EFFECTS OF DUST, HUMIDITY AND AIR VELOCITY ON SOLAR PHOTOVOLTAIC (PV) PANEL EFFICIENCY

FARDILA BINTI MOHD ZAIHIDEE

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(I.C/Passport No: 821106-06-5020)

Registration/Matric No: KGZ110003

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DR. MAHIDZAL BIN DAHARI
Senior Lecturer
Department of Engineering Design and Manufacture
Faculty of Engineering
University of Malaya
50603 Kuala Lumpur

Abstract

Transition from dependency on main source of electricity generation (fossil fuel) to the most promising renewable energy source (solar energy) in Malaysia is driven mainly by environmental and economic factors. However, to ensure the success of this process, solar PV technology in the country has to be reliable and efficient enough. There are many alterable and unalterable factors that can govern a PV module's efficiency. Dust, humidity and air velocity are some of the location-dependent environmental factors that fall under the unalterable factors group. Each of these three factors can degrade the efficiency of a PV panel by causing e.g. incoming solar radiation attenuation, changes in electrical characteristics, physical damages, temperature rise etc. One factor can also affect the other factor hence indirectly impact the panel performance. In more severe cases, undesired total module failure has been recorded upon extreme exposure. On the other hand, wind speed can enhance PV panel performance by promoting heat transfer. This work reviews, elaborates and summarizes the effects of dust, humidity and air velocity on solar PV cell efficiency.

Abstrak

Peralihan dari kebergantungan kepada sumber utama untuk penghasilan tenaga elektrik (bahan api fosil) ke sumber tenaga boleh diperbaharui yang paling mempunyai harapan di masa hadapan (tenaga suria) di Malaysia didorong sebahagian besarnya oleh faktor persekitaran dan ekonomi. Namun begitu, untuk memastikan kejayaan proses ini, teknologi suria fotovoltaik di negara ini perlu cukup andal dan cekap. Terdapat banyak faktor boleh ubah dan faktor tidak boleh ubah yang boleh mempengaruhi kecekapan sesebuah modul fotovoltaik. Habuk, kelembapan dan halaju angin ialah sebahagian daripada faktor persekitaran yang bergantung kepada lokasi yang tergolong di dalam kumpulan faktor tidak boleh ubah. Setiap satu daripada tiga faktor ini boleh mengurangkan kadar kecekapan sesebuah panel fotovoltaik melalui sebagai contoh mengurangkan kemasukan radiasi suria, mengubah ciri-ciri elektrikal, kerosakan fizikal, kenaikan suhu dan sebagainya. Setiap faktor juga boleh mempengaruhi faktor lain dan menjejaskan prestasi panel secara tidak langsung. Dalam kes-kes yang lebih teruk, kegagalan modul yang tidak diingini telah direkodkan pada pendedahan yang melampau. Sebaliknya, kelajuan angin boleh meningkatkan prestasi panel dengan menggalakkan pemindahan haba. Kerja ini mengkaji, menghuraikan dan meringkaskan kesan-kesan habuk, kelembapan dan halaju angin terhadap kecekapan sel suria fotovoltaik.

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%	percentage
kWh/m^2	kilowatt hour per meter square
MJ/m^2	megajoule per meter square
Wh/m^2	watt hour per meter square
$MJ/m^2/day$	megajoule per meter square per day
η	efficiency
P_{out}	output power (W)
P_{solar}	solar power (W)
A_C	collector`s surface (m^2)
G_T	total solar insolation on surface (W/m^2)
U	output voltage (V)
I	output current (A)
P_{in}	input power (W)
I_{SC}	short circuit current (A)
V_{OC}	open circuit voltage (V)
V_{MP}	voltage at maximum power (V)
I_{MP}	current at maximum power (A)
µm	micrometer
$\mu g/m^3$	microgram per cubic meter
g/m^2	gram per meter square
$\Delta\tau$	transmittance reduction (%)
ρ_d	dust density (g/m^2)
°	degree
β	tilt angle (°) ; temperature coefficient

<	less than
$\tau_{b(\theta)}$	beam light transmittance at different incidence angle
Q_e	particle extinction efficiency
$A_{c(\theta)}$	total area covered at different incidence angle (m^2)
°C	degree Celsius
n	model constant
k	Boltzmann`s constant (J/K)
T	cell temperature (K)
q	electron charge (Coulomb)
I_L	photocurrent (A)
I_0	diode reverse saturation current (A)
$\Delta\eta_j$	efficiency difference between polluted and clean panel
η_0	efficiency of clean panel
A_j	dust type dependent coefficient ($0.06 \leq A_j \leq 0.24$) (m^2/g)
j	type of pollutant
ΔM_j	mass deposition of pollutant (g/m^2)
≈	approximately
m/s	meter per second
kmh^{-1}	kilometer per hour
θ	incidence angle (°)
R_s	series resustance (Ω)
I_{ph}	current generated by photon absorption (A)
wt %	weight percent
Q	heat transfer (W)
h	convection coefficient (W/m^2K)

dT	temperature difference (K)
A	panel surface area (m^2)
h_{forced}	forced convection heat transfer coefficient (W/m^2K)
$V_{\parallel}$	free-stream wind velocity parallel to module (measured near surface) (m/s)
±	approximately
€	Euro (currency)
kWp	kilowatt peak
mm	millimeter
μA	microampere

List of Abbreviations

PV	photovoltaic
FF	fill factor
RMAQG	Recommended Malaysian Air Quality Guideline
DC	dirt correction factor
P-V	power-voltage
I-V	current-voltage
EVA	Ethylene Vinyl Acetate
UV	ultraviolet
EQE	external quantum efficiency
a-Si:H	hydrogenated amorphous silicon
RH	relative humidity
EDS	electrodynamic screen, energy-dispersive spectral
IEC	International Electrotechnical Commission
CIGS	copper indium gallium selenide
TiO_2	titanium dioxide
SEM	scanning electron microscopy

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Electricity demand in Malaysia has risen by 64.5% in 10 years since 1999. Growth of energy consumption is expected at 4.8% annually from year 2000 for 30 years [1]. Fossil fuel e.g. natural gas, coal and oil has been the main source of electricity of the country as seen in Figure 1.1, where in year 2010, 93.5% of the total electricity is produced by the above-stated sources [2].

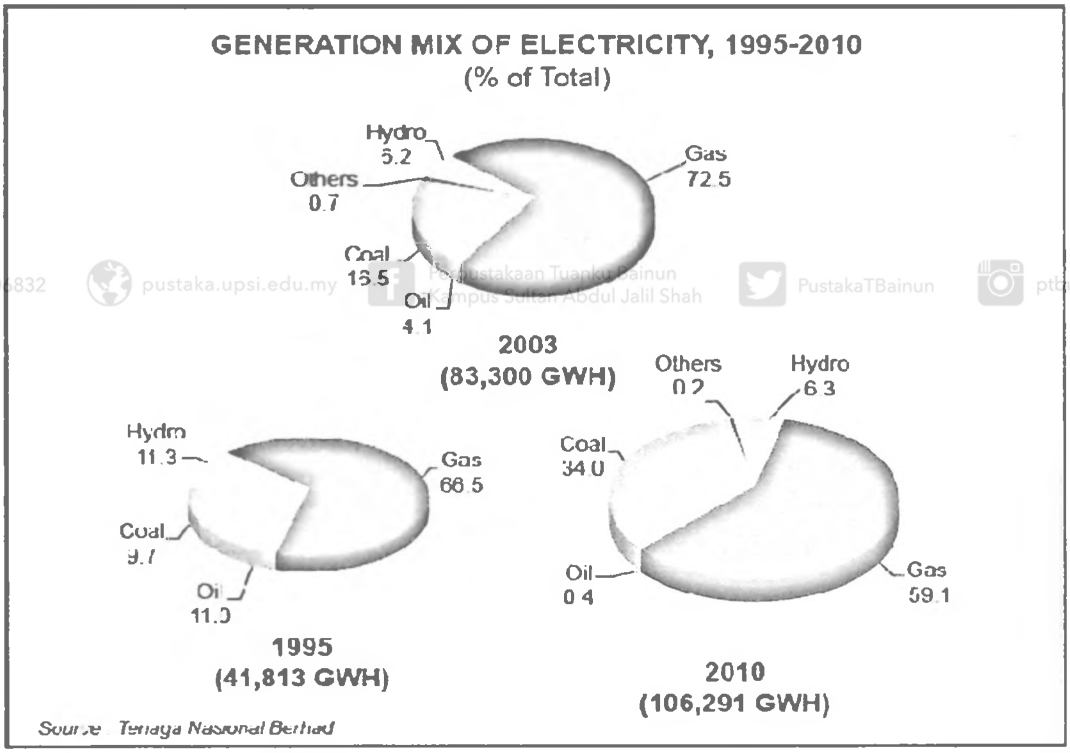

Figure 1.1: Generation mix of electricity in Malaysia (1995-2010) [2]

Transition towards power generation from renewable energy sources such as solar, wind, hydropower, biomass and tidal energy is driven by many factors which include increasing concerns on environmental impacts (climate change and global warming) and rapid growth in fuel prices. Solar energy is considered as the most promising renewable energy source due to its availability (natural, abundant and free) and cleanliness (free from emission and noise) [3].

With average solar radiation of approximately 1400-1900 kWh/m^2 yearly, 400-600 MJ/m^2 monthly and 4000-5000 Wh/m^2 daily and with average sunhour of 4-6 hours/day (refer figure) [1], solar energy has a high potential to be one of the significant energy sources in Malaysia.

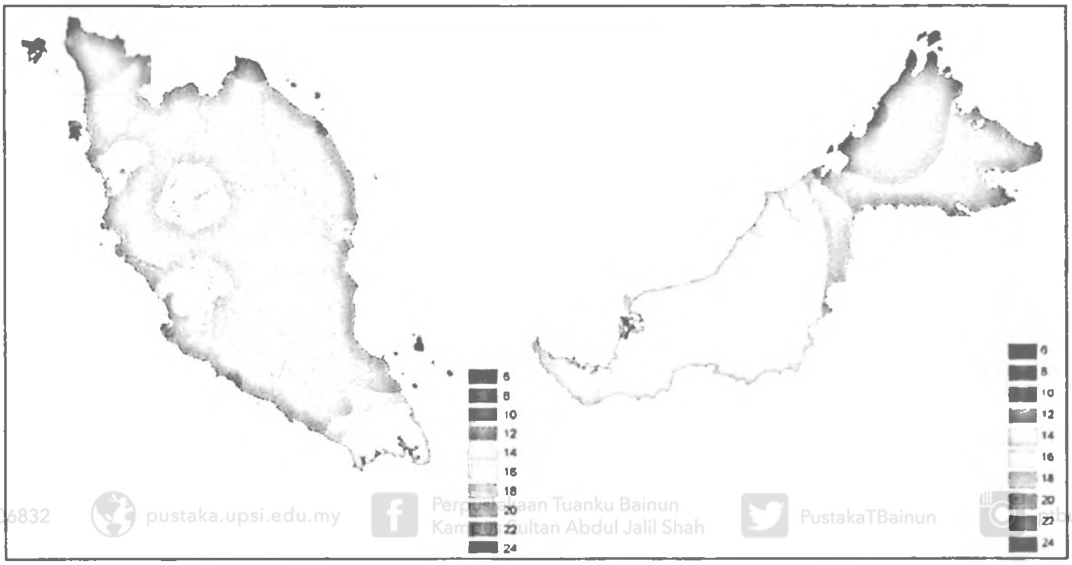

Figure 1.2: Annual average solar radiation in Malaysia (MJ/m^2/day) [1]

In 1980s, photovoltaic technology was introduced in Malaysia to supply electricity to rural areas, communication towers and consumer products [1]. Solar photovoltaic (PV) cell is a device that converts energy carried by optical electromagnetic radiation to electrical energy using photovoltaic effect of semiconductors [4]. Due to inherent material property of semiconductor, efficiency of PV system is limited within 15-20% [5]. However, other factors can cause further system losses e.g. inappropriate installation design and environmental factors. Denholm, et al. [6] claimed that PV system's efficiency can reduce 10-25% further, due to inverter, wiring and dust accumulation on panel.

The factors that govern PV system efficiency can be categorized into two groups; alterable and unalterable factors. From another perspective view, optimum yield of the system is affected by the characteristics of the PV module itself and solar insolation on the module [5].

PV module is an assembly of multiple solar cells in a sealed unit which is covered with glass for protection [7]. Its characteristics can be described in form of material of cell, coatings and type of glass used. Appropriate choice of module will result in maximum efficiency. On the other hand, the module material and structure itself can cause energy losses e.g. due to material efficiency limit and stacking in the structure. These factors are unalterable for a particular choice of module.

Solar insolation on a module is defined as solar radiation energy in a given time on a given surface. Quantitatively, it can be defined as the integral of solar irradiance over time, whereby solar irradiance is the instantaneous flux of solar radiation incident on surface [8]. Environmental factors (dust, wind movements and humidity etc) and PV installation design (tilt-angle, orientation etc) have huge impact on the solar insolation on the PV module. Environment is an unalterable factor in determining PV cell efficiency. However, appropriate protection and scheduled maintenance activities can eliminate or minimize their effects. Similarly, the limits from fix solar window and orientation (especially in retrofitted PV system) can be compensated using additional technologies such as sun-tracking devices and solar reflectors.

It is crucial to identify, distinguish and understand the relations between the alterable and unalterable factors governing the PV system efficiency. By doing so, the alterable factors can be optimally parameterized to minimize the effects of the unalterable factors.

Summary and overview of the factors governing the solar PV module efficiency are illustrated in diagram below.

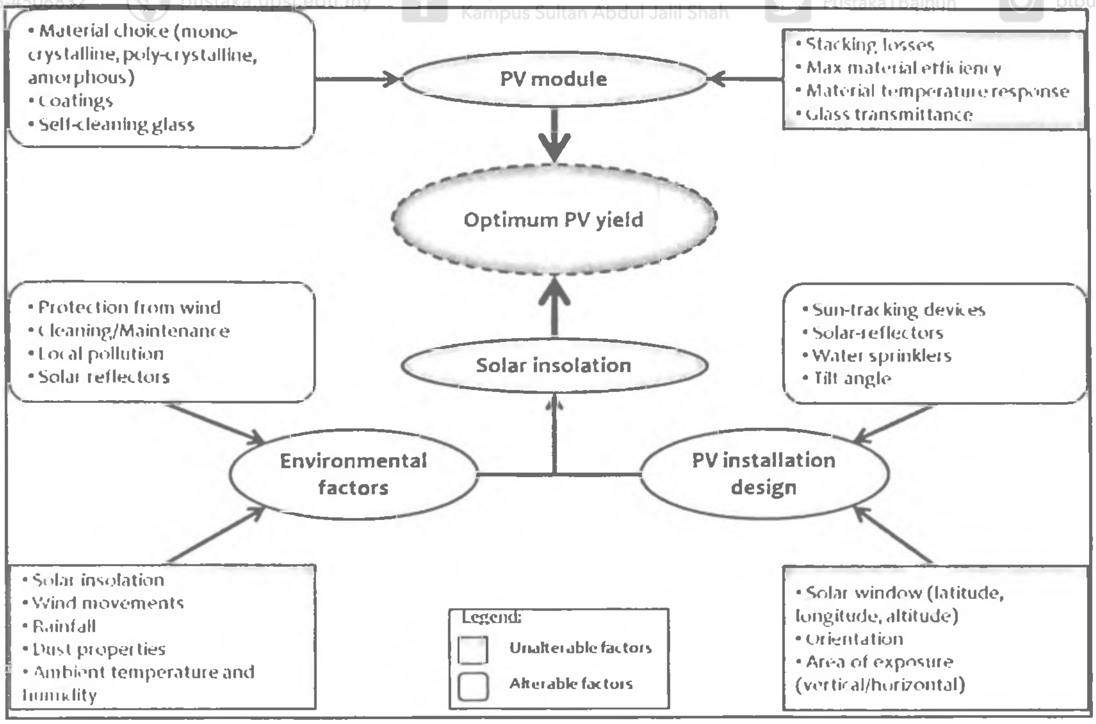

Figure 1.3: Factors governing PV cell efficiency [5]

Kaldellis and Kokala [9] stated that solar radiation intensity on surface is the main factor that affects the PV modules' output. Other major factors affecting the modules' efficiency are tabulated below, where soil and dirt can affect up to 15% of the efficiency of PV module.

Table 1.1: Factors affecting PV module's output [9, 10]

NO	FACTOR	RANGE
1	Temperature	1%-10%
2	Angle of incidence	1%-5%
3	Ageing	5% over lifetime
4	Soil and dirt	0%-15%
5	Snow	Location dependent
6	Partial shading	Location dependent
7	Diodes and wiring	3%

Figure 1.4 illustrates the processes that can affect PV cell's efficiency.

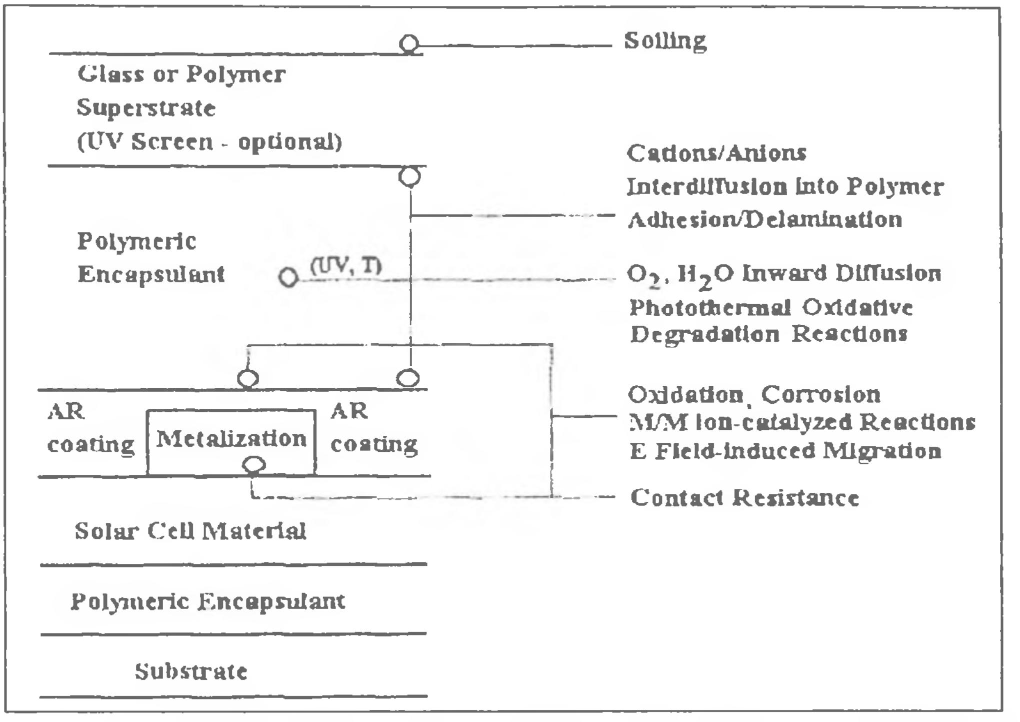

Figure 1.4 : Schematic cross section of a PV cell and processes affecting its efficiency [11, 12]

In general, energy conversion efficiency, η of a PV cell is the ratio of the output power to the incident solar power [6, 13, 14].

$$\eta = \frac{P_{out}}{P_{solar}} = \frac{P_{out}}{A_c G_T} = \frac{UI}{A_c G_T} \qquad \text{(Eq. 1.1-1)}$$

In terms of fill factor (FF), efficiency can be calculated with equation (Eq. 1.1-2) [15], where fill factor is defined by equation (Eq. 1.1-3) [16].

$$\eta = \frac{I_{SC} V_{OC} FF}{P_{in}} \qquad \text{(Eq. 1.1-2)}$$

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}} \qquad \text{(Eq. 1.1-3)}$$

1.2 Problem statement

Depends on module design, installation and environment, each photovoltaic panel has different level of performance. Environmental factors such as dust, humidity and air velocity are the varying parameters that should be considered in optimizing PV panel efficiency. Lack of understanding on how and to what extend these three factors can govern a PV panel's performance is the reason why their effects are often overlooked or sometimes simply considered as negligible by PV system designer. The challenge on investigating these effects lies in the time-fluctuating and location-dependent characteristics of dust, humidity and air velocity.

1.3 Scope of study

This project focuses on investigating the effects of dust, humidity and air velocity on solar photovoltaic (PV) panel efficiency which includes detail study on how these parameters are directly related to the panel, on how they cause indirect changes on panel electrical characteristics, visual and physical damages of panel, severity of their influence and the factors that can promote or demote their effects.

1.4 Objectives

The objectives of this project are:

- To study the multiple ways and different degrees of how dust, humidity and air velocity can affect the performance of a PV panel
- To recommend appropriate countermeasure and improvement to avoid performance degradation

1.5 Thesis outline

This research report is divided into seven chapters. The first chapter consists of introduction, problem statement, objectives of research, scope of study and outline. Chapter two, three and four elaborate on the effects of dust, humidity and air velocity on solar PV panel efficiency respectively. In chapter five, the effects of all three factors are discussed and summarized and appropriate recommendations are proposed. Conclusion and future work are presented in chapter six, followed by the list of references in the last chapter.