UNIVERSITI PUTRA MALAYSIA

ATMOSPHERIC CHAMBER TO STUDY THE EFFECTS OF AMBIENT PARAMETERS ON THE EFFICIENCY OF SOLAR CELLS

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By

ALI GHAHRAEI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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Dedicate

To

My dearest parents

For their extensively love

and

Their endless care

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirements of the degree of Master Science

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December 2014

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Solar energy offers a clean, climate-friendly, very abundant and inexhaustible energy resource for mankind, relatively well-spread over the globe. The efficiency of solar cells is affected by ambient parameters like as irradiance of the sunlight, the angle of the sunlight, ambient temperature and relative humidity. An environmental chamber was developed to simulate implied atmospheric parameters inside the chamber since the availability of various climate condition is hard to be predicted and sometimes is impossible. The irradiance is adjusted automatically by controlling the distance between solar cell's stand and the sunlight simulator. The angle can be adjusted by designing the solar cell's stand which can be rotated by a stepper motor. A heater and blower fan was used to change the internal temperature of the chamber. Also, relative humidity can be changed by designed humidifier and de-humidifier. Using the calibration data and provided off-line controller, the amount of irradiance can be set with precision of ~94% of the desired amount and the angle is set between 0° to 90° with maximum error of ±1.1 degree. A Madmani-type fuzzy controller was designed to control the temperature inside the chamber from the laboratory temperature until 60°C with the maximum steady-state error was obtained as 0.3 °C. The amount of relative humidity can be controlled between ~45% and 100% at 26°C to between ~29% and ~81% at 50°C by using a Mamdani-type fuzzy controller. The maximum steady-state error of RH controller was obtained as 1.4%from the experimental results. All of the atmospheric parameters can be controlled by designed interface circuits, data acquisition module and provided computer software. All of the software were developed with LABVIEW platform. The efficiency parameters can be calculated directly from the I-V curve obtained by the embedded source measurement unit and will be saved for further process by using the software.

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

KEBUK ATMOSFERA UNTUK MENGKAJI KESAN PARAMETER PERSEKITARAN PADA KECEKAPAN SEL SOLAR

Oleh

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Pengerusi: Nurul Amziah Md Yunus, PhD

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Tenaga solar menawarkan sumber tenaga bersih mesra iklim, banyak dan tidak putus untuk manusia, yang agak menye lurah di muka bumi. Kecekapan sel solar dipengaruhi oleh parameter seperti persekitaran sebagai contoh sinaran cahaya matahari, sudut cahaya matahari, suhu persekitaran dan kelembapan relatif. Peti alam sekitar telah dibina untuk mensimulasikan parameter atmosfera yang tersirat di dalam peti itu sejak adanya keadaan iklim yang pelbagai yang sukar dijangka dan kadang-kadang mustahil. Sinaran cahaya diselaraskan secara automatik dengan mengawal jarak antara pemegang sel solar dan simulator cahaya matahari. Sudut pula boleh diselaraskan dengan merekabentuk pemegang sel solar yang boleh diputar oleh motor. Pemanas dan pengipas telah digunakan untuk menukar suhu dalaman peti itu. Juga, kelembapan relatif boleh diubah oleh pelembapan dan penyahlembapan yang direka. Dengan menggunakan data penentukuran dan kawalan tanpa talian yang disediakan, jumlah sinaran boleh ditetapkan dengan ketepatan ~ 94% daripada jumlah yang dikehendaki dan sudut pula ditetapkan antara 0 ° hingga 90 ° dengan maksimum ralat ± 1.1 darjah. Sebuah kawalan samar jenis Madmani telah direka untuk mengawal suhu di dalam peti itu dari suhu makmal sehingga 60 °C dengan ralat keadaan mantap maksimum yang diperolehi 0.3 °C. Sekali lagi dengan menggunakan kawalan samar jenis Madmani, jumlah kelembapan relatif boleh dikawal antara ~ 45% dan 100% pada 26 ° C kepada antara ~ 29% dan 81% ~ 50 ° C. Keputusan eksperimen menunjukkan ralat keadaan mantap maksimum pengawal kelembapan relatif diperolehi ialah 1.4%. Dengan kajian ini, semua parameter atmosfera boleh dikawal dengan litar antara muka yang direkabentuk, modul perolehan data dan perisian komputer yang disediakan. Semua perisian disediakan dengan platform LabVIEW. Perisian parameter kecekapan boleh dikira secara terus daripada keluk I-V yang diperolehi oleh unit pengukuran sumber *(SMU)* terbenam dan akan disimpan untuk proses seterusnya.

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I certify that a Thesis Examination Committee has met on 31/12/2014 to conduct the final examination of Ali Ghahraei on his thesis entitled "ATMOSPHERIC CHAMBER TO STUDY THE EFFECTS OF AMBIENT PARAMETERS ON THE EFFICIENCY OF SOLAR CELLS" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

°	Degree
°C	Degree Celsius
μ	Micro [10^{-6}]
A	Area [m^2]
AC	Alternating current
AM(x)	Air mass x spectrum
As	Arsenic
BIPV	Building Integrated Photovoltaics
c(t)	Controller transfer function
Cd	Cadmium
CIGS	Copper indium gallium selenide
DAQ	Data acquisition
DC	Direct current
DSSC	Dye-sensitized solar cells
DTU	Device under test
E	Light irradiance [W/m2]
e	Error
e_c	Elementary charge
EJ	Exajoules (1018 joules)
E_{max}	Maximum Error
e_w	Partial pressure of water vapor [Pa, N/m2]
f	Function
FF	Fill Factor
Ga	Gallium
GPa	Giga Pascal
GUI	Graphical User Interface
GWh	Giga Watt-hours
Hz	Hertz
i	Irradiance [W/m2]
I	Electric current [Amp]
I/O	Input/output
I_L	Irradiance [W/m2]
I_{mp}	Maximum current
In	Indium
I_{sc}	Short-circuit current
J	Current density
k	Thermal conductivity [$W/m^{-1}.K^{-1}$]
k	Boltzmann constant ($1.3806488 \times 10^{-23}$ m^2 kg s^{-2} K^{-1})
l	Thickness or length [meters]
ml	milliliters
mm	millimeters
MPa	Mega Pascal
ms	milliseconds
n	Number of rotations
N_2	Nitrogen gas
NI	National Instruments
Ø	Relative Humidity
P_m	Maximum Power [Watts]

PV	Photo Voltaic
q	Heat energy [Watts]
R	Resistor
r	Radius
RH	Relative Humidity [%]
RS232	A standard protocol for serial communication
s	Seconds
Si	Silicon
SMU	Source Measurement unit
STE	Solar thermal electricity
T_e	temperature error
Te	Telluride
TiO2	Titanium dioxide
Torr	Unit of pressure (1⁄760 of a standard atmosphere)
TTL	Transistor–transistor logic
TWh	Terra Watt-hours
V	Voltage [Volt]
V_{mp}	Maximum voltage
V_{oc}	Open-circuit voltage
W	Watts
α	Angle [degree]
β	The nearest affordable angle
η	Efficiency of solar cell

CHAPTER 1

1 INTRODUCTION

1.1 Background

Energy demand is increasing continuously and it is assumed that the global primary energy demand will be more than double by 2050, i.e. from approximately 470 EJ in 2010 to around 1,100 EJ per year (Johansson, Nakicenovic, Patwardhan, & Gomez-Echeverri, 2012; Khatib, 2011).The share of renewable energies should grow regarding the WBGU (German Advisory Council on global change) scenario for ideal future energy sources (Schellnhuber et al., 2011). Thus, green and renewable energy, particularly solar energy is recently attracting tremendous interest all around the world.

Solar energy offers a clean, climate-friendly, very abundant and inexhaustible energy resource for mankind, relatively well-spread over the globe. The costs of solar energy have been falling rapidly and are entering new areas of competitiveness. Solar thermal electricity (STE) and solar photovoltaic electricity (PV) are competitive against oil-fuelled electricity generation in sunny countries, usually to cover demand peaks, and in many islands. The primary generation of solar cell was single-crystalline silicon (Si) base on p-n junction. The next generation was thin-film solar cells. These types have been developed because of the high cost of silicon solar cell (Carlson & Wronski, 1976). Since, the price of fabrication was high and production rate was low due to difficulty related to procedure, a third generation of solar cell which is Dye sensitized solar cell (DSSC) came to exist in 1991 (Grätzel, 2003; O'regan & Grfitzeli, 1991).

The most generally used factor to compare the functioning of a PV cell to other types is the efficiency. Recently, researchers have shown an increased interest in environmental influences on solar cells (Cristaldi, Faifer, Rossi, & Ponci, 2012; Mekhilef, Saidur, & Kamalisarvestani, 2012; Meral & Dinçer, 2011). Temperature is one of the components of the climate system that effects on the energy yield of solar cells. In recent years, there have been growing investigations on the temperature effect (Lo Brano, Orioli, & Ciulla, 2012; Park, Kang, Kim, Yu, & Kim, 2010; Skoplaki & Palyvos, 2009; Toivola, Halme, Peltokorpi, & Lund, 2009; Vandenbroucke, McLaughlin, & Levin, 2012). In the history of the development of solar cells, light intensity is another important ambient factor which has been mentioned in some literatures (CHEN, 2009; Hagfeldt, Boschloo, Sun, Kloo, & Pettersson, 2010). The next main environmental parameter is the angular effect of solar cell due to sunlight (Granqvist, 2007). Another climatic factor which could be pointed out as an influential parameter on the performance of solar cells is relative humidity (Ettah, Udoimuk, Obiefuna, & Opara, 2012).

The standard efficiency measurement is with air mass 1.5 spectrum solar light and 25°C ambient temperature (Smestad, 2002). But since solar cell output power is affected by ambient parameters, thus in recent years, researchers have tried to develop an artificial climate condition for studying the behavior of solar cells and their energy yields. (Gevorgyan, Jørgensen, Krebs, & Sylvester-Hvid, 2011; Katkar, Shinde, & Patil, 2011; Ray, 2010).

Since by convention, the efficiency of solar cells should be measured under standard test conditions (section 2.7), the term “yield” or “percentage of yield” is used in this thesis to express the amount of efficiency under non-standard test conditions.

1.2 Problem Statement

In general, there is a need for an atmospheric chamber in which atmospheric parameters (temperature, relative humidity, irradiance of light and angle of incidence) can be independently varied.

Efficiency and energy yield of solar cells is an essential requirement for photovoltaic industries, so building such chambers is helpful for them. Although in some researches, these four environmental parameters have been investigated on the silicon-based and thin-film generations of solar cells and new on Dye sensitized generation, none of them have studied all of the effects simultaneously and independently.

Not only for testing, but also for improving the efficiency of solar cells in the future, a complete database and comprehensive estimation of these solar cell efficiency and yield is needed.

1.3 Research Objective

The objectives of the research are:

1) Construction of a test environmental chamber with four adjustable atmospheric parameters; irradiance of light, incident angle of light, temperature and relative humidity.
2) To develop mechanisms to adjust and set the irradiance of the light, angle of incidence, ambient temperature and relative humidity for the device under test (DTU).
3) To provide software to set and control all of the mentioned parameters automatically and measure the energy yield of the PV cell or PV mini module under the test.

1.4 Research Scope

This work is part of research about solar cell studies where the yield of solar cells can be measured with different ambient parameters. The constructed chamber provides an artificial atmospheric environment to expand the study on the efficiency of PV cells.

1.5 Thesis Organization

The organization of this thesis is as follows:

1- Chapter 1 serves as an introduction to the solar cells, type of photovoltaic technologies, and the effect of ambient parameters followed by motivation, objectives, problem statement and research scope are discussed.
2- Chapter 2 begins with an overview of the solar cell history and fundamental of photovoltaic. Effects of ambient parameters on the energy yield of solar cells, including thermal effect, irradiance and angle effect and relative humidity impact, are introduced. Also a standard efficiency measurement is introduced and

environmental chambers for solar cell study and the related literatures are presented.

3- In Chapter 3, the methodology is discussed. The process of selection and installation of components and operation of the systems is explained. Also the data acquisition module and overall operation are presented at the end of the chapter.
4- In Chapter 4, the details of the applied algorithms and developed control systems are discussed. The result of applying the control method to the systems and precisions are shown and discussed.
5- Chapter 5 draws the conclusion and future works.

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