DESIGN OF SELECTIVE HARMONIC ELIMINATION TECHNIQUE FOR THREE PHASE VOLTAGE SOURCE INVERTER

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DESIGN OF SELECTIVE HARMONIC ELIMINATION TECHNIQUE FOR THREE PHASE VOLTAGE SOURCE INVERTER

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DECLARATION

I declare that this thesis entitled "DESIGN OF SELECTIVE HARMONIC ELIMINATION 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 :

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Date : 5 JULY 2021

APPROVAL

I hereby declare that I have checked this report entitled “Design of Selective Harmonic Elimination Technique for Three-Phase Voltage Source Inverter” and in my opinion, this thesis complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honour

Signature :

Supervisor Name : DR WAHIDAH BINTI ABDUL HALIM

Date : 5 July 2021

DEDICATIONS

This project is wholeheartedly dedicated to my beloved parents, Mr. Sim Hang Ung and Mrs. Linsay Wagner Anak Bantin, who have been sources of my inspiration and gave me strength when I thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. And also, to my siblings, friends, and all lecturers, thank you for your endless support and unconditional love given.

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ABSTRACT

Nowadays, the performance of the inverter has become an integral part of contributing to an efficient power system. The development of Selective Harmonic Elimination Inverter Technology plays a vital role in electrical applications. This development has increasingly taken over from conventional two-level inverters in industrial applications. In this project, a two-level inverter with the SHE-PWM technique is used to eliminate specific low-order harmonics, thus improving the THD of the waveform output. Since the structure of the equation derived from the Fourier transform is non-linear and transcendental, the amplitude of any odd harmonics in the output signal is calculated using any specific modulation index and Fourier series. In this project, a method is proposed to obtain the required switching angles for the SHE PWM technique is the Newton-Raphson method which is used to solve transcendental equations to find switching angles for a three-phase inverter with some random initial assumption that would yield all desirable solutions. Seven switching angles for modulation index 1.0 have been solved by using the Newton-Raphson method and MATLAB/SIMULINK program where the first harmonic was controlled and 5^{th}, 7^{th}, 11^{th}, 13^{th}, $17^{th,}$ and 19^{th} harmonics was eliminated. The simulated results of the three-phase two-level Voltage Source Inverter for the phase voltage, output current, and line-to-line voltage, and total harmonic distortion has been analyzed. The simulation results also demonstrated using various RL loads and a motor. The overall simulation results meet the IEEE STD. 1547 Requirements for maximum Harmonic Distortion.

ABSTRAK

Pada masa ini, prestasi penyongsang telah menjadi peranan penting dalam menyumbang kepada sistem kuasa yang berkesan. Dengan keperluan tenaga lestari, pengembangan teknologi penyongsang pemilihan harmonik selektif memainkan peranan penting dalam aplikasi voltan, arus, dan kuasa. Perkembangan ini secara beransur-ansur diambil alih dari penyongsang dua tingkat tradisional dalam pelbagai aplikasi industri. Dalam projek ini, penyongsang dua tingkat dengan teknik *SHE-PWM* digunakan untuk menghilangkan harmonik pesanan rendah tertentu, dan menambah baik *THD* dari keluaran bentuk gelombang. Oleh kerana struktur persamaan yang berasal dari transformasi *Fourier series* dan transendental, maka indeks modulasi dan *Fourier Series* digunakan untuk mengira amplitud harmonik ganjil dalam isyarat keluaran. Satu kaedah telah dicadangkan untuk mendapatkan sudut beralih yang diperlukan untuk teknik *SHE-PWM*. Dalam projek ini, kaedah *Newton-Raphson* digunakan untuk menyelesaikan persamaan transendental untuk mencari sudut beralih untuk penyongsang tiga fasa dengan beberapa anggapan awal rawak yang akan menghasilkan semua penyelesaian yang mungkin. Di sini, tujuh sudut beralih untuk 1.0 indeks modulasi telah dikira dengan menggunakan kaedah *Newton-Raphson* dan program *MATLAB / SIMULINK* di mana harmonik pertama dikendalikan dan harmonik ke-5, ke-7, ke-11, ke-13, ke-17 dan ke-19 dihapuskan. Hasil simulasi Inverter Sumber Voltan dua tahap tiga fasa untuk voltan fasa, arus keluaran, dan voltan talian ke garis, dan *Total harmonic distortion* (*THD*) telah dianalisis. Hasil simulasi juga diuji dengan menggunakan pelbagai beban dan motor. Hasil simulasi keseluruhan memenuhi *IEEE STD. 1547* Keperluan untuk Penyelewengan harmonik maksimum.

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LIST OF SYMBOLS AND ABBREVIATIONS

VSI	-Voltage source inverter
IGBT	- Insulated Gate Bipolar Transistor
SHE	- Selective Harmonic Elimination
PWM	- Pulse Width Modulation
THD	- Total Harmonic Distortion
V_{dc}	- Direct Current Voltage (V)
V_{ac}	- Alternating Current Voltage (V)
f_1	- Fundamental frequency
M_a	- Modulation index
M_f	- Switching frequency
α_n	- n^{th} switching angle
V_1	- Magnitude of fundamental frequency
MATLAB	- MATrix LABoratory program
FFT	- Fast Fourier Transform
FPGA	- Field Programmable Array
VHDL	- VHSIC Hardware Description Language
VHSIC	- Very High Speed Integrated Circuit
ROM	- Read Only Memory
LUT	- Look Up Table
VFD	- Variable Frequency Drive

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter briefly describes the background of Selective Harmonic Elimination Technique and Three-phase Voltage Source Inverter (VSI). This idea to design of Selective Harmonic Elimination Technique for Three-phase Voltage Source Inverter.

1.2 Background

The inverter is a DC to AC converter which takes DC power input and converts it to 400V 50 Hz AC in Malaysia. Inverters are required as most household items use AC power rather than DC. This is achieved by switching the DC input on and off. There are three common types of inverters which are the sine wave, square wave, and modified sine wave inverters.

A square-wave inverter is the simplest to generate and is best suited to low sensitivity devices like lights. Square-wave inverters are relatively inefficient as a lot of the power is going into higher harmonics which can affect the operation of some devices. In motors, this can cause spikes in the torque and large heat build-ups. The next type of inverter is the sine wave inverter. Although the output of these is not perfect sine waveforms, they are very close and have significantly less distortion than the modified sine wave and square wave inverters. These inverters produce the least amount of heat when used in devices such as motors and reduce the risk of damage through torque spikes. However, they are also the most expensive of the three options. An example of each of the three waveforms can be seen in Figure 1.1. The final type of inverter is the modified sine wave. These inverters output a non-square waveform that approximates a sine wave. This waveform has a small dead time in the normal square wave output. This method produces fewer harmonics than the square wave but power is still being provided to unwanted frequencies. Most cheap inverters are either square or modified sine wave inverters due to being relatively inexpensive.

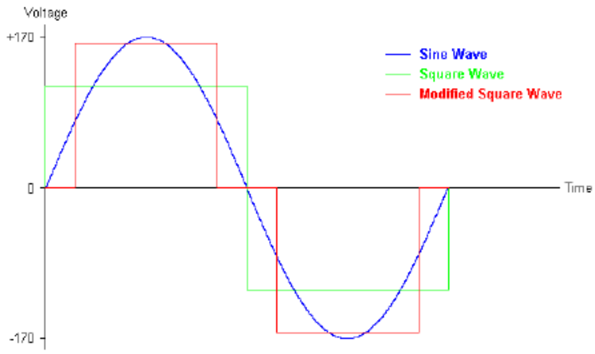


Figure 1.1: Square Wave, Sine Wave, and Modified Sine Wave [20]

The Total Harmonic Distortion (THD) and its limits standard is tabulate in Table 1. are specified as the harmonic content standard. The table indicates that harmonic current content has to be less than a specific percentage of the fundamental for certain ranges of the harmonics and that the total harmonic distortion cannot exceed 5%.

Table 1.1: IEEE STD. 1547 Requirements for maximum harmonic Distortion [14]

Individual Harmonic Order	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	Total Harmonic Distortion
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

The switching control circuit is the brains of the inverter and controls the switching of the inverter. For a sine wave inverter, the waveform is encoded onto a Pulse Width Modulation signal (PWM) and sent to the three-phase voltage source inverter. PWM is a method used to encode messages onto a signal. The method switches a signal on and of very quickly. When the switch is ON longer compared to the duration it is OFF, will translate to a high amount of power being sent to the load. The ratio of on-time to off-time is known as the duty cycle. Thus, the amplitude of the message signal is encoded onto the width of the pulses. This is easily done by comparing a sine wave to a triangle wave. PWM is advantageous in that there is little power loss in the switches and most of the power goes to the load.

SHE-PWM will potentially have the highest quality performance of all the PWM methods. Since the early 1960s, this technique has been a research subject. In 1973, Patel and Hoft invented the SHE PWM technique. The concept of this technique is that the square-wave output is “chopped” numerous times that obtained by sufficient off-line estimated calculation. To store the result, a look-up table is used or the result can be computed by a simple function for real-time operation. The SHE-PWM method switches the DC input on and off based on pre-calculated points in the square wave. This is said to be ‘chopping’ the waveform and the angles that we chop at are known as the switching angles. The results of this is a PWM with M chops as seen in Figure 1.2.

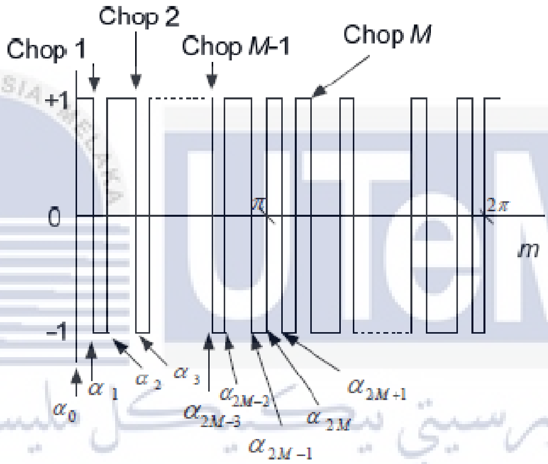


Figure 1.2: Chopping points [20]

Fourier Series and optimization method is the technique used to determine the switching angles. To find ideal angles where the Nodd harmonics are $i = N + 1$. For example, to eliminate odd harmonics (3rd, 5th, 7th, 9th, 11th, 13th, and nth) where for single-phase systems is $n = 2N + 1$ and three-phase systems $n = 3N + 1$, and control of the fundamental is also achieved.

1.3 Problem Statement

To obtain nonlinear transcendental equation analysis solutions containing trigonometric terms that naturally indicate various solutions is the main challenge associated with the SHE-PWM technique. Getting exact solutions using computational techniques for starting value can be sought even for a large number of harmonics to be eliminated. Moreover, convergence is achieved by the similarity of the initial values to the same solutions. Although the algorithm is mentioned in some papers and many solutions for the three-phase case are discussed, the performance of the technique does not report on its effectiveness to analyze all possible solutions. For a reasonably more harmonics to be eliminated, the algorithm does seems to be a better approximation. Later, the performance of these techniques was evaluated where the techniques are studied with two structures in mind, which are line-to-line output voltage and output current for Three-phase inverter.

1.4 Objective

The main propose for this project is to design of Selective Harmonic Elimination Technique for Three-phase Voltage Source Inverter. To achieve the main goal, other specific objectives of this project include:

1. To study and develop the Selective Harmonic Elimination for Three-Phase Voltage Source Inverter using Newton Raphson method in MATLAB/Simulink.
2. To simulate and analyse the Selective Harmonic Elimination for Three-Phase Voltage Source Inverter with various modulation indices and loads.
3. To generate the gating signals into Altera FPGA module using Quartus II software.

1.5 Scope

The scopes of the study to achieve the objectives in this study are:

- Construct the Selective Harmonic Elimination Technique for Three-phase Voltage source inverter simulation using MATLAB/Simulink.
- Identify the simplest method to develop Selective Harmonic Elimination Technique for Three-phase voltage source inverter.
- Analyse the Total Harmonic Distortion $THD_i$and THD_v for modulation index 0.1 until 1.0.

- Test the Selective Harmonic Elimination Technique for Three-phase voltage source inverter with RL load and motor.
- Program the switching signal data using Quartus II software and run into EP4CE22F17C6 Altera FPGA DE0-Nano module and observe the switching signal using oscilloscope.

1.6 Dissertation Outline

This dissertation is composed of five chapters. Each chapter discuss a diverse point closely related to this project. The following is the brief outline of the chapters:

Chapter 1: Introduction

The current chapter explains and focuses on the research background, problem statement, objectives, and scopes of the project followed by rationale of design and summary of methodology.

Chapter 2: Literature Review

This chapter focuses on the project background which consists of a literature review of the related topics in the project such as Selective Harmonic Elimination Technique, Three-phase Voltage Source Inverter, Fourier Series for Single-phase and Three-phase (VSI), and discussion about method for optimization, bipolar and unipolar case.

Chapter 3: Methodology

This chapter highlights the methodology to design and development Selective Harmonic Elimination Technique for Three-phase Voltage Source Inverter produce Three-phase two-level unipolar Voltage Source Inverter using PSO method. In general, it includes the overall framework on how the project is carried out step by step.

Chapter 4: Result and discussion

This chapter is pinpointed on the collected data throughout the project. The data is then interpreted and discussed.

Chapter 5: Conclusion

This chapter gives a detailed summary of all the chapter described in the dissertation. It also provides the final research conclusions and the various lessons, learn from the study. Provide the ending of opportunity for improvement, areas which lead the continuity of further study in this field.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

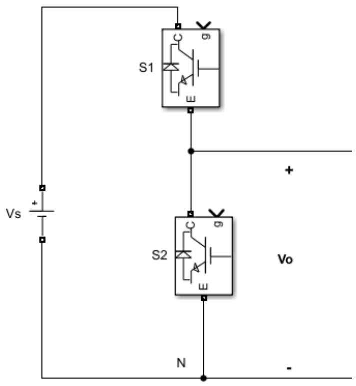
The focus of this chapter is to review and study earlier researches conducted by other researchers that are applicable or relevant to Selective Harmonic Elimination Technique and Three Phase Voltage Source Inverter. The literature review is an overview of the research of journals, articles, and the internet relevant to the project title. In general, the topic that reviewed are the information, formulas and research data collection result that are relevant to the studies. In this study, a specific discussion on the Selective Harmonic Elimination Technique and the Three-phase Voltage Source Inverter was discussed. The main focus of this chapter to study the design of Selective Harmonic Elimination Technique for Three-phase Voltage Source Inverter.

2.2 Inverter

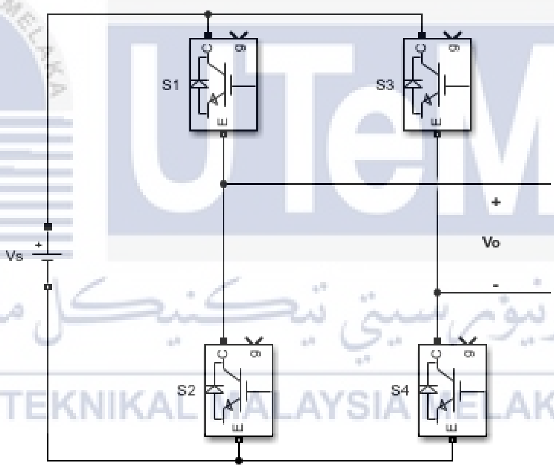
In power electronic circuits, the converter DC input to AC output is frequently named as an inverter. There are two categorized of inverter which are voltage source inverter (VSI) and current source inverter (CSI). The advantage of an inverter is simple execution and low costs. The output voltage of the inverter can be increased or decreased by changing the duty ratio of its switch at the input voltage level. Additionally, the inverter paraphrase can be done moreover by forbidden turn ON and turn OFF devices such as GTOs, BJTs, IGBTs, and MOSFETs. The DC power input to the inverter may be a battery, fuel cell, or solar cell. The three-phase inverter voltage source circuit converts the DC input voltage to the three-phase variable frequency output of the variable voltage. The three-phase inverter circuit consists of three legs, one leg present for each phase. The voltage blocking capability of each system specifies the maximum output voltage level for two-level inverters in three VSI phases, often considered as a two-level inverter. As the inverter level increases, the workload on each device can be decreased proportionally, resulting in an improvement in the inverter's voltage handling ability and preventing a bulky and costly step-up transformer from the application.

2.3 Single Phase Voltage Source Inverter

Single-phase inverters can be defined by their input source such as impedance source inverter (ISIs), current source inverter (CSIs) and voltage source inverter (VSIs). The operating principles of each converter are different.



(a)



(b)

Figure 2.1: Single-phase VSI circuit diagram (a) half bridge (b) full bridge

Figure 2.1 (a) half-bridge and (b) full-bridge are the common topologies for Single-phase Voltage Source Inverter. The converter consists of diodes, switches, and capacitors and an array of two switches is considered as an "inverter leg”. For example, the half-bridge inverter leg is comprised of S_1 and S_2. The large capacitors needed to provide a neutral point N, so that a consistant voltage is maintained by each capacitor. The following guidelines are standard practice for the proper functioning of the voltage source inverter: