HIGH EFFICIENCY STEP-DOWN SWITCHED CAPACITOR DC-DC CONVERTER

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

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NOVEMBER, 2010

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Date : 11 NOVEMBER 2010

ACKNOWLEDGEMENT

First of all, I would like to thank my project supervisor, Miss Laili Binti Ismail, who has given me much strong logistic support while implementing the project given. She has always assisted me when I handling my project. Besides, I would like to express my sincere appreciation for her valuable advices, guidance and encouragement. This has inspired me to be more confident in trying new things.

Secondly, I would like to thank my family members especially my father Rosdi Mohamed and my mother Masitah Hasan for giving me their loves and supports throughout my four years of studies in Universiti Malaysia Pahang (UMP), Gambang, Pahang.

Special thanks to Siti Zahirah Zulkapri who have given me inspiration and strength to finish this project.

Then, I would like to thanks to staff FKEE, who have given me a great help in accomplishing this project.

Last but not least, I would like to say millions of thanks to all my coursemates and those who has lending me their helping hand.

Thank you.

ABSTRACT

The power requirement for vehicles increased continuously in the 20th century as consumers required more from 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 added to the power requirements.

To solve the power crises in vehicles of the future, a new standard for automotive electrical systems, one based on a voltage, 42V, which is three times higher than used in today's vehicles is proposed. The need for this higher voltage is being driven by the expectation that automotive electrical loads will continue to rise sharply in the future. Increasing the vehicle voltage will allow the addition of higher power loads without more expensive and heavier wiring. But some loads, such as the existing vehicle lighting, would be better served by 5V. Therefore a possible architecture, 42V power from the main battery is stepped down to 5V by a "High Efficiency Step-Down Switched Capacitor DC-DC Converter".

In this thesis, a prototype "Switched Capacitor Converter" is designed and developed. This converter is capable of supplying 22A at 5V. This converter has an overall efficiency of 80.69%. This prototype can act as a milestone for a better performance, higher power and improve efficiency in tomorrow's vehicles.

ABSTRAK

Pada zaman ini, keperluan kuasa untuk kenderaan terus meningkat pada abad ke-20 dan sebagai pengguna mengharapkan sesuatu yang lebih baik dari kenderaan; pengeluar kereta telah meambah baik peralatan dan memperbanyakkan pilihan untuk memenuhi tuntutan tersebut. Selain itu, hampir 25 tahun pihak kerajaan telah menguat kuasa undang-undang mengenai peralatan keselamatan dan juga menambah baik untuk memenuhi keperluan kuasa.

Untuk mengatasi krisis kuasa di dalam kenderaan masa depan, satu piawaian baru untuk sistem otomotif, yang didasarkan pada voltan, 42V yang tiga kali lebih tinggi daripada yang digunakan dalam kenderaan saat ini dicadangkan. Keperluan voltan yang lebih tinggi ini didorong oleh keperluan penggunaan beban elektrik automotif akan terus meningkat di masa depan. Peningkatan voltan kenderaan akan membolehkan penambahan beban kuasa yang lebih tinggi tanpa kabel lebih mahal dan lebih berat. Tetapi beberapa beban, seperti lampu kenderaan yang ada, akan lebih baik jika menggunakan 5V. Oleh kerana itu, reka bentuk 42V kuasa dari bateri utama diturunkan kepada 5V dengan menggunakan "Kecekapan Tinggi Suis Kapasitor Pengubah Penurunan DC-DC".

Dalam tesis ini, prototaip "Switched Capacitor Converter" telah dirancang dan direalisasikan. Pengubah ini mampu membekalkan keluaran 22A dan 5V. Pengubah ini mempunyai kecekapan keseluruhan 80,69%. Prototaip ini boleh bertindak sebagai tunggak untuk prestasi yang lebih baik, kuasa yang lebih tinggi dan meningkatkan kecekapan dalam kenderaan masa hadapan.

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CHAPTER 1

INTRODUCTION

This chapter will explain the background of the project, objective of the project, scope of the project and problem statement. In this introduction section the review of step-down switch capacitor converter (SCC) explained. At the end of chapter 1 the thesis outline is briefly describe.

1.1 Background of Study

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 input. Portable electronic devices, such as cell phones, PDAs, pagers and laptops, are usually powered by batteries. After the battery has been used for a period of time, the battery voltage drops depending on the types of batteries and devices. This voltage variation may cause some problems in the operation of the electronic device powered by the batteries. So, DC-DC converters are often used to provide a stable and constant power supply voltage for these portable electronic devices.

According the components used for storing and transferring energy, there are two main kinds of topologies in DC/DC converters: inductive converters and switched capacitor converters. The inductive converter using inductor as energy storing and transferring component has been a power supply solution in all kinds of applications for many years. It is still a good way to deliver a high load current over 500mA. But in recent years, since the size of portable electronic device is getting smaller and smaller, and the load current and supply voltage are getting lower and lower, the inductorless converters based on switched capacitor are more and more popular in the space constrained applications with 10mA to 500mA load current. Such converters avoid the use of bulky and noisy magnetic components, inductors. They are available in small packages, operate with very low quiescent current and require minimal external components. They have been the main power supply solution for handheld portable instrumentations.

The purpose of a DC-DC converter is to provide a predetermined and constant output voltage to a load from poorly specified or fluctuating input voltage source. Linear regulators and switching converters are two common types of DC-DC converters. In a linear regulator the output current comes directly from the power supply, therefore the efficiency is approximately defined as the ratio of the output voltage to supply voltage. It is obvious that a worse efficiency will be obtained when the supply voltage is much larger than the output voltage. Switching converters are more efficient than linear regulators due to intercepted energy transfer. This is done by periodically switching energy storing components to deliver a portion of energy from the power supply to the output.

The capacitive converters based on switched capacitors are widespread in applications requiring small power and no isolation between input and output. Their features relatively low noise, minimal radiated EMI, and in most cases as fabricated as integrated circuits which have made capacitive converters popular for use in power management for mobile devices. An additional goal of such converters is the option for unloaded operation with no need for dummy loads or complex control. However, capacitive converters suffer from inherent power loss during charging and discharging of a capacitor connected in parallel with the voltage source or another capacitor. Theory predicts that this power loss is proportional to the squared voltage difference taking place before the corresponding circuit has been configured. As a result, capacitive converters exhibit a rather high efficiency if the capacitors pre-charged to certain voltages are paralleled with components maintaining similar voltages.

1.2 Objective of the Project

The design process was considered successful when a proper topology and control had been chosen to exceed the performance requirements and when protection techniques and parts were selected to exceed the required reliability.
So the main objective will be:

(i) To design high efficiency of step-down switched capacitor converter by using switched capacitor.

(ii) To show good behavior of the converter, small ripple of the output voltage, and the efficiency above 80%.

(iii) To select suitable components for converter that ensures the best performance.

1.3 Scope of the Project

. Nowadays all applications emphasize on efficiency. Switch mode power supply (SMPS) design minimizes the use of loose components such as resistors and use components that are ideally lossless, such as diodes switches, capacitors, and MOSFETs. This project is developed step-down DC/DC switched capacitor converter (SCC) by using switched capacitor (SC) configuration concentrates on usage of power storage elements in the implementation of a power conversion process, and then transferring the stored energy to the load.

The design of the switching converter and the selection of switching elements and their configuration was the highest challenge. The simulation test has to be done under ideal considerations, so that the implementation and fabrication of hardware will be the real challenge. A proper topology was chosen that would exceed the performance requirements. At the end of the switched capacitor converter output will obtain high efficiency of voltage output.

1.4 Problem Statement

Switched capacitor converter requires more diode and capacitor than other converters. The switching currents in these switched capacitor converter are also high, and thus, electromagnetic inductance is a major concern. However, switched capacitor converters are useful for small output power applications that do not require isolation between the input and output [1].

Supply Mode Power Supply occupies between the two type of converters namely, the line regulated and resonant converters. The main problem of the line regulator is a high power loss which is being dissipated mainly as heat, and the efficiency level is very low, at around only 40%. On the other hand these types of regulators are cheap and simple, relative to resonant converters which are complex and expensive but are highly efficient.

The switching converter is a good choice for many applications, and so the development of this converter was the object under interest. The existence of a transformer in DC-DC conversion process of switching converter, would limit the control range of duty ratio to a small value.

The primary design problem of the system was to interconnect the converter components and to control the switches, so that desired results can be obtained. The secondary design problem was to avoid using loose components that will affect the converter performance and characteristics.

1.5 Thesis Outline

The thesis is organized as follows. The main goal of this thesis is to demonstrate the successful implementation of Switched Capacitor Converter into tomorrow's vehicles. This design must be able to cater high power consumption while maintaining high efficiency.

Following a brief introduction, Chapter 2 begins by providing background information about the 42V architecture in future vehicles. Overviews of pass and recent developments in relation to 42V architecture were discussed. Furthermore, theories on step-down converters are detailed, with particular references made to ripple voltage and waveform display.

Chapter 3 then proceeds to detailed design of proposed Switch Capacitor Converter topology. This chapter present the project structure from provide the 42 Volt standardization, design theory and considerations for step-down converters to obtain 5 Volt output voltage. Design consideration such as MOSFET switching frequency, DC-DC step-down converter, driver and pulse width circuitries also discussed.

Chapter 4 summarize on the expected result and discussion on the reasons behind the failure of the actual circuitry. Analytical view of the circuit operation is also presented. The problems faced during the implementation were brief too. Power efficiency and the operation of each stage are discussed in this Chapter.

Lastly, Chapter 5 closed this thesis by suggesting some possible future improvements and recommendation to increase the performance of the "Switched Capacitor Step Down 42-5V Converter". Following that, conclusions on the overall view of this thesis were made.

CHAPTER 2

LITERATURE REVIEW

This chapter includes the study of basic concept of DC-DC switch capacitor converter. In this chapter will explain in detail the structure and operation of switch converter.

2.1 Introduction

2.1.1 DC-DC Converters

DC conversion is of great importance in many applications, starting from low power applications to high power applications. The goal of any system is to emphasize and achieve the efficiency to meet the system needs and requirements. Several topologies have been developed in this area, but all these topologies can be considered as apart or a combination of the basic topologies which are buck, boost and flyback (Rashid, 2001).

For low power levels, linear regulators can provide a very high-quality output voltage. For higher power levels, switching regulators are used. Switching regulators use power electronic semiconductor switches in 'on' and 'off' state [2]. Because there is a small power loss in those states (low voltage across a switch in the 'on' state, zero current through a switch in the Off state), switching regulators can achieve high efficiency energy conversion (Rashid, 2001).

2.1.2 The Functions of DC-DC Converters are:

i. Convert a DC input voltage Vs into a DC output voltage Vo.
ii. Regulate the DC output voltage against load and line variations.
iii. Reduce the AC voltage ripple on the DC output voltage below the required level.
iv. Provide isolation between the input source and the load (if required).
v. Protect the supplied system and the input source from electromagnetic interference (EMI) (Krein, 1998).

The DC-DC converter is considered as the heart of the power supply (Perez, 2000), thus it will affect the overall performance of the power supply system. The converter accepts DC and produces a controlled DC output.

2.1.3 Overview of 42V System

42 volts is one of the key enabling technologies in the automotive industry for the 21st Century. It will enable other advanced technologies that bring enhancement to all areas of the vehicle. Without it many would struggle or not be applied at all. [3] The demand for electrical power in passenger cars has been growing steadily as vehicle performance increases and more features are added to improve performance, comfort and convenience, and safety.

Power demand on small cars has doubled from 500W in 1990 to approach 1KW today, while medium cars now average 1.5KW and large cars exceed 2KW. By 2005, demand will have reached 1.5, 2.8 and 3.5KW respectively. [3]

The practical limit for light vehicle electrical systems is about 200 amps, beyond which the wire diameter becomes too large and bulky to handle. 200 amps represents about 3KW for a 14V system, so it is clear that if future demand is to be met, then higher voltages will have to be used. Figure 2.1 displays the electrical power consumption trend from 1980-2005.

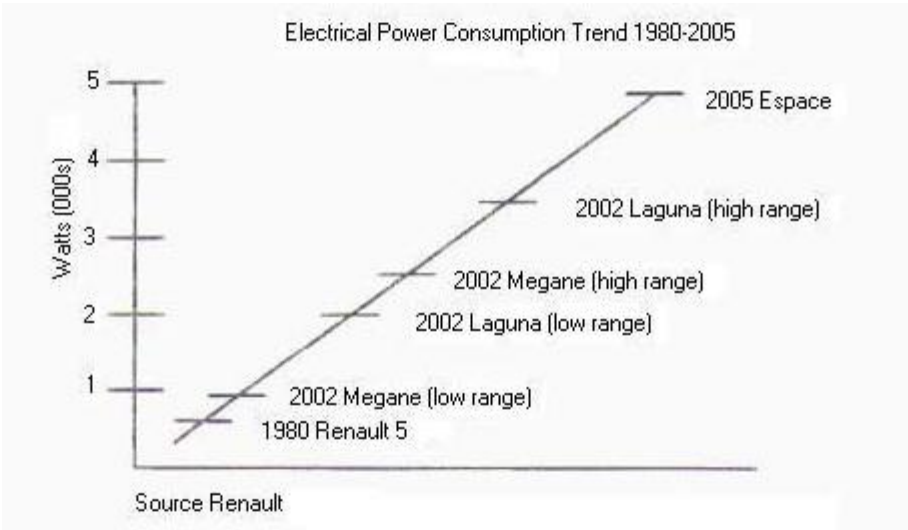

Figure 2.1 : Electrical power consumption trend [3]

42V has been internationally agreed as the maximum voltage that can be safety used in a conventional, unprotected vehicle system. Using 42V, a maximum power of 9KW can be achieved without exceeding 200amps. [3]

Thus 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]

2.1.4 Applications of 42V

The availability of 42V power will result in the enablement of many new systems throughout the vehicle, and in 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 2.2 shows some of the systems that will be enabled by 42V.

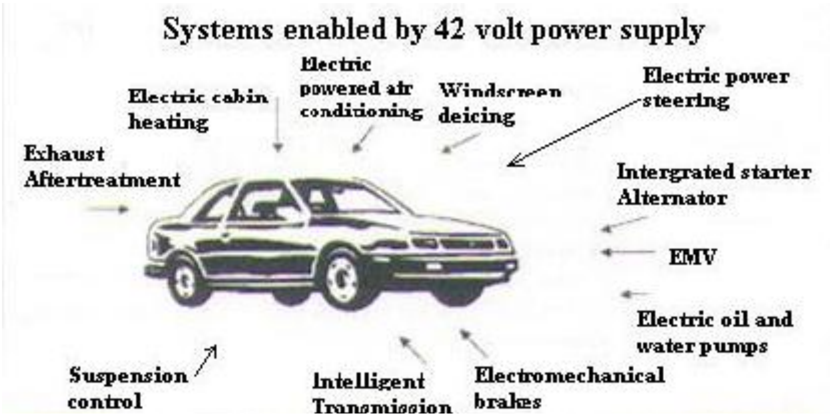

Figure 2.2 : Systems power by 42 volt supply [3]

(i) Electric Power Steering

Current 14V systems limit the application of electric power steering to small and medium size cars because of the large current needed for slow speed man oeuvres, 42V will allow the use of electric power steering on all sizes of cars and light commercial vehicles. [3]

(ii) Engine Water and Oil Pumps

Electrical loads such as speed variation and electronic control needed for the water pump motor is best provided by a 42V system, as this will save fuel while improving engine efficiency. [3]

(iii) Electromechanical Brakes

42V are essential to handle the power required for an emergency stop, and to minimize the system weight. [3]

(iv) Electrically Powered Suspension Control

42V system can cover suspension, steering and brakes. [3]

(v) Electromagnetic Valve Operation (EMV)

Allows engine valves to operate completely independently, giving more flexibility than any crankshaft driven variable valve system. EMV will not be possible until 42V systems are developed. [3]

42V systems will save fuel and cut CO_2 emissions by more efficient power generation, by more efficient and intelligent operation of systems and accessories, allowing the engine to operate in a stop/start regime. Currently, alternators are very inefficient and can provide up to 60% efficiency. Whereas 42V combined starter/alternators can achieve up to 80% efficiency. Figure 2.3 provides details on savings in fuel consumption with 42V system.

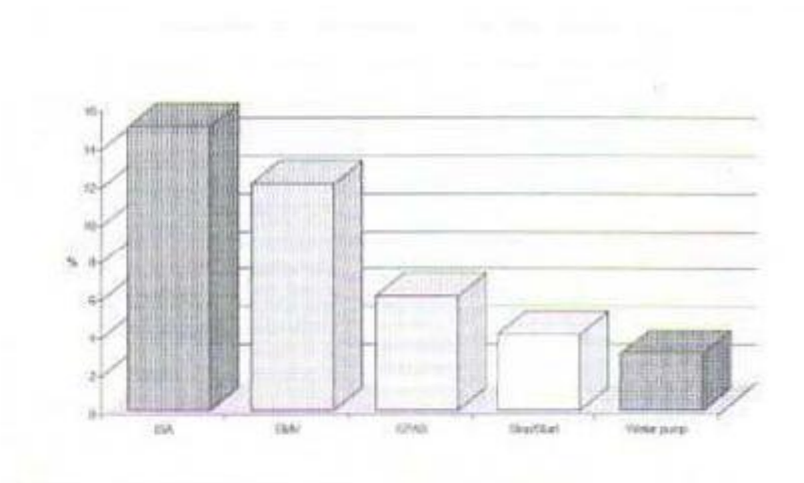

Figure 2.3 : Savings in fuel consumption (%) with 42V [3]

2.2 Power Electronic Applications

2.2.1 Operation of Power MOSFET

Before selection of Power MOSFET, it is better to have some understanding on the operation of Power MOSFET.

Metal-oxide-semiconductor field effect transistors (MOSFETs) 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 bucker 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.

The basic construction of 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 voltage (V_{GS}) is greater than threshold voltage (V_{TH}). [4]

$$V_{GS} > V_{TH} \text{ (On-Stage)} \quad (2.2.1.1)$$

$$V_{GS} < V_{TH} \text{ (Off-Stage)} \quad (2.2.1.2)$$

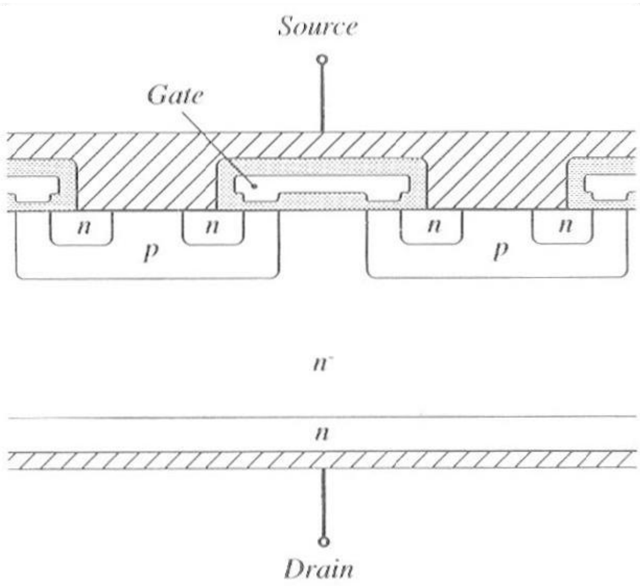

Figure 2.4 : Basic construction of N-channel MOSFET [5]

Figure 2.5 illustrates N-channel MOSFET operating in the 'off' stage. Gate-to-source voltage (V_{GS}) applied across the depletion region of the p-n^- junction. Since the gate-to-source voltage 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. [5]

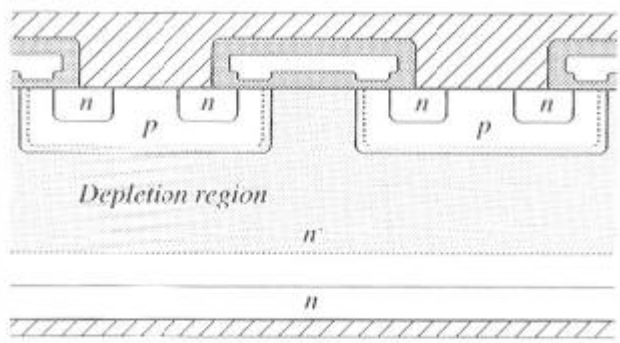

Figure 2.5: N-channel MOSFET in the off-stage [5]