RESEARCH MODE

Development Of An Active Cooling Mechanism To Increase The Efficiency Of Photovoltaic Module

by

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A thesis submitted in fulfillment of the requirement for the degree of Master of Science (Electrical System Engineering)

School of Electrical Systems Engineering
UNIVERSITI MALAYSIA PERLIS

2012

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

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Date of birth :10 June 1987

Title: :Development Of An Active Cooling Mechanism To Increase The Efficiency Of Photovoltaic Module

Academic Session :2011-2013

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ACKNOWLEDGMENT

This project would not have been a success without the help and attention of many parties. I would like to take this opportunity to express my sincere gratitude to all those who have contributed and assisted me in completing this project. Firstly, I am heartily thankful to my supervisor, Professor Dr. Ismail bin Daut, whose encouragement, guidance supervision and constant attention throughout the period of the project. It has been a pleasure to work under her supervision.

A special thanks to Mr. Muhammad Irwanto bin Misrun for his time in advising me, his suggestions and interest during our meetings. I also appreciate for his moral support and confidence in my work.

I would like to thank Miss Noor Syafawati binti Ahmad who has mentored and advised me during the different stages of the research work. In addition, I would like to thank my fellow masters in the Center of Excellence for Renewable Energy (CERE) for their shared the knowledge to fulfill my project.

Finally, I wish to thank my father, my mother, my husband and all my friends for all support, I would not have been able to successfully complete this endeavor.

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LIST OF ABBREVIATIONS

CERE	Center of Excellence for Renewable Energy
CF	Curve Factor
CFD	Computational fluid dynamics
CO_2	Carbon dioxide
CPV	Concentrating Photovoltaic Cells
DC	Direct Current
FF	Fill factor
I_L	Photo current
I_0	Solar constant
I_{sc}	Short Circuit Current
IR	Infrared
I-V	Current-voltage
P_{max}	Maximum output power
PV	Photovoltaic
P-V	Power-voltage
PV/T	Photovoltaic Thermal
STC	Standard Test Condition
V_{oc}	Open Circuit Voltage

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Pembangunan Mekanisma Penyejukan Aktif Untuk Meningkatkan Kecekapan Modul Fotovolta

ABSTRAK

Di dalam tesis ini, pengaruh suhu modul fotovolta (PV) terhadap kecekapan penukaran tenaga dari PV telah dikaji dengan teliti dan dianalisa secara mendalam. Objektif kajian ini adalah untuk mengkaji kesesuaian sinaran solar untuk penjanaan kuasa di Perlis dan juga menganalisis pengaruh suhu terhadap kecekapan penukaran PV. Seterusnya, reka bentuk yang sesuai mekanisme penyejukan akan dipilih untuk mengurangkan suhu operasi modul PV. Akhir sekali, kesan mekanisme penyejukan kepada prestasi modul PV akan disiasat. Dalam kajian ini, perolakan udara penyejukan secara paksa telah dipilih untuk mengurangkan suhu operasi modul PV. Eksperimen telah dijalankan di bawah keadaan luar untuk membandingkan pengaruh suhu apabila ia beroperasi di bawah penyejukan dan tanpa mekanisme penyejukan. Pada suhu operasi yang lebih tinggi, kecekapan PV modul boleh dikurangkan secara drastic. Secara teknikalnya, telah didapati bahawa, perolakan udara penyejukan secara paksa adalah sesuai untuk dipasang pada PV modul untuk mengurangkan suhu operasi. Pada awalnya, apabila modul PV beroperasi di bawah mekanisme penyejukan, suhu operasi telah menurun dengan ketara dan dapat meningkatkan kecekapan modul PV kepada 11%. Walaubagaimanapun, apabila modul PV dikendalikan tanpa mekanisme penyejukan, suhu operasi adalah tinggi berbanding keadaan sebelumnya, dan kecekapan penukaranhanya boleh mencapai 8.2%. Secara keseluruhannya, kajian ini menunjukkan bahawa modul PV dengan menggunakan mekanisma penyejukan ada;ah bagus untuk mengurangkan suhu operasi modul PV dn mempunyai kecekapan yang tinggi.

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Development of an Active Cooling Mechanism to Increase the Efficiency of Photovoltaic Module

ABSTRACT

In this thesis, the influence of the temperature of photovoltaic (PV) module on the energy conversion efficiency have been thoroughly investigated and analysed. The objectives of this research are to study the suitability of solar irradiance for power generation in Perlis and analyse the influence of the temperature towards the efficiency of PV power conversion. Next, the technique to design the cooling mechanism is determined in order to reduce the operating temperature of PV module. Lastly, the effect of cooling mechanism on PV module performance is investigated. In this research, forced convective air cooling method is selected to reduce the operating temperature of the PV module. The experiments were conducted under outdoor conditions to compare the influence of the temperature when it operates under cooling and without cooling mechanism. During high operating temperatures of the PV module, the power conversion efficiency of the PV module can be drastically reduced. The forced convective air cooling technique is suitable to be installing on PV module in order to reduce the PV operating temperature. At first, when the PV module operates under cooling mechanism, the operating temperature has significantly drop and able to increase the efficiency of the PV module by 11%. However, when the PV module operated without cooling mechanism, the operating temperature was high as to compare with the previous condition, and the conversion efficiency could only be achieve by 8.2%. In overall, it appears that in this research, the PV module with cooling mechanism is the effective technique to reduce the operating temperature of PV module at highest efficiency level.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The energy sector is currently an important issue has changed drastically over the last few years. The energy prices are perhaps more volatile and unpredictable than ever before. Over 80% of our energy use is based on fossil fuels such as natural gas, oil and coal. It is estimated that global energy demand continues to rise by 1-2% per year and will increase by 80% between 2010 and 2040 (ExxonMobil, 2010). Fig 1.1 shows the estimated global energy demand from 2010 to 2040.

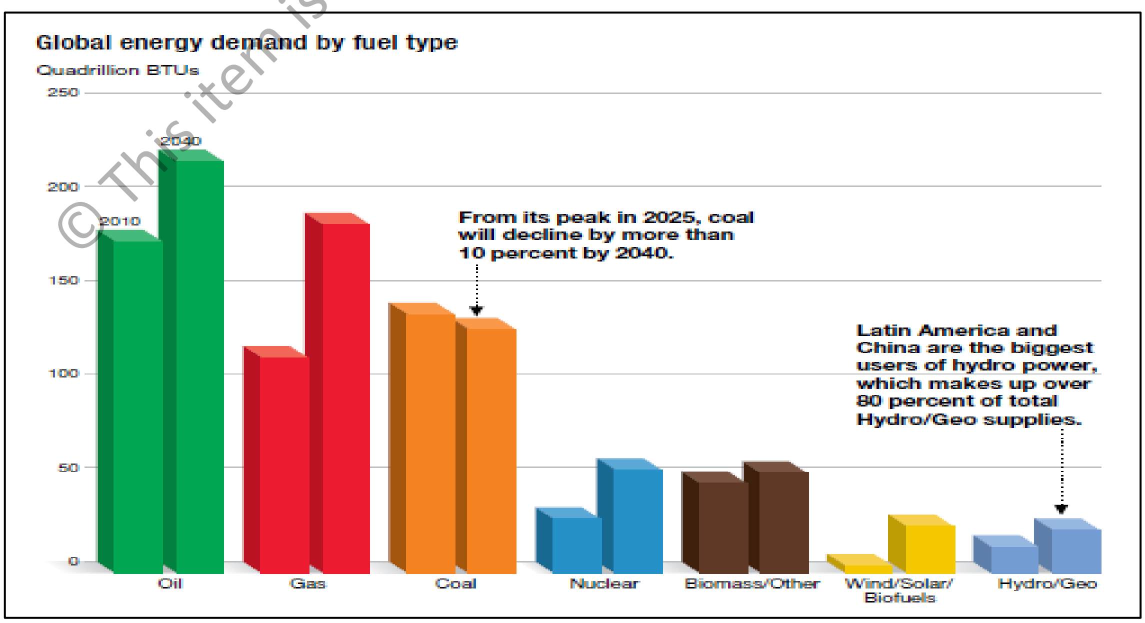

Figure 1.1: Global energy demands (ExxonMobil, 2010).

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Persistent dominance of fossil fuels such as oil, natural gas and coal as primary sources of energy will cause an inexorable rise in global carbon dioxide (CO_2) emissions. CO_2 is the gas mostly responsible for global warming. Gases CO_2 travel up into the upper atmosphere which is call troposphere and it act as a screen to sunlight. Troposphere allows the sun rays in but stops the heat radiation from re-emerging, much as happens with the glass in greenhouse.

The result is that the greenhouse, in this case the whole world, heats up. Global warming could result in the icecaps melting and this, coupled with the effects of the thermal expansion of the seas, would cause sea levels to rise (Selçuk Bilgen et al, 2008).

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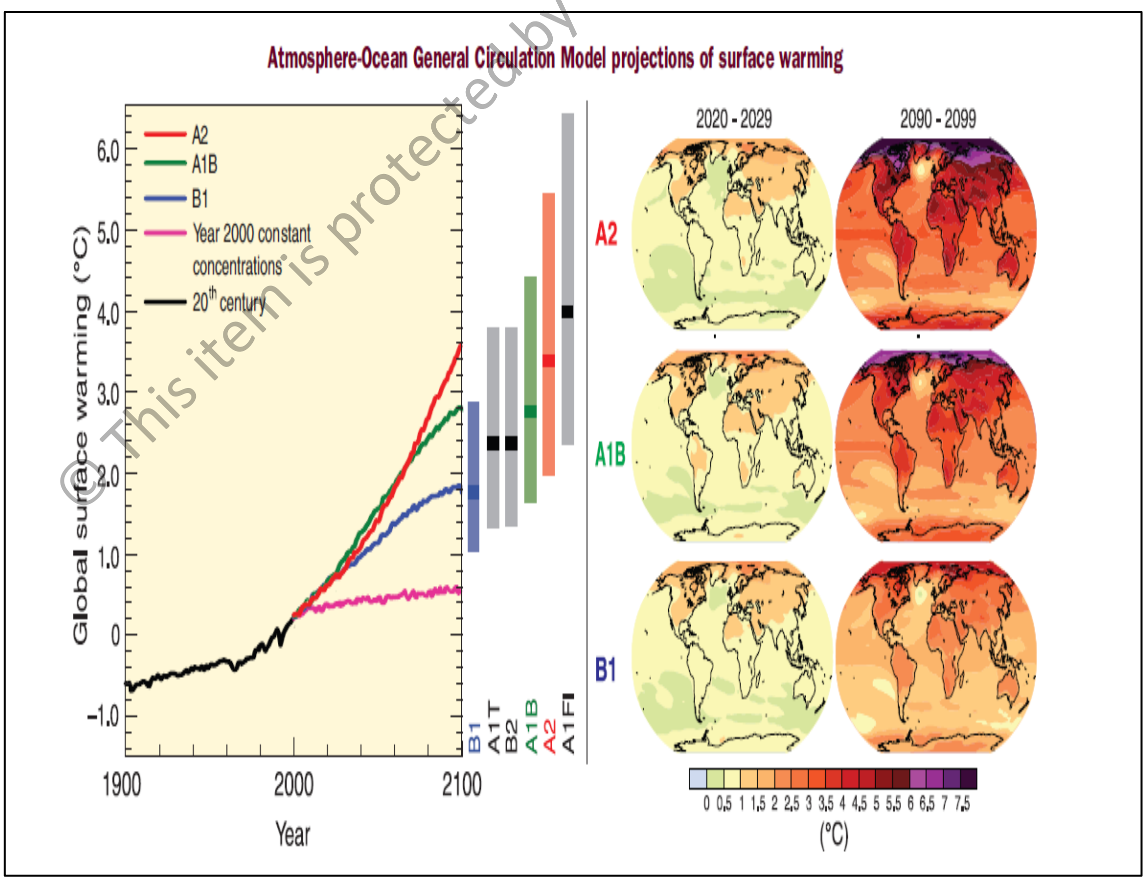

Figure 1.2: Atmosphere- Ocean general circulation model projections of surface warming (Lenny Bernstein et al, 2007).

In this regard, renewable energy resources including solar energy, wind energy, hydropower, biofuel, geothermal energy appear to be the one of the most efficient and effective solutions to resolve the global warming problem and alleviate the potential of energy crisis. Renewable energy competes with conventional fuels in four distinct markets which is can be used for power generation, hot water and space heating, transport fuels, and rural (off-grid) energy. Solar energy is one of the most valuable sources of energy and the only single energy source that can supply an additional energy the world needed over the next several decades.

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1.2 Problem Statement

With the rapid development of the global economy, energy requirements have increased remarkably, especially in emergent countries. The realization that fossil fuel resources required for the generation of energy are becoming scarce and that climate change is related to carbon emissions to the atmosphere has increased interest in energy saving and environmental protection (Banos et al, 2011). Renewable energy, particularly PV technology is one very effective solution available today which can convert the solar radiation into electricity which can be utilized to power household appliances.

Malaysia is one of the country in the world which received high solar radiation per year. This is the reason why Malaysia it is very suitable to build the Solar Power Station in order to generate the electricity by using the source from solar energy. PV module used in Malaysia was imported from the western country which is their specification of PV module is basically suitable for their environment. It is also known that, in western country, the ambient temperature quite low although during summer season. Meanwhile, Malaysia is one of the hottest country. The ambient temperature may achieve up until 45°C during daylight. When western PV module being use in Malaysia, it may consumed a major problem in the operating temperature.

According to the standard test condition (STC), the operating temperature and solar irradiance specified by manufacturer is 25°C and 1000 W/m^2 respectively. While, in Malaysia, high solar irradiance may occurs at high ambient temperature which is around 30°C to 40°C. This will cause the drop in electrical power generated by PV module due to the heat effect on the PV module. The efficiency of PV module may decreases with an increment in temperature. During the outdoor operation of the PV module, the PV module suffers from the high operating temperatures at high irradiation conditions. The temperature of PV module may reach up to 60 to 80°C. Therefore an efficient performance of PV module in Malaysia environment demands an effective cooling mechanism.

1.3 Aims and Objectives

The overall objectives of the research would be to design and to analyse PV module cooling mechanism. The specific objectives are:

1) To study the suitability of solar irradiance for power generation.
2) To analyse the influence of the temperature on the PV conversion efficiency.
3) To determine the technique to reduce the temperatures on PV module with design the cooling mechanism.
4) To investigate the effect of cooling mechanism on PV module performance.

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1.4 Scope of Project

This research is based on the development of PV module cooling mechanism due to the standard and availability of model size in market and for maximisation of power output under wet climate environment, suitable for the Malaysian environment. Project was conducted in a year from January 2011 to May 2012.

This research starts with collection of meteorological data from Vantage Pro2 Weather Station that have been installed at Center of Excellence for Renewable Energy (CERE). The data was recorded to obtain the solar radiation and ambient temperature for the entire projects period of time.

Next, the project was being design and set up the equipment and instrumentation. The data collection would be collected daily for the temperature measurement and the output power of PV module. In addition, the suitability of developing a Solar Power Station at Perlis also will be discussed later.

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1.5 Project Overview

This project starts by making a several reviews on factors that affect the performance of PV module in outdoor applications and some successful study through journal, thesis, papers and article on current issue in Malaysia. The meteorology data are used to obtain the correlation of changes in solar radiation with climate in Perlis. Midi Logger GL220 was used to record and collect the output data including operating temperature, output voltage and output power of PV module.

Next, draft a suitable experiment for measurement of temperature on PV module, design and installation the suitable fan for cooling mechanism. This fan is function to reduce the module operating temperatures in order to improve temperature uniformity and it performance. After the cooling mechanism is installed, the testing begins to collect the data and analysed.

Then, data collected regarding the cooling effect on temperature was analysed to achieve the objective of the research project. To fulfil the objective requirement, this process may take into several times. After the objective of the research project is fulfilled, the experimental result are properly analysed and discussed.

1.6 Thesis Synopsis

Chapter 1 presents an introduction and brief discussion of the importance and potential of solar energy, introduces project overview, scope of research, objectives and the problem statement.

Chapter 2 outlines detail description of PV module temperature and heat loss mechanisms. The understandings of each concept provide a suitable basis for this research. Review of previous work in temperature effect on PV module also included in this chapter.

Since the PV module cooling mechanism is discussed in this research, the detailed description of the design, development and implementation of hardware to build a PV module cooling mechanism is elaborated in Chapter 3.

Chapter 4 performs all the experimental results. The limitation and errors arises in the experiments are analysed in this chapter as well.

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In chapter 5, the result of experiment, economic benefits and environmental effect by using this cooling mechanism are discussed clearly.

Finally, chapter 6 represents conclusion of the research which made based on the results and discussion that obtain in the previous chapter. Besides, this chapter provides some ideas for future work which may significantly improve the overall performance of the cooling system.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Energy has become a fundamental part of people daily lives. People around the world use energy from a variety of sources for the provision of heating, cooling, lighting and so on. Therefore, energy becomes vital to the social and economic progress of every country. This situation will increase on energy demand and it has been linked with environmental problems like gas emissions, acid rain and the greenhouse effect. Hence, an alternative energy must be used to solve these environmental problems. In this regard, renewable energy resources such as solar and wind energy appear to be the one of the most efficient and effective solutions to replace the conventional fuels due to no air pollution or greenhouse gases.

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2.2 Photovoltaic Module

PV module can directly convert the solar radiation into electricity with maximum efficiency at around 9-12% depending on the types of PV modules. However, during the operation of PV module, more than 80% of solar radiation reaching the PV module is not converted into electricity. It is reflected or transformed into heat. The heat generated yields to an increase in PV module temperature and consequently to a decrease in conversion efficiency of electricity (Mazon-Hernandez et al, 2010). The general rule is the efficiency of PV module decreases with an increase of temperature.

There are three factors may affect the PV module temperature, ambient temperature, thermal resistance of the package, which is used to encapsulate a PV module and solar power, which receive from sun (Kozak et al, 2009). The decreasing rate of temperature effect in electrical efficiency was also found to be 0.1 %/°C (Teo Han Guan, 2010). Therefore, PV module cooling mechanism is of essential importance to boost the electrical efficiency by decrease the temperature of PV module.

During the operation of the PV module in the outdoor performance, the PV module suffers from the high temperatures reached under high irradiation conditions. The temperature of PV module can reach 60-80°C. Open circuit voltage (V_{oc}), short circuit current (I_{sc}), curve factor (CF) and efficiency are temperature dependent parameters and the performance of a PV module is influenced by temperature. Although high temperatures slightly help increase I_{sc}, but leads to a much higher drop in V_{oc} eventually leading to an overall drop in module power. When the temperature increase, V_{oc} will decrease at a rate of ~2.3 mV/K whereas I_{sc} increases slightly with temperature. CF also decreases all these lead to an overall decrease in the cell efficiency (Priyanka Singh, 2008).

Generally, in a number of studies, attention is focused on modifying the configuration of PV module by changging the structure of the module. Some techniques like a novel micro heat pipe array use in PV module cooling. Heat pipe has high heat transfer efficiency and a uniform temperature distribution can solve the PV module cooling issue. Moreover, there are large thermal contact resistance existing between conventional column heat pipe and flat PV module, which will result in poor heat transfer efficiency. The

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novel micro heat pipe array proposed by Xiao Tang et al. (2010) has a good contact with the PV module, as its flat shape.

Teo Han Guan et al. (2012) presented an active cooling system for PV Thermal (PV/T) system. In this study, the main focus is on the comparison of the electrical efficiency on the PV/T system with and without cooling. At higher operating temperatures of the PV/T system, the conversion efficiency of the module can be drastically reduces due to the significant reduction in the V_{oc} of the PV module.

To solve this problem, forced convective air cooling is utilised to reduce the operating temperature of the PV/T system. A series of simulations with different configurations of air duct is done using computational fluid dynamics (CFD) software, FLUENT. From the result, it can be seen most of the fluid flows through the centre channels resulting in the uneven heating of the PV modules.

It was found that without active cooling, the temperature of the module was high and PV modules can only achive an efficiency of 8-9%. However, when the module was operated under active cooling condition, the temperature dropped significantly leading to an increase in efficiency of PV modules to between 12% and 14%.

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