APPLICATION OF NATURAL COMMUTATION TECHNIQUE TO AN IMPROVED CYCLOCONVERTER TYPE HIGH-FREQUENCY LINK INVERTER WITH CENTER-TAPPED TRANSFORMER

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ABSTRACT

This thesis presents a new isolated cycloconverter type high frequency (HF) link dc to ac power converter (inverter) that consists of three arms of bidirectional switches at transformer secondary. This topology has the advantage of light weight and reduced switch count, compared to other types of HF link inverter. However, like all HF link inverter topologies, this topology also suffer high voltage surge problem and power device switching loss. In order to overcome these problems, two sets of switching technique, namely the asymmetric bipolar PWM control and edge-aligned unipolar PWM control, are introduced. These switching techniques utilize natural commutation technique that enables total soft switching operation and voltage surge reduction. Furthermore, the proposed switching techniques are able to reduce the transistor conduction loss due to the existence of freewheeling period. The research work verifies of the proposed topology and switching techniques by means of SPICE simulations. It also describes the natural commutation mechanism for HF link inverter in detail. An open loop laboratory prototype based on the Infineon C167 fixed-point microcontroller was constructed. The results obtained from the experimental rig were found to be in very close agreement with the theoretical prediction and simulation. The laboratory prototype was able to supply output voltage 340V_{rms} as well as 120V_{rms}, with THD less than 2.5%. The total power conversion efficiency reaches 86% when the output power was beyond 300W.

ABSTRAK

Tesis ini membentangkan satu penukar kuasa dc ke ac (penyongsang) terpisah transformer frekuensi tinggi jenis *cycloconverter* baru yang mempunyai tiga suis dwi-hala di bahagian sekunder transformer. Topologi ini mempunyai kelebihan ringan dan kurang bilangan suis, berbanding dengan jenis penyongsang terpisah transformer frekuensi tinggi yang lain. Namun demikian, seperti penyongsang terpisah transformer frekuensi tinggi yang lain, topologi ini juga mengalami masalah voltan pusuan dan kehilangan kuasa perkakasan yang tinggi. Untuk mengatasi masalah-masalah ini, dua set teknik pensuisan iaitu *asymmetric bipolar PWM control* dan *edge-aligned unipolar PWM control*, telah diusulkan. Teknik pensuisan ini menggunakan teknik komutasi tabii yang membolehkan operasi pensiusan lembut dan pengurangan voltan pusuan. Tambahan pula, teknik pensuisan yang diusulkan ini adalah berupaya untuk mengurangkan kehilangan konduksi transistor kerana kewujudan tempoh *freewheeling*. Usaha penyelidikan ini penentusahkan topologi dan teknik pensuisan yang diusul dengan melaksanakan simulasi SPICE. Teks ini juga menjelaskan teknik komutasi tabii bagi penyongsang terpisah transformer frekuensi tinggi dengan teliti. Satu prototaip makmal gelung terbuka yang dikawal oleh mikropengawal C167 telah dibinakan. Keputusan yang telah diperolehi daripada eksperimen ini adalah bertepatan dengan jangkaan teori dan simulasi. Prototaip makmal telah mampu membekalkan voltan keluaran $340V_{rms}$ dan $120V_{rms}$, dengan THD kurang daripada 2.5%. Efisiensi jumlah penukaran kuasa menjejaki 86% apabila kuasa keluaran melebihi 300W.

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LIST OF SYMBOLS AND ABBREVIATIONS

A_c	-	Winding area
ac	-	Alternating current
A_e	-	Core area
A_e	-	Inductance factor
ABPWM	-	Asymmetric bipolar pulse-width modulation
B	-	Flux density
B_{peak}	-	Peak flux density
B_{sat}	-	Saturation flux density
C_f	-	Filter capacitor
C_{out}	-	Transistor output capacitance
C_s	-	Snubber capacitor
CPLD	-	Complex programmable logic device
CPU	-	Center processing unit
dc	-	Direct current
DSTP	-	Destination pointer
EAUPWM	-	Edge-aligned unipolar pulse-width modulation
f	-	Output frequency
f_{CPU}	-	CPU clock frequency
H	-	Flux intensity
H_{peak}	-	Peak flux intensity
HF	-	High frequency
i_{out}	-	Output current
l_g	-	Magnetic core gap length
L	-	Inductance
LC	-	Inductor-capacitor combination
L_f	-	Filter inductor
N	-	Number of transformer/inductor turn
IGBT	-	Insulated gate bipolar transistor
m_f	-	Modulation ratio

M_I	-	Modulation index
M1 - M4	-	Transistors at transformer primary of the proposed topology
MX, *MY*, *MZ*	-	Transistors at transformer secondary of the proposed topology
SX, *SY*, *SZ*	-	Bidirectional switches of the proposed topology
MOSFET	-	Metal oxide silicon field effect transistor
N	-	Number of turn
NCPA	-	Natural commutation phase angle
RC	-	Resistor-capacitor combination
RCD	-	Resistor-capacitor-diode combination
R_s	-	Snubber resistor
SRCP	-	Source pointer
PWM	-	Pulse-width modulation
SPICE	-	Simulation program with integrated circuit emphasis
SPWM	-	Sinusoidal pulse-width modulation
THD	-	Total harmonic distortion
PEC	-	Peripheral event controller
PPx	-	Period register
PTx	-	Timer register
PWMCONx	-	Common register of PWM module
PWx	-	Pulse-width register
t_d	-	Dead time
t_{ov}	-	Overlapped turn-on time
v_{out}	-	Output voltage
V_{rms}	-	Root-mean-square voltage
V_s	-	Voltage source
ZCS	-	Zero current switching
ZVS	-	Zero voltage switching
ΔB	-	Total flux density swing
μ_ε	-	Effective permeability

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CHAPTER 1

INTRODUCTION

1.1 Overview

Prolonged global energy crisis has led to extensive research interest in renewable energy sources. As fossil and nuclear fuels are gradually depleting, wind and solar power can be explored to meet the growing electricity demand [1]. Such systems normally need dc to ac power converters or commonly known inverters as interfaces between the loads and the energy sources. The inverter generally serves two purposes: to convert dc voltage source to commercial ac voltage, and to provide electrical isolation. With bidirectional power flow ability, the inverter is able to allow the ac power produced to supply stand-alone electrical loads or to feed the grid.

Pulse-width modulated voltage source inverter with an output filter and a 50Hz isolation transformer is the conventional topology used to meet the abovementioned requirements. The inverter uses pulse width modulation (PWM) scheme to synthesize output voltage close to a sine wave, which is then filtered by using low pass filter. The isolation transformer electrically isolates the load from the source; hence preventing the output returns dc-common with the input returns. With the advancement of power semiconductor technology, the power switches can be operated at high frequency, thus reducing the size of filter. Nevertheless, the transformer size remains large so long as the transformer current is not alternating in high frequency. As a result, high-frequency (HF) link inverter configurations, which utilize HF transformer, have become an important alternative to the conventional 50Hz inverter [2].

There are two popular HF link inverter topologies, namely the “dc/dc converter” type and the “cycloconverter” type [3]. Dc/dc converter type HF link inverter is simple and robust, and is now commercially available. The dc link at the transformer secondary provides stability to the system but prevents bidirectional power flow. Another drawback of this inverter is that it consists of at least three power conversion stages. Cycloconverter type HF link inverter topologies are presently gaining more research interest. The topology allows bidirectional power flow, and is able to compensate harmonics and reactive powers. It normally consists of only two power conversion stages; hence reduce power device conduction loss.

However, both types of HF link inverter suffer from the problem of voltage surge at the transformer secondary because of fast alternating transformer current. Dissipative snubber proved to be effective to solve this problem but it reduces total efficiency. Active clamp circuits, which provide higher efficiency are also feasible but will lead to sophisticated circuit configuration and control method [4-5].

Another problem faced by HF link inverter is high transistor switching loss. Yonemori et al proposed the so-called “soft-switching phase-shifted PWM high-frequency inverter-linked cycloconverter”, which incorporates voltage-clamped quasi-resonant technique [6] to overcome this problem. It consists of a single-phase auxiliary resonant commutated pole inverter, and a bridge type cycloconverter. Chandhaket et al proposed a new HF link inverter that consists of energy regenerating snubber assisted SPWM inverter and the flyback type cycloconverter [7]. This technique is able to simultaneously provide soft-switching operation as well as voltage surge reduction. Matsui et al developed a more promising cycloconverter type HF link inverter topology that employs natural commutation technique to solve both problems without requiring additional circuit [8-10]. Asymmetric control is applicable to this topology, which further improves the total efficiency by reducing transistor conduction loss. The main drawback of this configuration is that, it requires four bidirectional switches at the transformer secondary.

1.2 Objective of Research

From the literature review conducted, it appears that natural commutated phase angle (NCPA) control HF link inverter proposed by Matsui is one of the most potential cycloconverter type HF link inverter topologies. The natural commutation technique employed is the key in solving the voltage surge and switching loss problems without additional circuitry. However, as already been mentioned, the number of power switches is high. This project is aimed at improving the topology by means of the following objectives:

- To propose a cycloconverter type HF link inverter that consists of only three bidirectional switches at transformer secondary. This would therefore result in reduced number of power devices, gate driver circuits and the associated supplementary circuits. It is also expected that the conduction loss would decrease.

- To describe the details of natural commutation technique, due to the absence of literature that describes natural commutation mechanism for HF link inverter. A summary of cycloconverter commutation process for different switching condition is provided to aid the design of modified overlapped switching technique.

- To introduce two sets of overlapped switching technique, namely the asymmetric bipolar PWM control and edge-aligned unipolar PWM control that adapt natural commutation technique. Simulation is performed to verify and analyze the proposed switching techniques.

- To develop a laboratory prototype in order to show the viability of the proposed topology and its switching techniques.

1.3 Thesis Structure

The work undertaken in meeting the above objectives is most logically divided into seven chapters. The content of these chapters are outlined as follows:

- Chapter 2 provides an overview to different HF link inverter topologies. Brief discussion on the building blocks of cycloconverter type HF link inverter is also presented to aid further discussion on the proposed topology.

- Chapter 3 presents a new HF link inverter topology with reduced switch counts. The commutation mechanism at primary and secondary stages is described detail. From the analysis on natural commutation technique, two sets of overlapped switching technique are introduced.

- Chapter 4 is dedicated to the SPICE simulation verification of natural commutation technique. Idealized models are used to perform time-domain analysis on the NCPA control and the proposed HF link inverter topologies.

- Chapter 5 explains briefly on how the laboratory prototype of the proposed topology is built. This includes the discussions on the design power circuit and gate signal generation circuits.

- Chapter 6 explains experimental work that completes the verification effort of the proposed ideas. The operating waveforms obtained from SPICE simulations are compared with those of the experimental results.

- Chapter 7 summarizes the work undertaken and highlights the contribution of this thesis. It offers suggestions for future work.

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