CASCADED PUSH-PULL AND CASCADED H-BRIDGE INVERTER FOR TOTAL HARMONIC DISTORTION REDUCTION IN STAND-ALONE PHOTOVOLTAIC SYSTEM

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Cascaded Push-Pull and Cascaded H-Bridge Inverter for Total Harmonic Distortion Reduction in Stand-Alone Photovoltaic System

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TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 RESEARCH METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
BJT	Bipolar Junction Transistor
BOS	Balance of System
CERE	Centre of Excellent for Renewable Energy
CMI	Cascaded Multilevel Inverter
CPS	Concentrated Solar Power
CSI	Current Source Inverter
CTHD	Current Total Harmonic Distortion
DC	Direct Current
DCMI	Diode-Clamped Multilevel Inverter
EEIES	Electrical Energy and Industrial Electronic Systems
EMF	Electromotive force
FCMI	Flying-Capacitor Multilevel Inverter
FF	Fill factor
IC	Integrated circuits
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconducting Field Effect Transistor
MPPT	Maximum power point tracking
NI	National Instrument
PCB	Printed circuit board
PF	Power factor
PIC	Programmable integrated circuits
PV	Photovoltaic

PWM	Pulse Width Modulation
rms	root means square
SCR	Silicon Controlled Rectifier
THD	Total Harmonic Distortion
THD	Total harmonic distortion
TNB	Tenaga Nasional Berhad
UPS	Uninterruptable Power Supplies
VSI	Voltage Source Inverter
ZVS	Ziro Voltage Switching

LIST OF SYMBOLS

%	Percentage
⁻	Negative
+	Positive
°C	Temperature (Degree Celsius)
A	Current (ampere)
Hz	Frequency (Hertz)
I	Constant current
i	Current that varies sinusoidal with time
m^2	Meter square
V	Voltage (volt)
W	Power (watt)
η	Efficiency
α	Displacement angle
Ω	Resistance (ohm)

Penyongsang Lata Tolak-Tarik dan Lata Titi-H untuk Pengurangan Herotan Harmonik Seluruh dalam Sistem Bersendirian Fotovolta

ABSTRAK

Tesis ini membentangkan penyongsang lata Tolak-Tarik dan lata Titi-H untuk pengurangan herotan harmonik seluruh dalam sistem bersendirian fotovolta. Kajian ini melibatkan pembangunan penyongsang yang dicadangkan iaitu lata Tolak-Tarik dan lata Titi-H untuk sistem bersendirian fotovolta. Kajian ini juga melibatkan pengumpulan data daripada sinaran suria, suhu dan keluaran elektrik modul fotovolta. Keluaran modul fotovolta adalah dalam bentuk arus terus. Walau bagaimanapun, kebanyakan penggunaan kuasa di Malaysia adalah dalam bentuk arus ulang alik. Oleh itu, satu teknik penukaran diperlukan untuk menukarkan elektrik arus terus ke dalam elektrik arus ulang alik yang dikenali sebagai penyongsang. Gelombang keluaran voltan penyongsang ideal adalah dalam bentuk sinusoidal. Walau bagaimanapun, gelombang penyongsang praktikal adalah bukan sinusoidal dan mengandungi harmonik. Tujuan kajian ini yang terutamanya adalah untuk mengkaji dan membangunkan reka bentuk penyongsang yang sesuai diaplikasikan dalam sistem bersendirian fotovolta. Oleh itu, tiga reka bentuk penyongsang iaitu Tolak-Tarik, lata Tolak-Tarik dan lata Titi-H telah dibangunkan untuk sistem bersendirian fotovolta dan herotan harmonik seluruh telah dianalisis ke atas tiga penyongsang tersebut. Pengumpulan data sinaran suria dan suhu dianalisis untuk mengetahui potensi aplikasi tenaga suria di Perlis. Data-data ini diukur dengan menggunakan stesen kaji cuaca di Pusat Kecemerlangan untuk Tenaga Boleh Diperbaharui, di Kangar, Perlis. Sinaran suria dan suhu merupakan pemboleh ubah yang penting untuk dipertimbangkan dalam merekabentuk sistem fotovolta kerana pemboleh ubah tersebut boleh menjejaskan keluaran elektrik modul fotovolta. Berdasarkan purata bulanan sinaran suria untuk tahun 2011, jumlah tahunan sinaran suria di Perlis adalah 4715.95 W/m². Ini menunjukkan bahawa keamatan sinaran suria adalah sangat tinggi dan mempunyai potensi untuk penjanaan kuasa fotovolta di Perlis. Sementara itu, kebolehupayaan penyongsang yang dicadangkan telah dinilai dari segi bentuk keluaran gelombang dan herotan harmonik seluruh. Penyongsang Tolak-Tarik, penyongsang lata Tolak-Tarik dan penyongsang lata Titi-H telah disimulasi dengan menggunakan perisian OrCAD. Tiga reka bentuk penyongsang ini dimodelkan dengan beban rintangan. Berdasarkan keputusan simulasi, penyongsang lata Titi-H lebih baik berbanding penyongsang lata Tolak-Tarik dan penyongsang Tolak-Tarik. Eksperimen juga telah dijalankan dengan menggunakan beban induktif 20 W AC pam air untuk penyongsang Tolak-Tarik dan lata Tolak-Tarik manakala penyongsang lata Titi-H telah diuji dengan beban rintangan tulen 50 Ω. Keputusan eksperimen menunjukkan bahawa keluaran gelombang penyongsang lata Titi-H adalah hampir kepada bentuk sinusoidal dan herotan harmonik seluruh voltan adalah kurang daripada penyongsang lata Tolak-Tarik dan penyongsang Tolak-Tarik. Satu kajian perbandingan antara bentuk keluaran gelombang dan herotan harmonik seluruh antara simulasi dan eksperimen telah dijalankan dan disahkan. Keputusan yang diperolehi menunjukkan bahawa keputusan eksperimen lebih kurang sama dengan keputusan simulasi. Satu kajian perbandingan bentuk keluaran gelombang dan herotan harmonik seluruh telah dijalankan antara penyongsang Tolak-Tarik dan penyongsang dicadangkan iaitu lata Tolak-Tarik dan lata Titi-H. Hasil kajian menunjukkan bahawa penyongsang dicadangkan iaitu lata Titi-H

adalah lebih baik daripada penyongsang lata Tolak-Tarik dari segi bentuk keluaran gelombang dan herotan harmonik seluruh. Ia juga menunjukkan bahawa herotan harmonik seluruh bagi penyongsang yang dicadangkan iaitu lata Tolak-Tarik adalah lebih baik daripada penyongsang Tolak-Tarik. Secara keseluruhannya, pada dasarnya ketiga-tiga reka bentuk penyongsang tersebut sesuai untuk penggunaan sumber arus terus dan boleh diaplikasikan untuk sistem fotovolta yang mana bergantung kepada jenis penggunaan beban.

Cascaded Push-Pull and Cascaded H-Bridge Inverter for Total Harmonic Distortion Reduction in Stand-Alone Photovoltaic System

ABSTRACT

This thesis presents the cascaded Push-Pull and cascaded H-Bridge inverter for total harmonic distortion (THD) reduction in stand-alone photovoltaic (PV) system. This study involves the development of the proposed cascaded Push-Pull inverter and cascaded H-Bridge inverter for stand-alone PV system applications. This study also involves the data collection of solar irradiance, temperature and PV module electrical output. The output of PV module is in direct current (DC) form. However, the power utilisation in Malaysia is mostly in alternating current (AC) form. Therefore, a sophisticated conversion technique is required in converting the DC signal into AC signal which is known as inverter. The output voltage waveform of ideal inverters should be sinusoidal. However, the waveform of practical inverter is non-sinusoidal and contains harmonics. The aim of this research is mainly to study and develop the suitable inverter design that can be applied in stand-alone PV system. Therefore, three inverter designs which are Push-Pull inverter, cascaded Push-Pull inverter and cascaded H-Bridge inverter have been developed for stand-alone PV system and THD has been analyzed over these three inverters. The data collection of solar irradiance and temperature were analyzed in order to know the potential of solar energy application in Perlis. These data were measured using weather station at the Centre of Excellence for Renewable Energy (CERE), in Kangar, Perlis. Solar irradiance and temperature are two important variables to be considered in designing a PV system because these variables will affect the PV module electrical output. Based on the average monthly solar irradiance for the year 2011, the annual total solar irradiance in Perlis is 4715.95 W/m². This shows that solar irradiance intensity was very high and has a potential for PV power generation in Perlis. Meanwhile, the performances of the proposed inverters have been evaluated in terms of output waveform and THD. The Push-Pull inverter, cascaded Push-Pull inverter and cascaded H-Bridge inverter has been simulated using OrCAD software. These three inverter designs are modelled with the resistive load. Based on the simulation results, the performance of cascaded H-Bridge inverter is better compared to cascaded Push-Pull and Push-Pull inverters. The experiment also has been carried out using inductive load of 20 W AC water pump for Push-Pull and cascaded Push-Pull inverter while the cascaded H-Bridge inverter was tested with pure resistive load of 50 Ω. The experimental result shows that the output waveform of cascaded H-Bridge inverter is nearly to sinusoidal shape and the voltage THD is less than cascaded Push-Pull and Push-Pull inverter. A comparative study between output waveform and THD between simulation and experiment has been conducted and validated. The results obtained show that the experimental results are close enough to the simulation results. A comparative study of output waveform and THD between Push-Pull inverter and the proposed cascaded Push-Pull and cascaded H-bridge inverters has been also conducted. The result shows that the proposed cascaded H-Bridge inverter is better than cascaded Push-Pull inverter in terms of output waveform and THD. It also shows that the THD of proposed cascaded Push-Pull is better than Push-Pull inverter. Overall, these three inverter designs are basically suitable for DC source applications and can be applied for PV system applications which are dependent upon the load application.

CHAPTER 1

INTRODUCTION

1.6 Background of Study

Nowadays, the increase of environmental concerns about global warming and the harmful effects of carbon emissions have created a new paradigm shift to green energy resources. The growing demand for energy, high oil prices and concerns of environmental impacts have increased the development of renewable energy such as wind, solar, sea, biomass and geothermal power. These resources do not cause any significant environmental pollution or substantial health hazards and apparently available as natural abundant resources.

Solar energy is among the most popular development of renewable resources. Solar energy is a clean natural energy as a new energy system that can provide sustainable development of the humanity. The basic concept of solar photovoltaic (PV) system is to collect solar energy in space and transfer it for distribution as electrical power.

In any solar PV based system, the inverter is a critical component responsible for the control of electricity flow between the module, battery and load. The inverter is an electrical device that converts electrical power from direct current (DC) form into alternating current (AC) form at desired output voltage or current and frequency using appropriate devices such as transformer, switching and control circuits. The inverter is widely used in many industrial applications like DC power source utilization, variable

speed drives for single phase and three phase AC motors, standby or emergency supplies and uninterruptable power supplies (UPS).

Malaysia is one of the countries that receive abundant of sunlight on average mostly in the northern side of Peninsular Malaysia. Perlis, Kedah and Penang have high potential in solar energy application. Therefore, this research will study the potential of solar energy in Perlis in order to apply the stand-alone photovoltaic system. In this research, the studies will be focused on developing several inverters that are suitable for photovoltaic system application. It will be based on the basic theories of the inverter design and topologies. The simulation and experiment will be conducted in order to validate the performance of the inverter. A harmonic analysis is carried out to justify the performance of the inverter. The performance of the inverter will be analysed and compared with the results obtained from the simulation and experiment.

1.7 Problem Statement

Increasing the energy demand leads the utilities to increase their power generation and capacity. A large number of capital investments are required in the expanding transmission and distribution system including land and electrical equipment. Moreover, the continuing rise of oil price and concerns of environmental impacts has increased the development of renewable energy such as solar, wind, biomass and geothermal. However, there are a few problems in order to apply this kind of renewable energy.

The specific problems are given below:

1. These renewable sources energy, in particular solar energy needs a sophisticated conversion technique to make it usable to the consumer which is known as inverter. The output of photovoltaic (solar) panel is in direct current (DC) form. Therefore, it needs to be converted to alternating current (AC) form because the power utilisation in Malaysia is mostly in AC form.
2. The output voltage waveform of ideal inverters should be sinusoidal. However, the waveform of practical inverter is non-sinusoidal and contains harmonics.

1.8 Aims and Objectives

The aim of this research is mainly to study and develop the suitable inverter design that can be applied in stand-alone PV system. The specific objectives of this research can be summarized as follows:

1. To develop three inverter designs which are Push-Pull, cascaded Push-Pull and cascaded H-Bridge single-phase inverters for a stand-alone photovoltaic system.
2. To reduce the Total Harmonic Distortion (THD) based on the topology differences over these three inverter designs.

1.9 Scope of Project

This research focused on the development of inverter for stand-alone photovoltaic system. This research began with the collection of solar irradiance, temperature and PV electrical output data. The data is applied to study the potential of solar energy in Perlis in order to obtain and develop the inverter design for a PV system. Draft the circuit design of inverter based from the basic theories and literature studies. The research follow by the simulation of the Push-Pull inverter, cascaded Push-Pull inverter and cascaded H-Bridge inverter circuit designs using power electronic simulation software. Then, develop the hardware design for testing and measuring the practical performance. The data from the simulation and experimental is used to analyse and compare the performance of these inverter designs.

1.10 Organisation of Thesis

This thesis is divided into five chapters. Chapter one presents the introduction of the research project. This chapter consists of background of study, problem statement, aims and objectives, scope of research and organisation of thesis.

Chapter two discusses the literature review of this research. It consists of trend in photovoltaic systems, development of inverter in photovoltaic system applications and current inverter design. A summary review of previous work is presented at the end of this chapter.

Chapter three explains the detail description of the methodologies used in this research. This chapter presents the method of data collection for solar irradiance, temperature and PV output voltage. It also describes the design and development of the