DESIGN AND ANALYSIS OF TWO-PHASE DC/DC BOOST CONVERTER WITH PI CONTROLLER

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To my beloved parents, thank you.

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ABSTRACT

in this study, design and analysis two-phase DC/DC boost converter with Proportional-Integral (PI) controller for battery charger application has been enhanced. The DC/DC converters in the power field are electronic devices used to efficiently convert DC electrical power from one voltage level to another. The inherently nonlinear characteristic of the DC/DC converters, including one known as the boost converter, is induced by the operation of the switching devices. And also, in conventional boost converter, it's not suitable for high power conversions, since it requires large duty ratio to reach desired output voltage, which produces extremely power losses in semiconductors. since this two-phase boost converter project was developed with a PI controller using MATLAB/Simulink software. Compare open-loop analysis with closed-loop using PI for the upgrade of the learning process. And also, to evaluate the close-loop system's transient response in terms of the system's overshoot and response time by using two tuning methods, the Ziegler Nichols method and the manual method. The performance was compared between the open loop and the PI controlled counterpart with the same parameters by MATLAB/Simulink simulation. Comparing these findings, it was found that manual method tuning of the PI controller converters performs surprisingly better (settling time and overshoot reduced) than the open loop equivalents.

ABSTRAK

Dalam kajian ini, reka bentuk dan analisis dua fasa penukar DC / DC dengan pengawal Proportional-Integral (PI) untuk aplikasi pengecas bateri telah dipertingkatkan. Penukar DC / DC di medan kuasa adalah alat elektronik yang digunakan untuk menukar kuasa elektrik DC dengan cekap dari satu tahap voltan ke yang lain. Karakteristik tidak linier penukar DC / DC, termasuk yang dikenali sebagai penukar rangsangan, disebabkan oleh operasi peranti pensuisan. Dan juga, dalam penukar rangsangan konvensional, ia tidak sesuai untuk penukaran kuasa tinggi, kerana memerlukan nisbah tugas yang besar untuk mencapai voltan keluaran yang diinginkan, yang menghasilkan kehilangan kuasa yang sangat tinggi pada semikonduktor. kerana projek penukar dua fasa ini dikembangkan dengan pengawal PI menggunakan perisian MATLAB / Simulink. Bentuk gelombang output dengan pelbagai input dalam analisis gelung terbuka dan kawalan gelung tertutup dibandingkan dan dianalisis secara terperinci. Dan juga, tindak balas sementara sistem loop tertutup dari segi masa pengambilan berlebihan dan masa tindak balas menggunakan dua kaedah penalaan, kaedah Ziegler Nichols dan kaedah manual dibincangkan. Prestasi dibandingkan antara loop terbuka dan rakan kawalan PI dengan parameter yang sama dengan simulasi MATLAB / Simulink. Membandingkan penemuan ini, didapati bahawa kaedah penalaan manual penukar pengawal PI menunjukkan prestasi yang lebih baik (masa penyelesaian dan pengurangan pukulan berlebihan) daripada setara gelung terbuka.

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LIST OF SYMBOLS AND ABBREVIATIONS

L_{min}	Minimum Inductor Current
L_{max}	Maximum Inductor Current
L	Inductance
I_l	Inductor Current
C	Capacitance
V	Voltage
ΔV	Output Voltage Ripple
V_o	Output Voltage
V_i	Input Voltage
ΔI_l	Inductor Current Ripple
MOSFET	Metal Oxide Silicon Transistor Effect Transistor
LDO	Low Dropout
IBC	Interleaved Boost Converter
AC	Alternating Current
LC	Interleaved Boost Converter
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode
POL	Point Of Load
PWM	Pulse Width Modulation

LR	linear regulator
SMPS	Switch Mode Power Supply
L1	Inductor one
L2	Inductor two
S1	Switch One
S2	Switch Two
ANN	Artificial Neural Network
FLC	Fuzzy Logic Control
E	Error
Kp	Proportional Gain
Ki	Integral Gain
u(s)	Control Signal
C(s)	Signal Output
R(s)	Refrences Signal
D(s)	Disturbance Signal
PV	Photovoltaic
TBCTR	Time Base Counter
CPU	Central Processing Unit
TBPRD	Time Base Period
CMP	Compare
ZN	Zeigler Nichols
M1	MOSFET One
M2	MOSFET Two
D	Diode

CHAPTER 1

INTRODUCTION

1.1 Background Study

DC/DC converter converts input direct current (DC) voltage into another DC voltage level. The output voltage of DC/DC converter can be greater than or less than input DC voltage. The converter supplies to required power supply to the loads. The DC/DC converter uses switch to control connection and disconnection of power supply to loads. it consists of switching elements such as diode and transistor, and storage elements such as capacitor and inductor. DC/DC can be using as linear regulator or switching mode regulator commonly these converters are used to give constant DC power supply to the loads [1].

There are two families of DC/DC converter, linear and switch-mode DC-DC converter.in linear converters, isn't suitable for high power application, since its losses is proportional current needed by load. Whereas, switch-mode converters are using high power applications[2]. The DC/DC converter can be use in healthcare like dental imaging laboratory and medical, also communications, computing, and business system and in electric motors drives.

DC/ DC boost converter convert input DC voltage into high output voltage. The input of converter is DC from photovoltaic (PV) array that isn't constant since the radiation of sun is changing. Therefore, the output voltage of converter must be control to the required voltage. DC/DC boost converter is operate two mode which are known as continuous and discontinuous mode, its operation mode depend on the storage capacity and frequency of switching[3]. DC/DC boost converters are two types conventional and interleaved boost converter. Boost converter are very common in solar photovoltaic applications. Additionally, DC/DC boost converter provide one polarity output voltage, high efficiency compared to linear regulators, easy to analyse and understanding and its simple circuit.

Interleaved boost converter is combination of two boost converter that is parallelly connecting. The two converters have common source, capacitor and load. In interleaved boost converter, increases efficiency and power density of converter by reducing total losses in inductor, since it divided current. [4]

1.2 Problem Statement

In power electronics, the efficiency and the size of converter are become issue, since it has affected the efficiency of whole power system. Therefore, there are various boosters in power converters, boost, buck-boost, series resonant full-bridge and push-pull converter. Those converters are causing to produce large ripple input and output side. In conventional boost converter, it's not suitable for high power conversions, since it requires large duty ratio to reach desired output voltage, which produces extremely power losses in semiconductors. It requires large capacitor to reduce output ripple. In addition, it has low voltage gain due to resistances and inductance that leads to produces high voltage drops across it [5][6]. Without a constant system to control the voltage output size when placed into actual use, the stability of the system may probably affect the change from lower load to higher load, for instance. This will make the output voltage reduction smaller than the required voltage. The same applies to the shift from higher to lower loads, which will result in a higher output voltage than necessary. For this purpose, it is very important to have an output voltage control device in order to keep the output voltage steady.

Aforementioned problems can be overcome by using interleaving techniques with PI controller, the interleaving technique, reduces both input current ripple and output voltage ripple, therefore the size and power losses of filtering stage will reduce. Furthermore, it has high voltage gain; the switching losses will also reduce.

1.3 Objectives

The objectives of this project are:

I. To analyse the two-phase DC/DC boost converter to reach a constant output voltage at 24 Volts by using PI controller.

II. To analyse the system performance of closed-loop system PI controller with try and error (manual tuning) and Nichols Ziegler method.

1.4 Scope of Study

This project is divided into two major phases:

i. This project focuses on designing two-phase boost converter with open-loop and closed-loop by using MATLAB/Simulink software.

ii. For comparing and analysing the performances of DC/DC converters in term of system performance. Interleaving technique with closed-loop will increase efficiency and performance, whereas it reducing power dissipation of semiconductors.

iii. Specification of converter
   - The input voltage range is from 10V-20V
   - The output voltage set to be constant at 24V
   - the switching frequency is set to 25KHz

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss a previous researcher work related to the DC-DC boost converter, and any topics would be taken as a reference.

2.2 DC/DC Converter

Nowadays, the photovoltaic (PV) source is one of the major players in the world's portfolio. It will make one of the most extensive contributions to electricity generation among all renewable energies since it's a clean, free emission and electrical generation with high reliability. However, the PV's output voltage is very low, and it required to connect the appropriate DC-DC converters to match the needs of the grid[7].

DC-DC converters are power electronic device which converts input DC voltage into regulated or unregulated DC voltage with higher or lower or equal to the input voltage [8]. However, their conversion methods are different such as electronics, linear, magnetic, switch and capacitive.

The most DC-DC converters are designing as uni-direction from input to output. Still, switching converters can be bi-directional by replacing all diode with independent controlled active rectification, for example, in regenerative braking of the car, where power is provided to the wheels while driving but is supplied to the wheels when braking. Therefore, the bidirectional conversion is useful.

2.2.1 Application of DC/DC Converter

In electric cars, trolley cars, marine hoists, and forklift vehicles, DC converters are commonly used for traction engines. They deliver smooth control of acceleration, high efficiency and fast dynamic response. In the regenerative braking of the dc motor, the DC converter can be used to return energy baked into the supply. This feature results in energy saving for a frequent stop transportation system; and is used in dc voltage regulation [9].

In many applications, from low-power applications to high-power applications, DC conversion is necessary. The key to every system is to achieve productivity in order to satisfy device requirements. In this field, different topologies have been created. Even, both of these topologies can be considered part of a combination of buck, boost and fly back simple converter topologies. For low power levels, linear regulators can provide a high-quality output voltage. Switch regulators are utilised for higher energy levels. Electronic semiconductor switches are used by switch regulators to transform situations on or off. Additional switching regulators can achieve high energy conversion efficiency because their small power losses during on and off state of switch compared to linear.

Clean energy resources like wind Turbine, photovoltaic panels or fuel cells have been used to develop renewable energy generation systems. The multi-input DC-DC converter is useful in combining different power sources whose capacity and voltage levels vary for a well-regulated output voltage[10].

DC-DC converters are well developed for low and medium power applications. The development of highly efficient and cost-effective DC-DC converters for vehicle applications is in continuous progress. This is due in part to stringent electromagnetic interference (EM) Standards and temperature issues[11]. Most transportation around the world relies on petroleum vehicles for emitting greenhouse gases. Moreover, the fuel rate increase motivates researchers to work on photovoltaic (PV) and electric vehicles (EV). In these applications, electronic power circuits, especially high-speed DC current converters, play a vital role in electric vehicle charging stations to take full advantage of the energy generated by the PV and help integrate with a network's supply.

2.3 Classification of DC/DC converter

There are two main types of DC-DC converters, linear and switching converters. Both regulators are using to change input DC voltage into another DC voltage level. However, in switch-mode regulators can step-up and step-down input voltage while linear regulator can only step-down input voltage.

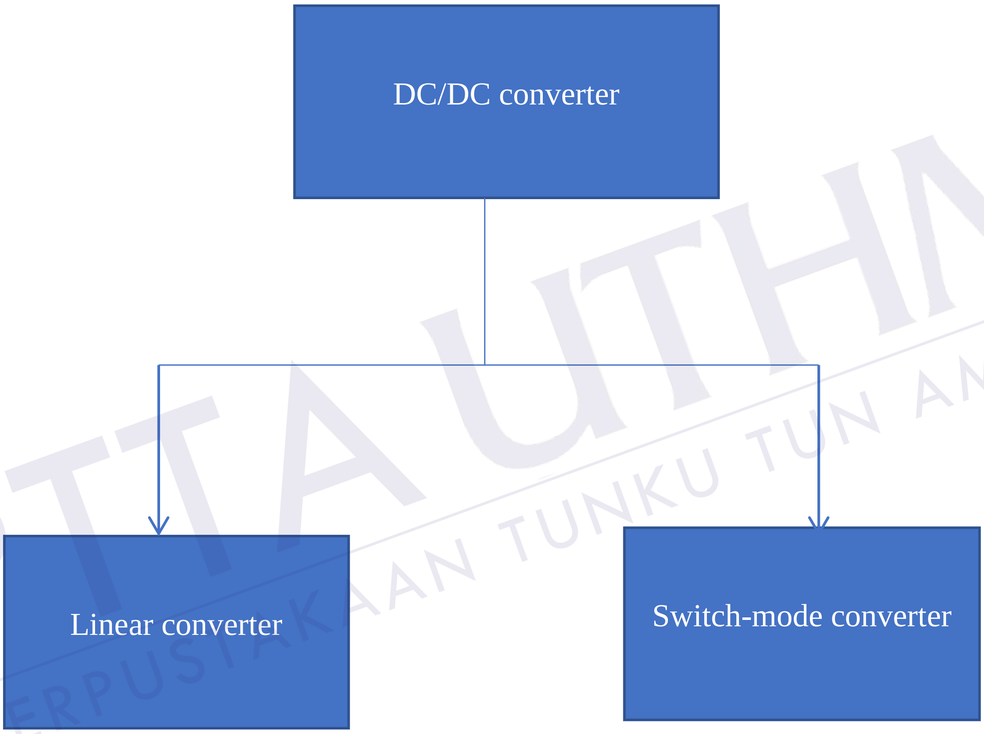

Figure 2.1: Classification of DC/DC converter

2.3.1 Linear converter

A linear regulator converts one level of dc into lower dc level, generally uses a series pass element, the transistor. This series pass transistor operates in linear region characteristic. However, it requires a specific minimum voltage drop known as the threshold voltage, between discharge to the MOSFET source, which is to start the process in terms of energy level for majority carriers[12][13][14]. The first regulators required low drop-out voltage greater than one volt, whereas most regulators are low drop-out (LDO) design that can operate a few hundred millivolts.

The internal circuit of linear regulator contains an error amplifier, reference voltage source and transistor. Its circuit is a feedback loop and is one of the primary control circuits that use an operational amplifier. The pass element can be transistor types such as MOSFET that act as a variable resistance. There are different variate of linear regulators, and some regulators regulate negative outputs, some converters have fixed outputs, and some regulators have output programmable by the resistor divider. Some other regulators have small output voltage it known as low drop-out regulators.

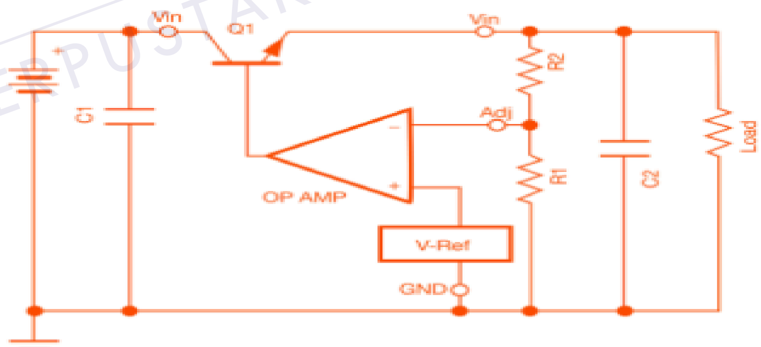

Figure 2.2: Basic diagram circuit of linear regulator [36]

2.3.2 Switch-mode converter

DC-DC switching converters have been used as a modern power source in recent decades. DC-DC Switching converters are power converters that generate regulated output voltage to the loads while protecting overcurrent and short circuits. These converters are fed by AC single phase or three phase network or a conventional rectifier diode. Switch-mode converters are non-reversible converters, gives unipolar output voltage and current to the DC load. Before the DC-DC converter, the AC network connects to transformer and diode rectifier. The transformer dedicates current and voltage adaptation. Afterword, diode rectifier converts AC to DC. The output DC voltage from diode isn't regulated. The LC filter is using to minimise or cancel strong ripple voltage from diode rectifier in this situation. Therefore, this filter act as a voltage source to DC-DC converters [2].

The switch-mode converters are divided into two main parts, isolated and non-isolated converters. In isolated converters, isolated structures are used to increase the voltage to high levels. Besides, it leads to a safe system against external disturbances or low voltage part[15][16]. In non-isolated converters uses inductor as a storage element. However, their topologies are different to realise different types of the non-isolated converter. The most-useful converters are buck, boost and buck-boost converter. Converters mentioned above are basic topologies that drive all other topologies of non-isolated converters.

Basically, in switching converter has a two-mode operation, CCM (continuous current mode) and DCM (discontinuous current mode). In CCM, the inductor current never reaches zero during discharging. But in DCM, the inductor current starts from zero and falls to zero levels during charging and discharging of an inductor, respectively[2].

2.3.2.1 Buck Converter

In power electronics, the Buck converter is a circuit used to convert DC voltage to lower DC voltage. It contains two types of switch: control switch (made by transistor or MOSFET) and the other is not controlled (made by diode). When the transistor is on, the diode is off, and the current version is through the inductor and load. When the transistor is turned off, the current is float through diode and decoys. The direct current operation is achieved by correctly selecting the on and off frequency and inductance value [17]. They are used as an interface between battery and components in Notebooks, as Point-of-load (POL) converters in servers, and in advanced telecom and datacom systems.

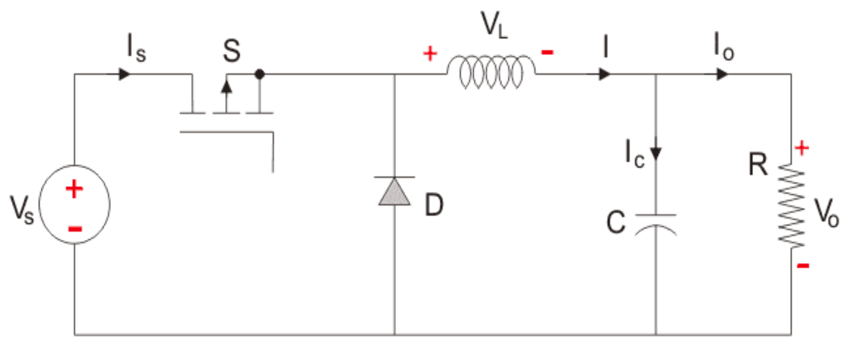

Figure 2.3: Buck converter

Table 2.1: Advantages and disadvantages of buck

Advantages	Disadvantages
The circuit efficiency is high	Input current is discontinuous and smoothing input filter is required
Stable not sensitive to noise	High output ripple
The Current ripple of load current is controlled by inductor	Slow transient response

2.3.2.2 Buck-Boost Converter

In Buck-boost converter, is the combination of a buck with a boost converter, generate an output voltage that greater or less than input DC voltage. It can either work as a buck -mode or boost-mode. It has two types of topologies, inverting and non-inverting. For Inverting, the output voltage has different polarity than the input voltage. And non-inverting, the input and output voltage has the same polarities[18][19]. It mostly used in the automated power supplies, power amplifier applications and the battery power systems.

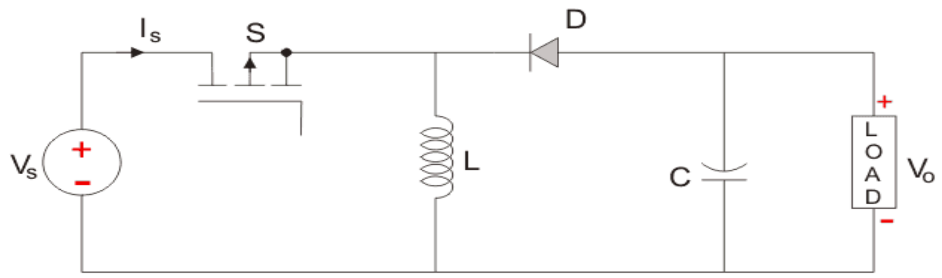

Figure 2.4: Buck-boost converter

Table 2.2: Advantages and disadvantages of buck boost converter

Advantages	Disadvantages
It performs step-up and step-down operation using small components	It has no isolation between input and output which is critical for many application
It provides lower operation duty cycle	It requires large filter since input and discharge current at capacitor are discontinuous
Less expensive compared to the most converter	Efficiency for gain is low since it can't reach high gain
It provides high efficiency	It's very difficult to control such converter type.

2.3.2.3 Boost Converter

DC-DC boost converter topology converts DC low levels to higher levels by temporarily storing input power and then releasing it at the output at a higher voltage level. This storage can occur in magnetic field storage components (single inductor/coupling inductor) or electrical field storage components (capacitors) through the use of various active or passive switching elements (power switches and diodes) [20].

In boost converter, the inductor is storage elements, while the two others are switching elements. These switching elements are divided into two, passive and active switch. A passive switch switches automatically, for instance diode. Active switching controls switching by a controller like PWM (pulse width modulation) or digital controllers, these active switches are transistors [20].

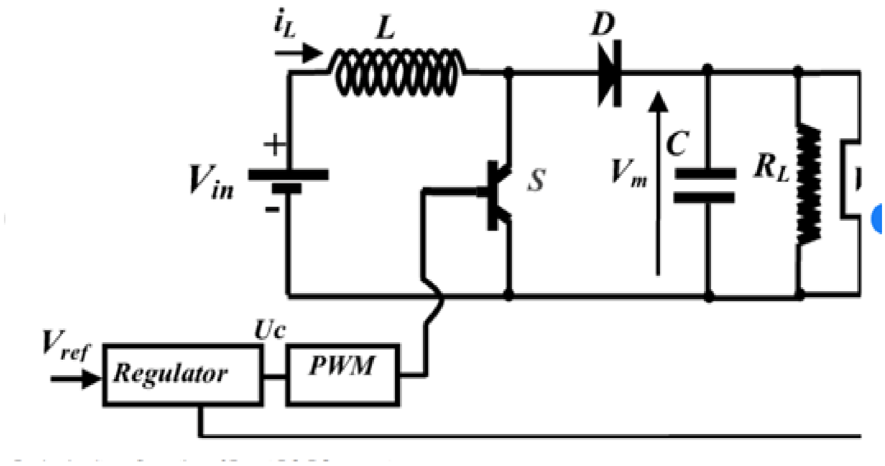

Figure 2.5: DC/DC boost converter with pulse width modulation

Table 2.3 Advantages and disadvantages of boost converter

Advantage	Disadvantage
It will boost the output voltage without a transformer	High peak current flows through to switch
It gives high-efficiency due to single switch operation	Output voltage is highly sensitive to changes in duty cycle

2.4 Comparison of Linear and Switch-Mode DC/DC Converter

A power converter produces load current and voltage from a defined power source, which provides load current and voltage for the load. In case of a fault, fluctuation or failure, it also protects load components and the system. According to the explicit application, a linear regulator (LR) or switched power supply (SMPS). In DC-DC switching converters can provide ripple in the output voltage due to the switching process; whereas, a linear regulator eliminates this ripple and produces an overcurrent that the switching converters do not provide [21] [14].

In linear regulator, a series pass element is a transistor, this series of transistors operates in linear region characteristics which cause much greater loss than switching converter. In terms of efficiency, this converter's efficiency depends

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