SIMULATION OF SINGLE PHASE FUEL CELL POWERED TRANSFORMERLESS MULTILEVEL INVERTER USING H-BRIDGE CASCADED TOPOLOGY

by

Nurhafiza Bt Azizan

(1332220852)

A dissertation submitted
in partial fulfillment of the requirements for the degree of
Master of Science (Electrical Power Engineering)

School of Electrical System Engineering
UNIVERSITI MALAYSIA PERLIS

2014

ACKNOWLEDGMENTS

All thanks to God for his blessings, mercy, giving me strength and ideas for completing this thesis. Writing this thesis is like putting together a big jigsaw puzzle. Without the clues along the way, the final picture might have appeared much later and perhaps fuzzier. I would like to thank the kind individuals, who supplied these clues and some of the missing pieces.

I would like to express my gratitude to my supervisor Dr Muhammad Irwanto Bin Misrun for his valuable supervision, inspiring suggestion, and guidance in the research and preparation of this thesis. I would also like to thank my friends Mohd Hafiz, Norjasmi, Norhanisa, Diyya, Arizadayana and Habibah who encouraged me and shared important knowledge to complete my research thesis.

My outmost gratitude to my family especially my parents Mr Azizan Bin Ibrahim and Mrs Siti Hajar Binti Ibrahim@Hamid for never questioning the path I wanted to take and supporting me in whatever I choose to do. Most of all, I would like to thank my beloved husband Ahmad Zaidi Bin Abdullah, for his endless support and patience throughout my graduate school experience. For all those whom I may not mention here I apologize and thank everyone who have been a part of my success.

TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
THD	Total Harmonic Distortion
PEM	Proton Exchange Membrane
PWM	Pulse Width Modulation
SVM	Space Vector Modulation
SHEPWM	Selective Harmonic Elimination Pulse Width Modulation
SHE	Selective Harmonic Elimination
SPWM	Sinusoidal Pulse Width Modulation
RMS	Root Mean Square
GDL	Gas Diffusion Layers
PSO	Particle Swarm Optimization
MOSFET	Metal Oxide Semiconductor Field Effect Transistor

SIMULASI SATU FASA PENYONGSANG BERBILANG ARAS TANPA PENGUBAH BAGI KUASA SEL BAHAN API DENGAN MENGGUNAKAN TOPOLOGI LATA TETIMBANG-H

ABSTRAK

Tesis ini mensimulasi satu fasa penyongsang berbilang aras tanpa pengubah bagi kuasa sel bahan api. Penyongsang berbilang aras dibina menggunakan litar lata Tetimbang-H bagi menghasilkan voltan keluaran pada tahap tiga, lima, tujuh dan sembilan peringkat. Ia dikendalikan tanpa pengubah untuk mendapatkan voltan nominal iaitu 240V. Ia memerlukan voltan DC (arus terus) dari sel bahan api yang akan menukar kepada voltan nominal AC (arus ulang alik). Kajian ini membincangkan tentang bentuk voltan keluaran daripada lata penyonsang Tetimbang-H berbilang aras seumpama sebagai gelombang sinus tulen menerusi simulasi. Simulasi ini menggunakan perisian MATLAB untuk mendapatkan voltan keluaran dari sel bahan api dan lata penyongsang topologi Tetimbang-H berbilang aras. Topologi ini adalah untuk mendapatkan nilai optimum sudut voltan. Keputusan optimum sudut voltan akan mengurangkan jumlah herotan harmonik terendah dan akan digunakan dalam kajian ini. Keputusan simulasi akan dibandingkan berdasarkan keputusan THD. Apabila meningkatnya tahap tiga sehingga tahap sembilan peringkat, THD menunjukkan peningkatan yang ketara pengurangan dari 36.13 % kepada 10.14 %. Oleh itu , antara tahap tiga sehingga tahap sembilan peringkat lata penyonsang Tetimbang-H berbilang aras , hanya tahap sembilan peringkat yang dipilih untuk analisis selanjutnya. Analisis adalah menggunakan teknik pensuisan PWM (permodulatan lebar denyut). Keputusan perbandingan analisis bagi tahap sembilan peringkat untuk indeks modulasi 0.75 sehingga 1 telah diperolehi bahawa 10.14 %. Penyelidikan diteruskan menggunakan indeks permodulatan 1 untuk mensimulasikan penyongsang bertingkat tahap tiga, lima, tujuh dan sembilan dengan beban kapasitif. Keputusan peratusan THD ialah terdapat sedikit perbezaan apabila penambahan peringkat. Daripada analisis simulasi di atas didapati bahawa THD sistem akan dikurangkan dengan meningkatkan bilangan peringkat dalam gelombang keluaran dan dengan itu kecekapan sistem akan diperbaiki.

SIMULATION OF SINGLE PHASE FUEL CELL POWERED TRANSFORMERLESS MULTILEVEL INVERTER USING H-BRIDGE CASCADE TOPOLOGY

ABSTRACT

In this thesis, a multilevel inverter is constructed using H-Bridge Cascaded circuit to obtain output voltage for three, five, seven and nine level. It is operated without transformer to obtain a nominal voltage of 240V. It needs DC voltage from fuel cell that will convert to the AC nominal voltage. This research was discussed about the output voltage waveform of the H-Bridge Cascaded multilevel inverter approaches the pure sine wave simulation. The simulation uses MATLAB software to get the output waveform from fuel cell and the H-Bridge cascaded multilevel inverter topology. The topology is to obtain optimal values of voltage angle. The optimum voltage angle results will reduce the lowest (THD) total harmonic distortion and to be implemented in this research. The simulation results will be compared based on the THD results. As the level increases from three to nine levels, the THD shows significant improvement of reduces from 36.13% to 10.14%. Therefore, among three to nine levels of H-Bridge Cascaded multilevel inverter, only the nine levels was chosen for further analysis. The analysis was using SHEPWM switching technique. Comparison between the results analysis of nine levels for modulation indexes 0.75 to 1, has obtained that 10.14% is the best THD results. The comparison results are approximately equal between fuel cell and reference of previous researcher based on the simulation. Therefore, fuel cell also can be used as DC voltage source transformerless multilevel inverter.

CHAPTER 1

INTRODUCTION

1.1 Background Study

The inverter is an electronic component used in a wide range of applications that converts direct current (DC) to alternating current (AC). While, if compared to the traditional two-level voltage source inverters, the stepwise output voltage is the major advantage of multilevel inverters (Yousefpoor, et al. 2012).

Multilevel inverters have received more interest in power electronics systems and industrial applications because of their increasing use for commercial. For example, a multilevel inverter is suitable for connecting distributed DC energy sources (solar cells, fuel cells and rectified output of wind turbines) to an existing AC power grid (Ray, et.al. 2009).

In recent years, among the different topologies for multilevel converters, the cascaded multilevel inverter has received special attention due to its modularity and simplicity of control (Jeevabharathi & Padmathilagam, 2012).

Normally, the inverter of 50Hz uses transformer. It is usually big in size, heavy and expensive. It also has high losses, so it will reduce its efficiency. A transformerless multilevel inverter is more suitable in order to reduce the size, cost and it can also increase the efficiency and reduce harmonics.

The advantages mentioned above cause this thesis proposed a simulation of fuel cell transformerless multilevel inverter. The multilevel is constructed by cascaded full bridge circuit to obtain three, five, seven and nine levels. It is operated without transformer to obtain a nominal voltage of 240V. It needs DC voltage from fuel cell which will convert to the AC nominal voltage. Moreover, the advantages of multilevel inverter are higher power quality, better electromagnetic compatibility, lower switching losses, higher voltage capability and transformerless at distribution voltage level, thereby reducing the costs (Taghizadeh &Tarafdar, 2008).

1.2 Problem Statement

The inverters are developed by using electronic components which produce harmonics. The simplest technique to invert DC power into AC power is to generate a square wave. However, not only the harmonic content of the square wave is relatively high, but also the efficiency of this waveform is relatively low.

In a general power electronic design, most inverters in the world require a low frequency. The low frequency (50Hz) inverter uses transformer that is big in size, heavy and expensive. It is operated by battery which drop quickly when connected to the load, and also its life time is not long.

1.3 Objectives

The aims of the research of fuel cell powered transformerless multilevel inverters are:

a) to develop H-Bridge cascaded multilevel inverter.
b) to optimize switching angle
c) to simulate fuel cell powered transformerless multilevel inverter.

1.4 Scope of Work

The goal of this research is to simulate fuel cell powered transformerless of single phase H-Bridge Cascaded multilevel inverter. This project will simulate H-Bridge Cascaded multilevel inverter topology that required least number of components compared with the other examples. MATLAB/Simulink is used to simulate voltage and total harmonic distortion in the single phase multilevel inverter design circuits.

1.5 Thesis Outline

This thesis consists of five important chapters. Chapter one introduces the background of the project, objectives, problem statement, scope of work and thesis outline.

Chapter two provides literature review related to overall project. Including information on operation of fuel cell and multilevel inverter, multilevel inverter topologies and total harmonic distortion (THD) analysis.

Chapter three contains description of the methodologies on how this project is conducted in sequence. This project is based on software and circuit design. In this stage, MATLAB/Simulink is fully utilized to design and simulate the fuel cell powered and single phase multilevel inverter.

Chapter four provides the detailed results and discussion that can be obtained from this project. The simulation results to be discussed including the output voltage waveform and THD.

Finally, chapter five presents the conclusion of the thesis along with the summary of results. Future work has also been recommended.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Multilevel inverters are commonly used in industrial applications to overcome the major disadvantages presented by classical two level inverters. Thus, more interest is focused on the field of high voltage and high power applications taking into account the power quality delivered by these inverters (Kouzou, et al. 2011). Referring to that research, the multilevel inverters have drawn tremendous interest in the power industry. For these reasons, a new family of multilevel inverters has emerged as the solution for working with higher voltage levels and providing an enhanced power quality.

The three major physical domains of fuel cell systems are electrical, fluidic, and thermal. A stand-alone proton exchange membrane (PEM) fuel cell stack itself cannot be used directly as an energy supply. It requires stack control and energy management. DC output voltage of fuel cell is highly dependent on the current which imposes a high-output voltage variation. Most of the DC electrical devices is not acceptable for the voltage variation range. Besides, the fuel cell system must be connected to an inverter to provide alternating current if the electrical device needs an AC supply (Gao, et al. 2011).

2.2 Multilevel Inverter Topologies

Multilevel inverter can be found in many different topologies. Three most popular topologies usually used are H-Bridge Cascade multilevel inverter, Diode Clamped multilevel inverter and Flying Capacitor multilevel inverter.

2.2.1 H-Bridge Cascaded Multilevel Inverter

Multilevel voltage-source inverters are a suitable configuration to reach high power ratings and high quality output waveforms besides reasonable dynamic responses. The cascaded multilevel inverter has received special attention among the different topologies for multilevel converters, due to its modularity and simplicity of control. Furthermore, inverter principle operation is usually based on synthesizing the desired output voltage waveform from several steps of voltage and typically obtained from dc voltage sources (Jeevabharathi, et al. 2010).

Topologies based on series-connected H-bridge inverters are particularly attractive among multilevel inverter structures, due to their modularity and simplicity of control. Different sinusoidal pulse width modulation (PWM) and space-vector PWM schemes are suggested to control the output voltage and reduce the undesired harmonics for multilevel inverters (Hagh, et al. 2009). This topology has a fewer component count than the other multilevel inverter.

H-Bridge Cascaded multilevel inverter can generate almost sinusoidal staircase voltage with each bridge has its own separated DC source (Verma, et al. 2011). This topology can optimize circuit layout. Therefore packaging is possible because each level has the same structure. Besides, there are no extra clamping diodes or voltage-balancing capacitors. Soft-switching techniques can also be used to reduce switching losses and device stresses (Chin, et al. 2008). Figure 2.1 displays the circuit of H-Bridge Cascaded multilevel inverter.

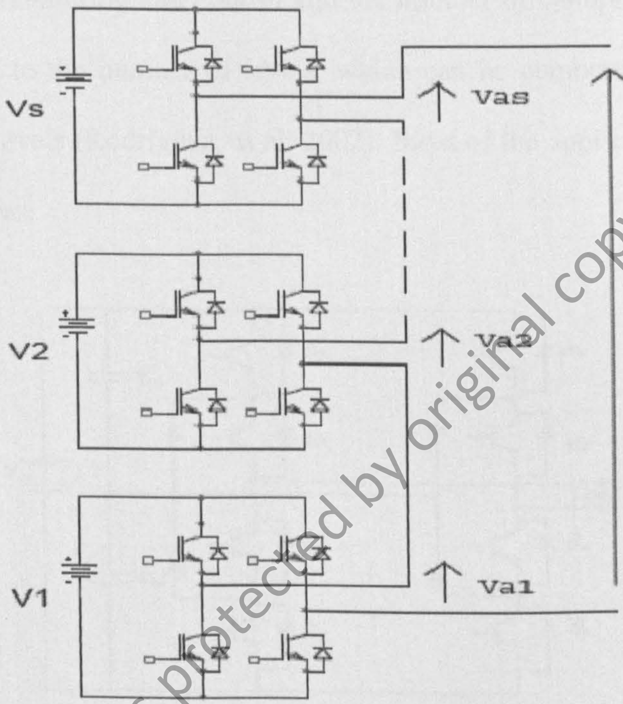

Figure 2.1: H-Bridge Cascaded Multilevel Inverter Circuit

2.2.2 Diode Clamped Multilevel Inverter

Diode-clamped inverter also known as Neutral Point Clamped Inverter was introduced in the early 80's and has been extensively used today in various applications. The advantage is when the level increases the harmonic content is low enough to avoid the need for filters thus the efficiency is high because all devices are switched at the fundamental frequency (Panagis, et al. 2008).

Moreover, this multilevel inverter has the easy switching control and the protection circuit required is least compared to the other inverter. For the real power flow is difficult because the intermediate DC levels will tend to overcharge or discharge without precise monitoring and control and the number of clamping diodes required is quadratic related to the number of levels, which can be cumbersome for units with a high number of levels (Rodriguez, et al. 2002). Most of the applications of this inverter are as motor drives.

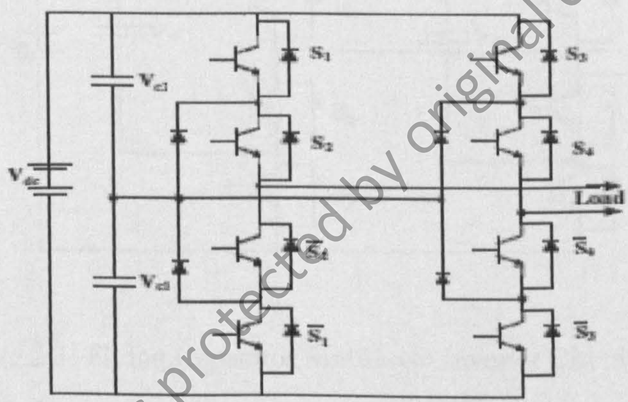

Figure 2.2: Diode-clamped Multilevel Inverter Circuit Topology

2.2.3 Flying Capacitor Multilevel Inverter

The structure of this inverter is similar to the diode-clamped multilevel inverter except that instead of using clamping diodes, the inverter uses capacitors in their place. This topology has a ladder structure of DC side capacitors, where the voltage on each capacitor differs from the next capacitor. The voltage increment between two adjacent capacitor legs gives the size of the voltage steps in the output waveform (Khazraei, et al. 2010).

The most common problem associated with the Flying Capacitor Multilevel Inverter (FCMI) is the capacitor balancing. The proper balancing is essential for the FCMI since the voltage on the capacitors will set the voltage steps on the output waveform. If the capacitors get too unbalanced, the output will have a higher THD and the load will not work properly, especially if it is a motor. (Maldonado, et al. 2012)

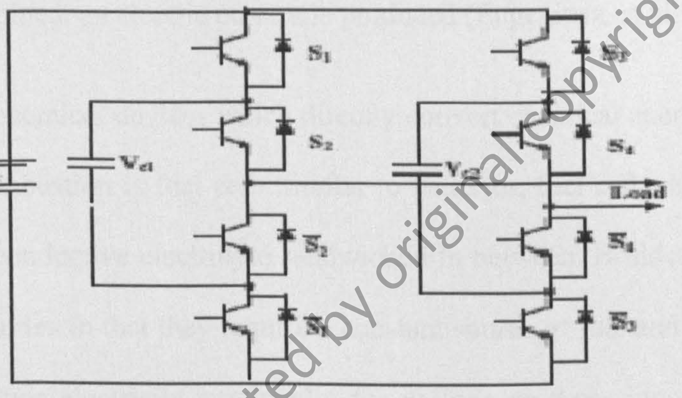

Figure 2.3: Flying Capacitor Multilevel Inverter Circuit Topology

2.3 PEM fuel cells

In general, a basic PEM fuel can be made of three components. There are namely an anode that accommodates the fuel, a cathode that supplies oxidant, and an electrolyte which separates the anode and the cathode and provides a passage for the transport of ions. Three distinct components the catalyst layer, the gas diffusion layer and the gas channel are owned by both the anode and the cathode. The fuel and the oxidant are distributed through the gas channel to the diffusion layer across the fuel cell. The gas diffusion layer and the catalyst layer are made of porous materials so that the fuel and the oxidant can be further transported from the diffusion layer to the catalyst layer where electro-chemical reactions take place in order to generate electricity (Carcadea, et al. 2007).

William Grove was the first person, who in 1839 demonstrated the fuel cell and explained principle of its operation. He noticed that during the electrolysis of water the energy is consumed. Because the electrolysis process is reversible, during the hydrogen and oxygen recombined, an electric current is produced (Eugeniusz, et al. 2006).

One of electrochemical devices which directly convert chemical energy to electrical energy without combustion is fuel cell. Similar to batteries, fuel cells are made of two electrodes with a conductive electrolyte sandwiched in between. Besides, fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied (Rahul, et al. 2012).

The fuel for the fuel cell can be hydrogen or any other hydrogen-containing compound which on reprocessing can produce hydrogen. At the hydrogen electrode (anode), hydrogen ions (protons) and electrons are formed. Protons migrate through the electrolyte to the oxygen electrode (cathode) while electrons move through an external circuit to a load and then return to the cathode. At the oxygen electrode, oxygen, hydrogen and electrons combine to form water. Thus, by forcing the electrons to take an external path, low temperature direct energy conversion is achieved (Raissi et al. 2006)

2.4 Multilevel Inverter PWM Modulation Startegies

In general, modulation control methods are fundamental switching frequency and high switching frequency PWM. In fundamental switching frequency there are two methods for controlling the modulation which is Space Vector Modulation (SVM) and Selective Harmonic Elimination Pulse Width Modulation (SHEPWM). While for H-Bridge Cascade topology, MATLAB/Simulink is being chosen to be implemented with the SHEPWM method.

To control the output voltage and reduce the undesired harmonics, different sinusoidal pulse width modulation (PWM) and space-vector PWM schemes are suggested for multilevel inverters. However, PWM techniques are not able to eliminate low-order harmonics completely. Another approach is to choose switching angles so that specific lower order dominant harmonics are suppressed. This method is known as selective harmonic elimination (SHE) or programmed PWM technique in technical literatures. (Hagh et al. 2009).

According to Fourier analysis, choosing the right values of the switching angles can control the amplitudes of the harmonic components of the inverter output, including the amplitude of the fundamental frequency. (Al-Judi, et al.2011).

2.4.1 Pulse Width Modulation

In the early 1970s, majority of PWM inverters used PWM techniques based on a method of sampling. Sinusoidal pulse width modulation is one of the primitive techniques, which used to suppress harmonics presented in the quasi-square wave.

Over the years, PWM techniques have been developed where the objectives are to improve performance, to simplify the PWM strategies and subsequent microprocessor implementations, to produce minimized harmonic distortion, and to reduce switching losses. Principles of several two-level carrier-based PWM techniques have been extended as means of controlling the active devices in a multilevel converter.

In order to use PWM method, the basic knowledge about the method is to control two or more signal in condition turn ON and turn OFF in several periods.

2.4.2 Sinusoidal Pulse Width Modulation.

The most popular control technique for traditional two-level inverters is the sinusoidal pulse width modulation method (SPWM). The term sinusoidal PWM refers to the production of PWM outputs with sine wave as the modulating signal. The ON and OFF instants of a PWM signal in this case can be determined by comparing a reference sine wave (the modulating wave) with a high frequency triangular wave (the carrier wave) as shown in Figure 2.2 . The sinusoidal PWM technique is commonly used in industrial applications. The frequency of the modulating wave determines the frequency of the output voltage. The peak amplitude of the modulating wave determines the modulation index and in turn controls the RMS value of output voltage.

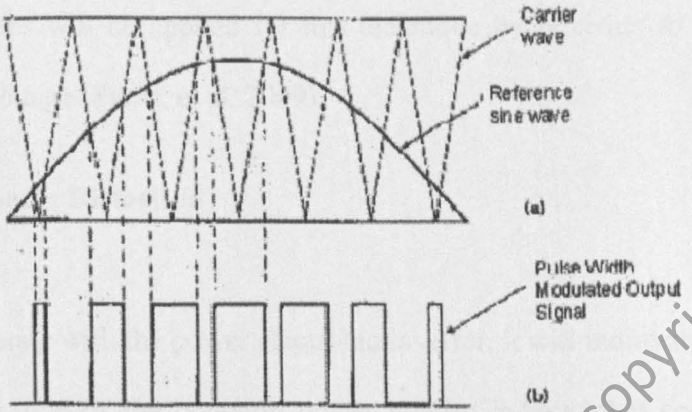

Figure 2.4: Sinusoidal Pulse Width Modulation.

The RMS value of the output voltage can be varied by changing the modulation index. Output voltage of the inverter contains harmonics. However, the harmonics are pushed to the range around the carrier frequency and its multiples.

2.4.3 Selective Harmonic Elimination Pulse Width Modulation.

In the 1990s, Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) technique was applied to multilevel inverters. This scheme features superior harmonic performance compared to other PWM modulation techniques. Referring to the research from (Hosseini, et al. 2009) based on the simulation result between the SPWM and SHEPWM technique, SHEPWM technique result is better than SPWM technique in term of the efficiency perspective, controlling unit and the most importantly, cost reduction. Another advantage of using SHEPWM is to produce a continuous range of switching angles.