UNIVERSITI PUTRA MALAYSIA

DUST MATERIAL AND MATHEMATICAL RELATIONSHIP IDENTIFICATION FOR PHOTOVOLTAIC

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By

MOHAMMAD REZA

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

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DEDICATION

I dedicate this thesis to my parents' Gholam Reza Maghami and Zari Bashiri Zadeh. I hope that this thesis achievement will be complete the dream that you had for me all those many years ago when you chose to give me the best education you could.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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February 2015

Chairman: Associate Professor Hashim Hizam, PhD

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Photovoltaic (PV) systems are one of the next generation's renewable energy sources for our world energy demand. PV modules are highly reliable. However, in polluted environments, over time, they will collect grime and dust. There are also limited field data studies about soiling losses on PV modules. This study is to investigate the effect of accumulated dust material on PV performance.

The study includes two arrays of mini-modules. Each array has 12 PV modules tilted at 15º on the ground. The first array called "cleaned" was cleaned every week. The second array called "dusty" was never cleaned since the first day. Three types of data were required. The first type of data related to PV electrical characteristics. The second type related to environmental conditions, and the last type was associated with dust materials analysis. Required data were collected for eight months from April until first of December 2013. Due to a fault in the system, for 38 days there was no record of data and the final record was for a total of 209 days. Data from PV array and environmental data were collected with an online monitoring system and recorded every one minute over eight months. The data were analyzed to investigate the effect of dust on daily and monthly soiling, as well as transmitted solar insolation and energy production by PV modules.

The main objective of this research is to conduct an experimental investigation on the effect of dust accumulated on the surface of PV array on output power in an open area where the effect of dust is unavoidable. For purposes of improvement, a mathematical relationship was predicted for the dust effect on PV generator performance. A comparative analysis was conducted to evaluate the effect of dust on PV array performance.

The study shows that during the period of April through December 2013 there was an average loss due to soiling, of approximately 2.83% on dusty array. Comparing these two arrays for different months also was done and the results show that there are significant differences of output power among different months between the two arrays. Scatter plot was also employed for output power and environmental data to assess the relationship between the amount of output power generated from the dusty array and irradiation. The result shows that there was a positive correlation between the output power and irradiation variables, Correlation coefficient between

thickness and power output indicated a moderate and negative relationship. Two mathematical relationship were predicted despite the dust thickness for dusty array and without dust, thickness for clean array and the validation of both prediction models was evaluated.

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

BAHAN HABUK DAN HUBUNGAN MATEMATIK PENGENALAN UNTUK FOTOVOLTA

Oleh

MOHAMMAD REZA MAGHAMI

Februari 2015

Pengerusi: Profesor Madya Hashim Haizam, PhD

Fakulti : kejuruteraan

Sistem Photovoltaic (PV) adalah salah satu sumber tenaga boleh diperbaharui akan datang kerana permintaan tenaga dunia kita. Modul PV sangat dipercayai. Walau bagaimanapun, dalam persekitaran yang tercemar, dari semasa ke semasa, mereka akan mengumpul kotoran dan habuk. Terdapat juga kajian yang terhad data lapangan mengenai kekotoran kerugian modul PV. Kajian ini menunjukkan betapa pentingnya adalah untuk mengkaji kesan bahan terkumpul debu di PV.

Kajian ini merangkumi dua tatasusunan modul mini. Setiap susunan mempunyai 12 modul PV condong pada 15º tanah dipasang. Susunan pertama dipanggil "Dibersihkan" telah dibersihkan setiap minggu. Susunan kedua dipanggil "berhabuk" yang tidak pernah dibersihkan selepas hari pertama. Tiga jenis data diperlukan. Jenis pertama data yang berkaitan dengan ciri PV elektrik dan suhu tatasusunan PV bersih dan berdebu dipasang di laman web ini. Jenis kedua ialah data yang berkaitan dengan keadaan persekitaran, dan jenis terakhir adalah data yang berkaitan dengan analisis bahan-bahan debu. Data yang diperlukan telah dikumpulkan selama lapan bulan dari April hingga Disember 2013 dan kerana kesilapan dalam sistem, selama kira-kira 38 hari tidak ada rekod data, oleh itu terdapat rekod data untuk jumlah 209 hari. Data dari susunan PV dan persekitaran data dikumpulkan dengan sistem pemantauan dalam talian dipantau dan direkodkan setiap satu minit lebih daripada 8 bulan. Data yang telah dianalisis untuk mengkaji kesan debu pada kekotoran setiap hari dan bulanan, dan dengan itu insulasi tenaga solar dan pengeluaran tenaga oleh modul PV telah dihantar.

Objektif utama kajian ini adalah untuk menjalankan siasatan ujikaji tentang kesan debu terkumpul pada permukaan susunan PV pada output kuasa di kawasan terbuka yang kesan debu yang tidak dapat dielakkan. Dalam usaha untuk meningkatkan, model matematik untuk meramalkan kesan debu pada prestasi penjana PV dipasang dalam keadaan cuaca tropika. Analisis perbandingan dijalankan untuk menilai kesan debu prestasi susunan PV.

Kajian ini menunjukkan bahawa dalam tempoh April hingga Disember 2013 terdapat kerugian purata kerana kekotoran kira-kira 2.83% ke atas susunan debu. Perbandingan antara kedua-dua susunan untuk bulan berlainan juga dilakukan dan keputusan menunjukkan terdapat perbezaan yang besar pada output kuasa antara

bulan yang berbeza di antara dua susunan. Sebaran plot juga menggunakan output kuasa dan persekitaran data untuk menilai hubungan antara jumlah keluaran kuasa penjanaan dari susunan berdebu dan penyinaran. Hasil menunjukkan terdapat korelasi positif antara output kuasa dan pembolehubah penyinaran, Korelasi pekali antara ketebalan dan kuasa ouput menunjukkan moderator dan hubungan negatif. Dua model Matematik meramalkan walaupun ketebalan debu untuk susunan berdebu dan tanpa ketebalan debu untuk susunan yang bersih dan kedua-dua pengesahan daripada kedua-dua model ramalan dinilai.

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I certify that a Thesis Examination Committee has met on 18 February, 2015 to conduct the final examination of Mohammmad Reza Maghami his thesis entitled "Dust material and Mathematical Relationship Identification for Photovoltaic" 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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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 were as follows:

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Declaration by graduate student

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Committee this is to confirm that:

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Signature:	______________________
Name of Member of Supervisory Committee:	______________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PV	Photovoltaic
MPP	Maximum power point
I-V curve	Current-voltage curve
V-P Curve	Voltage-power curve
DC	Direct current
DC-DC	Direct current to direct current
MPPT	Maximum power point tracking
GaAs	Gallium arsenide
CdTe	Cadmium telluride
CIGS	Copper indium gallium selenide
KCL	Kirchhoff's current law
V_{pv}	Output voltage of the PV module
I_{pv}	Output current of the PV module
I_D	Diode current
T	Temperature
^oC	Degree Celsius
I_{scr}	Short-circuit current of the PV at standard test condition
STC	Standard test condition
DART	Data acquisition and real-time:
cRIO	Compact reconfigurable input output SPMS
SPMS	Solar PV monitoring station

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview of this study

This chapter provides a general overview on the study that includes the Background of the Study, Problem Statement, followed by the Research Objectives and Research Questions. Also included are the scope and limitations of the study as well as the conceptual and operational definition of key terms used in the thesis. To round up, an outline of the Organization of the thesis is provided before the presentation of the chapter summary.

Solar energy, which comes from the sun in the form of solar irradiance, can be directly converted to electricity by using photovoltaic (PV) technology. PV technology uses solar cells made of semiconductors to absorb the irradiance from the sun and convert it to electrical energy. Currently, solar energy has drawn worldwide attention and is playing an essential role in providing clean and sustainable energy (EL-Moghany, 2011; Lobera, 2010). However, the research related to the nature of semiconductors, which are used in solar cells, has limited the efficiency of the PV system to 15-20%. Thus, in order to increase the efficiency of the PV system, some improvements such as applying sun trackers and maximum power point tracking controllers, have been made to the PV system installation. However, although these improvements have enhanced the efficiency of the PV systems, there are factors such as the deposition of soil, salt, bird droppings, snow, etc., on the PV modules that can significantly decrease the efficiency of PV systems. Therefore, the investigation of dust on solar panels is necessary to ensure optimal performance and maximum energy yield(Chen, Quinn, Hsu, & Lehman).

In Europe, for example, frequent rainfall usually takes care of any soiling that might accumulate on the solar panels. In arid regions, on the other hand, the panels must be frequently cleaned with water to ensure clear and dirt free surfaces. This task might not pose a big problem if it is on a small scale in the kW scale. However, as more and more PV power plants are built in the future in the upper MW and GW ranges, there is a need for more attention to be paid to this problematic area, which directly affects the efficiency of the power generation.

The power output of the PV module is a function of solar irradiance, which reaches the solar cells inside the PV modules, and influences the module temperature (Pandey, Dasgupta, & Mukerjee, 2008). The amount of irradiance received by solar cells is less than the irradiance arriving on the surface of PV modules due to some reflection and absorption loses by surface material covering the solar cells. Furthermore, soil accumulation on the surface of the PV modules is another factor, which prevents the solar irradiance from being completely absorbed by solar cells, thus leading to power loss. In addition, accumulation of soil on PV modules eventually will cause high-energy dissipation in the long term. Soil accumulation is one of the critical factors, which could lead to losing especially domestic markets of PV systems, due to decrease in energy efficiency.

1.2. Problem of Statement

The output power delivered from a PV module depends highly on the amount of irradiance, which reaches the solar cells. Furthermore, the extent of dust on the module surface affects the solar irradiance reaching the solar cells. The accumulated dust over time aggravates the soiling effect. In fact, the amount of accumulated dust on the surface of the PV module affects the overall energy delivered from the PV module on a daily, monthly, seasonal and annual basis. Thus, the primary objective of this study is to quantitatively identify the effect of dust and dust particles on PV arrays. As such, it is essential to quantitatively evaluate the effect of dust on power, energy, and efficiency of PV modules.

1.3. Research Questions

1-How much power output and energy loss are due to dust or soiling?
2- What is the correlation between PV array characteristics and local environment weather data?
3- How can a mathematical relationship forecast the power output with or without dust particles?

1.4 Aims and Objectives

The main goal of this study is to conduct an experimental investigation on the effects of accumulated dust on the surface of PV array on power output of PV array in an open area where the effect of dust is unavoidable. In order to improve the situationissue, a mathematical model is used to predict the dust accumulation effect on the performance of a PV generator installed under tropical weather conditions. A comparative analysis is conducted to evaluate the effect of dust on PV array performance. The overall objectives of the study are:

- To determine the dust materials accumulated on the surface of the PV array.
- To determine the average power generated by PV, for both clean and dusty array, overall and by monthly..
- To determine the correlation between environmental data (temperature, irradiance, and humidity), and data from PV array (power and module temperature).
- To find theidentify regression modelmathematical relationship for dust accumulated on the surface of the PV array, and electrical parameters of the PV array, in order to predict power losses due to dusty surface.

1.5 Scope and Limitations

Although the performance of PV arrays depends on different parameters, in this study the parameter of dust accumulated on PV array is investigated. To do this, the scope of this work includes:

- Installation of two specific fixed flat plate (FFP) mono-crystalline PV arrays with two strings and six series PV Modules, in an open area at Universiti Putra Malaysia (UPM). These PV arrays are completely identical. One of these arrays is left for eight months without cleaning the dust on the surface. The another PV array is cleaned weekly.
- Collecting and monitoring the weather-related parameters (temperature, irradiation, wind speed, humidity, and air pollution) of PV site in the area under study (UPM); and electrical parameters of PV such as voltage and current, using a data logger system for two dusty and clean arrays, for a time period from April to December 2013
- Using Scan electron micron (SEM) and energy-dispersive X-ray (EDX) spectroscopy to measure size, shape, weight and thickness of the dust during this research.
- To quantitatively analyze the effect of accumulated dust on surface of the PV Array, in respect to output power, delivered energy and PV array efficiency.

1.6 Organization of the Thesis

The rest of this thesis organized as follows: The overall structure of the study takes the form of five chapters, including this introductory chapter and the rest of this thesis organized as follows:

Chapter 1 provides a general overview concerning the reusability of performance of solar generation and provides a general background of this research. First, we briefly describe the solar generation losses in a global context, define the problem with dust on PV array and introduce the research questions in relation to the aims and objectives of the study.

Chapter 2 contains an overview of the photovoltaic containing solar cells, different types of solar cells, and characteristics of PV modules. This is followed by a discussion of the performance of the PV module and different parameters which affect the performance of the PV system. Then, the effects of soiling on the PV system’s performance are explained in two aspects of: partial shading of PV module by soil patch, and the effect of soft shading and hard shading by soiling on PV modules and PV arrays. Finally, a literature review of related previous works is provided at the end of this chapter.

Chapter 3 deals with the main approach used in this research to achieve the objectives, and contains the different steps for designing the methodology. The monitoring system used is online monitoring system which can go viewed in http//:www.smart-pv.net through general packet radio services (GPRS) communication. This chapter also explains the field setup of the two Fixed Plate Photovoltaic PV array configurations plus weather station equipped with related environmental sensors.

Chapter 4 presents the results of data analyses, including descriptive statistics for output Power and Energy yield using SPSS version 21. Two mathematical relationship are predicted to consider the effects of dust on PV performance and both models are evaluated.

Chapter 5 concludes the research presentation developed in this thesis with a summary of the contributions. In addition, the conclusions and several limitations drawn from our experiments are presented. Finally, a range of potential research directions and suggestions for further work are outlined.

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