UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF LOW POWER CONVERTER SOLAR-BASE SYSTEM

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By

MOHAMED AGRIBI FARHAT

Thesis Submitted in Fulfilment of Requirement for the
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Dedicated to

My

Parents, Brothers, Sisters, Wife and Daughter

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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With the recurrent oil crises and the new environmental boundary conditions for energy production and use, the photovoltaic, PV, system development can be a very promising strategic solution, which releases together with the photovoltaic energy cost effectiveness goal, an actual clean, renewable, and alternative energy option. However, the continues decline in photovoltaic module prices in the international market gives more attention to design the supplementary equipment with low cost and high reliability, such as battery charger and DC-to-AC inverter.

The objective of this project is study the effect of irradiation and temperature on the output of solar module and to design, construct, and test battery charger and DC-to-AC inverter for stand alone system. The proposed stand-alone system consists of 5

solar panels, a battery charger, a sealed lead acid battery, a DC-to-AC inverter, and AC loads.

The solar energy has been converted to an electric energy using a panel of photovoltaic cells. The electric energy stored in a sealed lead acid battery 30Ah, 12V. The storage process was controlled by an electronic charger, which has been designed and developed for this purpose.

A low cost, PWM inverter has been designed and constructed using power BJT switches and electronic components that are common and cheap to convert the stored DC energy to an AC one, and to provide the AC voltage for a small and medium AC loads. Both charging and discharging of the stored energies have been examined, and good results have been obtained.

Results of the experimental and simulation work showed that there was a good agreement between the hardware and software. This indicated that the proposed stand-alone system was successfully developed.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi syarat keperluan untuk ijazah Master Sains

PEMBANGUNAN PENUKAR KUASA RENDAH BAGI PENGGUNAAN SISTEM BERASASKAN SOLAR

Oleh

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Dengan berlakunya kekurangan minyak dan kondisi pembaharuan kuasa yang terbatas, pengeluaran dan pembangunan untuk menggunakan photovoltaic sistem ialah satu penyelesaian yang paling baik, yang mana boleh melepaskan secara bersama-sama dengan kuasa photo voltaic yang efektif, bersih, diperbaharui dan kuasa alternatif yang baik. Walau bagaimanapun, kejatuhan harga modul fotovolta dalam pasaran antarabangsa akan memberikan perhatian yang lebih untuk merekabentuk alatan tambahan dengan kos yang rendah dan ketahanan yang tinggi, seperti pengecas bateri dan penukar arus terus ke arus ulang alik.

Objektif penyelidikan ini ialah untuk mempelajari kesan penyinaran dan suhu pada keluaran solar modul dan untuk merancang, membina pengecas bateri dan penukar arus terus ke arus ulang alik untuk sistem yang berdiri sendiri. Sistem berdiri

sendiri ini terdiri dari 5 solar panel, pengecas bateri, bateri asid plumbum terkedap, penukar arus terus ke arus ulang alik, dan beban arus ulang-alik.

Kuasa solar telah diubah kepada kuasa elektrik dengan menguna panel sel fotovolta. Kuasa elektrik disimpan di dalam , bateri asid plumbum terkedap 30 Ah, 12 V. Proses penyimpanan ini dikawal dengan sebuah pengecas elektronik, yang sudah dirancang dan dibina untuk tujuan ini.

PWM penukar telah dirancang dan dibina dengan menggunakan kuasa suis BJT dan komponen-komponen elektronik yang dasar dan dengan kos rendah untuk merubah penyimpan kuasa arus terus kepada yang arus ulang alik, dan meyediakan voltan arus ulang alik untuk beban-beban arus ulang alik yang kecil dan menengah.

Keputusan-keputusan dari hasil kajian dan kerja simulasi memperlihatkan hasil yang bagus antara perkakasan dan perisian. Ini menunjukan sistem berdiri sendiri telah berjaya dibina.

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I certify that an Examination committee met on 5th November 2001 to conduct the final examination of Mohamed Agribi Farhat on his Master of Science thesis entitled "Development of Low Power Converter Solar-Base System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been dully acknowledged. I declare that this thesis has not been previously or concurrently submitted for any other degree at UPM or any other institutions.

(MOHAMED AGRIBI FARHAT)

Date: December 11, 2001

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LIST OF ABBREVIATIONS

AC	Alternate Current
Ah	Ampere hour
ARC	Anti-reflection Coating
a-Si	Amorphous Silicon
BJT	Bipolar Junction Transistor
C	Capacitor
CSI	Current Source Inverter
D	Diode
D1	Light Emitting Diode
f	Frequency
FF	Fill-Form
HZ	Hertz
I_{SC}	Short Circuit Current
DC	Direct Current
eV	Electron Volt
KTOE	Kilo Ton Oil Equivalent
L	Inductance
P_C	Power Loss
Ppm	Parts per million
PV	Photovoltaic

PWM	Pulse Width Modulation
Q	Transistor
R	Resistance
S	Switch
S1	Switch 1
S2	Switch 2
SOA	Safe Operation Area
T	Temperature
T_{rr}	Reverse Recovery Time
VIS	Voltage Source Inverter
V_{OC}	Open Voltage Circuit
θ	Thermal Resistance
δ	Solar Declination

CHAPTER I

INTRODUCTION

Prologue

This thesis is in three parts. The first is a study of the photovoltaic (PV) system and related topics, such as solar radiation and the solar cell. The photovoltaic effect is the direct conversion of light energy into electricity by solar cells. Electricity is a high quality energy, suitable for almost every type of application.

The second and main part is the design and construction of a charger for sealed lead acid batteries. The charger comprises of two units - a power processor and battery control. The power-processor is based on step-down DC-to-DC converter topology, while the battery control is based on constant voltage mode control.

The third part is the design and construction of a DC-to-AC half bridge inverter – a circuit to convert DC, or direct current, from a battery to AC, or alternating current, for home applications, such as lighting and radio.

Importance of the Project

A PV system is a very attractive primary energy producer as its source of power - the sun - is virtually inexhaustible, universally available and not subject to any business or political monopoly. PV modules are solid-state devices that passively convert sunlight to electricity. By adding modules, a PV system can be built to any size, and it is highly reliable and requires little maintenance. Of all the energy sources, photoelectricity poses the lowest environmental and safety risk.

Photoelectricity is more important in developing countries where much of the population live in dispersed rural communities. Electrification of the areas is difficult and costly and generally not economic for the small power loads required.

Malaysia lies in the centre of the tropics, just above the equator between latitudes $1^{o}20$ N to $6^{o}40'$ N and longitudes $99^{o}35'$ E to $103^{o}20$ E. It possess the requisite sunshine with which to exploit photoelectricity.

Another attraction about photoelectricity is that amorphous silicon absorbs sunlight extremely well, so that only a very thin layer is required (about 1 μm as compared with 100 μm or so for the crystalline cell), allowing considerable savings in the silicon wafer used for the solar cell.

The battery charger provides constant voltage charging as the most efficient and fastest way of charging sealed lead acid batteries. The charger must be simple in design to minimize maintenance in the rural areas where it is likely to be used.

As the bulk of electricity used today is AC, the inverter is a very important requisite in a PV system to convert DC from the storage battery to AC for use.

Objectives of the Project

This project has four objectives.

1. Study of the PV module - the effect of sunlight intensity and cell temperature on conversion efficiency. The study will encompass factors such as geographical location, collector orientation throughout the day and atmospheric transparency.

2. Designing a battery charger for sealed lead acid batteries using solar energy.

3. Designing a DC-to-AC single phase half bridge inverter to convert DC to AC for home use.

4. Simulating a DC-to-AC single phase inverter using Pspice software.

Thesis Layout

The thesis is divided into five chapters. Chapter 1 introduces the work and states the objectives.

Chapter 2 reviews the literature on the environmental benefits of renewable energy, solar radiation and the solar cell, battery charger and the general structure of a DC-to-AC converter.

The work done, including designing, construction and testing separately each component of the battery charger and inverter, and simulation of the DC-to-AC inverter, is presented in Chapter 3.

The performance of the battery charger, inverter and simulation are discussed in Chapter 4. Finally, Chapter 5 gives the conclusion and suggestions for future work.

CHAPTER II

LITERATURE REVIEW

History of PV

The physical effect underlying photovoltaics (PVs) was first observed by Becquerel (1839) when he produced a current by exposing silver electrodes to radiation in an electrolyte. Adams and Day (1877) described the effect in more detail later when they exposed selenium electrodes to radiation and produced a current.

In the 20th century, work by Lange (1930), Grondall (1933) and Schottky (1930) on selenium and cuprous oxide cells led to the photographic exposure meter and many other photo cell applications.

In 1954, Chapin and co-workers at Bell laboratories, USA developed the first solar cell based on crystalline silicon with an efficiency of 6%. This efficiency was increased to 10% within a few years. The first viable use for solar cells was in satellite power supply, and PV convincingly proved its worth in this application.

The main driving force for the widespread use of PV for terrestrial power supply came in 1973 with the first oil crisis, and PV conversion has since become a significant element in most renewable energy programmes.

Fossil Fuels and the Challenge of Carbon Dioxide Pollution

The combustion of fossil fuels releases CO_2 to the atmosphere and this is increasingly seen as one of the major causes of global warming. A 1000 MW coal-fired power plant emits 270 kg/second of CO_2. In pre-industrial times, the atmospheric CO_2 concentration was <290 parts per million (ppm) but by 2000 it was 377 ppm and by 2050 is expected to be double or triple the pre-industrial level. The CO_2 concentration is expected to peak towards the end of the 21st century, by which time most of the world's fossil fuels would have been consumed. Such a dramatic increase in atmospheric CO_2 concentration will almost certainly result in significant warming of the earth (Danial *et al.*, 1983).

It is estimated that in 2025 the global CO_2 emission will be 2.4 times that of the present, but to stabilize the atmospheric concentration at the current level would require a more than 60% reduction from the present emission. The developed countries are the main villains with their 20 per cent of the world's population emitting more than half the CO_2 (Shuzo, 1993).

The earth receives an enormous amount of solar radiation daily. To maintain its temperature, the planet must radiate off the equivalent energy. But radiation has a wavelength inversely proportional to the fourth power of the temperature of its source. Thus the very hot sun emits shortwave radiation, and the very much cooler earth longwave radiation. CO_2 is transparent to shortwave radiation but absorbs the long wavelengths, including that emitted by the earth, thus trapping the heat. The