Faculty of Electrical Engineering

HARMONIC ELIMINATION PULSE WIDTH MODULATION USING DIFFERENTIAL EVOLUTION TECHNIQUE FOR THREE PHASE VOLTAGE SOURCE INVERTER

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DECLARATION

I declare that this thesis entitled “Harmonic Elimination Pulse Width Modulation using Differential Evolution Technique for Three Phase Voltage Source Inverter” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....

Name :Norazelina binti Kamisman

Date :.....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature	:……
Supervisor Name	:Dr Azziddin bin Mohamad Razali
Date	:……

DEDICATION

Special dedicated to my beloved

Mum, Amilah binti Othman,

Dad, Kamisman bin Sahadi,

also, to my siblings.

ABSTRACT

Differential Evolution (DE) has been gaining popularity among researchers as an effective yet simple evolutionary algorithm to solve the optimization problems. This thesis presents an efficient and reliable DE based solution applied to the Harmonics Elimination Pulse Width Modulation (HEPWM) switching technique for three phase voltage source inverters. The proposed DE algorithm is able to compute optimal switching angles in HEPWM so that the switching scheme is able to eliminate lower order harmonic components of the three-phase inverter output voltage. Performance of the DE algorithm is highly affected by the mutant vector which is generated through a specific mutation process. Explanation of DE algorithm execution is given, and the best approach of mutation strategy selection used in DE has been investigated. Computation of DE algorithm and simulation of voltage source inverter using the calculated switching angles are carried out by using Matlab/Simulink software package. The proposed DE algorithm is also applied to the in-house developed experiment set-up which consists of three-phase inverter, gate driver, DC supply, resistive load and dSPACE software (ControlDesk Next Generation version 4.2.1) and dSPACE DS1104 R&D controller board. It has been confirmed through simulation and experiment that the proposed DE is able to eliminate lower order harmonics components and reduce the total harmonic distortion of three phase inverter output voltage.

ABSTRAK

Evolusi Perbezaan (DE) semakin popular di kalangan para penyelidik sebagai algoritma evolusi yang berkesan dan mudah untuk menyelesaikan masalah pengoptimuman. Tesis ini membentangkan penyelesaian berasaskan DE yang cekap dan boleh dipercayai yang digunakan untuk teknik pensuisan Penghapusan Harmonik Permodulatan Denyut Lebar (HEPWM) untuk penyongsang sumber voltan tiga fasa. Algoritma DE yang dicadangkan dapat menghitung sudut suis HEPWM yang optimum agar teknik pensuisan tersebut dapat menghapuskan beberapa urutan rendah komponen harmonik yang terdapat di dalam voltan keluaran penyongsang tiga fasa. Prestasi algoritma DE amat dipengaruhi oleh vektor mutan yang dihasilkan melalui proses mutan yang tertentu. Penerangan kepada proses pelaksanaan algoritma DE diberikan di dalam tesis ini, dan pendekatan didalam pemilihan strategi mutasi terbaik juga dikaji. Pengiraan algoritma DE dan simulasi penyongsang sumber voltan menggunakan sudut pensuisan yang dikira dilakukan dengan menggunakan pakej perisian Matlab / Simulink. Algoritma DE yang dicadangkan juga digunakan pada set percubaan eksperimen yang terdiri daripada penyongsang tiga fasa, get pemacu, bekalan arus terus, beban rintangan dan perisian dSPACE (ControlDesk versi Generasi Baru 4.2.1) dan DS1104 R&D papan kawalan dSPACE. Ia telah disahkan melalui simulasi dan ujikaji bahawa DE yang dicadangkan dapat menghapuskan komponen harmonik yang lebih rendah dan mengurangkan jumlah herotan harmonik penyongsang tiga fasa.

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LIST OF SYMBOLS AND ABBREVIATIONS

a_k	-	*k*th Switching Angle
a_n	-	Fourier Coefficient
CR	-	Crossover Rate
F	-	Scaling Factor
f_s	-	Sampling Frequency
G_{max}	-	Maximum Generation
Ha	-	Upper Boundary
La	-	Lower Boundary
M	-	Modulation Index
N	-	Number of Harmonic Eliminated
PS	-	Population Size
r_1, r_2, r_3, r_4	-	Mutual Integer
T_s	-	Sampling Time
$u_{i,g}$	-	Trial Vector
V_d	-	Voltage on *d*-axis
V_{dc}	-	DC link Voltage
V_i	-	Input Voltage
$v_{i,g}$	-	Mutant Vector
V_o	-	Output Voltage
V_q	-	Voltage on *q*-axis

V_{ref}	-	Reference Voltage
VTR	-	Tolerance
$x_{i,g}$	-	Target Vector
AC	-	Alternating Current
ASD	-	Adjustable Speed Drive
CBPWM	-	Carrier Based Pulse Width Modulation
CSI	-	Current Source Inverter
DC	-	Direct Current
DE	-	Differential Evolution
EA	-	Evolutionary Algorithm
EMI	-	Electromagnetic Interference
EP	-	Evolutionary Programming
ES	-	Evolutionary Strategies
FACTS	-	Flexible Alternating Current Transmission System
GA	-	Genetic Algorithm
GP	-	Genetic Programming
HEPWM	-	Harmonic Elimination Pulse Width Modulation
HWS	-	Half Wave Symmetry
IGBT	-	Insulated Gate Bipolar Transistor
PI	-	Proportional Integral
PSO	-	Particle Swarm Optimization
PWM	-	Pulse Width Modulation
QWS	-	Quarter Wave Symmetry
RMS	-	Root Mean Square
SHEPWM	-	Selective Harmonic Elimination Pulse Width Modulation

SPWM	-	Sinusoidal Pulse Width Modulation
SVPWM	-	Space Vector Pulse Width Modulation
THD	-	Total Harmonic Distortion
UPS	-	Uninterruptible Power Supply
VAR	-	Voltage Ampere Reactive
VSC	-	Voltage Source Converter
VSI	-	Voltage Source Inverter

LIST OF PUBLICATIONS

1. Azziddin M. Razali, Norazelina Kamisman, Jurifa Mat Lazi and Norhazilina Bahari, “Differential Evolution Technique of HEPWM for Three-Phase Voltage Source Inverter”, ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 14, July 2016.

2. Azziddin M. Razali, Norazelina Kamisman, Jurifa M. Lazi, Norhazilina Bahari, and Wahidah A. Halim, "Differential evolution technique in solving HEPWM switching angles of three-phase voltage source inverter," in *Power and Energy (PECon), 2016 IEEE International Conference on*, 2016, pp. 489-494.

3. Azziddin. M. Razali, Norazelina Kamisman, Jurifa M. Lazi, and Norhazilina Bahari, "HEPWM using differential evolution technique for three phase voltage source inverter," in *Energy Conversion (CENCON), 2015 IEEE Conference on*, 2015, pp. 325-330

CHAPTER 1

INTRODUCTION

1.1 Background

Differential Evolution (DE) has been gaining popularity among researchers as an effective yet simple evolutionary algorithm to solve the optimization problems. Performance of differential evolution algorithm is mainly affected by the mutant vector which is developed through a specific mutant operation. This project presents an efficient and reliable DE-based solution for Harmonic Elimination Pulse Width Modulation (HEPWM), applied to the three-phase voltage source inverter (VSI).

The proposed differential evolution algorithm is able to eliminate lower order harmonics for the output voltage of three-phase VSI. The equations to calculate switching pulse angles are derived from a nonlinear transcendental equation of the VSI quarter-wave symmetric PWM output voltage. The generated switching pulse angles are able to generate bipolar PWM output voltage and eliminate several numbers of low order harmonic components.

The objective function used in DE algorithm is able to computes the corresponding switching angles of the bipolar output voltage for any number of harmonic components to be eliminated. While minimizing the objective function, the individual selected harmonics can be controlled within allowable limits by incorporating the constraints in the differential evolution algorithm. Some differential evolution strategies are used to solve the global optimization problem.

The scaling factor *F* is varied randomly within a certain range and the auxiliary set is employed to enhance the population diversity. An extensive angle error analysis will be carried out to determine the accuracy of the algorithm in comparison to the exact solution. The advantages of the proposed algorithm include simplicity in real implementation and flexibility in generating PWM output voltage waveforms. Simulation and experimental setup will be carried out to verify the workability of the proposed algorithm.

HEPWM methods remain of greatest interest for the control of high-voltage high power VSI, where the main concerns are minimizing the switching losses and HEPWM provides an ideal solution, especially for inverters that are operated in a low switching frequency range (less than 1kHz). The advantages of HEPWM over the conventional sinusoidal PWM (SPWM) for voltage source inverter, as listed below:

a) About 50% reduction in the inverter switching frequency is achieved which contributes to a diminution in the switching losses of the VSI.
b) For a given VSI switching frequency, the incidence of the first non-zero harmonic is almost double in PWM scheme, resulting in a greater pole switching waveform harmonic spectrum.
c) Lower order harmonics can be eliminated by reducing harmonic interference to the system.
d) Higher voltage gain due to over-modulation is possible, leading to higher utilization of the power conversion process.

Considering these issues, HEPWM can be a useful alternative to the more popular SPWM, especially for the high-power inverters used in the mains and drives applications. For this reason, this research proposes a simple off-line HEPWM scheme that can be suitably implemented using a fixed-point microprocessor.