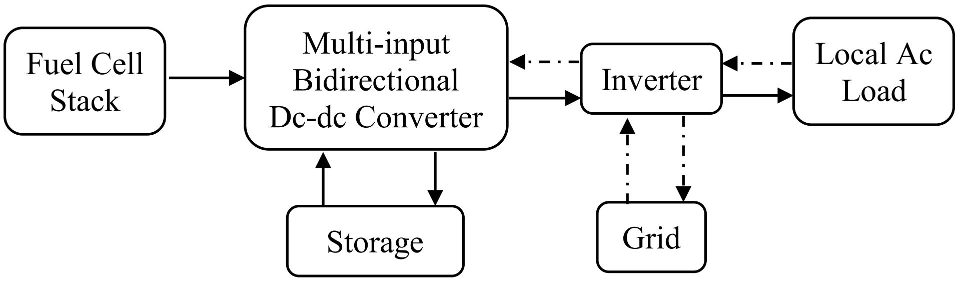


**Figure 2.7 :** A fuel cell system for domestic application [6]

In addition, for a renewable energy application, the function of multiple-input bidirectional DC-DC converter is it used to combine different types of energy sources. Figure 2.7 above shows a fuel cell based system in domestic applications. Therefore, this multi-input bidirectional DC-DC converter is the main core that interconnects storage elements and power sources and also manages the power flow.

All of these are some of the application that has been applied by using the bidirectional DC-DC converter method. However, these converters also had their own difficulties even though it is a simple structure and easy to control. Basically the bidirectional converters are divided into two types, which is non-isolated and isolated converters, which meets a requirement with different application.

### 2.6.2 Non-Isolated Bidirectional DC-DC Converters

Usually in this power conversion systems, boost type and buck type DC-DC converter always has been chosen. In Figure 2.8 it is shows about the basic bidirectional DC-DC converter circuit which includes the structure of buck and boost. These power conversion type is more attractive in term of improving size, cost, weight and efficiency compared to the high frequency transformer of a based system that is interesting in obtain the isolation between the load sides and source. Beside that, in the high power application or spacecraft power system applications, weight or size will be the main concern. Thus, the transformer-less type is more attractive and better for the applications of high power.

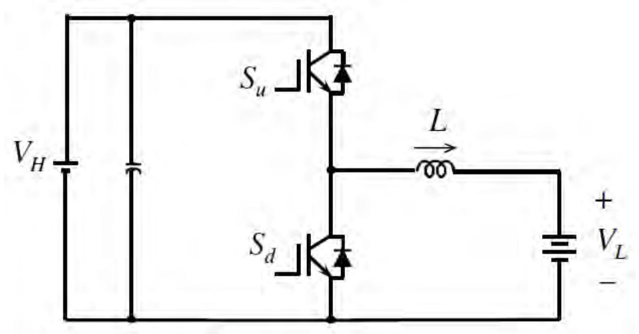


**Figure 2.8 :** Basic bidirectional DC-DC converter with buck and boost structure [6]

### 2.6.3 Isolated Bidirectional DC-DC Converters

For the bidirectional DC-DC converters design, transformer normally provides the isolation. Moreover, the additional of transformer causing additional cost and losses. However, it is an alternative for all the applications since with additional of the transformer, it can isolate the two voltage sources in the circuit and provide the impedance matching between those two voltage sources. Then for a current source, inductance normally is important and needed in between. But in isolated bidirectional DC-DC converters, the sub-topology can be a half-bridge, a full-bridge, a push-pull circuit, or any variations instead.

In isolated bidirectional DC-DC converter, the operation of the circuit includes the utilization of the leakage inductance of the transformer as the transferring element and main energy storing. In addition, the half-bridge topologies have been designed and developed so far to increase the efficiency and reduce the device count. However, between the two split capacitors, a voltage imbalance exists, thus it's required for an additional control circuit to eliminate the voltage imbalance. The shown in Figure 2.9 below shows the full-bridge