THE PRE-SIZING APPROACH OF DC-DC CONVERTER AS THE APPLICATION TO DESIGN A BUCK CONVERTER FOR THE AUTOMOTIVE DOMAIN

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Power System)

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I declare that this thesis entitled "THE PRE-SIZING APPROACH OF DC-DC CONVERTERS AS THE APPLICATION TO DESIGN A BUCK CONVERTER FOR THE AUTOMOTIVE DOMAIN" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 30 NOVEMBER 2010

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ABSTRACT

Choosing the right DC-DC converter for automotive applications can be a challenging task when one considers all the requirements that need to be met. The requirement for vehicles increased continuously in the 20^{th} century as consumers required more from their vehicles. Because of that, car manufacturers have provided both standard and optional equipment to meet these demands. In this project, a prototype of DC-DC Converter is designed and developed. This converter includes buck converter, controller, and driver. The purpose of this project is to propose a pre-sizing approach that includes a step to formalize the converter architecture and component choices and to design a Buck converter system in order to produce the desired voltage that suitable for automotive domain. This approach can be conducted in two steps. The first step is by the calculation to find the specific parameter for the design. The second step uses specific models developed from the manufacturer datasheets as reference to choose the architecture and appropriate component technologies and will be applied to pre-size a Buck DC-DC power converter for the automotive domain. The pre-sizing results will show the specifications that respected to the proposed approach.

ABSTRAK

Memilih penukar DC-DC untuk aplikasi automotive adalah tugasan yang mencabar kerana semua keperluan perlu dipertimbangkan. keperluan untuk kenderaan telah berterusan meningkat dalam abad ke-20 kerana pelanggan mahu lebih untuk kenderaan mereka. Oleh sebab itu, pengeluar kereta perlu menyediakan tahap dan pemilihan alatan untuk memenuhi permintaan pelanggan. Dalam projek ini, prototaip penukar DC-DC direka dan diperkembangkan. Penukar ini termasuk penukar buck, pengawal, dan pemandu litar. Tujuan dari projek ini adalah untuk mencadangkan suatu pendekatan pra-sizing yang meliputi langkah untuk merumuskan pilihan konverter arkitektur dan bahagian-bahagian dan merancang suatu sistem penukar Buck untuk menghasilkan voltan yang dikehendaki yang sesuai untuk domain otomotif. Pendekatan ini boleh dilakukan dalam dua tahap. Langkah pertama ialah dengan perhitungan untuk mencari parameter khusus untuk desain. Langkah kedua menggunakan model khusus yang dikembangkan dari helaian data pengeluar sebagai rujukan untuk memilih teknologi arkitektur dan bahagian-bahagian yang tepat dan akan dilaksanakan pada pra-saiz Buck converter DC-DC power untuk domain otomotif. Keputusan melaras saiz akan menunjukkan spesifikasi yang sesuai dengan pendekatan yang dipilih.

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LIST OF ABBREVIATIONS

PWM	-	Pulse-Width Modulation
DC	-	Direct Current
MOSFET	-	Metal Oxide Silicon Field Effect Transistor

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CHAPTER 1

INTRODUCTION

1.1 Background

DC to DC converters are considered to be one of the great economical importance in today society. They are built in their millions every year, and are perhaps one of the few electronic disciplines that use in our daily life.

In general, DC to DC converters are widely used at home and industries to produce the desired output power. The different types of converters include buck, boost, buck-boost, cuk, and etc. With these converters, the different types of applications can be performed, such as step-down voltage, step-up, and conversion dc to ac and vice versa.

Nowadays, with the proposed of a 42V in future automotive electrical system, which is three times higher than used in today vehicle, it becomes inevitable that high power converter has gained popularity in automotive industry.

For this reason, the purpose of this thesis is to propose the pre-sizing approach that includes the step to formalize the converter architecture and component choices. Particular attention is now being placed on the idea of combining Buck converter, Mosfet driver and controller.

1.2 Research Problem

This project concentrates in power electronic conversion technique for Buck converter topology. Therefore, the parameters necessary for implement this converter based on system design.

1.3 Objective

The aim of this project is to propose the pre-sizing approach of DC-DC converters as the application to design Buck converter for the automotive domain. To achieve this aim, the project carried out for the following objectives.

i. To propose a pre-sizing approach that includes a step to formalize the converter architecture and component choices.
ii. To design Buck converter system in order to produce the desired voltage that suitable for the automotive domain.

1.4 Scope of Work

The scope of project is focused on designing the Buck converter (DC-DC step-down converter) for converting the voltage that suitable for automotive domain which step-down the voltage from 42Vdc supply to 14Vdc supply.

1.5 Importance of Study

This project is essential in terms of power efficiency and power handling deliver to output system. It is important because this aspect related to the most electrical and electronic equipment requirements.

1.6 Thesis outline

This thesis contain of 5 chapters they include Chapter 1: Introduction, Chapter 2: Literature reviews, Chapter 3: Methodology, Chapter 4: Software development, Chapter: Result and discussion. Each chapter will contribute to explain different focus and discussion relating with the corresponding chapters heading.

Chapter 1 contain introduction which present about the overviews of the project that is constructed. It consists of project background, objective, problem statement and project scope.

Chapter 2 contain literature review which discussed about the reference that is taken for this project completion.

Chapter 3 will discuss about the methodology in this project which consist of characteristic study of rotation and elevation technique, the construction of the hardware and development of controller for this project.

Chapter 4 contain result and discussion focused on the analysis of the result acquired and discussed the outcome that is obtained.

Chapter 5 contain conclusion and recommendations for this project

CHAPTER 2

LITERATURE REVIEW

2.1 DC-DC Converter

2.1.1 Introduction

Power consumption in vehicles increased tremendously in the 20th century as consumers required more for their vehicles, car manufacturers have provided both standard and optional equipment to meet these demands. In addition, during the last 25 years, government legislation for emissions and safety equipment has also contribute to the increased in vehicle's power consumption.[1]

Because of the rise in power consumption, automakers and suppliers were forced to evaluate the possibility of higher supply voltages and alternative power supply architectures.[2]

As a result, a new standard for automotive electrical systems, one based on a voltage, 42V, which is three times higher than today's vehicles. The need for the higher voltage is been driven by the expectation that electrical loads in vehicles will continue to increased sharply in the future.[2] The tremendous increased in power and current over the years are shown in figure below.

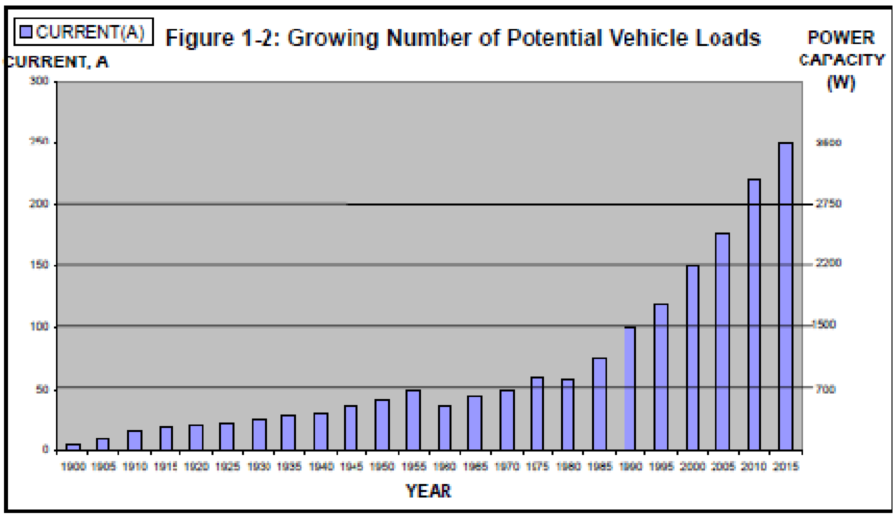

Figure 2.1: The tremendous increased in power and current over the years [2]

Advantages of 42V to 14V system:

i) Can meet increasing demand of load in the future.
ii) Cheaper to implement as no expensive and heavier wiring is required.
iii) No modification circuitry is needed for existing equipment.
iv) A universal standard for car manufacturers to follow.
v) Easier to troubleshoot as the circuit is simple in the case of fault.
vi) Reduction in fuel consumption and carbon dioxide emissions.

Having 42V system does not always suit all the applicants in vehicles. Some loads, such as the existing vehicle lighting will have a shorter life span by a 42V supply. There must be a trade-off between 42V and existing 14V. Therefore, a better choice would be implementing a high power DC 42V to DC 14V converter. In this way, not only can solve the power crises in future but also can provide system that prefer 14V supply.

The 42V will be essential to meet future electrical demands on passenger cars, but it will also bring major benefits, both in overall fuel consumption, and in the performance and efficiency of many vehicle systems. 42V alternators are significantly more efficient at all engine speeds than current 14V and will offer major savings in fuel consumption.[3]

2.1.2 Applications of 42V

The availability of 42V power will result in the enablement of many new systems throughout the vehicle and the demand of many components. Almost all the accessories driven mechanically from the engine could be operated much more efficiently by electricity if sufficient power were available. In terms of comfort and convenience, 42V power will be important as a source of heat. In terms of safety, electronically controlled electric powered systems will offer benefits in steering, braking and handling. Figure below shows some of the systems that will be enabled by 42V.

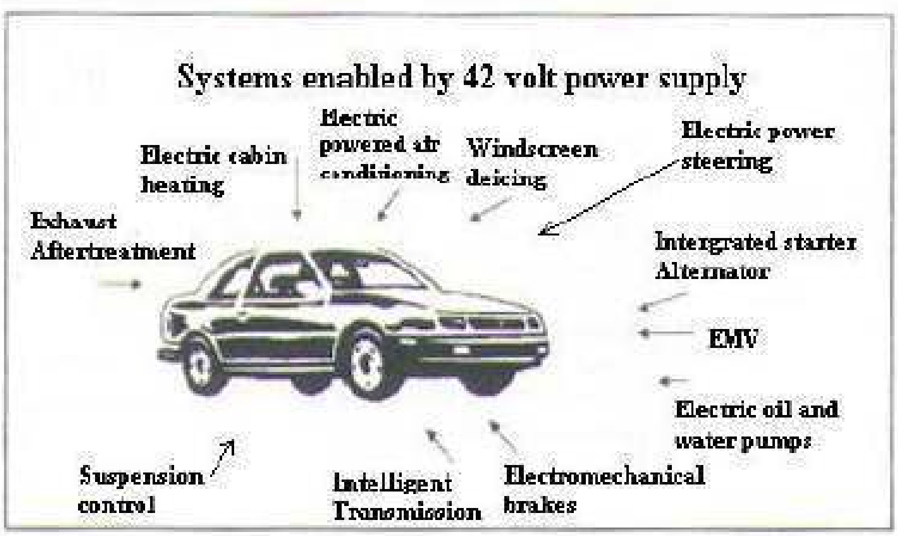

Figure 2.2: Systems Power by 42V supply [3]

2.1.3 Buck converter

A DC-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-DC converters are used to provide noise isolation, power bus regulation, etc.[4]

Buck converter is a step-down DC-DC converter. Voltage divider circuit is the simplest way to reduce the voltage but it wasting the energy used. The ability to convert voltages by controlling the duty cycle of the switching devices makes it suitable for many applications. Thus, the design of a buck converter is simple and cheaper to manufacture as compared to other converters and makes it more economical and easier to build. The important factors to consider about when designing buck converters are ripple current, duty cycle, capacitor internal resistance, inductor current (rms), MOSFET drain current operating frequency.[12]

Buck converter operates with an inductor and two switches such transistor and diode that function to control the inductor. Buck converter circuit operates in three states. The first state corresponds to the case when the switch is on where the current trough the inductor rise as the source voltage would be greater than the output voltage. The current of the capacitor may be in either direction depends on the inductor current and the load current. When the current of inductor rises, the energy stored is increases. During this state, the inductor acquires energy. The second state relates to the condition when the switch is off and diode is on. The energy stored in the inductor falls and the inductor discharges its energy and the capacitor current may be in either direction. In third state, both the diode and the switch are off. During this state, the capacitor discharges its energy and inductor is at rest, with no energy stored in it. The inductor does not acquire energy or discharge energy in this state.[2]

The principle of buck converter is illustrated by figure 2.3. When switch is closed for a period of t_1, the input voltage V_s appears across the load. On the other hand, the voltage across the load is zero if the switch remains off for a time $t_s - t_1$. The chopper switch can be implemented by using power BJT, power MOSFET, GTO, or forced-commutated thyristor. These devices has a finite voltage drop ranging from 0.5V to 2V, and for the sake of simplicity the voltage drops of these power semiconductor devices are neglected.[2]

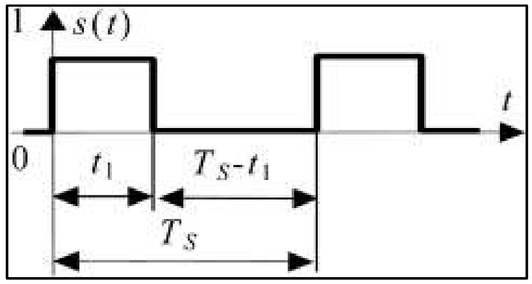

Figure 2.3: Step-down chopper with resistive load [2]

DC-DC converters with extreme step-down voltage conversion ratios are required in newly emerging power electronics applications, such as automotive power systems, telecommunications power systems, data communications systems, industrial controls, and distributed power systems. For example, the emergence of 42V automotive power systems needs a large step-down converter to supply the newly integrated circuit (3.3V or 1.5V) [9-10].

In [11], one DC-DC converter, like those utilized in electric vehicles is investigated. The measurements on an electric vehicle emphasize the role of the DC-DC converter on the automotive market. There are utilized three DC-DC converters in total which two of them are used for feeding the electrically excited DC motor and one for charging the board system battery.

2.2 Design Concept

In the field of high voltage power conversion, the circuit designer is often confronted with difficulties in finding semiconductors that capable of sustaining the desired voltage.[3]

In terms of the high power converter, the most important things to consider are power efficiency and the selection of components.

2.3 Component Review

2.3.1 MOSFET

Metal-oxide-semiconductor field effect transistors (MOSFET) is a three-terminal device where the input, the gate controls the flow of current between the output terminals, the source and drain.[4]

In the DC-DC buck converter application, the MOSFET is used as a switch to control the duty cycle. By controlling the duty cycle, the desired output voltage can be achieved [4]. Switching times of the MOSFET are determined by the number of times required for the gate driver to charge the internal capacitance. The rate of changes in drain circuit is dependent on the rate of gate-to-source capacitance charged by the driver circuit.

The basic construction N-channel MOSFET is illustrated in Figure 2.4. The basic operation of N-channel MOSFET is such that the drain current (I_D) will flow provided gate-to-source (V_{GS}) is greater than threshold voltage (V_{TH}) [4].

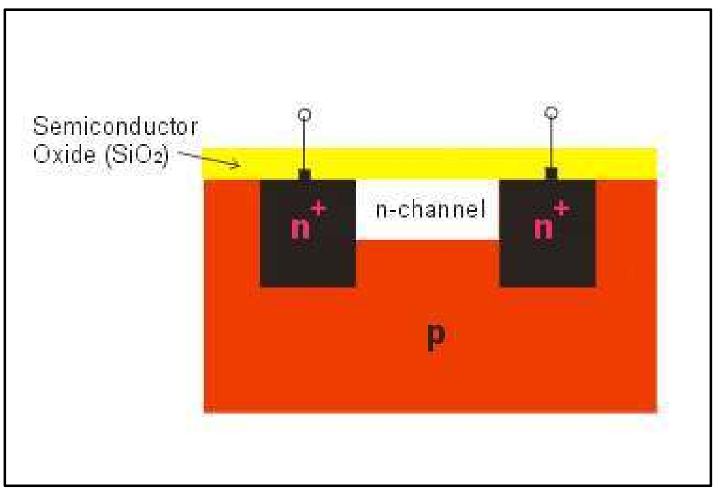

Figure 2.4: Basic construction of N-channel MOSFET

Figure 2.5 illustrates N-channel MOSFET in the off-stage. Gate-to-source (V_{GS}) applied across the depletion region of the p-n junction. Since the V_{GS} is not sufficient high enough to attract the minority carrier to form a channel at the surface of the P-region, therefore no drain current is flowing.

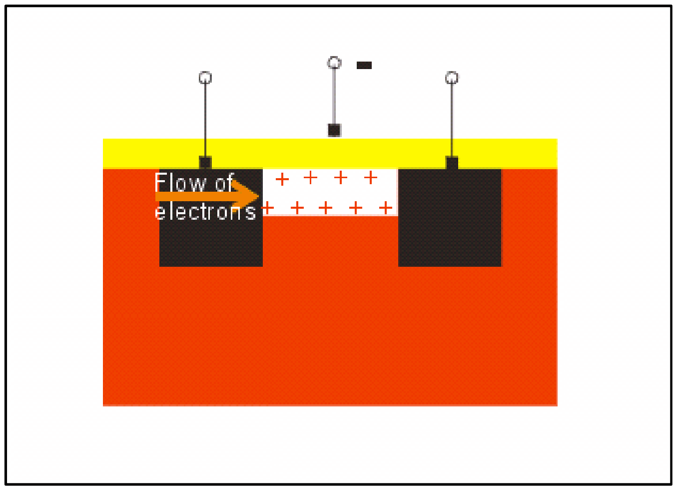

Figure 2.5: N-channel MOSFET in the off-stage

Figure 2.6 shows the N-channel MOSFET operating in the on-stage. Now that the positive V_{GS} applied is greater than threshold voltage and is sufficient to form a channel at the surface of the P-region, underneath the gate.

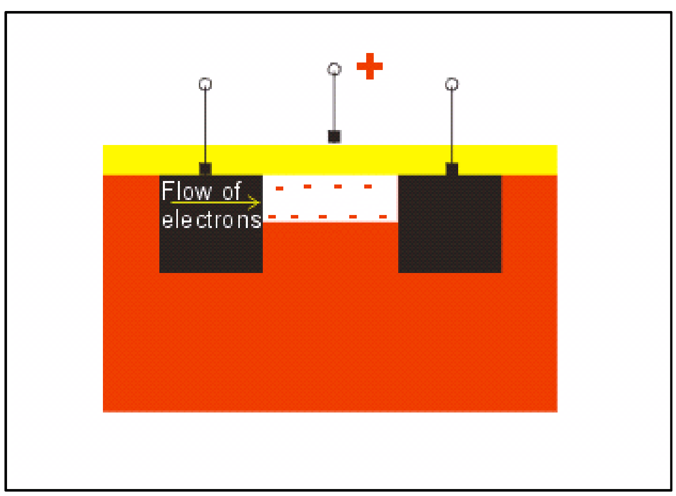

Figure 2.6: N-channel MOSFET in the on-stage