



澳門大學
UNIVERSIDADE DE MACAU

**A Generalized 3D Pulse Width Modulator
for Multi-level Voltage Source Inverters
in Three-phase Four-wire Power Systems**

by

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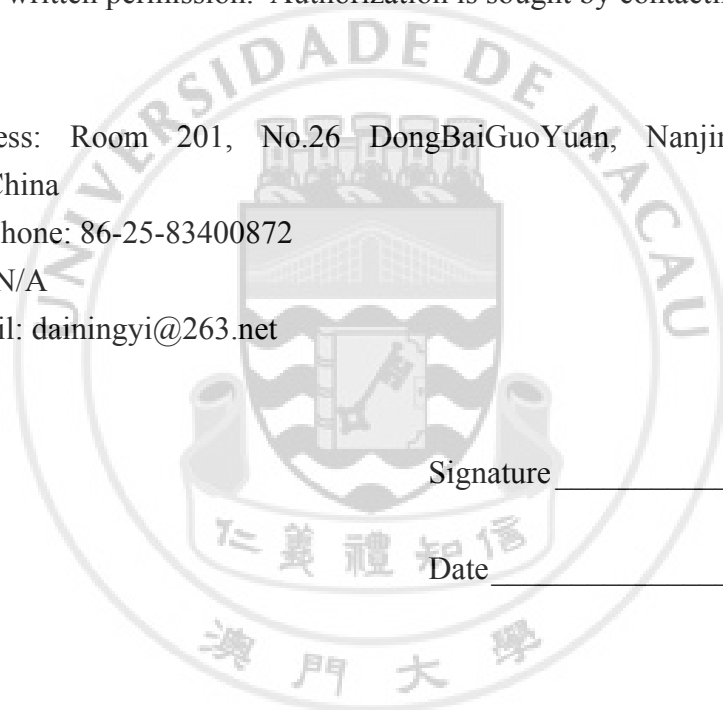
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ABSTRACT

A GENERALIZED 3D PULSE WIDTH MODULATOR FOR MULTI-LEVEL VOLTAGE SOURCE INVERTERS IN THREE-PHASE FOUR-WIRE POWER SYSTEMS

by Ning-Yi Dai

Thesis Supervisor: Prof. Ying-Duo Han

Co-Supervisor: Dr. Man-Chung Wong

Electrical and Electronics Engineering

The three-phase four-wire voltage source inverters (VSIs) with a neutral wire connection are important for power electronic applications in power distribution systems, such as three-phase four-wire active power filters, uninterruptible power supply, etc. For the medium and large capacity applications, a multi-level three-phase four-wire VSI is a better solution than a two-level one. Since the increase of the inverter levels results in a fast increase of the number of the power switches to be controlled, the implementation of the pulse width modulation (PWM) for multi-level three-phase four-wire VSIs is one of the most challenging tasks, which also directly affects the performance of the whole system.

Three-leg centre-split inverters and four-leg inverters are two most widely used three-phase four-wire VSIs. Firstly, a detailed comparison is carried out between the two topologies, mainly focusing on the output capability, control complexity as well as costs. In this study, the result indicates that two-level four-leg VSI is preferred in low-voltage applications, especially when large neutral current needs to be manipulated. However, for medium and large capacity applications, multi-level three-leg centre-split VSIs are more preferable due to lower cost and less switching devices to be controlled.

Since a neutral wire connection is provided and the zero-sequence output needs to be manipulated, 3-dimensional (3D) PWM methods need to be proposed for the three-phase four-wire VSIs. A 3D space vector modulation (SVM) in the α - β -0 coordinates for multi-level three-leg centre-split VSIs is firstly proposed in this study. By decomposing the reference voltage vector, the time-consuming multi-level SVM issue is simplified to a

two-level case, and the procedure for implementing the two-level 3D SVM is further simplified. As a result, the 3D direct PWM is proposed in this study. The complex mid-steps of the 3D SVM, such as determining neighboring vectors, calculating dwell times, are all eliminated in the novel 3D direct PWM.

By introducing a shifting voltage to modify the reference, the 3D direct PWM is further extended to control four-leg VSIs. Therefore, a generalized 3D direct PWM is proposed in this study, which can achieve PWM for controlling three-leg centre-split VSIs and four-leg VSIs with greatly reduced computational cost. The proposed generalized 3D direct PWM can also be applied to control three-phase three-wire VSIs to track balanced reference voltages. The same output voltage range can be achieved by the 3D direct PWM and the conventional 2D SVM. Simulation results are provided to show the validity of the proposed 3D direct PWM.

A FPGA-based generalized 3D pulse width (PW) modulator is designed and tested based on the generalized 3D direct PWM in this work. Prototypes of a two-level three-leg VSI, a two-level four-leg VSI and a three-level three-leg neutral-point-clamped VSI are implemented. Experimental results are given to show the validity of the generalized 3D PWM in controlling three-phase four-wire VSIs to track given balanced and unbalanced reference voltages.

The FPGA-based generalized 3D PW modulator can be embedded in the control system of different applications, where a three-phase four-wire VSI needs to be controlled. The prototypes of three-phase four-wire active power filters are developed, in which the three-phase four-wire VSIs are used as the core units. Experimental results show that current harmonics, reactive currents and neutral currents can be compensated simultaneously by an APF using my proposed generalized 3D PW modulator.

KEY WORDS

3D Direct PWM

3D Pulse Width Modulator

Active Power Filter

Four-leg Voltage Source Inverter

Multi-level Voltage Source Inverter

Three-leg Centre-split Voltage Source Inverter

Three-phase Four-wire Power Systems



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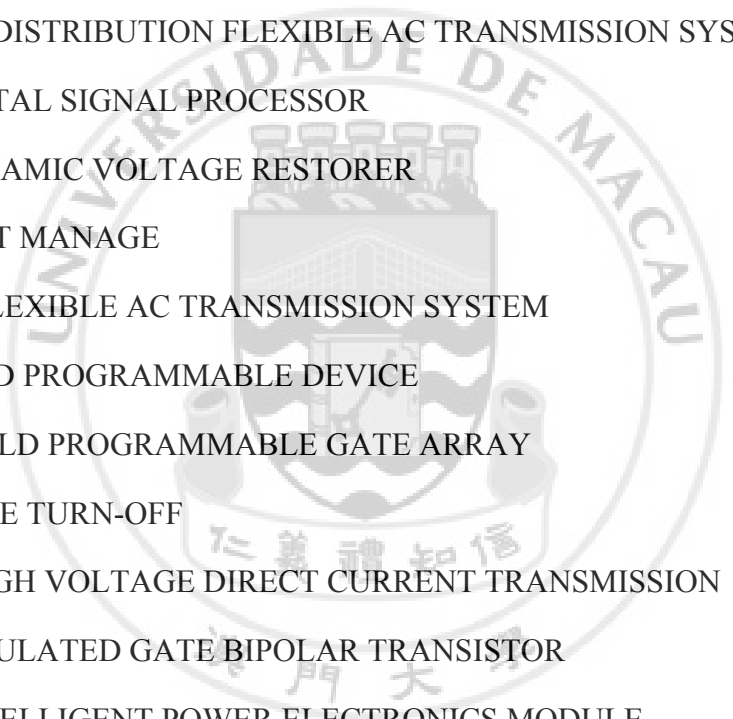
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Dai Ning Yi

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LIST OF ABBREVIATIONS



APF.	ACTIVE POWER FILTER
ASIC.	APPLICATION-SPECIFIC INTEGRATED CIRCUIT
ASD.	ADJUSTABLE SPEED DRIVE
BJT.	BIPOLAR JUNCTION TRANSISTORS
CMN.	COMMON MODE NOISE
CSI.	CURRENT SOURCE INVERTER
DFACTS.	DISTRIBUTION FLEXIBLE AC TRANSMISSION SYSTEM
DSP.	DIGITAL SIGNAL PROCESSOR
DVR.	DYNAMIC VOLTAGE RESTORER
EV.	EVENT MANAGE
FACTS.	FLEXIBLE AC TRANSMISSION SYSTEM
FPD.	FIELD PROGRAMMABLE DEVICE
FPGA.	FIELD PROGRAMMABLE GATE ARRAY
GTO.	GATE TURN-OFF
HVDC.	HIGH VOLTAGE DIRECT CURRENT TRANSMISSION
IGBT.	INSULATED GATE BIPOLAR TRANSISTOR
IPEM.	INTELLIGENT POWER ELECTRONICS MODULE
IPM.	INTELLIGENT POWER MODULE
MCU.	MICROCONTROLLER
MOS.	METAL OXIDE SEMICONDUCTOR
MOSFET.	METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTORS
PCB.	PRINTED CIRCUIT BOARD
PCC.	POINT OF COMMON COUPLING
PLD.	PROGRAMMABLE LOGIC DEVICE
PWM.	PULSE WIDTH MODULATION

SHE. SELECTIVE HARMONIC ELIMINATION

STATCOM. STATIC SYNCHRONOUS COMPENSATORS

SVM. SPACE VECTOR MODULATION

TDD. TOTAL DEMAND DISTORTION

THD. TOTAL HARMONIC DISTORTION

RMS. ROOT MEAN SQUARE

UPQC. UNIFIED POWER QUALITY COMPENSATOR

UPS. UNINTERRUPTIBLE POWER SUPPLY

VHDL. VHSCH HARDWARE DESCRIPTION LANGUAGE

VLSI. VERY-LARGE-SCALE INTEGRATION

VSI. VOLTAGE SOURCE INVERTER



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