ASSESSMENT OF AUTOMATIC AIR COOLING SYSTEM USING DC FAN FOR PHOTOVOTAIC PANEL

by

AMELIA BINTI ABD RAZAK
(1430911541)

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School of Electrical System Engineering
UNIVERSITI MALAYSIA PERLIS

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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog Digital Converter
AM	Air Mass
BIPV	Building Integrated Photovoltaic
BIPVT	Building Integrated Photovoltaic Thermal
CERE	Centre of Excellence for Renewable Energy
CFM	Cubic Feet per Meter
DC	Direct Current
e.m.f	Electromagnetic Force
EM	Electromagnetic
FiT	Feed-in-Tariff
LCD	Liquid Crystal Display
PIC	Peripheral Interface Controller
PSH	Peak Sun Hour
PV	Photovoltaic
PWM	Pulse Width Modulator
RE	Renewable Energy
RPM	Revolution per Minute
SAPV	Stand-alone Photovoltaic
SEDA	Sustainable Energy Development Authority
STC	Standard Test Condition
UniMAP	University Malaysia Perlis
UV	Ultraviolet

LIST OF SYMBOLS

CO_2	Carbon dioxide
I_{sc}	Short-circuit current
V_{oc}	Open-circuit voltage
I_{max}	Maximum current
V_{max}	Maximum voltage
P_{max}	Maximum power
η	Efficiency
P_{in}	Total power on sunlight falls onto PV panel
P_{out}	Output power of PV panel
A_s	Cross-sectional area of PV panel
Q_{conv}	The rate of heat transfer by convection
T_{PV}	PV panel temperature
T_{amb}	Ambient temperature
h_c	Heat transfer coefficient
v	Speed of wind
$\dot{m}$	Mass flow rate
C_p	Specific heat capacity
p	Density
T_{film}	Film temperature
T_{min}	Minimum PV panel temperature
T_{max}	Maximum PV panel temperature
T_{av}	Average of PV panel temperature
ΔT	Temperature difference

Penilaian Sistem Penyejukkan Udara Automatik Menggunakan Kipas AT untuk Panel Fotovoltaik

ABSTRAK

Panel fotovoltaik (PV) menderita dalam penukaran kecekapan yang rendah dalam menjana kuasa keluaran. Ini kerana haba yang terkumpul yang dijana melalui panel PV membawa panel PV beroperasi pada suhu yang tinggi. Suhu panel PV yang tinggi mengurangkan kuasa keluaran yang dihasilkan oleh panel PV. Untuk menangani isu ini, penilaian sistem penyejukan udara automatik menggunakan kipas arus terus (AT) untuk meningkatkan kuasa keluaran panel PV telah digambarkan. Objektif pertama kajian ini adalah untuk mengkaji kesan sinaran solar dan suhu panel PV ke atas prestasi keluaran panel PV dengan menggunakan perisian PVsyst. Dalam simulasi ini, panel PV dengan kuasa penarafan 100 W dianalisis. Keputusan simulasi menunjukkan bahawa kurang kuasa keluaran dari panel PV dipengaruhi oleh suhu panel PV yang tinggi. Objektif kedua memberi tumpuan kepada reka bentuk dan pembangunan sistem penyejukan udara automatik untuk panel PV. Dalam pembangunan sistem penyejukan udara automatik, bilangan kipas AT yang dikehendaki telah ditentukan untuk panel PV yang dipilih. Oleh itu, prestasi panel PV tanpa sistem penyejukan telah diselidik di luar Pusat Kecemerlangan Tenaga Boleh Diperbaharui (CERE), Universiti Malaysia Perlis, Malaysia. Taburan suhu panel PV bagi pengukuran luar telah digunakan ke dalam persamaan penggubalan pengekstrakan haba untuk mengira aliran udara yang diperlukan kipas AT. Untuk mengesahkan keputusan pengiraan, kesan kedua-dua unit kipas AT ke atas prestasi panel PV telah dikaji dengan menggunakan perisian PVsyst. Keputusan mendapati bahawa bilangan kipas AT yang dikehendaki untuk meningkatkan kuasa keluaran yang dihasilkan oleh panel PV adalah ditentukan oleh dua unit. Selain itu, operasi kipas AT dikawal oleh mikropengawal PIC18F4550, yang bergantung kepada nilai purata suhu panel PV. Oleh itu, kipas AT tidak perlu untuk beroperasi selama 24 jam. Objektif terakhir adalah untuk menyiasat prestasi panel PV dengan pemasangan sistem penyejukan udara automatik di bawah keadaan luar. Kaedah penyejukan terdiri daripada kepingan zink yang dipasang dengan bilangan kipas AT yang berbeza, kemudian dilampirkan di bahagian belakang panel PV. Eksperimen luar telah dilaksanakan ke atas panel PV tanpa dan dengan mod operasi sistem penyejukkan automatik yang berbeza. Keputusan jelas menunjukkan bahawa peningkatan jumlah kipas AT tidak selalu membawa kepada sistem penyejukan yang produktif. Dengan membandingkan prestasi bagi semua mod operasi, panel PV dengan dua unit kipas AT telah menjana kuasa keluaran bersih yang tertinggi. Kesimpulannya, sistem penyejukan udara automatik dengan dua unit kipas AT diperhatikan mempunyai keupayaan dalam menjana tenaga elektrik yang maksimum dan sistem PV yang ekonomi dengan tempoh bayaran balik pelaburan yang lebih pendek.

Assessment of Automatic Air Cooling System using DC Fan for Photovoltaic Panel

ABSTRACT

Photovoltaic (PV) panel suffers in low conversion efficiency in generating the output power. This is because of the accumulated heat generated through PV panel leads the PV panel operates at the high temperature. The high PV panel temperature reduces the output power generated by the PV panel. To address this issue, the assessment output power of the automatic air cooling system using direct current (DC) fan for increasing the output power of PV panel has been figured out. The first objective of this study is to investigate the effect of solar irradiance and PV panel temperature on output performance of the PV panel by using PVsyst software. In this simulation, a PV panel with the rating power 100 W was analyzed. Simulation results imply that less output power from the PV panel influenced by the elevated PV panel temperature. The second objective is focused on the design and development of the automatic air cooling system for PV panel. In development of the automatic air cooling system, the desired number of DC fan was determined for the selected PV panel. Therefore, the performance of PV panel without cooling system was investigated at the outdoor of Centre of Excellence for Renewable Energy (CERE), University Malaysia Perlis, Malaysia. The distribution temperature of the PV panel for the outdoor measurement was applied into formulation equations of heat extraction to calculate the required air flow of the DC fan. In order to verify the calculation results, the effect of the two units DC fan on PV panel performance was investigated by using the PVsyst software. Results found that the desired number of DC fan to improve the output power produced by a PV panel is determined by two units. Besides, the operation of DC fan was controlled by the PIC18F4550 microcontroller, which depending on the average value of PV panel temperature. Thus, DC fan will not run for 24 hours. The last objective is to investigate the PV panel performance with the installation of automatic air cooling system under outdoor conditions. The cooling method consists of zinc sheets installed with the distinct unit of DC fan, then was attached on the back side of the PV panel. The outdoor experiment was performed for PV panel without and with different operation of automatic air cooling systems. The results clearly show that the increasing number of DC fans not always leading to a productive cooling system. By comparing the performance for all mode operation, the automatic air cooling system with two units of DC fan was observed has capability in generating the maximum electrical energy and economical PV system with the shorter payback period of investment.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Energy is one of the most vital human needs in the 21st century. Ehsan and Wahid (2014) reported that about 80 % of the world energy supplies are provided by fossil fuels, causing a lot of problems, especially to the environment. The combustion of fossil fuels has led to serious climatic problems such as large emission of carbon dioxide (CO_2) gas and air pollution. A renewable energy resources is going to be a main substitute for fossil fuels in recent years for their clean and renewable nature. Therefore, the use of renewable energy (RE) resources plays a crucial role to satisfy energy demand without environmental degradation. The predominant RE sources are biomass, solar photovoltaic, hydropower, geothermal and wind energy. Among the many options available, solar energy has been a major source of RE in meeting future energy demand.

Zarmai, Ekere, Oduoza and Amalu (2015) stated that the installation lifetime photovoltaic (PV) system is estimated near about 20 years. During this period of use, the PV panels are going to undergo degradation mechanism, which could lead to breakdown in energy production. The main limit of PV systems is the low conversion efficiency of PV panels, which are strongly influenced by their operating temperature (Dubey, Sarvaiya, & Seshadri, 2013). PV panels suffers in reduction of output power when they operate at high temperature. This drawback affected by the waste heat generated due to the absorption of solar radiation. Zhang, Shen, Xu, Zhao and Xu (2014) stated that only up to 20 % of the incident solar energy are converted to electricity from the radiation falling onto a PV panel. The remaining major part is converted to heat.

Therefore, the effective working operation of a PV panel can be achieved by extracting out the heat energy produced (Ndiaye, Charki, Kobi, Kébé, Ndiaye, & Sambou, 2013). The rate of heat transfer in a certain direction depends on the dimension area of PV panel and its operating temperature (Rekha, Vijayalakshmi, & Natarajan, 2013). Heat is capable of being transferred from the PV panel through fluid by convection. Fluids which are classified as either liquid or gases that can be used as a medium in removing heat from the PV panel (Richard Fitzpatrick, 2016). If the heat transfer fluid removes too much heat, the PV panel temperature decreases, hence reducing the heat loss. This research work is focused on cooling system that used air as a cooling medium for PV panel. Air is one type of the gases, which its movement can be generated either using forced or natural flow. This type of cooling technology presents a non-expensive and reliable method of cooling the PV panel.

1.2 Problem Statement

The reliability and lifetime of a PV system mainly depend on the energy performance by PV panels (Mohammed, Boumediene, & Miloud, 2016). Normally, the efficient functioning of PV panel varies with atmospheric factors, especially on solar irradiance (Dirnberger, Blackburn, Müller, & Reise, 2014). During the operation of the PV panel, not all absorption of solar irradiance is converted into electrical energy and almost 80 % of them is turned to waste in the form of heat (Santbergen & Zolingen, 2007). Consequently, PV panel suffers from a drop in output power with the rise of its operating temperature due to heat energy generated (Temaneh-nyah & Mukwekwe, 2015). Under standard test condition (STC), the conversion efficiency of the PV panel is decreased by about 0.40-0.50 % for each degree rise in temperature (Natarajan, Mallick, Katz, & Weingaertner, 2011). It is necessary to cool the PV panel by removing the excess heat generated from the PV panel in some way. The cooling system needs to be properly designed, hence power consumption of PV panel and capital investment installation required can be minimized. In addition, Moharram, Abd-Elhady, Kandil, and El-Sherif (2013) stated that the cooling system for PV panel is not required all the time. Most of the existing cooling systems were designed to operate within 24 hours (Farhana, Irwan, Azimmi, Razliana, & Gomesh, 2012). The cooling systems are not required for a whole day since PV panel does not generates electricity during night time. Ndiaye et al. (2013) stated that PV panels have major part of investment cost for solar developers in developing PV system. Return of investment for PV system development is directly dependent upon electrical energy generated from PV panels (Mohammed et al., 2016).

1.3 Research Objectives

The main goal of this research work is to assess the automatic air cooling system by using DC fan for PV panel applications. There are sub-objectives as the purpose to achieve the research goal:

1. To investigate the effect of solar irradiance and PV panel temperature on PV panel output performance by using PVsyst software.

2. To design and develop the automatic air cooling system with the desired number of the DC fan for a unit of PV panel.

3. To implement and analyse the automatic air cooling system on PV panel under outdoor conditions with considering economic aspect.

1.4 Scope of the Project

The scope of this study will focus on the assessment of the automatic air cooling system using DC fan in enhancing the output power produced by the PV panel. The scopes of this research are as below:

1. The scope area of the study is located at the Centre of Excellence for Renewable Energy (CERE), University Malaysia Perlis (UniMAP), Malaysia.

2. The weather data of solar irradiance, ambient temperature and wind speed of the site location will be collected for the whole year 2014.

3. The flat-plate of monocrystalline PV panels with the rated power 100 W will be used for this research study. This type of PV panel is selected because the monocrystalline is very sensitive to the PV panel temperature when compares to other type of PV panel.

4. This study is only limited to the DC fan cooling system because of its low power consumption and low cost.

5. The PIC184550 microcontroller will be used for the automatic air cooling system. This type of microcontroller is selected because it has 13 analog input/output compares to other type microcontrollers which have only 8 analog input/output.

6. The heat transfer rate for the back side of the PV panel is presumed to be half of the front side (Zhou, Wang, & Ye, 2015). Thus, this study will focus to cool the PV panel from the backside of the PV panel.

7. Four units of LM 35 temperature sensors will used to measure the distribution of PV panel temperature on the backside PV panel. In most applications, the PV panel temperatures are the same as the temperature measured at the backside PV panel (Hughes, Cherisa, & Beg, 2011).

1.5 Thesis Outline

The thesis is organized into five main sections, which involve of introduction, literature review, research methodology, results and discussion and lastly with the conclusion.

Chapter 2 covers the basic theory of PV panel including its operation and technology system. Besides, the heat transfer mode of PV panel has also been discussed through this chapter. Then, the relevant research studies were reviewed through several journals and conference papers. As air is selected as the working fluid in cooling the PV panel, the details study of the characteristics and selection fan have been discussed. Besides, the theoretical of microcontroller also has been studied since the operation cooling system will be controlled automatically.

Chapter 3 focuses on the research methodology to assess the automatic air cooling system for PV panel. This chapter is divided into four sections which evaluate overall flow of the research study. Firstly, a preliminary study on the weather data of site location was collected in order to analyse the potential of PV system installation. Then, the output performance of PV panel was analysed using the PVsyst software. Next section discusses on the development of automatic air controller system for DC fan operation. The last section is observed the implementation of automatic air cooling system on PV panel under outdoor exposure.

Chapter 4 discusses the results produced which consists of four major sections. The first section study the potential of solar radiation and ambient temperature at the site location for the whole year of 2014. Secondly, the sensitivity of solar irradiance and PV panel temperature on the output performance of the PV panel was investigated using the PVsyst software. The third section is focused on the development of the automatic air cooling system. The desired number of the DC fan was determined based on outdoor measurements through the calculation. Fourthly, the result produced was verified by investigating the effect of the calculated number of DC fan on the PV panel output performance. Lastly, automatic air cooling system was implemented on the PV panel under outdoor conditions. The implementation was conducted by comparing PV panel without and with different modes of cooling operation. After that, analysis on economic aspect was done to identify a desirable mode of automatic air cooling system for PV panel.

Chapter 5 presents the summary of the research study, main research contribution and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter consists of nine sections, which describe the overall review factor and application method of air cooling technology on photovoltaic (PV) panel. Section 2.1 represents the introduction of every section in the literature review. Section 2.2 presents the solar energy potential study especially in Malaysia and Perlis. The next section briefly discusses on PV system technology. Section 2.4 elaborates on the losses occurred through the PV panel. Section 2.5 discusses on the effect ambient temperature and solar irradiance on PV panel. After that, the effect of PV panel temperature on PV panel is discussed in Section 2.6. Section 2.7 presents the heat transfer through PV panel using the forced-air convection. Then, various of air cooling technologies for PV panel is discussed in Section 2.8. The last section summarizes the whole chapter.

2.2 Solar Energy Potential Study

Kumar, Shrivastava and Untawale (2015) stated that sunlight is the largest carbon-free energy source of the earth. The surface temperature of the sun is 5762 Kelvin (K) (Jeffery L. Gray, 2011). Jean, Brown, Jaffe, Buonassisi and Bulovi (2015) reported that the light which radiated by the Sun refers to a specific type of electromagnetic (EM) radiation that is visible with a wavelength between 400 and 750 nanometers (nm). The fundamental quantized unit of light is the photon, which represents the smallest isolable packet of EM radiation of a given wavelength. The energy harnessed from the sun is known as solar energy. This alternative energy can serve as a major RE source in the future because it is known as an unlimited, clean and environmentally friendly energy. Generally, solar energy was utilized using PV panel.

According to Renewable Energy Policy Network for the 21st Century (REN21) report for 2015, about 40 Gigawatt (GW) of solar energy capacity added at the end of year 2014 (Christine, Musolino, Petrichenko, Rickerson, L.Sawin, Seyboth, Skeen, Sovacool, Sverrisson, & E.Williamson, 2015). By referring to this report, the total global capacity of PV installation becomes 177 GW throughout the world. All countries around the world have some PV systems in operation. To date, China is positioned at the top rank market of solar energy followed by Japan and the United States (Christine et al., 2015). With the sunshine time is less than 1800 hours per year (Zhao, Zhao, Deng, & Zheng, 2015), the capacity solar energy increase more than 200 % in 2014 with electrical energy generated about 25 billion kWh. Elsewhere in Asia, South Korea has the largest market in PV capacity installation followed by India and Thailand (Christine et al., 2015).

2.2.1 Solar Energy Potential in Malaysia

Malaysia is promoting the renewable energy (RE) to reduce the high dependency on fossil fuel and contribute towards mitigating the environmental issues. The tropical country of Malaysia with a latitude of 3.164 °N and 101.7 °E, is located in the South East of Asia (Borhanazad, Mekhilef, Saidur, & Boroumandjazi, 2013). Also known as an equatorial country, Malaysia is categorized has abundant solar insolation per year, ranging from 1400 to 1900 $kWhm^{-2}$. The average annual solar insolation is about 1643 $kWhm^{-2}$ with more than 10 sun hours per day (Gomesh, Daut, Irwanto, Irwan, & Fitra, 2013). The climatic condition of Malaysia which the sunshine occurs throughout the year encouraged the progressive development of PV system.