UNIVERSITI PUTRA MALAYSIA

FORMULATION OF EMPIRICAL MODELS FOR SOLAR MODULE BY OPTIMISATION OF ITS TILT-ANGLE UNDER NATURAL CONDITIONS

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Faculty: Science and Environmental Studies

Malaysia is a tropical country with abundant sunshine all the year round. The use of solar energy as an alternative to the conventional should be developed urgently as the conventional fuels will be exhausted within this century. Information of global irradiance at any site of the country is essential for proper design and assessed for optimum solar energy conversion. The aim of this study is to find suitable empirical models to explain the incident global irradiance on solar modules for electrical conversion at a fixed optimum tilt-angle throughout the entire day and under the natural conditions.

This research presents a comparative assessment of tilted insolation models using hourly measurements of constant global insolation on solar modules tilted at 0°, 15°, 30° and 45° oriented south in Universiti Putra Malaysia. The experimental research was carried out for six months by exposing the solar modules to natural environment where their environmental parameters such as

global insolation, ambient temperature, solar cell temperature, wind speed, time, module-current and voltage at various load conditions were recorded.

By using the recorded data, a variety of graphical and statistical analyses were performed in order to deduce the module's internal parameters and formulation of models. The analysis reviewed that the optimum tilt-angle was 15° due south as the solar module achieved the highest average global insolation and power production for the entire day during the test. Statistical regression analyses were also performed to formulate empirical models for showing the relationship between these environmental parameters. The formulated empirical models maybe able to predict the outcome of solar electricity production under various tilt-angles and environmental parameters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

FORMULASI MODEL EMPIRIKAL DENGAN KAEDAH OPTIMISASI SUDUT CONDONG MODUL SURIA DI BAWAH KEADAAN SEMULAJADI

Oleh

SIOW WEE SIONG

Julai 2001

Pengerusi: **Prof. Hj. Mohd. Yusof Sulaiman, Ph. D.**

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Malaysia adalah sebuah negara tropik yang hanya dengan sianaran suria sepanjang tahun. Penggunaan tenaga suria sebagai satu tenaga alternatif wajib dibangunkan dengan segera kerana bahan api konvensional akan pupus dalam abad ini. Maklumat mengenai sinaran suria global di negara ini sangat diperlukan untuk mereka-cipta dan menilai penukaran optima tenaga suria. Kajian ini bertujuan mencari model empirikal yang sesuai bagi menerangkan fenomena sinaran suria tuju ke atas modul suria untuk penukaran kepada tenaga elektrik pada satah sudut-condong yang tetap sepanjang hari serta terdedah kepada persekitran semulajadi.

Kajian ini juga memberi penilaian bandingan modul suria yang tercondong pada sudut 0°,15°,30°dan 45° menghala ke selatan di Universiti Putra Malaysia. Segala catatan sinaran tuju yang tetap adalah berdasarkan sukatan masa dalam unit jam pada siang hari. Eksperimen ini dijalankan selama enam bulan di

Universiti Putra Malaysia di mana parameter alam sekitar seperti sinaran tuju global suria, suhu ambang persekitaran, suhu sel suria, kelajuan angin, masa, arus dan beza keupayaan modul suria pada beban elektrik yang berbeza dicatatkan.

Dengan menggunakan data yang tercatat, pelbagai analisis dalam bentuk graf dan statistik dilakukan untuk mentahkik parameter dalaman modul dan pemformulasi model. Analisis tersebut dapat menjelaskan sudut condong yang optima modul suria ialah 15° menghala selatan kerana modul suria telah menghasilkan purata sinaran yang tertinggi dan menghasilkan kuasa elektrik maksimum pada keseluruhan hari dalam tempoh kajian. Analisis statistik regresi juga dijalankan bagi memformulasi medel empirikal bagi menunjukkan hubungan antara parameter-parameter alam sekitar tersebut. Rumusan model empirikal ini mungkin digunakan bagi meramal penghasilan kuasa elektrik suria pada pelbagai sudut condong dan keadaan persekitaran semulajadi yang berbeza.

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LISTS OF SYMBOLS AND ABBREVIATIONS

Pm	Peak power
Vm	Peak voltage
Im	Peak current
Voc	Open circuit voltage
H	Global radiation
h	Planck's constant
ν	Frequency
ϕ	Work function
E_f	Fermi energy level
L	Latitude
h	Hour angle
δ	Solar declination
z	Zenith angle
H_{Bn}	*Beam* radiation at normal incidence
H_B	Beam radiation on a horizontal surface
H_{Bt}	Beam radiation on a tilted surface
R_B	Beam radiation tilt factor.
ρ_g	Diffuse reflectivity
$\bar{K}_T$	Monthly average clearness index
h_s	Sunset hour angle in degrees

$\bar{H}$	Monthly average daily total radiation
$\bar{H}_d$	Monthly average daily diffuse radiation
$\bar{R}$	Monthly mean *total radiation tilt-factor*
s	Tilt of the surface from the horizontal
I_{ph}	Photocurrent
I_D	Diode current.
I_o	Saturation current
A	Ideality factor
Q	Electronic charge
K_B	Boltzmanns gas constant
T	Junction temperature
R_s	Series resistance
R_{sh}	Shunt resistance.
Eg	Band-gap energy
A_O	Ideality factor of the saturation current
Tc	Cell temperature
WS	Wind speed
TA	Ambient temperature
Nmax	Maximum efficiency of solar module
FF	Fill factor
GI	Global insolation

Chapter I

Introduction

What is Solar Energy?

In general terms, solar energy means all the energy that reaches the earth from the sun. It provides daylight, makes the earth hot, and is the source of energy for plants to grow. Solar energy is classified into two types, which are solar heating and solar electricity.

Solar Heating

This application of solar energy simply makes use of the heating effect of sunlight. It has been used for centuries for drying crops, bricks, and pots and to make salt from salty water in solar evaporation ponds. Solar ovens are made with mirrors that concentrate the sun's heat onto a black-painted box for cooking food. Nowadays, solar water heater are quite common in use and they are easily recognised by rectangular black panels mounted at a slight slope and sometimes with a small water tank fixed near to the top end. A pipe is bent back and forth in the panel and water flowing through the pipe becomes hot since the black surface of the panel absorbs a lot of heat when the sun is out. Hot water flows from the panel up to a tank, which is insulated to prevent the water cooling down too much before it is used.

Solar Electricity

Another major use of solar energy is solar electricity. This is electricity generated directly from sunlight using solar or photovoltaic cells. The word

‘ photovoltaic’ refers to an electric voltage caused by light. Solar cells were first developed to power satellites for the space programme in the 1950s. Most solar cells are made of silicon. This is a hard material that is either dark blue or red in appearance. These blue cells are made as thin discs or squares, which are quite fragile. The red type of silicon is coated on to glass as a thin film. As sunlight shines on the surface of silicon, electricity is generated by a process known as the photoelectric effect. Each silicon solar cell produces about 0.4 volt, so solar cells are connected in series to produce a higher voltage. The connection in this way is often called solar panels or photovoltaic modules.

Applications of Solar Electricity

Solar cell modules are made in many sizes, depending on their use. The smallest ones power electronic calculators and digital wrist-watches, while arrays of large modules can supply electricity for a whole village. Solar modules are good source of electricity because they are very reliable, simple to operate, and do not require fuel. However, since they are also expensive to make, these advantages have to be carefully balanced against their high cost before purchase. The main application for solar electricity is in remote sunny areas that have no main electricity and where the supply of fuel for generators is unreliable or expensive. Solar electricity is already used in many large scaled projects: pumping water for drinking and irrigation, lighting and signaling in small stations along a railways line, powering telecommunications stations, and providing cathodic protection of pipelines to prevent rusting. All electrical appliances have low power or wattage requirements need very little electricity to operate. They are well suited to being run on solar electricity because only a small number of solar modules are required in the system. Appliances that produce a lot of heat, such as an electric cooker, clothes iron, or kettle, are all rated in kilowatts. It is possible to run them on solar electricity. However, they would need many solar modules that would be very expensive and would not be an economical use of solar electricity [1].