“I hereby declare that I have read through this report entitle “New Optimization method in Three-Phase inverter” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronics and Drive)”

Signature : ....

Supervisor’s Name : ....

Date : ....

NEW HEPWM OPTIMIZATION METHOD IN THREE PHASE INVERTER

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A report submitted in partial fulfillment of the requirements for the Bachelor Of Electrical Engineering (Power Electronics and Drive)

Faculty of Electrical Engineering
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I declare that this report entitle "*New HEPWM Optimization method in Three-Phase Inverter*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

To my beloved Mak and Abah

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First and foremost, many thanks to Allah SWT for blessing me with good health and lots of patience in completing this project. My greatest appreciations and thank you to my supervisor, Puan Hazilina Binti Bahari for guiding, supervising and also advising me to complete this final year project successfully.

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ABSTRACT

This project is represent New Harmonic Elimination Pulse Width Modulation (HEPWM) methods to the control of high power voltage-source inverter, where the main concerns are about the application of differential evolution to obtain switching angle until for higher harmonic order. **Problem statement:** PWM waveform have harmonic at low frequency. Differential evolution is one of method regarding to provide lower total harmonic distortion to generate highest quality output by calculate the accurate value of switching angle. **Approach:** It consists of four basic in Differential Evolution which is starting by initialize the population of switching angle. Then it proceed by mutation, recombination and lastly is selection. The objective function of the DE is designed to minimize (to near zero) the selected harmonic and at the same time allow for the fundamental component of the output voltage to be controlled independently. In this project, MATLAB Simulink programming is use to find suitable switching angle using differential evolution (DE) algorithm in order to drive VSI and to verify the eliminating number of harmonic through amount of Total Harmonic Distortion (THD) until higher harmonic order. **Result:** The result can be proving in order to accomplish this project through the reduction of distortion which can observe through the Total of Harmonic Distortion by MATLAB from the output of phase voltage and line voltage. The value of switching angle can be observed through the trajectories waveform certain harmonic order. **Conclusion:** So, this report are successfully explain the term of algorithm of Differential Evolution that has been used in order determine the value of switching angle that will be used to obtained the good quality of output.

ABSTRAK

Projek ini adalah mengenai kaedah baru untuk penghapusan harmonik di dalam pulse width modulation dalam mengawal kuasa penyonsang sumber voltan tinggi, di mana masalah utama mengenai aplikasi evolusi pembeza untuk mendapatkan sudut bagi pensuisan sehingga maksima harmonik nombor. **Kenyataan masalah:** Berbeza evolusi adalah satu kaedah yang berkenaan untuk mengurangkan jumlah bagi keseluruhan gangguan harmonik. **Pendekatan:** Kaedah ini terdiri daripada empat asas utama, iaitu bermula dengan mengenal pasti parameter iaitu populasi bagi sudut pensuisan. Kaedah ini diteruskan oleh mutasi, penggabunagn semula dan dan yang terakhir sekali ialah pemilihan. Fungsi objektif kaedah ini direka untuk meminimumkan harmonik iatu menghampiri sifar bagi amplitud voltan tersebut. Dalam aspek ini, simulasi MATLAB digunakan untuk mencari sudut yang sesuai dengan menggunakan kaedah berbeza evolusi ini. Algoritma ini di gunakan untu memacu kuasa penyonsang sumber voltan di mana keluarannya akan memaparkan pembuktian bahawa jumlah bagi keseluruhan gangguan harmonik berkurang. **Hasil:** Hasil yang yang terkandung di dalam report ini akan membuktikan projek ini dengan dilakukan cara yang betul melalui pengurangan jumlah nilai keseluruhan gangguan harmonik. **Kesimpulan:** Report ini berjaya menerangkan konsep algoritma yang akan di implikasikan untuk menentukan sudut pensuisan seterusnya menghasilkan kualiti keluaran yang baik.

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CHAPTER 1

INTRODUCTION

This chapter will described about the introduction of this project which includes the overview of the whole project, the problem statement that occur before this entire project will be complete. The objectives and scope that are needed as a fulfillment of this project are completely described in this chapter.

1.1 Project Overview

The Harmonic Elimination Pulse Width Modulation (HEPWM) is a technique which to combines the square-wave and PWM to control the fundamental output voltage as well as the function to eliminate the number of harmonics from the output. In PWM control, the converter switches are turn on and off in certain times during a half cycle and the output voltage is controlled by varying the pulse widths [1]. As the equations to calculate switching angles in a HEPWM scheme are non-linear and transcendental, so they need to be calculated off-line using Differential Evolution [2]. Differential evolution is one of method regarding to lower total harmonic distortion to generate highest quality output. This method introduced by Storn and Price and proved that it is more efficient compared to other genetic algorithm [3]. The objective function of the DE is designed to minimize (to near zero) the selected harmonic by using an accurate value of switching angle. This project is also focusing in a three phases Voltage Source Inverter part. A Voltage Source Inverter employing thyristor as switches, some type of forced commutation is required, while the VSIs made up of using GTOs, power transistor, power MOSFETs or IGBTs, self commutation with base or gate drives signals for their controlled turn-on and turn off. In this project the concept of HEPWM technique is described with performance analysis of waveform. Total Harmonic Distortion (THD) is helped to proof the calculation by showing the reduction value of THD. Finally, the simulation result with all analysis for the strategy applies in differential evolution and for three phase inverter using HEPWM is presented.

1.2 Problem Statement

1.1.1 High Harmonics distortion at low frequency.

HEPWM inverters usually have high harmonic distortion and low input power factor before some techniques was introduced to improve the performance of PWM. As one of the objectives of this project is to describe the advantage using HEPWM technique in reducing the harmonic by provide voltage or current wave shaping customized to the specific need of the application under consideration, and its superior harmonic performance compared to the sinusoidal PWM [4] [5]. Unfortunately, the equations that used to calculate the number of switching angle for HEPWM are non-linear and transcendental in nature. Hence, it is required an iteration programming method and it's too difficult to calculate in online method. As a result, off-line commutation need to be carried out with various numerical techniques which are possible and in this project the method that will be used is the Differential Evolution method. This method will calculate the value of switching angle and good convergence will produce the preliminary guesses to achieve the angles close to local minima [3]. However, if the initial value is not correctly chosen, it can result in large iteration cycles and at times, non concentration result.

1.1.2 Determine the suitable switching angle.

Differential Evolution will be used to determine the value switching angle for PWM to reduce distortion by eliminating the harmonic until higher harmonic order by produces the amplitude voltage at a fundamental frequency to be zero.

1.3 Project Objectives

The objectives of this project are:

i. To determine the suitable switching angle until to eliminate harmonic order by using Differential Evolution algorithm using M-file of MATLAB 6.5.
ii. To simplify the programming of differential evolution by using looping method in MATLAB 6.5.
iii. To design the circuit for HEPWM and VSI circuit and obtain the computer simulation results using Simulink-MATLAB 6.5.

1.4 Project Scope

The scope of work need to be done in this project will be more to analysis the concept of Differential Evolution method programmed using Simulink-MATLAB 6.5. This technique will be used to obtain the quality output waveform of HEPWM with lower harmonics before applied to VSIs by finding the accurate value switching angle under higher harmonic order condition. Since the computer simulation involving MATLAB software, my supervisor had narrowed the using two kinds of method that contain in it which is M-File and Simulink-Block diagram. But, using Simulink-MATLAB 6.5, both HEPWM and VSIs output waveform from the simulation result will be presented and analyzed.

Therefore, all the result from the amount of Total Harmonic Distortion can prove the simulation result. But, there is problem of getting the number of switching angle for high harmonic order because of its higher iteration or commutation. Therefore, it will take for a long time once other strategy will be used. Even though the simulation result is cause the use of time, the best commitment of finding and searching for the result of switching angle for other strategy that are needed in this simulation has been done.

1.5 Method of Analysis

This project performed in two stages. The first stage deals with the programmed process to get proved the expected result of HEPWM technique and VSIs process. This involves the using of M-File MATLAB 6.5 to simulate the method of differential evolution in order to find the number of switching angle which will obtain all the result in term of the best number of switching angle and also the trajectories curve after complete the iteration or commutation according to the equation of Fourier Series that apply in Differential Evolution Method. Then, the result for this method will be analyzed and compared the strategy of differential method based once their complete the commutation.

For the second stage, an implementation number of switching angle HEPWM that hoped to get the waveform of quadratic is performed. This stage involves with the designing HEPWM and VSIs using Simulink-MATLAB 6.5 which will obtain the result in term of output waveform such as voltage line to line, voltage phase and simple Fourier analysis. Finally, the result will be analyzed based on their performance such as appropriate Total Harmonic Distortion (THD), Fast Fourier Transform (FFT), and spectrum analysis of the output waveform. Some of the formation in the process of expanding the idea of analysis of the result are referred from the research journal of related website, power electronic reference book and from my supervisor who had contributes greatly guiding me for the entire project.

1.6 Project Report Summary

This project report contains of five chapters which will describe this project details. The first chapter is the introduction part where in this chapter, the overall description of the project is highlighted. The objectives of this project, the scopes and the methodology are described.

Second chapter of this report will be discussing about the research and analysis of this project. Each of the facts and the information from the analysis will be explained.

The third chapter will describe the method used in implement the project task. The technique and methodology of this project is split into two major part that is programmed M-File and Simulink-Block diagram. In this chapter, each part will be described in depth.

The fourth chapter will described is the most important part that is the result for this project. In this chapter all of result will be showed include the entire figure for each harmonic number and the analysis and discussion about entire of result include the equation of formula that being used. All of analysis and discussion that had been done will be stated clearly. The analysis is using the two kind's method in MATLAB 6.5.

The final chapter is the conclusion and any suggestion. A conclusion about the achievement of the project objectives and knowledge gain while doing this project is being stated in this chapter. The suggestion and the future work is highlighted to improve the project for next reference.

CHAPTER 2

THEORY AND LITERATURE REVIEW

This chapter will described about the background of this project and the literature review which includes the previous related project and the development made by the people in Electronic Engineering Field all over the world and the mathematicians people that developed the equation in differential evolution method.

2.1 Introduction

This chapter includes the study of the generalized method of harmonic elimination pulse width modulation (HEPWM), Differential Evolution theorem and the harmonic elimination technique for 3 Phase voltage source inverter using Differential Evolution algorithm to obtain switching angle through four basic step that consist in the method which is iteration of Differential Evolution algorithm consists of 4 basic steps that is **initialization**, **mutation**, **crossover** and **selection**

2.2 Fundamental of Switching Angle.

According to book Power Electronics Handbook-Device, Circuit and Application, 2nd Edition by Muhammad H. Rasyid , switching angle or conducting angle can be chosen to reduce the total of harmonics distortion. Normally, we choose the minimum angle of PWM wave so that the major lower frequency harmonics can be eliminated.

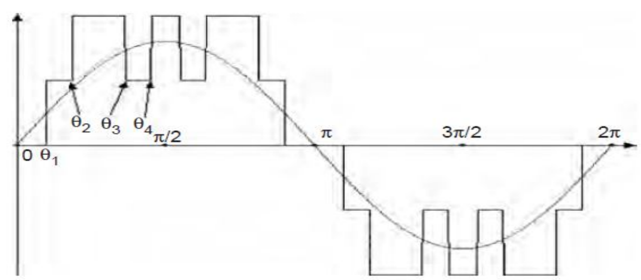

Figure 2.2: PWM output waveform with selective switching angle

2.3 Harmonics Elimination Pulse Width Modulation (HEPWM)

HEPWM is subset of Optimized PWM switching strategies (OPWM). OPWM is designed to optimize some specific performance criteria such as harmonic voltage elimination, harmonic current minimization and harmonic torque and rotor speed ripple minimization. The term harmonics is refer to a component frequency of the signal that is an integer multiple of fundamental frequency. Let say, if fundamental frequency is f, the harmonics have frequencies of $2f$, $3f$, $4f$ etc. harmonics energy are tend to be distributed which resulting losses. This technique involves determining the switching angles of generalized PWM waveform using numerical minimization search techniques when applied to a set of non-linear and transcendental equation which been specify to eliminate lower order of harmonics at the output of voltage source inverter.

The common practical implementation of the HEPWM technique is by programming the pre-calculated switching angles into an EPROM or microprocessor memory. This allows Online generation of switching angle by using look-up tables or BCD down-counter to generate pulse width in time domain.

2.4 Generalized Method of Harmonic Elimination Pulse-Width Modulation (HEPWM)

A generalized quarter-wave symmetric PWM pole switching can be defined as shown in Figure 2.4. Through this figure, there is a half cycle with M chops and in negative cycle is a symmetric for this M chop [1] The basic square wave is chopped a number of times and a fixed relationship between the number of chops and possible number of harmonics that can be eliminated is derived. The periodic waveform can be noted as half-wave symmetry and unit amplitude [1] Therefore:

$$f(\omega t) = -f(\omega t - \pi) \qquad (1)$$

$f(\omega t)$ = M chop per half cycle of two state periodic functions. Let $a_1, a_2 \ldots . a_{2M}$ define the M-chops as shown in Figure 2.1 below.

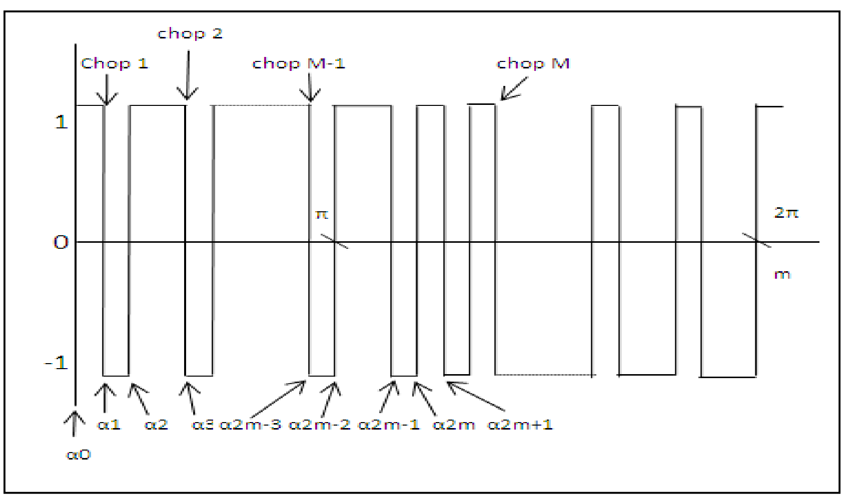

Figure 2.4: Generalized quarter-wave symmetric PWM waveform [8]

The Fourier series equation can be use to determine the waveform, below is the equation of Fourier series:

$f(\omega t) = \sum_{n=1}^{\infty}[a_n \sin(n\omega t) + b_n \cos(n\omega t)]$ (2)

Where

$a_n = \frac{1}{\pi}\int_0^{2\pi} f(\omega t)\sin(n\omega t)d\,(\omega t)$ (3)

$b_n = \frac{1}{\pi}\int_0^{2\pi} f(\omega t)\cos(n\omega t)d\,(\omega t)$ (4)

By substituting f $((\omega t)$ in equation (3) included the property of half-wave symmetry:

$$a_n = \frac{2}{\pi}\sum_{k=0}^{2M}(1)^k\int_{a_k}^{a_{k-1}}\sin(n\omega t)d\,(\omega t) \quad (5)$$

Where $a_1 = 0, a_{2M+1} = \pi$, and $a_0 < a_1 < a_2 \dots . < a_{2M+1}$

Evaluating the integral for (4),

$a_n = \frac{2}{n\pi}\sum_{k=0}^{2M}(-1)^k[\cos(na_k) - \cos(na_{k+1}]$ (6)

$$a_n = \frac{2}{n\pi}\left[\cos na_0 - \cos na_{2M+1} + 2\sum_{k=1}^{2M}(-1)^k\cos na_k\right]$$

But a_0 and $a_{2M+1} = \pi$. Hence,

$$\cos na_0 = 1$$

$$\cos na_{2M+1} = (-1)^n$$

Therefore, (5) reduce to

$$a_n = \frac{2}{n\pi}[1-(-1)^n + 2\sum_{k=0}^{2M}(-1)^k \cos(na_k)] \quad (7)$$

Similarly

$$b_n = -\frac{4}{n\pi}\sum_{k=1}^{2M}(-1)^k \sin na_k \quad (8)$$

For even n number the property of half-wave symmetry can be determined the waveform for $a_n = 0$ and $b_n = 0$ as followed equation:

$$a_n = \frac{4}{n\pi}[1 + 2\sum_{k=0}^{2M}(-1)^k \cos na_k] \quad (9)$$

$$b_n = \frac{4}{n\pi}[-\sum_{k=0}^{2M}(-1)^k \sin na_k] \quad (10)$$

Equation (9) and (10) are function of $2M$ variable$a_1 \dots a_{2M}$. To find the unique of 2M variable, the 2M equation is needed. By equating any M harmonic to zero, $2M$ equation is derived from equation (9) and (10).

The M equation is derived by equating $b_n = 0$ for M values of n and it solved by letting $f(\omega t)$ as quarter-wave symmetry.

$$f(\omega t) = f(\pi - \omega t)$$

Regarding to Figure 2.1, below is the relation of common quarter-wave symmetry:

$$a_k = \pi - a_{2M-k+1} \quad (11)$$

For $k = 1,2, \dots \dots M$

Therefore,

$$sin\, na_k = \sin n\,(\pi - a_{2M-k+1})$$

$$= [\sin n\pi \cos na_{2M-k+1} - \cos n\pi \sin na_{2M-k+1}] \quad (12)$$

For $k = 1,2, \dots . . M$

For odd n,

$$\sin n\pi = 0,$$

$$\sin n\pi = -1$$

Substituting (11)

$$\sin na_k = \sin na_{2M-k+1},$$

For $k = 1,2, \ldots M$ (13)

Substituting (12) in (9), we get

$$b_n = \frac{4}{n\pi}\sum_{k=1}^{M}(\sin na_k - \sin na_{(sM-k+1)}) = 0$$

From (10):

$$\cos na_k = \cos n(\pi - a_{(2M-k+1)}) \quad (14)$$

For $k = 1,2, \ldots . M$

For odd n, (13) becomes

$$\cos na_k = -\cos na_{2M-k+1)} \quad (15)$$

For $k = 1,2, \ldots . M$

Substituting (14) into (8), we get

$$a_n = \frac{4}{n\pi}[1 + 2\sum_{k=1}^{M}(-1)^k \cos na_k] \quad (16)$$

Referring to figure 2.4, the elimination of M harmonic can be determined by solving M equation by letting equation 15 to be zero. HEPWM are created by Patel and Hoft [6] design to reduce harmonic of PWM spectra.

Unfortunately, the widespread use of HEPWM is somewhat hindered due to the difficulty to calculate the switching angles on-line. This is because the switching angle equations are non-linear and transcendental in nature; restricting it to off-line approach. There is no general solution for these types of equations and the transcendental nature of the equations suggests a possibility of multiple solutions [6-7]. For off-line computation, various numerical techniques are possible; most common is the Newton-Raphson method as done by the Patel and Hoft.. However, if the initial value is not correctly chosen, it can result in large iteration cycles.

2.5 Differential Evolution Theorem

Evolutionary algorithm is new class of non-calculus, search and optimization technique that has become very popular in many engineering applications. These methods search from a population of points instead of a single point as in conventional search and optimization processes. Furthermore they do not require a “suitable” initial value. The initial points can be randomly generated from the search space. Genetic algorithm (GA) is one example of evolutionary algorithm that has been used associated with HEPWM [5]. Differential evolution (DE) algorithm is known to be a simple and fast evolutionary algorithm. It is similar to GA but with one main difference: DE adopts a mutation strategy that allows it to be self adaptive in the selection process [6]. Compared to GA, it consumes much shorter time to reach optimum point [6], [7]. Although recently introduced (in relation to other evolutionary algorithms), DE has been widely used in optimization problem. In this work, only DE is used to search for the HEPWM angles that will eliminate specified number of harmonics without comparing to latest advanced algorithms.

The iteration of DE algorithm consists of 4 basic steps that is initialization, mutation, crossover and selection. An iteration of the DE algorithm consists of the four basic steps – initialization of a population of vectors, mutation, crossover or recombination and finally selection. The main steps of DE are given below [8]: