PHOTOVOLTAIC MODULE PERFORMANCE ANALYSIS AT DIFFERENT MODULE ORIENTATIONS AND OPERATING TEMPERATURES.

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PHYSICS WITH ELECTRONICS PROGRAMME
SCHOOL OF SCIENCE & TECHNOLOGY
UNIVERSITI MALAYSIA SABAH

2006

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THIS DISSERTATION IS SUBMITTED AS A PARTIAL FULFILLMENT CONDITION FOR THE AWARD OF THE BACHELOR DEGREE (HONOURS) OF SCIENCE

PHYSICS WITH ELECTRONICS PROGRAMME
SCHOOL OF SCIENCE & TECHNOLOGY
UNIVERSITI MALAYSIA SABAH

APRIL 2006

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Photovoltaic Module Performance Analysis at Different Module Orientations and Temperatures

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ACKNOWLEDGMENTS

There are many people whose contributions make the completion of this dissertation possible and successful. I owe each a debt of gratitude and want to take this opportunity to offer my sincere thanks.

First and foremost, a million thanks to my supervisor, Mr. Alvie Lo Sin Vui for his countless hours spent on guiding me through the completion of this dissertation. His advices and suggestions are most heartfelt without which it would be impossible to complete this dissertation.

Special thanks to my lecturers, Mr. Saafie Salleh and Dr. Jedol Dayou, who have helped me tremendously with their ideas for solving various problems I encountered in my experiments. Without their assistance, it would take me much longer to solve the problems. Thanks to lab assistant Mr. Abdul Rahim Ahmad, who has helped me with the measurement equipments used in my experiments. Thanks to my friends and fellow students, Chee Siew Wei and William Cheong for their assistance in carrying out my experiments.

ABSTRACT

This research was conducted to study the effects of module orientations and operating temperature on the performance of 3 identical photovoltaic modules. The objective of the research is to study and verify how the performance of the modules varied according to the parameter changes. Additionally, the daily distribution of solar irradiance is also looked into. The modules are monocrystaline silicon modules, each with 36 cells, each with a $100cm^2$ surface area. They are each tilted at an angle of 5.98°, 15.98° and 25.98° and faced South. A wedge shaped wooden frame is used for each panel at each tilt angle. The results show that during the period when the experiment was conducted, the module tilted at 5.98° has a higher coefficiency at low irradiance while the coefficiency of the module tilted at 25.98° has the highest increase rate when irradiance increases. The effect of temperature is inconclusive because the result contradicts the fact that monocrystaline silicon solar cells have a negative temperature coefficient. The result shows that the modules have a slightly positive efficiency increase as temperature increase.

ABSTRAK

Kajian ini adalah bertujuan untuk melihat kesan-kesan mencodongkan panel-panel suria dan suhu sekeliling ke atas kecekapan relatif 3 panel suria yang sama jenis. Objektif kajian ini adalah untuk mengkaji dan menentukan bagaimana kecekapan relatif panel-panel suria ini berubah dengan merujuk kepada perubahan parameter-parameter kajian. Di samping itu, taburan harian tenaga suria sepanjang hari juga dikaji. Panel-panel suria yang digunakan adalah jenis monokristal silikon. Setiap panel ini mempunyai 36 sel suria dengan luas permukaan $100cm^2$ setiap sel. Sudut condongan panel-panel adalah 5.98°, 15.98° dan 25.98° dan ditujukan ke arah Selatan. Satu rangka kayu berbentuk baji direka untuk setiap sudut condongan ini untuk menyokong panel-panel suria. Keputusan kajian menunjukkan bahawa sepanjang jangka masa eksperimen dijalankan, panel suria dengan sudut condongan 5.98° mempunyai kecekapan relatif yang tertinggi pada paras tenaga suria rendah. Namun, panel yang dicondongkan pada 25.98° pula menunjukkan peningkatan kecekapan relatif yang tertinggi apabila tenaga suria meningkat. Kesan suhu ke atas kecekapan relatif panel-panel suria gagal dikenalpasti, ini kerana keputusan yang diperolehi bercanggah dengan hasil kajian oleh penyelidik sebelum ini.

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Symbol	Definition
E_λ (in Equation 2 – 1)	Emissive power per unit area, Wm^{-2}
λ	Wavelength, m or μm
T	Temperature, K or °C
exp	Exponential
E (in Equation 2 – 2)	Total blackbody emission rate, W
σ	Stefan-Boltzmann constant, $5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$
A	Surface area, m^2
m	Air mass ratio, dimensionless
H_2	Path length traveled by Sun's ray in the Earth's atmosphere to reach the surface
H_1	Shortest possible path length a Sun's ray can travel to reach the surface
β	Altitude angle of the Sun, degrees (°)
E_g	Band gap energy, eV
E (in Equation 2 – 5)	Photon energy, J
h (in Equation 2 – 5)	Planck's constant, 6.626×10^{-34} J-s
υ	Frequency, hertz
c	Speed of light in vacuum, $3.0 \times 10^{8}\ ms^{-1}$
eV	Electron volt, $1.6 \times 10^{-19}\ J(eV)^{-1}$

Symbol	**Definition**
T_m	Tilt angle of the PV module, degrees (°)
Z_s	Zenith angle of the Sun, degrees (°)
AZ_s	Azimuth angle of the Sun, degrees (°)
AZ_m	Azimuth angle of the PV module, degrees (°)
$\mathrm{I_{sc}}$	Short circuit current of a PV module, A
I	Radiation intensity perpendicular to the surface plane of PV module, Wm^{-2}
I_0	Incoming radiation intensity, Wm^{-2}
$\mathrm{I_{mp}}$	PV module current at maximum power, A
$\mathrm{V_{oc}}$	Open circuit voltage across a PV module, V
$\mathrm{V_{mp}}$	Voltage across PV module at maximum power, V
$\mathrm{P_{mp}}$	Maximum power of a PV module, W
δ	Solar declination angle, degrees (°)
n	Day number, dimensionless
L	Local latitude, degrees (°)
H	Hour angle, degrees (°)

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Since 1973, the word "energy" has been continuously in the news. The energy crisis of the 1970s exposed the vulnerability of the world's energy dependency, which almost exclusively rely upon fossil fuels namely oil, natural gas and coal. Since then, a number of international conflicts erupted where the security of energy resources was the expressed or implied motive, rather than the widely reported claims of human rights abuses or nationalism.

1.1.1 Depleting Fossil Fuels

It became obvious that energy derived from fossil fuels will not last forever. A careful study of the world's energy production rate and fossil fuel reserves indicate that under current production rate and current proven reserves, oil will be depleted by 2045, natural gas by 2069, and coal by 2255 (UN, 2004).

One could claim that other than renewable and fossil energy resources, man could depend on nuclear energy. However, with current technology and proven, extractable uranium reserves, nuclear energy resource will not be sustainable for over a century (UN, 2004).

The obvious solution to the depletion of fossil fuels and the environmental hazards posed by current energy production methods is the new renewable energies. Before the steam engine was invented, man has been using traditional renewable energies for millennia. The traditional renewable energies can solve the dilemma of depleting fossil fuels, but they are not very desirable as the harmful effects towards the environment pose additional problems. Therefore, the long-term solution for world energy security lies in the new renewable energies.

1.1.2 New Renewable Energies for Energy Security

With the booming global population, which creates seemingly insatiable demand for more and more energy, we need to look at our future energy security seriously. It is crucial to ensure that our future generations do not suffer the consequences of our actions today. To ensure future energy security, we must find a viable solution to meet future energy demands, while minimizing the negative impacts on the environment and ensure sustainability of our energy resource.

To differentiate the new renewables from traditional renewables, we identify the new renewables as: 1. Small hydropower; 2. Geothermal energy; 3. Wind energy; 4. Solar energy; 5. Modern biofuels, and 6. Marine energy.

If applied in a modern way, renewable energy sources may be highly responsive to environmental, social and economic goals (UN, 2004). As the various renewable energies derive its energy from specific sources, this will diversify energy carriers, technologies and infrastructure for the production of heat, fuel and electricity. Due to the relative scalability of renewable energy systems, they can provide clean energy even in currently remote, inaccessible areas.

1.2 MOTIVATION

Amongst all of the new renewables, solar energy stands out as being the only one where its resource- sunlight is available globally in a fairly predictable amount and pattern. More importantly, it is available as a free resource. It is also worth noting that everyday, the Earth receives the equivalent of the electricity consumption of 5.9 billion people for 27 years in the form of solar energy (BP Solar, 2000). Photovoltaic (PV) technology enables us to turn this energy directly into electricity.

PV systems directly convert sunlight into electricity- the most common way of transporting energy. PV is an attractive alternative to conventional sources of electricity for many reasons: it is silent, non-polluting, and renewable; it requires no special training to operate; it is modular and versatile; with no moving parts, it is extremely reliable and virtually maintenance free; and, it can be installed almost anywhere.

1.2.1 Building Integrated Photovoltaics (BIPV)

For many years, PV systems have been the preferred power source for remote areas not served by the utility grid. As the cost of PV modules continuously decline, distributed PV systems on buildings are starting to emerge as the first application where PV systems finally make inroads into the urban, utility connected area.

BIPV avoid the cost of land required for ground-mounted systems, as well as the cost of site development, foundations, structural support systems, underground electrical distribution and the utility connection. The building provides the PV aperture area and support structure, and the building's utility service becomes the PV system's grid interface.

PV systems are often integrated into buildings in 3 general areas: integral roof modules; roofing tiles and shingles, and integral modules for vertical facades and sloped glazing. Many BIPV systems have been integrated into roofs because these have the highest solar exposure and so provide the highest power output. As such, this dissertation seeks to understand how atmospheric parameters, particularly solar radiation and temperature affect the performance of these roof mounted PV systems.

1.3 PROJECT AIM

This project aims to provide practical information for developers and parties concerned with the issue of designing and installing BIPV on building roofs in and around Kota Kinabalu, Sabah. Although the installation of PV systems is not something new in the state, the author hopes the information obtained from the study will prove useful.

1.4 PROJECT OBJECTIVES

This project wish to achieve the following main objectives:

1. To study and understand the variation in annual solar radiation at Kota Kinabalu, Sabah, and how it affects the coefficiency of PV modules;
2. To study and understand how PV module orientations affect its coefficiency, and;
3. To study and understand the effects of temperature on the performance of PV modules.

1.5 PROJECT SCOPE

This project limits the type of PV module used in the study to the crystalline silicon PV modules. This is choice is made based on the fact that crystalline silicon PV modules are amongst the most efficient of all types of solar panels. They are also usually heavy, making them more suitable for roof mounting, as they are more durable and able to withstand harsh weather conditions.

Secondly, the chosen location for this project is Kota Kinabalu, Sabah where the author is currently based. This allows a more refined and focused study, as the variability of solar radiation is geographically dependant.

CHAPTER 2

LITERATURE REVIEWS

2.1 THEORETICAL REVIEWS

Historically, two time-of-day dependant factors have complicated the characterization of PV module and array performance. They are: 1. Changes in the solar spectrum over the day, and; 2. Optical effects in the module that vary with the solar angle-of-incidence (King et al, 1997). Temperature effects on PV module performance are treated separately, as they are PV module technology dependant, rather than time-of-day dependant.

2.1.1 Solar Spectral Effects on Photovoltaic Module

To understand terrestrial solar radiation, we must study the extraterrestrial solar spectrum first. We then study how the Earth's rotation and the atmosphere affects the solar radiation received on its surface. Finally, we study how the changing terrestrial solar radiation affects the performance of crystalline silicon PV cell.

a. The Solar Spectrum

Every object emits radiant energy in an amount that is a function of its temperature. To describe the radiation emitted by the Sun, we compare it to a theoretical abstraction called the blackbody. The wavelengths emitted by a blackbody is described by *Planck's Law*:

$$E_{\lambda} = \frac{3.74 \times 10^{8}}{\lambda^{5}\left[\exp\left(\frac{14400}{\lambda T}\right) - 1\right]} \qquad (2-1)$$

Where E_{λ} is the emissive power per unit area of a blackbody (Wm^{-2} μm), T is the absolute temperature of the blackbody (K), and λ is the wavelength (μm).

The area under the curve (*Planck's curve*) between any two wavelengths is the power emitted between those wavelengths. Thus, the total area under the curve represents the total radiant power emitted by the blackbody. This is expressed by the *Stefan-Boltzmann Law of Radiation*:

$$E = A\sigma T^{4} \qquad (2-2)$$

Where E is the total blackbody emission rate (W), σ is the *Stefan-Boltzmann constant* = 5.67×10^{-8} Wm^{-2}K^{-4}, T is the absolute temperature of the blackbody, and A is the surface area of the blackbody (m^{2}).

To know the wavelength with the highest intensity in the spectrum, we need *Wien's displacement rule*:

$$\lambda_{max} = \frac{2898}{T} \mu m \qquad (2-3)$$

Where the wavelength is in microns (μm) and the temperature in Kelvin.

While the interior of the Sun is estimated to have a temperature of around 15 million Kelvin, the radiation that the Sun radiates closely matches that of a 5800K blackbody. Figure 2.1 shows the closeness of the actual extraterrestrial solar spectrum to that of a 5800K blackbody (Masters, 2004).

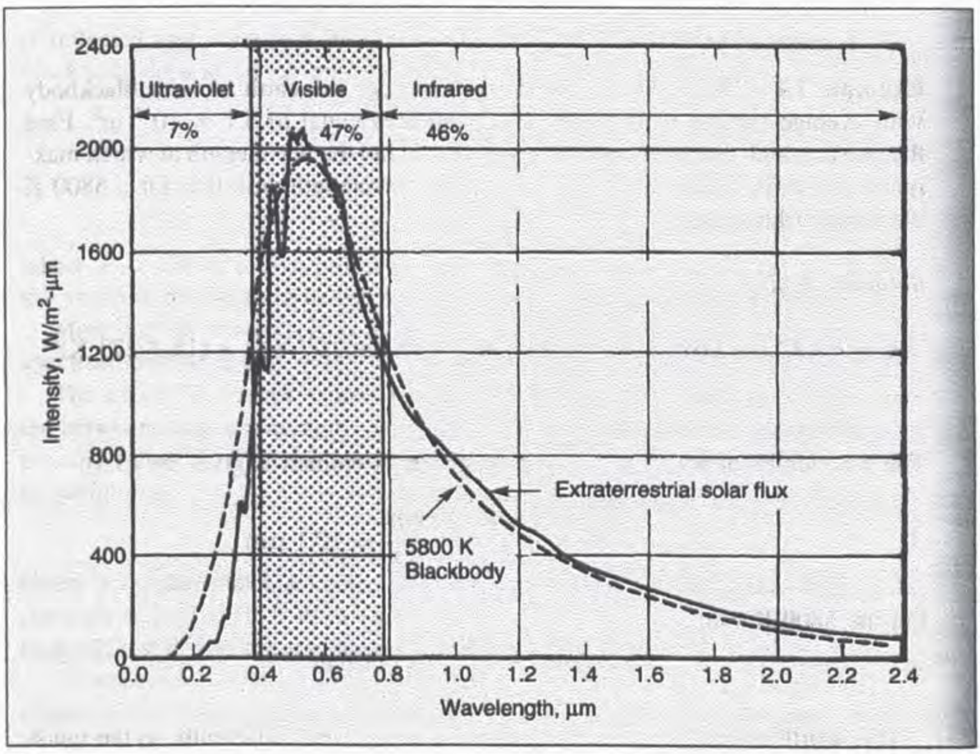

Figure 2.1 The extraterrestrial solar spectrum compared to a 5800K blackbody.

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