DESIGN AND ANALYSIS OF MULTIIPHASE DC/DC BOOST CONVERTER WITH MINIMIZED INPUT CURRENT RIPPLE

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ABSTRACT

Nowadays, the DC source has become alternatives options to solve global warming and energy consumption. DC/DC converter is widely used in many low voltage application such as telecommunication, electric vehicle, aircraft, etc. which range between 12V until 48V. Besides, the DC/DC converter also can be applied in home applications; television, radio, washing machine, CCTV and so on. DC/DC boost converter is used to step up the input voltage into the desired voltage. To increase the conventional boost converter capability, the multiphase structure with interleaved technique is proposed. This design capable to reduce current stress, input current ripple and conduction losses. Moreover, the input current ripple only can be alleviated by using a suitable duty cycle. Therefore, the Modified Pulse Width Modulation (MPWM) is applied to reduce the input current ripple in wide ranges. Besides, the Zero-Voltage Switching (ZVS) technique is used to reduce the switching losses across the switch. The proposed converter is simulated by using OrCAD Pspice software programs. The PWM switching scheme is designed using Quartus II software before it uploaded into Altera DE2-70 device. A hardware prototypes with 15 V to 30 V input voltage,30 V to 60V output voltage, 50W to 200W output power and 100 kHz switching frequency is built and tested to demonstrate the effectiveness of the proposed converter. The 3-level multiphase boost converter with ZVS technique achieves 91.95% efficiency compared to hard-switching multiphase boost converter. Despite that, the switching loss is completely reduced by using ZVS technique in certain power ranges. Additionally, the input current ripple also can be reduced by using a modified PWM switching signal compared common interleaved technique in wide duty ranges.

ABSTRAK

Pada masa kini, sumber DC telah menjadi pilihan alternatif untuk menyelesaikan pemanasan global dan penggunaan tenaga. DC / DC converter digunakan secara meluas dalam banyak aplikasi voltan rendah seperti telekomunikasi, kenderaan elektrik, pesawat terbang, dan lain-lain yang berkisar antara 12V hingga 48V. Selain itu, penukar DC / DC juga dapat digunakan dalam aplikasi rumah; televisyen, radio, mesin basuh, CCTV dan sebagainya. DC / DC boost converter digunakan untuk meningkatkan voltan masukan ke voltan yang diinginkan. Untuk meningkatkan keupayaan penukar rangsangan konvensional, struktur multiphasa dengan teknik interleaved dicadangkan. Reka bentuk ini mampu mengurangkan tekanan semasa, arus riak input dan kehilangan konduksi. Selain itu, riak arus input hanya dapat dikurangkan dengan menggunakan kitaran tugas yang sesuai. Oleh itu, Modulasi Pulse Width Modified (MPWM) diaplikasikan untuk mengurangkan riak arus input dalam jarak yang luas. Selain itu, teknik Zero-Voltage Switching (ZVS) digunakan untuk mengurangkan kerugian beralih di seluruh suis. Penukar yang dicadangkan disimulasikan dengan menggunakan program perisian OrCAD Pspice. Skema pensuisan PWM dirancang menggunakan perisian Quartus II sebelum dimuat naik ke dalam peranti Altera DE2-70. Prototaip perkakasan dengan voltan input 15 V hingga 30 V, voltan output 30 V hingga 60V, kuasa output 50W hingga 200W dan frekuensi pensuisan 100 kHz dibina dan diuji untuk menunjukkan keberkesanan penukar yang dicadangkan. Penukar rangsangan berbilang tahap 3 dengan teknik ZVS mencapai kecekapan 91,95% berbanding dengan penukar rangsangan berbilang fasa yang sukar ditukar. Walaupun begitu, kehilangan suis dikurangkan sepenuhnya dengan menggunakan teknik ZVS dalam julat daya tertentu. Selain itu, riak arus input juga dapat dikurangkan dengan menggunakan isyarat pensuisan PWM yang diubah berbanding teknik interleaved biasa dalam rentang tugas yang luas.

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LIST OF SYMBOL AND ABBREVIATIONS

A	-	Ampere
DC	-	Direct Current
HEA	-	Home Electrical Appliances
PWM	-	Pulse Width Modulation
MPWM	-	Modified Pulse Width Modulation
ZVS	-	Zero-voltage switching
EMI	-	Electromagnetic Interference
ZCS	-	Zero-current switching
ZVT	-	Zero-voltage transition
V	-	Voltage
W	-	Watt
AC	-	Alternating Current
PPPS	-	Parallel-primary parallel-secondary structure
PPSS	-	Parallel-primary series-secondary structure
SPPS	-	Series-primary parallel-secondary structure
SPSS	-	Series-primary series-secondary structure
SEPIC	-	Single-ended primary inductance converter
CBC	-	Conventional DC/DC boost converter
PRCC	-	Passive Ripple Cancelling Circuit
RM	-	Ripple Mirror
CCM	-	Continuous current mode
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
R_{on}	-	ON-resistance
dv/dt	-	Rate of voltage
di/dt	-	Rate of current
CM	-	Common-mode
DM	-	Differential-mode
I_{rr}	-	Current diode in reverse direction
DCM	-	Discontinuous current mode

T	-	Switching period
f_s	-	Switching frequency
N	-	Number of phase/level
D	-	Duty cycle
I_L	-	Inductor current
V_{GS}	-	Voltage gate source
I_{DS}	-	Current drain source
V_{DS}	-	Voltage drain source
ISSBC	-	Interleaved soft-switching boost converter
PV	-	Photovoltaic
PVPCS	-	PV power conditioning system
QRCs	-	Quasi-resonant converter
P_{out}	-	Output power
DSP	-	Digital Signal Processing
FPGA	-	Field Programmable Gate Arrays
VHDL	-	Very High Description Language
I_{in}	-	Input current
S	-	Switch
C	-	Capacitor
R	-	Resistor
L	-	Inductor
D	-	Diode
V_o	-	Output voltage
dI_L/dt	-	Rate of inductor current
$\Delta I_{L(rising)}$	-	Rising slope
$\Delta I_{L(falling)}$	-	Falling slope
P_{in}	-	Input power
V_{in}	-	Input voltage
Δr	-	Ripple voltage
BJT	-	Bipolar Junction Transistor
IGBT	-	Insulated Gate Bipolar Transistor
ΔI_L	-	Inductor ripple
k	-	Integer number

V_{tri}	-	Carrier waveform
V_{ref}	-	Reference waveform
$\Delta duty$	-	Duty cycle resolutions
$counter$	-	Number of counts
Δsc	-	Shifted count
PLL	-	Phase-Locked Loop
L_r	-	Resonance Inductor
C_r	-	Resonance Capacitor
t	-	Time
max	-	Maximum
min	-	Minimum
P_{SW}	-	Switching loss
W_{on}	-	Energy loss during on transition
W_{off}	-	Energy loss during off transition
V_F	-	Forward voltage
I_F	-	Forward current
P_{cond}	-	Conduction loss
$P_{cond,MOSFET}$	-	Conduction loss in MOSFET
$P_{cond,diode}$	-	Conduction loss in diode
I_{diode}	-	Diode current
CH	-	Channel

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chapter 1 presents the details information of this research which consist background of study, problem statement, objectives, scope of studies and thesis outline. The background studies covers up the surface of proposed research and the information of DC/DC boost converter applications. The next subtopic explains the ideas of proposed researched to solve the problem in DC/DC boost converter. The main objectives of proposed research are listed in this topic. Finally, the scope of the studies and thesis outlines are shown.

1.2 Background of Study

Throughout human civilization, electrical energy has become a necessity for all human beings. As the growth of the year, the depletion of fossil fuels has become a serious concern for the future generation. Thus, renewable energy becomes the best solution for this fear [1], [2]. Renewable energy comes from limitless sources such as solar, wind, wave, thermal and hydro, which can replenish itself in short amount time. Besides, renewable energy has a great benefit to the global atmosphere as most of them has zero pollution in the environment. Generally, all renewable energy system provides DC electrical energy as their output [3]. Renewable energy commonly applied in distribution generation; grid-connected [4],[5] and stand-alone configuration [6],[7]. Also, fuel cell and micro-turbine can be considered as renewable energy if the input DC voltage comes from that energy [8]. However, most renewable energies provide low voltage output and need to regulate before applied to the equipment. Therefore, a suitable converter is required to interface the DC voltage from the supply to increase output voltage level and input current [1], [9], [10].

Recently, power converter has become one critical part of low voltage applications. Referring in [3], the range of low voltage is 120V or below than that. The low voltage application with high output power such as electric vehicles, communication, aircraft and data centre are used DC supply to operate the system. These applications are used DC supply because it has reliability in the backup source and not bound to frequency variation and power factor. Moreover, low DC voltage has largely applied in various equipment such as portable electronic devices, and digital electronic system. For example, most of the mobile phone used 5 V as their standard voltage; meanwhile, the voltages around 24 V until 48 V has been applied in mid-power applications such as laptops and computer screen [3]. In addition to, DC voltage has been applied in various high-power home electrical appliances (HEA) such as ovens [11], [12], washing machines [11] and irons, air conditioners [11], [12] and refrigerators [11], [13].

There are various DC/DC converter such as buck, buck-boost, and boost converter [14] is used to control the output voltage. The most popular converter used to step up input voltage among researchers is non-isolated DC/DC boost converter. This converter has advantages such as a simple arrangement of the circuit, low cost and less complexity compared to other typical converters [15], [16]. Conventional boost converter consists of several passive components which are diode, inductor, switch and filter capacitor. Typical boost converter usually not preferred in high-power, high-current application because the converter required an extreme duty cycle to gain high output voltage which can be degrading the overall conversion efficiency [17]. Instead of that, the boost converter is frequently utilized in renewable energy systems [15], [18], motor drives [15], electric vehicles [15] and lighting system [19]. Though, the problems in terms of current stress, input current ripple and power losses still unease to the performance of the application. There are several improvements to the conventional converter made to resolve the problem, as mentioned earlier.

Multiphase boost converter with the aids of the interleaving technique is presented among the researchers to increase the output voltage with low current stress. This method is required two or more power stages (inductor, switch and diode) which arrange in the parallel with the common filter capacitor. The interleaved technique is applied to phase shifting the power stages with the same switching frequency and duty cycle. This converter provide low input current ripple [18], [20]–[22], low component temperature , low conduction loss [22], [23] and reduce component size [18]. Still, this converter has a drawback when some application required a high switching frequency to reduce the size of the converter [24]. The abruptly switching transition due to high switching frequency is causing great switching loss in the converter.

In power electronic converter, the output voltage is controlled using Pulse Width Modulation (PWM) in the switch. Normally, the power converter is operated in hard-switching conditions which is the voltage and current across the switch are rectangular and overlapped to each other. The overlapped switching transitions during turn-on and turn-off switch cause switching losses, switching stress and electromagnetic interference (EMI) to the converter. This drawback is obviously can be observed when the high switching frequency is applied. This is because high switching frequency allows the high switching transitions between voltage and current across the switch. Hence, many researchers proposed auxiliary circuit or known as snubber cells to reduce those problems [25], [26]. One of the effective methods is using a resonant component known as a soft-switching technique to smooth the shape of current or voltage across the switches. The resonant circuit can be categorised into three types which are resonant, quasi-resonant and multi-resonant [27]. Consequently, causing zero switching losses during turn-on or turn-off conditions. Soft-switching can be categorised into two types which is zero-voltage switching (ZVS) and zero-current switching (ZCS). Besides, the zero-voltage transition (ZVT) and zero-current transition (ZCT) also been used by the researcher to reduce the losses in the converter. The advantage of ZVS and ZCS technique is only power losses can be reduced [28], [29] meanwhile ZCT and ZVT technique can restore their power losses [28]. In this technique, the soft-switching technique only occurs during the switching transitions, others than that the operation still in the hard-switching mode [30].

This research proposes multiphase boost converter with the combination of interleaving technique and soft-switching technique. The outcome of this research are expected to have low current stress, low conduction loss and low power loss which has explained in the previous paragraph. The ZVS is applied in the converter by paralleling the resonant capacitor with the switch. The comparison in terms of power losses and current stress will be made between hard-switching and soft-switching technique.

1.3 Problem Statement

Recently, the DC/DC boost converter is widely used to step up the unregulated voltage from renewable energy or battery into the desired output voltage. Besides, this converter is used in many low voltage applications such as communication, military, aircraft and electric vehicle. Moreover, home electrical appliances (HEA) such as oven, refrigerator, television and radio used DC supply to operate the system. A conventional boost converter is selected among researchers due to simple arrangement, less component requirement and less space area. Nevertheless, the conventional boost converter has several drawbacks such as high current stress, high current ripple, high conduction and switching losses to the converter.

In high power application, the conventional boost converter suffers high current stress across components. A concern on high current stress has been outlined in [31]–[34]. High current stress cause the temperature of the component increase and eventually reduce the reliability of the component. Besides, the conduction losses are increase when the high current flow across the semiconductor device. The multiphase structure is one of the effective solutions in reducing current stress and conduction losses. The terms of multiphase come when the conventional boost converter is parallel in several levels. The ideas of this structure are to reduce the current flow across the components by splitting the input current in each level. Moreover, this structure reduce the rating of the components as well as the size of the converter.

Conventional boost converter required large inductor to reduce the input current ripple in the converter. The higher input current ripple shortened the lifetime of the component, which cause degrading to the performance of the converter. Therefore, the research on reducing input current ripple has been outlined in [35]–[39]. Multiphase with interleaved technique is a promising solution to reduce input current ripple and has been proved in. Interleaved technique is created by phase-shifting the signals with similar duty cycle and switching frequency. This method is used to shifting the time turn-on and turn-off between switches. Hence, the current flow in each inductor will eventually phase shifted. The phase-shifted current inductors are cancelling each other to reduce input current ripple. However, the input current ripple only can be reduced when the signals are not overlapped. Thus, a suitable duty cycle is needed to reduce input current ripple. Moreover, the reduction of the input current ripple increases the size, weight and complexity of the circuit. As solution, the higher switching frequency is proposed to reduce the size of the converter.

High switching frequency causes the fast switching transitions during turn-on and turn-off semiconductor devices. The frequent overlapping between the current and voltage waveform causes high switching loss during switching transition. Hence, there are several solutions proposed in [40]–[42] to overcome that problem. One effective technique is using a resonant circuit or known as soft-switching technique. The soft-switching technique is used to smooth the switching transition during turn-on and turn-off of the switch. The soft-switching technique occurs when the voltage and current flow through the switch is slowing down using the resonant circuit. Thus, it will reduce the spiking when the switch is overlapped. The reduction of switching losses lowers the electromagnetic interference (EMI).

In this project, 3-level multiphase DC/DC boost converter is proposed. The modified PWM scheme is introduced to allow the proposed converter to operate in low input current ripple with wide duty ranges. Besides, the soft-switching technique is applied to reduce the switching losses in the multiphase converter. Combining the features of the multiphase structure, interleaved technique and soft-switching technique are made to reduce the input current stress, input current ripple, conduction losses and switching losses in the converter.

1.4 Objectives

The main objective of this research is;

a) To proposed multiphase DC/DC boost converter using interleaving technique with minimization of input current ripple.

b) To analyses the performance of multiphase DC/DC boost converter in hard-switching and soft switching technique in terms of current stress and semiconductor losses.

1.5 Scope of Study

This research is focused on the development Multiphase Boost Converter to achieve the best performance. To achieve the objective of this project, the scope of study minimize as follows;

I. OrCAD PSpice software is used for designing circuit simulation.

II. Altera DE2-70 board is used as a microcontroller.

III. The parameters for simulation and hardware prototype are approximately similar.

IV. The number of levels used is limited to 3-phase.

V. Input voltage is 15 V-30 V.

VI. The output voltage is 30 V until 60 V

VII. The output power is 50 W until 200 W.

VIII. Switching frequency is set to 100 kHz.

IX. Passive components used are 220 μH inductor and 470 μF capacitor.

1.6 Thesis outlines

The research consists of six chapters and is organized as follows;

Chapter 2 (Literature review) explains in details about renewable technologies. The basic concept of the multiphase converter will explicitly be discussed. Next, the overview of the soft-switching technique is well described in this chapter. The previous work related to the proposed topic are discussed. The research gap on the previous multiphase DC/DC converters is outlined.

Chapter 3 (Methodology) provides the operation of a multiphase boost converter with soft-switching technique circuit in details. The mathematical expression is shown to get the best parameter design for the converter.

Chapter 4 (Input current ripple minimization analysis) discussed on input current ripple in multiphase boost converter. This chapter covers the results for objective 1 of this research.

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