NOVEL SOFT SWITCHING ISOLATED DC-DC CONVERTERS TOPOLOGIES

by

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LIST OF ABBREVIATIONS

AWG	American Wire Gauge
DC	Direct Current
DCM	Discontinuous Current Mode
EMI	Electromagnetic Interference
HEX	Hexadecimal
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RC	Resistor-Capacitor
RF	Radio Frequency
ZCS	Zero Current Switching
ZVS	Zero Voltage Switching
ZVZCS	Zero Voltage Zero Current Switching

LIST OF SYMBOLS

A	Ampere
A_c	Core Cross-sectional Area
A_p	Area of Product
$A_{wp(B)}$	Primary Bare Wire Area
B	Flux Density
C_f	Flying capacitor
C_n	Capacitor
D_n	Diode
$D_{(max)}$	Maximum Duty Cycle
E_n	Emitter
f	Frequency
f_s	Switching Frequency
Hz	Hertz
I_{CC}	Supply current
I_d	Current IGBT
$I_{d(avg)}$	Diode Average Rated Current
I_{Dbn}	Current through Body Diode
I_{Epk}	Peak Current
I_{Erms}	Rated rms Emitter Current
I_f	Forward Current
I_f	Voltage across Flying Capacitor
I_{FAVM}	Maximum Average Forward Current
I_{FLH}	Threshold Input Current Low to High
$I_{F(on)}$	Input Current (ON)
I_{in}	Input Current
I_n	Current
I_o	Output Current
I_p	Transformer Primary Current
I_{RM}	Reverse Recovery Current
I_{rr}	Reverse Recovery Current

I_{RRM}	Maximum Recovery Current
J	Current Density
k	Kilo (10^3)
K_f	Constant of Proportionality
K_u	Winding Fill Factor
L_o	Output Inductor
L_r	Leakage Inductance
n	Transformer turn ratio
N_p	Transformer Primary Turn
N_s	Transformer Secondary Turn
P_I	Input Power Dissipation
P_{in}	Rated Input Power
P_o	Output Power Dissipation
P_{off}	Off-state Power
P_{on}	On-state Power
P_t	Total power
R	Resistor
$R_{DS(on)}$	On-state Resistance
R_L	Load Resistor
S_n	Switch
T	Time
t_f	Fall Time
t_{off}	Off Time
t_{on}	On Time
t_r	Rise Time
T_{rr}	Reverse Recovery Time
T_P	Primary Transformer
T_S	Secondary Transformer
V	Voltage
V_{BD}	Breakdown Voltage
V_{cc}	Supply Voltage
V_{CE}	Collector-emitter voltage
$V_{ce(max)}$	Maximum Collector-Emitter Voltage

V_{Cf}	Voltage Across Flying Capacitor
V_{dc}	Direct Current Voltage
V_{DD}	Drain Voltage
$V_{D(rr)}$	Diode Reverse Recovery Voltage
V_f	Forward Voltage
V_f	Voltage across Flying Capacitor
V_{FLH}	Threshold Input Voltage High to Low
V_{GE}	Gate-emitter voltage
V_{in}	Input Voltage
V_{ITH}	Input Threshold Voltage
V_o	Output voltage
V_p	Primary Voltage
V_{RM}	Maximum DC reverse voltage
V_s	Secondary Voltage
W	Watt
α	Regulation
η	Efficiency
%	Percentage

TOPOLOGI SUIS PENUKAR ARUS TERUS TERPENCIL YANG NOVEL

ABSTRAK

Penukar arus terus banyak digunakan di dalam pelbagai aplikasi seperti di dalam sistem penjanaan kuasa, aplikasi tenaga suria, aplikasi sistem tenaga yang boleh diperbaharui dan aplikasi industri. Walaubagaimanapun, masalah utama penukar arus terus adalah kehilangan pensuisan di mana kadar kecekapan dan kepadatan tenaga penukar arus terus turut dipengaruhi. Oleh yang demikian, di dalam thesis ini mengetengahkan pembaharuan pelancar suis penukar arus terpencil. Pembaharuan dibuat adalah untuk mengurangkan kehilangan pensuisan terhadap penukar arus terus. Tiga topologi penukar arus terus terpencil yang diketengahkan di dalam tesis ini, iaitu penukar arus terus terpencil separa dengan litar tambahan, penukar arus terus terpencil penuh dengan penyongsang bertahap dan penukar arus terus terpencil penuh dengan litar tambahan. Penukar arus terus terpencil separa dengan litar tambahan telah direka dan diuji dengan litar penerus titi gelombang penuh dan litar penerus gelombang penuh sadap tengah.Topologi-topologi yang deketengahkan direka dan diuji dari segi pelancaran suis. Operasi pelancar suis ini dikecapi melalui proses mengecas dan menyahcas kapasitor dan suis tambahan di dalam setiap topologi. Didapati kesemua suis beroperasi dalan pelancar suis. Oleh itu, kehilangan pensuisan dapat dikurangkan. Voltan keluaran litar adalah dikawal melalui pemodulatan lebar denyut. Keberkesanan topologi-topologi yang dikemukakan dinilai daripada hasil simulasi dan ujikaji yang diperolehi daripada prototaip yang berkala kecil. Hasil ujikaji didapati sama dengan hasil simulasi. Penukar arus terus terpencil dengan litar tambahan dan litar penerus gelombang penuh sadap tengah adalah yang terbaik di antara topologi-topologi yang

dikemukakan kerana topologi ini mencapai kadar kecekapan 81% pada kuasa keluaran 25W.

NOVEL SOFT SWITCHING ISOLATED DC-DC CONVERTERS TOPOLOGIES

ABSTRACT

DC-DC converters are widely used in many applications such as power supplies, PV system, renewable energy systems and industrial applications. One of the main problems in dc-dc converters is the switching loss which affects efficiency and also the power density of the converter. To alleviate the switching loss problem this thesis proposes novel soft switching PWM isolated dc-dc converters topologies. Three topologies of dc-dc converters are presented in this thesis. These are half-bridge dc-dc converter with auxiliary circuit, full-bridge dc-dc converter with multilevel inverter leg and full-bridge dc-dc converter with auxiliary circuit. The proposed half bridge dc-dc converter with auxiliary circuit is designed and tested both with diode bridge rectifier and centre-tapped transformer rectifier. The proposed converters are designed and evaluated in term of soft switching. Soft switching operations are achieved by charging and discharging process of the flying capacitor. In proposed topologies, all the power switches operate under soft-switching conditions. Therefore, overall switching loss of the power switches is greatly reduced. The output voltages of the converters are varied by PWM control. The effectiveness of the new converters topologies is evaluated both by simulation and experimental results of a laboratory scale down prototype. The obtained experimental results are found in good agreement with the simulation results. The proposed half-bridge dc-dc converter with auxiliary circuit and centre-tapped transformer rectifier has highest efficiency among all the proposed topologies. Its efficiency is 81% at the output power of 25W, so it is considered best among all the proposed topologies.

CHAPTER 1

INTRODUCTION

1.1 General View and Motivation

Power supplies come with different types of power ratings. The design of the power supplies are depending on their applications. For example in telecommunication system, industrial motor and welding machine require high ratings of power supplies (Jain, et al., 2002; Iannello, et al., 2002; Wu, et al., 2004). Meanwhile, in portable products and in computer system operate in low power and hence low power rating power supply is needed (Kaewarsa, et al., 2004; Panda, et al., 2009; Rodrigues, et al., 2009). Commonly, few topologies are used in designing the power supply either non-isolated or isolated converters. Nowadays, designing power supply has become a great challenge as the requirement of higher efficiency and power density of the power supply (Abedinpour, et al., 2001; Jain, et al., 2002; Wu, et al., 2004).

Looking back at the power supply technology in the early of fifties and late of sixties, linear regulator becomes a dominant core in power conversion. Linear regulator comes with ease of operation, simple and inexpensive (Simpson; Bu, 2007; Daniel, 2011; Saiful, 2011). However, there are some limitations of linear regulator in operating in high power (Bu, 2007; Saiful, 2011). Operating linear regulator in high power causes few drawbacks such as high power dissipation, low efficiency and bulky (Daniel, 2011; Saiful, 2011; Li, 2012). Power dissipation produced by linear regulator is high due to huge different of the input and output voltage, thus low efficiency is obtained when operating in high power (Rogers, 1999; Chava, et al., 2004).

Linear regulator has become a main core in power conversion for a few decades. However, in the late of sixties the linear power supplies are replaced with high frequency switch mode power supplies. The introduction of the high voltage bipolar power transistor in the late of sixties has driven the replacement of the linear power supplies with switch mode power supplies (Jovanovic, 2012). Significantly, allows the reduction of the size and weight and higher efficiency power supplies (Jovanovic, 2012; Li, 2004; Saiful, 2011).

The size and weight reduction of the power supplies are mainly determined by the switching frequency as the switching frequency is inversely proportional to the size and the weight of the supplies (Carr, et al., 2009; Sugimura, et al., 2009; Ting, et al., 2012). Thus, switch mode power supplies offer higher efficiency compared with the linear power supplies. However, the tradeoffs of the switch mode power supplies are between the switching frequencies and the losses such as switching loss and conduction loss (Sugimura, et al., 2009; Sivavara, et al., 2012; Songboonkeaw and Jangwanitlert, 2012).

Earliest, the switch mode power supplies are limited to its switching frequencies to several kilohertz only with the implementation of the bipolar power devices (Jovanoic, 2012). Thus, with the debut of power MOSFET allows the switching frequencies go beyond hundreds-hertz even mega-hertz (Jovanovic, 2012). This will significantly allow more reduction of the size and weight of the power supplies (Abedinpour, et al., 2001; Carr, et al., 2009). Together with the advancement technology in the magnetic component allows further reduction of the size and weight of the power supplies (Chen and Ruan, 2005; Hu, et al., 2012). For an example, in computer voltage regulator with the advancement of the technology allows the switching frequency of the voltage regulator goes up to 1 Megahertz (Jovanovic, 2012). Thus, smaller power supply of the computer is obtained.

Until recent, the power supplies efficiency is depend on the power density. Thus, the optimizations of the design tradeoffs are needed in order to meet these requirements. The losses produced from the higher switching frequencies are the major drawbacks of the current power supplies (Sugimura, et al., 2009; Sivavara, et al., 2012; Ting, et al., 2012). In early of nineties, the governments of the most of the countries have urge power supplies to a better efficiency due to the environmental and economic concerns (Jovanovic, 2012; Abedinpour, et al., 2001; Sivavara, et al., 2012). Thus due to this requirement has given a great challenge to power supplies manufacturers and designers.

1.2 Problem Statement

There has been continuous effort to increase the power density and efficiency of the power supplies. Higher frequency operation of power supplies result in smaller size due to reduction of the size of magnetic component (Chen, et al, 2005; Zhang, et al., 2011; Hu, et al., 2012). However, the switching loss and conduction loss of the power devices are higher (Hong, et al., 2008). Thus, bigger heat sink is needed for each of the power devices. Moreover, operating at high switching frequency also agitate the overvoltage stress across the power devices (Ayyanar and Mohan, 2001; Iannello, et al., 2002; Wu, 2004; Uslu, 2006). This may cause damage to the component or higher rating component need to be used in the design. This indirectly will increase the cost of the power supplies.