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LIST OF ABBREVIATIONS

AC	Alternating Current
Ah	Ampere hour
BDCM	Brushless DC Motor
BIPV	Building Integrated Photovoltaic
DC	Direct Current
FiT	Feed-in Tariff
Hz	Hertz
IGBT	Insulated Gate Bipolar Transistor
kW	Kilowatt
kWh	Kilowatt Hour
LED	Light Emitting Diode
LV	Low Voltage
MBIPV	Malaysia Building Integrated Photovoltaic
MCU	Main Controller & Synchronizing Unit
MOSFET	Metal Oxide Silicon Field Effect Transistor
MPPT	Maximum Power Point Tracking
NOCT	Nominal Operating Cell Temperature
OCC	Open-Circuit Test
PF	Power Factor
PV	Photovoltaic
PWM	Pulse Width Modulation
ROI	Return of Investment
SCC	Short-Circuit Test
SEDA	Sustainable Energy Development Authority

SSR	Solid-State Relay
THD	Total Harmonic Distortion
TNB	Tenaga Nasional Berhad
UPS	Uninterruptible Power Supply
W	Watt

Hibrid Suria dan Penyambungan-Grid dengan Operasi Multi-Mod

ABSTRAK

Tenaga suria sedang mula mengambil alih sebagai sumber tenaga alternatif menggantikan bahanapi konvensional seperti minyak petroleum, arang batu dan gas asli. Ini adalah disebabkan keperluan terhadap tenaga di mana bahanapi fosil tidak mampu untuk memenuhi permintaan masa hadapan kerana kekurangan sumber bekalan dan semakin mahal. Dengan pemasangan sel fotovolta suria (PV) atau panel suria dalam menghasilkan bekalan elektrik untuk tempat terpencil, rumah dan bangunan, teknologi yang berhubung-kait dengan tenaga elektrik suria sedang mengalami permintaan yang sangat tinggi. Tujuan projek penyelidikan ini secara khususnya adalah memperkenalkan suatu konsep baru sistem PV suria dengan operasi multi-mod, bersama dengan komponen-komponen yang berkenaan atau sub-sistem, untuk membekalkan tenaga elektrik di antara suria dan grid kepada beban elektrik dalam keadaan lebih berkesan dan terbaik. Beberapa contoh kebaikan dan kekurangan terhadap alat penyongsang semasa jenis bersendirian dan sambung-grid dibandingkan dalam konsep cadangan ini. Ianya memperkenalkan penggunaan satu motor DC dan janakuasa segerak sebagai penyongsang elektromekanikal untuk menjadi suatu pilihan lain terhadap kaedah tersohor menggunakan penyongsang keadaan pepejal dalam menukarkan bekalan DC suria kepada AC, mampu menjalankan perkakasan elektrik biasa. Ini memperkenalkan kepada sistem bekalan elektrik suria yang lebih bebas untuk membekalkan kuasa untuk kegunaan berbeza tanpa terhad hanya kepada satu penggunaan. Sebagai rujukan kepada asas penggunaan kuasa dalam satu rumah, sistem penjanaan berkuasa 2 kW yang dicadangkan tersebut adalah lebih serba guna, dengan 6 jenis mod operasi berbeza yang berfungsi samada dalam keadaan sambung-grid atau luar-grid di waktu siang dan malam yang mampu menambah faktor penggunaan suatu sistem suria PV dari 25% kepada 100% sehari. Alat Kawalan Utama (MCU) yang mempunyai litar kawalan dan perisian program adalah dicipta khas sebagai perintis untuk sistem yang berfungsi sepenuhnya. Ciri-ciri berkaitan dan parameter penyongsang elektromekanikal tersebut telah ditentukan menerusi pelbagai simulasi dan tatacara amali. Untuk kajian perbandingan, ujian prestasi terhadap penyongsang keadaan pepejal iaitu penyongsang gelombang sinus terubah, penyongsang gelombang sinus sebenar dan penyongsang elektromekanikal yang dicadangkan telah dilaksanakan sebagai perbandingan terhadap jumlah harmonik dan kecekapan terhadap beban yang berbeza, di mana kecekapannya ialah 64% dan jumlah herotan harmonik (THD) voltan adalah di antara 8.10% hingga 10.32%. Kecekapan penyongsang gelombang sinus terubah adalah didapati pada 90.2% dengan voltan THD di antara 27.64% hingga 28.97%, manakala kecekapan penyongsang gelombang sinus sebenar disahkan pada 76.1% dengan voltan THD di antara 2.018% dan 3.275%. Sambungan sebenar penyongsang yang dicipta itu kepada grid telah dilakukan dengan data ujian di ambil untuk menilai prestasi ketika operasi selari dan operasi luar-grid. Cara penyambungan dari sudut ekonomi terhadap sistem PV suria tersebut untuk mendapatkan pulangan pelaburan terbaik, pertimbangan wajar saiz bateri dan penjanaan terpisah, telah dibincangkan secara meluas. Hasil keseluruhan telah menunjukkan yang teknologi PV suria yang dicipta ini mempunyai kelebihan-kelebihan unik untuk mengatasi kelemahan-kelemahan sistem sambungan-grid PV suria yang sediaada. Sebagai rumusan, dengan realisasi sistem berkenaan, sistem PV yang berkebolehan melebihi keupayaan semasa PV suria dan teknologi sambungan-grid tersedia sebagai suatu pilihan baru untuk pertimbangan masa hadapan.

Hybrid Solar and Grid-Connected System with Multi-Mode Operations

ABSTRACT

Solar energy is beginning to take place as the most important alternative energy source in replacing conventional fuels such as crude oil, coal and natural gas. This is due to the increasing of energy demand in which fossil fuels are no longer be able to fulfill future needs because of depleting resources and costly. With the wide installations of solar photovoltaic (PV) cells or solar panels to provide electricity in remote places, homes and buildings, the technology regarding solar electricity is highly demanding. The purpose of this research project particularly introduces to the new concept of solar PV system with multi-mode operations, together with its related components or subsystems, effectively selecting suitable conditions between solar and grid supply in providing electricity to loads. Several advantages and disadvantages of the present stand-alone and grid-connected static inverters are compared with the proposed concept. It introduces to the use of a DC motor and synchronous generator as an electromechanical inverter as an alternative option to present popular approach of using solid-state static inverters in converting the solar DC supply into AC, suitable to run common electrical appliances. This initiates to a more resourceful solar electricity supply system to provide power on different occasions rather than having it to be limited to one dedicated application. As a household benchmark power consumption, the proposed 2 kW output power system is highly versatile, featuring 6 different modes of operation which can be used to function in either grid-connected or off-grid conditions, day and night which could increase the utilizing factor of a solar PV system from 25% to 100% per day . The Main Controller Unit (MCU) with its controlling circuits and programming firmware are specially designed to establish a pioneering fully functional system. The relevant characteristics and parameters of the electromechanical inverter were determined through various simulations and practical procedures. As for the comparative study, performance tests to the static inverters, i.e. modified sinewave, a true sinewave and to the proposed electromechanical inverter were done to evaluate their total harmonics and efficiencies with respect to different load conditions, where the efficiency is determined to be 64% and voltage THD is in between 8.10% to 10.32%. The modified sinewave inverter efficiency is found to be 90.2% with voltage THD is in between 27.64% to 28.97%, while the true sinewave unit efficiency is verified to be 76.1% with voltage THD is in between 2.018% and 3.275%. Actual connection of the designed electromechanical inverter to grid was made with tests data taken to see its performance during parallel operation and off-grid operations. Proper connection of the proposed solar PV system for the most economical way to get better return of investment, proper battery-sizing and isolated generation are extensively discussed. The overall results show that the designed solar PV technology has unique advantages to overcome the weaknesses of present grid-connected solar PV system. As a conclusion, with the realization of such a proposed system, a more versatile PV system that extending the capability of present popular solar PV and grid-connected technology is available as another option for future consideration.

CHAPTER 1

INTRODUCTION

1.1 Background

With the increase of human population reaching to 7 billion inhabitants globally (World population, 2011), many countries have started to consider alternative energy sources into their major energy policies as to fulfill future energy demands. Energy is accepted as one of the driving forces of economic development and political stability of all the nations. Inadequate supply of energy will certainly jeopardize any countries into economic recession, politically unstable and public unrest.

In relation to electrical energy, Malaysia has taken serious efforts under several national policies to diversify the conventional four-fuel mix (oil, coal, natural gas and hydro) to the five-fuel mix strategy in expanding the resources to incorporate renewable energy and nuclear. In view of the country will become a net energy importer by 2020, the increase in alternative energy shares at least will provide stable energy security, more economical and greener environment.

With the ever increasing prices related to conventional fuels of crude oil, coal and natural gas, the rationale of seeking into solar energy as one of the renewable energy sources seems to be vital and place this research into one of present major interests.

Solar energy is presently becoming the most important renewable energy source in replacing conventional fuels such as crude oil, coal and natural gas for electrical power generation. Solar energy is freely available, non-polluting and produces no air or water pollution, no carbon-dioxide and greenhouse gases. In recent years, manufacturing costs of solar photovoltaic (PV) cells have dropped by 3-5% per year while government subsidies

have increased, thus making solar energy systems in future to be ever-more affordable. The energy output of a 1 kWh solar PV unit with a daily average of 5 peak sunshine hours in 1 year (365 days) is approximately equivalent to the burning of 913 kilograms of coal with 2683 kilograms of carbon dioxide being released into the atmosphere (Coal, 2012). With an average of 6 hours of sunshine Malaysia receives per day (Jabatan Meteorologi Malaysia, 2012), it is estimated that one-third of the present energy consumption could be saved by using solar energy and will definitely save our environment from air or water pollution and greenhouse gases.

This research in particular will focus on the design of a solar PV system, together with its related components or subsystems, necessary to effectively optimize conditions with several operating modes between solar and grid supply in providing electricity to homes and buildings.

1.2 Problem Statements

In this research, the problem statements are listed as follows:

a) Most of existing solar PV systems commonly available are dedicated to operate only in one particular mode of operation. The system operation is only limited during daytime whenever enjoying enough sunlight and becomes useless for operation at night or in inadequate sunshine. Furthermore, if it is designed as grid-connected system, grid power failure will prevent the PV system from supplying power to loads even though in ample sunshine due to anti-islanding protection imposed on the system. It is also not possible to be used as a stand-alone unit or as a UPS to back-up critical loads.

b) Common static power inverters used in stand-alone solar PV units are vulnerable to high inductive loads such as motor compressors. From past experiences, the inverters were unable to power-up refrigerators, chillers and air-conditioners. They are easily subjected to severe damage if forced to supply power to those loads.

c) Considering the high initial set-up cost for a solar electricity system, with the present low equipment utilization factor of 25% per day (refer to Section 5.8) will slow down the time to achieve return of investment (ROI) where 75% of the time leaves the equipment idling.

d) High level penetration of grid-connected inverters through present aggressive promotion by PV installers to capture the Feed-in Tariff (FiT) is expected to cause power quality problems and instability to the utility in future.

1.3 Aim and Objectives

The specific aim of this research is mainly to develop a suitable and viable solar and grid-connected hybrid electricity system and exploring the broad areas of technical and economical feasibilities; for commercial implementation towards supplying electricity to homes and buildings in comparison to existing systems.

The main objectives of this research can be summarized as follows:

a) To validate the concept of using synchronous generator as a voltage supply source, where grid-connected and off-grid / stand-alone operations are possible which the capability of a solar PV system can be extended from one single-mode to multi-mode operations. The proposed involves design, assemble and program the relevant circuits in the Main Controller Unit (MCU) to control the whole operation of the solar PV system that can be selected from these modes; Grid-Only Mode, Hybrid Mode, Grid-Tie (With Anti-Islanding) Mode, Grid-Tie (With Islanding) Mode, UPS Mode and Stand-Alone Mode.

b) To introduce the concept of using electromechanical inverter system for the conversion of DC to AC power. The use of such inverter with a brushless DC motor and a synchronous generator though it is a conservative approach, may resort to problems

encountered by most static inverters due to their inabilities to supply heavy current loads with motor compressors.

c) To introduce the multi-mode functions of the PV system in order to increase the usage time (utilization factor) of the equipment where the installation can also be used at other occasion regardless day or night and not strictly dependent to adequate sunshine, hence provides better investment justification.

d) To conduct comparative studies of the electromechanical inverter with regard to other commercial available static inverters to obtain the performance profiles in terms of voltage and current harmonics and efficiencies between the inverters. In view to the results, in order to avoid power quality problems by the grid-connected inverters, operating the system in hybrid mode (alternate solar or grid) may become a better option and eventually towards the implementation of isolated generation in future.

1.4 Scope of Project

To realize a solar PV and grid-connected system to generate a maximum of 2 kW of power capable of operating in multiple modes of operation.

1.5 Project Overview

This project begins in consideration to the limitations faced by the existing solar PV systems, specifically on the usage of static inverters and low utilization factor. Technical and economic factors contribute to the research of finding other alternatives in this solar PV system to increase the overall performance.

It is no doubt that static inverters are generally capturing the interest of most people in the related field because of advancing technology and knowledge in power electronics are

getting better and stronger. Nevertheless, the knowledge and technology of using classical approach on motor and generator set as a potential inverter system should not be neglected as having its own unique advantages in contrast to the present systems.

In this research, methodology, circuit diagrams, firmware programs, results comparisons and discussions with elaborate descriptions and explanations are given in details for better justification in analysis, exploration and providing path for future improvement.

1.6 Thesis Organisation

The dissertation of thesis is organised into five chapters. Chapter 1 introduces on background of the research, problem statement, aim and objectives, scope of project and project overview.

Chapter 2 presents on the literature reviews on types PV system installations, i.e. off-grid, grid-connected and hybrid systems stating their merits and demerits. Then reviewing of other researchers' works on system considerations, stand-alone and grid-connected PV systems are generally discussed to be taken into design considerations. Technical overviews on grid-connected static inverter and synchronous generators are also presented, discussing on the effect to the grid and synchronization techniques for parallel operation chosen in the proposed design.

Chapter 3 explains the research design framework of the system design is presented to visualize the whole research work and the methodology used in realizing the concept. The electromechanical inverter characteristics, control loop, system transfer function and relevant parameters of the brushless DC motor and synchronous generator are determined. The effects of ambient temperature on the overall system output power are also to be considered. Parallel operations of the synchronous generator with grid are simulated against different voltage and phase conditions to predict the actual performance during operation.

Chapter 4 involves the practical design of the vital circuits built into the Main Controller Unit (MCU) with their respective functional block diagrams, actual schematics and illustrations of the programming flowcharts for six modes operation together that masterminds the whole operation of the system.

Chapter 5 presents the performance tests and comparisons between the 3 types of inverters; modified sinewave, true sinewave and the proposed electromechanical inverter with graphical information of the voltage and current harmonics of the inverters' outputs together with their efficiencies. The operation times of related modes are determined and identified in relation to the switch-over and start-up times between generator and grid supply. Parallel operations between generator and grid are preformed to show the technical feasibility of the system. Practical connection of the designed inverter to grid is also proposed for proper energy billing through promoting the economical and environmental aspects of the system. Proper battery-bank storage sizing is also explained for frequent off-grid operations to avoid power interruption through examples of battery connections and relevant calculations.

Chapter 6 states the conclusion for the research and recommendations on future researches based on the results obtained.