HARMONIC REDUCTION OF A SINGLE-PHASE MULTILEVEL INVERTER USING GENETIC ALGORITHM AND PARTICLE SWARM OPTIMIZATION

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I dedicate this thesis to my beloved parents, supervisor, sisters, family and friends.
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ABSTRACT

Inverter play important role in power system especially with it capability on reducing system size and increase efficient. Recent research trend of power electronics system are focusing on multilevel inverter topic in optimization on voltage output, reduce total harmonics distortion, modulation technique and switching configuration. Standalone application multilevel inverter is high focused due to the rise of renewable energy policy all around the world. Hence, this research emphasis on identify best topology of multilevel inverter and optimize it among the diode-clamped, capacitor clamped and cascaded H-bridge multilevel inverter to be used for standalone application in term of total harmonics distortion and voltage boosting capability. The first part of research that is identify best topology multilevel inverter is applying sinusoidal pulse width modulation technique. The result shown cascade H-bridge give the best output in both total harmonics distortion (9.27%) and fundamental component voltage (240 V_{rms}). The research proceed with optimization with fundamental switching frequency method that is optimized harmonic stepped waveform modulation method. The selective harmonics elimination calculation have adapt with genetic algorithm and particle swarm optimization in order to speed up the calculation. Both bio-inspired algorithm is compared in term of total harmonic distortion and selected harmonics elimination for both equal and unequal sources. In overall result shown both algorithm have high accuracy in solving the non-linear equation. However, genetic algorithm shown better output quality in term of selected harmonics elimination where overall no exceeding 0.4%. Particle swarm optimization shows strength in finding best total harmonics distortion where in 7-level cascaded H-bridge multilevel inverter (m=0.8) show 6.8% only as compared to genetic algorithm. Simulation for 3-level, 5-level and 7-level for each multilevel inverter at different circumferences had been done in this research. The result draw out a conclusion where the possibility of having a filterless high efficient invert can be achieve.
ABSTRAK

Inverter memainkan peranan penting dalam sistem kuasa terutamanya dengan keupayaan mengurangkan saiz sistem dan meningkatkan efisien. Kajian terhadap elektronik kuasa sistem amat giat dalam kategori optimisme kualiti voltan output, mengurangkan jumlah herotan harmonik, teknik modulasi dan konfigurasi suis. Aplikasi inverter berdikari difokuskan dengan galakan penggunaan tenaga boleh diperbaharui di seluruh dunia. Oleh itu, kajian ini fokus kepada mengenal pasti konfigurasi suis inverter yang paling sesuai untuk aplikasi inverter berdikari dari diode clamped, capacitor clamped dan cascaded H-bridge inverter bertingkap. Kajian mula dengan simulasi ketiga tiga inverter dengan mengaplikasi teknik sinusodal pusle width modulation. Keputusan menunjuk bahawa cascaded H-bridge inverter merupakan terbaik berbanding dengan yang lain dengan jumlah herotan harmonik (9.27%) dan frekuensi asas komponen voltan (240 V<sub>rms</sub>). Kajian diteruskan dengan optimisme cascaded H-bridge inverter dengan teknik optimized harmonic stepped waveform modulasi. Selective harmonics elimination terlibat dengan kalkulus matematik yang rumit. Genetik algoritma dan partikel swarm optimistik diperuntukkan untuk menyelesaikan kalkulus yang rumit. Dalam proses simulasi, genetik dan partikel swarm optimisme dibandingkan satu sama lain. Keputusan menunjuk bahawa genetik algoritma menunjukkan superior atas partikel swarm optimistik secara keseluruhan(>0.4%). Tetapi, partikel swarm optimistik menunjukkan keupayaan mendapat output yang paling rendah jumlah heratan harmonik (6.8%). Semua simulasi dijalankan dengan cara dan spesifikasi berlainan dengan 3-level, 5-level dan 7-level. Kajian in akhir dengan konklusi bahawa filterless inverter mampu direalisasikan.
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# LIST OF SYMBOLS AND ABBREVIATIONS

| Symbol  | Meaning                                                      |
|---------|--------------------------------------------------------------|
| $A_c$   | Carrier amplitude                                           |
| $A_m$   | Modulation amplitude                                        |
| fval    | Fitness function value                                       |
| $m$     | Number of voltage level                                     |
| $P_{\text{best}}$ | Best fitness (PSO)                                    |
| $G_{\text{best}}$ | Global best (PSO)                                    |
| $V$     | Voltage                                                     |
| Hz      | Frequency                                                   |
| AC      | Alternate current                                           |
| CC-MLI  | Capacitor clamped multilevel inverter                       |
| CHB-MLI | Cascaded H-bridge multilevel inverter                       |
| CSI     | Current source inverter                                     |
| DC      | Direct current                                              |
| DC-MLI  | Diode clamped multilevel inverter                           |
| DG      | Distribution generation                                     |
| GA      | Genetic algorithm                                           |
| IGBT    | Insulated-gate bipolar transistor                           |
| MG      | Microgrid                                                   |
| MOSFET  | Metal–oxide–semiconductor field-effect transistor           |
| PD      | Phase disposition modulation                                |
| POD     | Phase opposition disposition modulation                     |
| Abbreviation | Description                                      |
|--------------|--------------------------------------------------|
| PS           | Phase shift modulation                           |
| PWM          | Pulse width modulation                           |
| OHSW         | Optimize harmonic stepped waveform               |
| SPWM         | Sinusoidal Pulse Width modulation                |
| SHE          | Selective harmonic elimination                    |
| THD          | Total harmonic distortion                        |
| VSI          | Voltage source inverter                          |
CHAPTER 1

INTRODUCTION

1.1 Project background

In conjunction with industrialization and increase of human population, resultant world energy demand continues to increase year by year. The population and energy consumption is increasing correspondingly with time which is also predicted to continue increasing in future [1]. This cause increasing demand of energy for future energy sustain [1]. The exploration in renewable energy show increasing trend in past decade. Examples of renewable energy sources (RES) such as sun, wind, geothermal, biomass which will not be exhausted. RES have advantage over traditional sources in less emission [2]. However, RES mostly experience problem related to inconsistent output. For example, solar energy are dependent source which differ by radiation and yet need to be covert form DC to AC. Renewable energy is always complemented with inverter which hold the key to generating high efficient and reliable power. To utilize the energy, inverters play an important role in energy conversion process.
Inverter can be classified into two main types that is voltage source inverter (VSI) and current source inverter (CSI). Each types have their own unique characterise which been listed in literatures [3-7]. From the literatures, a brief conclusion of VSI is more popular than CSI can be make [3]. In addition, VSI transformer-less inverter popular in renewable energy application due to overall size reduction. The most common use inverter is high power 2-level PWM inverter. However high power application ideally is require low switching losses.

In past decade, numberless of literature has proven multilevel inverter is a practical solution on resolving high switching losses problem exist in conventional inverter for high power application [8]. Research trend nowadays are more focusing on several multilevel inverter topologies for renewable energy sources application. Multilevel topologies inverter generate multilevel voltage source output which synthesize the staircase waveform form single or multiple low DC voltage source. The low input voltage source reduce the stress encounter by the switches with ability produce high output voltage source. Currently, cascaded H-bridge multilevel inverter (CHB-MLI) and it modified topologies is high grab attention due to the flexibility toward renewable energy.

Multilevel inverter system can be separate into two sector which is inverter topology system and switching strategy. Inverter topology system consist of the most part include switches power sources, topology configuration and filter system. Power source are mostly RE such as solar panel and wind turbine. For topology configuration, there are 3 main type which been frequently cited in literature that is diode clamped multilevel inverter (DC-MLI), capacitor clamped multilevel inverter (CC-MLI) and cascaded H-bridge multilevel inverter (CHB-MLI) [9-16]. Filter part is apply to remove harmonics and smoothen the inverter output quality.

The move on to next part that is switching strategy. This part manipulated the harmonics profile for the inverter output waveform. The conventional type are square wave. This type evolve into quasi-square wave which give better profile as compare to square wave. Current trend is pulse width modulation (PWM) which been widely
apply in currently VSI devices [17]. However, researcher explored other method on overcome the cons of PWM where different kind of add on method been apply in conjunction with PWM such as elective harmonic elimination (SHE). SHE consist of complex non-linear equation on resolving best switching timing. Hence, various calculation approach been tested to optimize the overall performance. The calculation method include newton-rapshon, Fourier transform, and even bio-inspired algorithm approach such as bee, ant, particle swarm, genetic, bat and others [18-23].

Multilevel inverter widely apply in power system area. The some of the power generated by renewable resources are capable on self-sustainable for the user or even excessive power can revert back to main grid. Hence, this research focus on the trend of self-sustainable type or so call standalone application.

1.2 Problem statement

At present, existing high power system using traditional multi-pulse converter which alone with bulky transform and filter system [24, 25]. The size of converter have given a limitation to the application of converter especially in small scale usage such as standalone application system. Beside of the sizing problem, traditional converter also have high switching loss and electromagnetic interference (EMI) problem according to the previous researches [26, 27]. In order to solve this problem, converter with smaller size and low switching loss criteria is needed. However in standalone system need to maintain or even performance better in term of harmonic distortions and voltage boosting capability. Hence, inverter are found to be the solution.

Inverter play important role in regaining quality AC current to the consumer. Multilevel inverter have been done individually research according to the literatures for capacitor clamped [28, 29], diode clamped [30], cascaded H-bridge [31] and other topologies [32-34]. Each research show the related topology to be suitable for standalone application but there has been no comparative research between each other.
Among the topologies comparison, modulation strategies also hot topic of research in inverter fields. Several literature found to be having difficulty in resolving high non-linear equation of getting best switching timing [35-39]. The mathematical approach have reach a limit in increasing calculation speed of the complex equation.

Due to all the problem mention in this section, the proposed solution will be presented in next section.

1.3 Aim and objectives

The aim of this research is to analyse the performance of multilevel inverter topologies for a standalone application. Hence following objectives had been listed to ensure objective achieved.

a) To compare the performance of multilevel inverter topologies with sinusoidal pulse width modulation in term of total harmonics distortion and the voltage boosting capability.

b) Apply proposed switching method to optimize the multilevel inverter with purpose to reduce total harmonic distortion and switching frequency.

c) To compare the capability of inverter system in adapting to balanced and unbalanced voltage sources with different bio-inspired algorithm for switching angle calculation.

1.4 Research scopes

Multilevel inverters are basically classified into three main categories which are capacitor clamped multilevel inverter, diode clamped multilevel inverter and cascaded H-bridge multilevel inverter. This research objective is to identify the most suitable topology in a single phase standalone application. The three topologies are the fundamental idea of the other latest modified topology. Hence, the scope has been narrowed into focusing only on these three multilevel inverter topology.
In simulation environment, topology construction and algorithm calculation is realised with the aid of Matlab/Simulink software. The overall specification for the simulation are listed as below. Total voltage input will always be 240 V, output voltage modulated to 50 Hz and the sampling time is $1 \times e^{-06}$s. MOSEF switches model is used. Hence, Matlab R2015a is used throughout the research with the aid of other software such as Microsoft Excel.

For the optimization of selected topology, optimized harmonic stepped waveform is proposed to be applied. The simulation input remain total 240 V and the sampling time is $1 \times e^{-06}$s. The calculation of selective harmonics elimination in this research is focus on comparison on genetic algorithm and particle swarm optimization. Both method under same simulation model with them own specification mention in methodology respectively.

In addition, three levels of multilevel inverter are applied in the research that is 3-level, 5-level and 7-level multilevel inverter. In this research, main key point is total harmonic distortion (THD), switching frequency, voltage boosting capability and the capability in adapting unequal sources.

1.5 Thesis outline

The thesis is doing performances analysis of multilevel inverter for standalone application. The literature studies of the project stated in chapter 2. Chapter 3 is the methodology of simulation topology and modulation method are discussed. Chapter 4 is where the result and analysis of the simulation are presented. Lastly chapter 5 is the conclusion and recommendation of the research.
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