



UNIVERSITI PUTRA MALAYSIA

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

ALI GHAEHRAEI

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

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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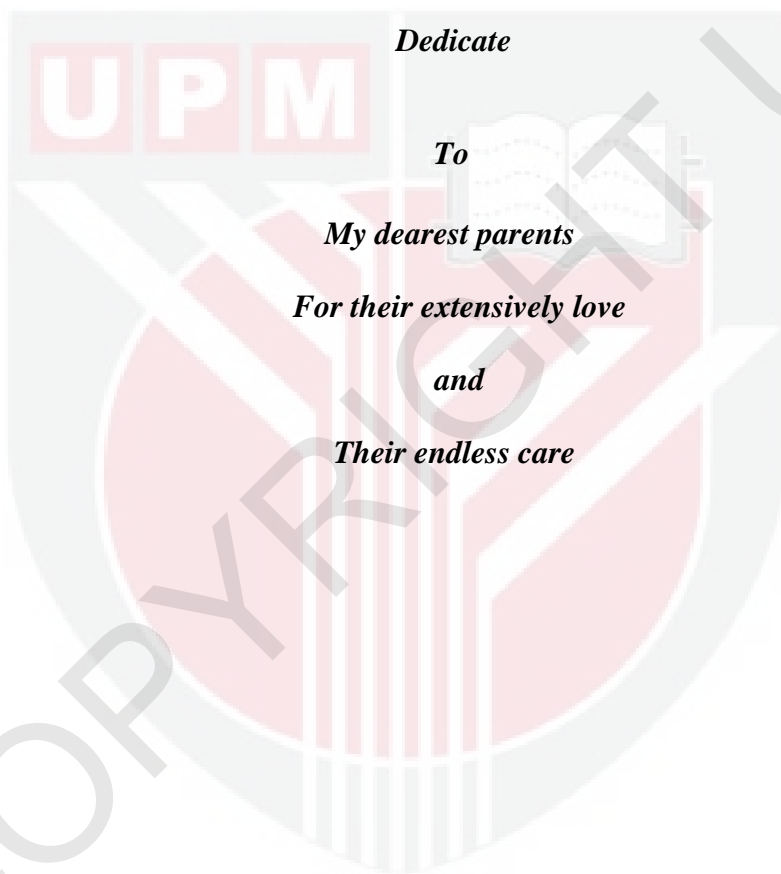
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Dedicate

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

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

By

ALI GHAHRAEI

December 2014

Chairman: Nurul Amziah Md Yunus, PhD

Faculty: Engineering

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 Mamdani-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 MENGAJI KESAN PARAMETER PERSEKITARAN PADA KECEKAPAN SEL SOLAR

Oleh

Ali Ghahraei

Disember 2014

Pengerusi: Nurul Amziah Md Yunus, PhD

Fakulti: Kejuruteraan

Tenaga solar menawarkan sumber tenaga bersih mesra iklim, banyak dan tidak putus untuk manusia, yang agak menyeduk 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 penentuan 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.

Members of the Thesis Examination Committee were as follows:

Rahman Wagiran

Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Suhaidi Shafie, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Siti Anom Ahmad, PhD

Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nowshad Amin, PhD

Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 March 2015

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

Nurul Amziah Md Yunus, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Chandima Gomes, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Member)

Nasri b. Sulaiman, PhD

Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Member)

Abdul Kariem Mohd Arof, PhD

Professor
Faculty of Science
University of Malaya
(External Member)

BUJANG BIN KIM HUAT, PhD

Professor and Dean
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TABLE OF CONTENTS

ABSTRACT	Page
ABSTRAK	i
ACKNOWLEDGMENTS	ii
APPROVAL	iii
DECLARATION	iv
LIST OF TABLE	vi
LIST OF FIGURE	xi
LIST OF ABBRIVIATION	xii
	xv

CHAPTER

1	INTRODUCTION	1
1.1	Background	1
1.2	Problem Statement	2
1.3	Research Objective	2
1.4	Research Scope	2
1.5	Thesis Organization	2
2	LITERATURE REVIEW	5
2.1	Introduction of Solar Cells	5
2.2	Solar Cell Fundamentals	5
2.3	Type of Solar Cells	5
2.3.1	Silicon-Based Solar Cells	6
2.3.2	Thin Film Technology	6
2.3.3	Emerging Technologies	7
2.3.4	State of the Art	8
2.4	Basics of Solar Cell	10
2.4.1	Short Circuit Current	10
2.4.2	Open Circuit Voltage	11
2.4.3	Fill Factor	11
2.4.4	Solar Cell Efficiency	12
2.5	Effects of Ambient Parameters on Efficiency	12
2.5.1	Role of Temperature	13
2.5.2	Irradiance	13
2.5.3	Angular Effect	14
2.5.4	Effect of Relative humidity on PV cells	14
2.6	Combined Effects of Atmospheric Parameters	14
2.7	Standard Efficiency Measurement	15
2.8	Environmental chambers	16
2.8.1	Commercial Level Environmental Chamber for Solar Cell Studies	17
2.8.2	Research Level Environmental Chamber for Solar Cell Studies	18
3	METHODOLOGY	21
3.1	Variation of Irradiance	21

3.1.1	Selection of components	22
3.1.1.1	Selection of Light Source	22
3.1.1.2	Selection of Linear Actuator and Rotary Encoder	23
3.1.1.3	Selection of DC Motor Driver	24
3.1.2	Installation of the components	25
3.1.2.1	Physical assembling	25
3.1.2.2	Electrical Schematic	25
3.1.3	Operation of System	26
3.2	Variation of Light Angle	27
3.2.1	Selection of Components	28
3.2.1.1	Selection of Stepper Motor	28
3.2.1.2	Driver of the Stepper Motor	28
3.2.1.3	Optical switch	29
3.2.2	Installation of Components	29
3.2.2.1	Physical assembling	29
3.2.2.2	Electrical Schematic	30
3.2.3	Operation of the System	31
3.3	Relative Humidity Control System	31
3.3.1	Selection of Components	33
3.3.1.1	Humidifier- Water pump	33
3.3.1.2	Humidifier- Water Solenoid Valve	34
3.3.1.3	Humidifier- Nozzle and Blower	34
3.3.1.4	Dehumidifier- Silica Gel, Tube and Vacuum Pumps	35
3.3.1.5	Dehumidifier- Nitrogen Gas and Solenoid Valve	36
3.3.1.6	Selection of Relative Humidity Sensor	37
3.3.2	Installation of Components	37
3.3.2.1	Humidifier Components	37
3.3.2.2	Dehumidifier Components	37
3.3.2.3	Place of the sensor	38
3.3.2.4	Electrical schematic	39
3.3.3	Operation of System	40
3.4	Temperature Control	41
3.4.1	Selection of Components	42
3.4.1.1	Selection of Heater Element	42
3.4.1.2	Selection of Sensor	43
3.4.1.3	Blower Fan	43
3.4.2	Installation of Components	43
3.4.2.1	Sensor Location	44
3.4.2.2	Installing Location of Heater Element and Blower Fans	44
3.4.2.3	Electrical Schematic	44
3.4.3	Operation of System	45
3.5	Measurement of the energy yield of PV cell	46
3.5.1	Selection of Power Source Meter	46
3.5.2	Installation of the SMU	47
3.6	Selection of Data Acquisition Module	48
3.7	Overall Operation	49
3.8	Physical Characteristics of the Chamber	50
3.8.1	The Cell's Stand	51

4	RESULTS AND DISCUSSION	53
4.1	Irradiance Adjustment System	53
4.1.1	Development of Algorithm	53
4.1.1.1	Control System Design	53
4.1.1.2	Relation between Shaft Movement and Encoder Value	54
4.1.1.3	Relation between Shaft Movement and Irradiance	54
4.1.2	Operation and Analysis	56
4.1.2.1	Precision of the adjustment system	57
4.2	Angle Adjustment System	58
4.2.1	Development of Algorithm	58
4.2.2	Operation and Analysis	59
4.2.2.1	Precision of the adjustment system	59
4.3	Temperature Control System	60
4.3.1	Development of Algorithm	61
4.3.1.1	Fuzzy Controller Design	61
4.3.1.2	Membership Functions	62
4.3.1.3	Fuzzy Rules	64
4.3.2	Operation and Analysis	65
4.3.2.1	Maximum Overshoot and Steady-State Error	66
4.4	Relative Humidity Control system	66
4.4.1	Development of Algorithm	66
4.4.1.1	Fuzzy Controller Design	66
4.4.1.2	Membership Functions	67
4.4.1.3	Fuzzy Rules	70
4.4.1.4	Control Diagram	72
4.4.2	Operation and Analysis	73
4.4.2.1	Achievable Relative Humidity Values	73
4.4.2.2	Maximum Overshoot and Steady-State Error	73
4.5	Setting Atmospheric Conditions	76
4.6	Overall Test	78
4.6.1	Test with Irradiance Meter	78
4.6.2	Test with Standard DUT	78
5	CONCLUSION AND RECOMMENDATIONS	81
5.1	Conclusion	81
5.2	Contribution of Study	81
5.3	Future Studies	81
	BIBLIOGRAPHY	83
	BIODATA OF THE STUDENT	89
	PUBLICATIONS	91

LIST OF TABLES

Table

4-1	Desired irradiance value, Measured value, Error and Error %.	58
4-2	Angle Adjustment Precision Test; Desired value, Measured value and Error.	60
4-3	Membership function data of the temperature error	62
4-4	Membership Funtion of the Temperature Changing Rate	63
4-5	Membership Function of the Duty Cycle of the Heater Running	64
4-6	Fuzzy Rules of the Temperature Fuzzy Controller	65
4-7	Overshoot and Steady-State Error of the Temperature Control System	66
4-8	Membership Funtion of the Relative Humidity Error.	68
4-9	Membership Funtion of the Relative Humidity Changing Rate.	69
4-10	Membership Funtion of the Output of the Relative Humidity Controller.	69
4-11	Fuzzy Rules of the Relative Humidity Fuzzy Controller	71
4-12	Maximum Overshoot, Steady-State Error, Rising and Falling Time of the RH Control System.	75
4-13	Temperature, RH and Irradiance Set-point Values and Measured Values.	78
4-14	Desired values of atmospheric parameters, I_{mp} , V_{mp} , P_{mp} , and the percentage of yield of 52 mm×76 mm multi-crystalline solar cell at each atmospheric condition.	78

LIST OF FIGURES

Figure

2-1	Timeline of highest efficiencies in various solar cell technologies (Laboratory, retrieved 2014).	9
2-2	Graphs of power and current density as a function of voltage for a solar cell along with key parameters (Potscavage, May, 2011).	10
2-3	Spectral irradiance of the AM1.5 G solar spectrum up to 1,350 nm (Potscavage, May, 2011).	12
2-4	Amount of water vapor in 100% of RH based on the temperature (Data, 1997).	15
2-5	Basic structure of a simple IV tester. The current and voltage are measured separately to overcome contact resistance problems (PVEDucation, retrieved 2013).	16
2-6	Ray, K. L's setup for testing the temperature effect (Ray, 2010).	18
2-7	Gevorgyan's chamber fully connected to the gas, water and electrical infrastructure and placed under the sun simulator (Gevorgyan et al., 2011).	19
3-1	Overall Mapping of the Methodology.	21
3-2	Light, or other conserved quantity emission from point source S toward in three dimensional space.	22
3-3	Relative intensity of xenon short arc lamp's spectrum	23
3-4	Spectrum of Xenon lamp versus spectrum of the sun. The solid line is xenon lamp and the long dash-short dash line is the sunlight	23
3-5	Left: The Linear Actuator XDT24-180. Right: The Rotary Encoder M50S.	24
3-6	Sketch of Components Places for Irradiance Control System	25
3-7	Schematic of connection L6203, DC Motor and Rotary Encoder	26
3-8	Block diagram of irradiance control system, interaction between components.	26
3-9	The angle between the light source and perpendicular line to the module surface.	27
3-10	The rotatable PV cell stand with stepper motor.	28
3-11	Optical Switch (Photo Interrupter) GP1A57HRJ00F	29
3-12	The physical assemble of the stepper motor and sensor on the cell stand.	30
3-13	Schematic of the stepper motor driver and sensor and connection to data acquisition device.	31
3-14	Block diagram of interconnection between components in angle control system.	31
3-15	Mechanism of humidifier part	33
3-16	12 watts submersible aquarium water pump.	34
3-17	Pneumatic Solenoid Valve BTB2LUS-25	34
3-18	Left: water spraying by water nozzle. Middle: AIS 1GPH water nozzle. Right: the nozzle with the holder.	35
3-19	Vacuum pump, AIRPO-D2028B	36
3-20	Humidity/temperature meter, TES-1360A.	37
3-21	De-humidifier components and mechanism	38
3-22	Relative Humidity/ Temperature Sensor Location	39
3-23	Electrical Schematic for Relative Humidity Control Part	40

3-24	General Configuration of a Closed-Loop System.	40
3-25	Block diagram of Relative Humidity control system.	41
3-26	The location of the heater element and blower fans.	44
3-27	Schematic of the Temperature Control Part	45
3-28	Block diagram of temperature control system	45
3-29	Keithley 2400 Power Source Meter	47
3-30	Source Meter Unit Connection	48
3-31	Data Acquisition Module. Left: NI Cdaq-9174, Middle: NI 9403 and Right: NI 9411	49
3-32	Overall operation of the system	50
3-33	- Left: Physical Dimensions of the chamber. Right: A Total View of The Constructed Chamber.	50
3-34	The Chamber from the Front View.	51
3-35	Physical dimensions of the cell stand and cell area.	52
3-36	The PV cell stand and its rotatable part.	52
4-1	Off-line Control System for Irradiance Adjustment.	53
4-2	Find The Relation Between The Encoder Values And The Shaft Movement.	54
4-3	Finding the relation between the rotary encoder value and irradiance value.	55
4-4	Measured Irradiances at Regular Intervals of the Encoder.	55
4-5	Measured Irradiance Values Based On the Shaft Movement in mm.	56
4-6	Implementing Fitting Curve to Obtain the Shaft Movement Based On Irradiance Values	56
4-7	Error between Desired Irradiance Values and Real Measured Values.	57
4-8	Flow Chart of the Angle Adjustment System.	59
4-9	Error bar Plot of Desired Value and Measured Value of the Angle.	60
4-10	Open Loop Temperature Increasing by the Heater Element.	61
4-11	Inputs and Output of the Temperature Fuzzy Controller	62
4-12	Membership Function of the Temperature Error.	62
4-13	(a): Smoothed Open Loop Temperature Increasing Versus Time. (b): Derivative of Plot (a) Versus Time.	63
4-14	Membership Function of the Temperature Changing Rate.	63
4-15	Membership Function of the Duty Cycle of the Heater Running	64
4-16	3D Graph of Input/ Output Relationship	65
4-17	Controlling the Temperature using Proposed Fuzzy Controller at 30, 40 and 50 °C.	66
4-18	Inputs and Output of the Relative Humidity Fuzzy Controller	67
4-19	Plot (a): Open loop RH Increasing by 100% Duty Cycle of Water Spraying. Plot (b): Derivative of Plot (a).	67
4-20	Plot (a): Open Loop RH Decreasing by Working Silica Gel Vacuum Pumps and Injecting N ₂ Gas Together. Plot (b): Derivative of Plot (a).	68
4-21	Membership Function of the Relative Humidity Error.	68
4-22	Membership Function of the Relative Humidity Changing Rate.	69
4-23	Membership Function of the Output of the Relative Humidity Controller.	69
4-24	3D Graph of Input/ Output Relationship	72
4-25	Control Diagram of the Relative Humidity Control System	72
4-26	Controlling the Relative Humidity using Proposed Fuzzy Controller at 60, 100 and 80 Percent at 26.5 °C.	73
4-27	Achievable RH Values at Temperatures 26.5, 30, 40 and 50	73

4-28	User interface of the main controller software.	76
4-29	Main GUI - Tab 1. Importing of ambient conditions from an excel file.	77
4-30	Main GUI - Tab 2. Setting the SMU, Keithley 2400, parameters and I-V curve graph output.	77
4-31	I-V Curves of the 52 mm×76 mm Polycrystalline solar cell at five different atmospheric conditions.	79



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/m^2]
e	Error
e_c	Elementary charge
EJ	Exajoules (1018 joules)
E_{max}	Maximum Error
e_w	Partial pressure of water vapor [Pa, N/m ²]
f	Function
FF	Fill Factor
Ga	Gallium
GPa	Giga Pascal
GUI	Graphical User Interface
GWh	Giga Watt-hours
Hz	Hertz
i	Irradiance [W/m^2]
I	Electric current [Amp]
I/O	Input/output
I_L	Irradiance [W/m^2]
I_{mp}	Maximum current
In	Indium
I_{sc}	Short-circuit current
J	Current density
k	Thermal conductivity [$W/m \cdot K$]
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
TiO ₂	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) based 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 & Grätzel, 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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