UNIVERSITI PUTRA MALAYSIA

OPTIMIZATION OF WIND-POWERED DUST REMOVAL PARAMETERS FOR PHOTOVOLTAICS SOLAR PANEL

OSAM HASSAN ATTIA

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OPTIMIZATION OF WIND-POWERED DUST REMOVAL PARAMETERS FOR PHOTOVOLTAICS SOLAR PANEL

By

OSAM HASSAN ATTIA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

January 2019

DEDICATION

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Mohammed (May Allah bless and grant him),

The memory of my parents,

All the people in my life who touch my heart,

I dedicate this research.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

OPTIMIZATION OF WIND-POWERED DUST REMOVAL PARAMETERS FOR PHOTOVOLTAICS SOLAR PANEL

By

OSAM HASSAN ATTIA

January 2019

Chairman : Professor Nor Mariah Adam, PhD
Faculty : Engineering

The dust accumulation is an undesirable phenomenon in a solar plant environment. The procedure for removing dust using traditional techniques is capital and labour intensive. Additionally, most of the cleaning techniques consumed power from energy produced by the solar system. Therefore, the aim of this study is to develop a wind powered dust removal technique from the solar panel. This was done by transforming wind energy into mechanical energy as a new approach to sustainability via mechanical vibrator. The mechanical vibrator is attached to the panel and will produce a harmonic excitation force to overcome the adhesion force of dust onto solar panel surface.

In this study, five levels of vibration forces were acquired through pre-experiment by varying the wind speed, while the range of the other working independent parameters such as dust quantity, dust size, wind speed and tilt angle of the solar panel were adopted from the previous studies. To determine how each of the parameters affects the dust removal index (DRI), a screening process was conducted using Plackett-Burman design (PBD) in Minitab with 12 runs each for the system with and without vortex generator. In response surface methodology (RSM) experiment, 50 runs were done for the optimizations of the working parameters with respect to DRI. The selection process was generally followed by statistical analysis known as Analysis of variance (ANOVA). Response Surface methodology (RSM) is an optimization method, which has been applied to optimization problems and provided a mathematical model for the DRI. Another model was built using another optimization technique called particle swarm optimization (PSO) and was used to verify the RSM model with modified code in MATLAB software.

The proof of concept experiment clearly shows that with an increase in wind speed the vibrating force increases accordingly. Also, according to the screening process with PBD, the studied parameters have been arranged in order of their effect either high or low based on the assessment criteria outlined in PBD with and without vortex generators. The arrangement of the parameters based on their effect on DRI without VGs from high to low is different from the arrangement with VGs; this indicated that VGs have asignifacant effect on parameters. The incorporation of the vortex generator, the levels and behaviour of the parameters were changed and the mean value of DRI increased from 0.50 to 0.58. Analysis for the optimization of the working parameters reveals that RSM-DRI model revealed high significant performance with CoV and SD value of 4.51% and 0.0448 respectively. While PSO-DRI model has CoV and SD value of 4.55% and 0.0445 respectively. Therefore, RSM model helps a designer to select the most suitable site for the solar plant provided that the tilt angle is within the range of 15° to 35°. In conclusion, the use of wind energy via mechanical vibrator for dust removal has an efficiency of 91% when compared with a demonstrative electric vibrator for cleaning the same quantity of dust from the solar panel.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOPTIMUMAN PARAMETER UNTUK MENYINGKIR HABUK SECARA KUASA ANGIN BAGI PANEL SOLAR PHOTOVOLTAIK

Oleh

OSAM HASSAN ATTIA

Januari 2019

Pengerusi : Profesor Nor Mariah Adam, PhD
Fakulti : Kejuruteraan

Pengumpulan habuk adalah fenomena yang tidak diingini dalam persekitaran loji solar. Prosedur untuk mengeluarkan habuk menggunakan kaedah tradisional melibatkan modal dan tenaga kerja yang intensif. Di samping itu, kebanyakan teknik pembersihan menggunakan kuasa dari tenaga yang dihasilkan oleh sistem solar. Oleh itu, matlamat kajian ini adalah untuk membangunkan teknik penghapusan habuk berkuasa angin dari panel solar. Ini dilakukan dengan mengubah tenaga angin menjadi tenaga mekanikal sebagai pendekatan baru untuk kemampanan menerusi alat penggetar mekanikal. Penggetar mekanikal dilampirkan pada panel dan akan menghasilkan daya pengujaan harmonik untuk mengatasi daya melekat.

Dalam kajian ini, lima tahap daya getaran diperolehi melalui pra-eksperimen dengan mengubah kelajuan angin, manakala pelbagai parameter seperti kuantiti debu, saiz debu, kelajuan angin dan sudut kecondongan panel solar telah diterima pakai dari kajian terdahulu. Untuk menentukan bagaimana setiap parameter mempengaruhi indeks penyingkiran habuk (DRI), proses pemeriksaan telah dijalankan menggunakan reka bentuk Plackett-Burman (PBD) di Minitab dengan 12 percubaan masing-masing untuk sistem dengan dan tanpa penjana vorteks. Walaupun pemilihan parameter dilakukan dengan menggunakan kaedah respons permukaan (RSM). Dalam eksperimen RSM, 50 run dilakukan untuk pengoptimuman parameter kerja berkenaan dengan DRI. Proses pemilihan umumnya diikuti oleh analisis statistik yang dikenali sebagai Analisis varians (ANOVA). Response Surface Methodology (RSM) adalah kaedah pengoptimuman, yang telah digunakan untuk masalah pengoptimalan dan menyediakan model matematik untuk DRI. Model lain dibina menggunakan teknik pengoptimuman lain yang disebut pengoptimuman swarm partikel (PSO) dan telah digunakan untuk mengesahkan model RSM dengan kod yang diubah suai dalam perisian MATLAB.

Bukti percubaan konsep dengan jelas menunjukkan bahawa dengan peningkatan kelajuan angin, daya getaran meningkat dengan sewajarnya. Juga, mengikut proses penapisan dengan PBD, parameter yang dikaji telah disusun mengikut kesannya sama ada tinggi atau rendah berdasarkan kriteria penilaian yang digariskan dalam PBD dengan dan tanpa generator vorteks. Susunan parameter berdasarkan kesannya terhadap DRI tanpa VGs dari tinggi ke rendah adalah berbeza daripada susunan dengan VGs; ini menunjukkan bahawa VG mempunyai kesan yang ketara terhadap parameter. Penggabungan penjana vorteks, tahap dan kelakuan parameter telah berubah dan nilai purata DRI meningkat dari 0.50 hingga 0.58. Analisis bagi pengoptimuman parameter kerja menunjukkan bahawa model RSM-DRI menunjukkan prestasi penting yang tinggi dengan nilai CoV dan SD masing-masing sebanyak 4.51% dan 0.0448. Model PSO-DRI mempunyai nilai CoV dan SD masing-masing sebanyak 4.55% dan 0.0445. Oleh itu, model RSM membantu pereka untuk memilih tapak yang paling sesuai untuk loji solar dengan syarat sudut kecondongan berada dalam lingkungan 15 ° hingga 35 °. Kesimpulannya, penggunaan tenaga angin melalui alat penggetar mekanikal untuk penyingkiran habuk mempunyai kecekapan sebanyak 91% jika dibandingkan dengan penggetar elektrik yang menunjukkan untuk membersihkan kuantiti debu yang sama dari panel solar.

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I would love to dedicate this thesis to the memory of my parents who paved the path of knowledge upon their shoulders before I became who I am now. Priceless gratitude to my wife, Ahlam for her great sacrifices, understanding and patience throughout the whole of our life together, which has made this study possible. Thanks to my lovely children who have also given a lot of moral support and encouragement for the whole duration of study in Malaysia.

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Osam Hassan Attia

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the Degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ARE	Absolute Relative Error
ANOVA	Analysis Of Variance
CCD	Centeral Composite Design
COV	Coefficient of Variation
CFD	Computational Fluid Dynimics
df	Degrees of freedom
DOE	Design of Experiment
D.Q	Dust Quantity
DRI	Dust Removal Index
DS	Dust Size
FEM	Finite Element Method
FVM	Finite Volume Method
GHI	Global Horizontal Irradiance
GIT	Grid Independent Test
LMS	Learning Manigment System
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MV	Mechanical Vibrator
M.S	Mean squares
O&M	Operation and Maintance
PI	Performance Index
PSO	Partical Swarm Optimization
PV	Photovoltaics (Solar Panel)
PS	Size of Seive

R^2	Coefficient of Determination
RMS	Root Mean Square
RMSE	Root Mean Square Error
RRMSE	Relative Root Mean Square Error
RSM	Rsponce Surface Methodology
STD	Standered Deveation
S.S	Sum of Squares
TA	Tilt Angle
TI	Turbulence Intensity
TKE	Turbulence Kinetic Energy
VF	Vibrating Force
VG	Vortex Generator
WS	Wind Speed

LIST OF NOMENCLATURES

a	Acceleration
F	Force
x_i	Variable in statistical calculation C.C.D
X_i	Coded variable in statistical calculation C.C.D
NS	Number of particles in swarm
W	Inertia weight factor used to balance the global exploration and local exploitation
$v_{j,g}^{(t)}$	Velocity of particle *j* at iteration *t*
$x_{j,g}^{(t)}$	*gth* components for the position of particle *j* at iteration *t*
M	Number of components for the v_j and x_j vectors
t	Number of iterations (generations)
C_0	Number of central points
c_1, c_2	Cognitive and social acceleration factors, respectively; “acceleration coefficients”
r_1 , r_2	Random variables uniformly distributed within range (*0,1*)
$pbest$	Best position found by the *ith* particle (personal best)
$gbest$	Best position found by swarm (global best, best of personal best)
y	Actual output value
$\acute{y}$	Predicted output value
Y	Response
σ_{sensor}	Error in the measuring sensor
$\sigma_{instrument}$	Error in the measuring instrument
I_b	Dust quantity before applying the effect
I_a	Dust quantity after applying the effect
H_i	Un-coded high level
L_o	Un-coded low level
k	Number of factors
α	Codified value
β_0	Constant
β_i	Slope or linear effect

X_i, β_{ii}	Factor is the quadratic effect
X_i, β_{ii}	Interaction effect
ε	Residual term
X_i and X_j	Input factors

CHAPTER 1

INTRODUCTION

1.1 Background

Photovoltaic (PV) power systems are simple, flexible, modular, and adaptable to many different applications in an almost infinite number of sizes and in diverse environments (Al-Otaibi *et al.*, 2015; Azah and Tamer, 2013; Mehmood *et al.*, 2017). In addition to these advantages, the PV system directly converts solar radiation into electricity through the PV system (Koad *et al.*, 2016; Sawant and Bhattar, 2016; Shi *et al.*, 2015). The operating condition of these systems is another challenge to its fullest performance (Mehmood *et al.*, 2017).

The dust particles which existing in the air can be accumulate on the surface of a photovoltaic (PV) module, and create a dust layer on it, which leads to a reduction of the valid solar irradiation onto solar cells (Jamil *et al.*, 2017; Mazumder *et al.*, 2017; Xingcai and Kun, 2018). the reduction in panel capacity due to surface dust accumulated over several months is up to 40%, and it decreases with the increasing of dust(Bouaddi *et al.*, 2017; Walwil *et al.*, 2017; Xingcai and Kun, 2018). Therefore dust accumulation is a major problem facing the solar energy technologies in terms of improvement of its capacity(Chang and Lee, 2016; Middleton, 2017). The systems are usually installed in an open space such as deserts (Blakowski *et al.*, 2016; Walwil *et al.*, 2017), where a high solar radiation exists. The solar radiation varies from one country to others as clearly indicated in Figure 1.1, and these areas also coincide with high rate of accumulated dust as shown in Figure 1.2.

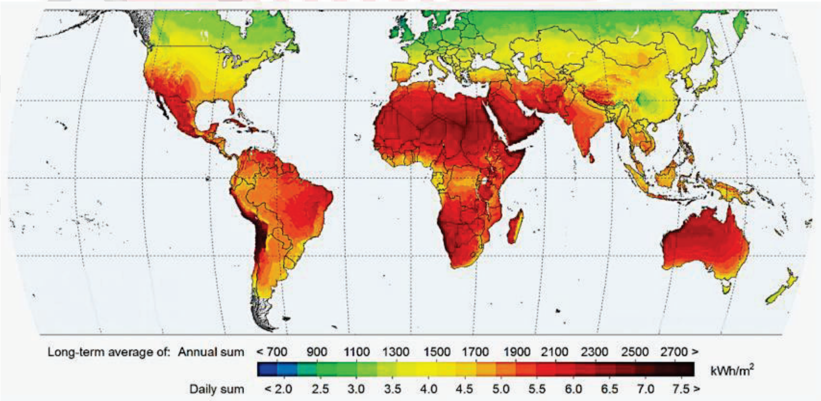

Figure 1.1 : Maps of global horizontal irradiation (GHI)
(Kannan and Vakeesan, 2016)

The strategy to prevent that chalange is the use of a suitable dust removing technique to increase the capacity of solar energy conversion into electricity (Ba *et al.*, 2017; Hassan *et al.*, 2017; Manokar *et al.*, 2018).

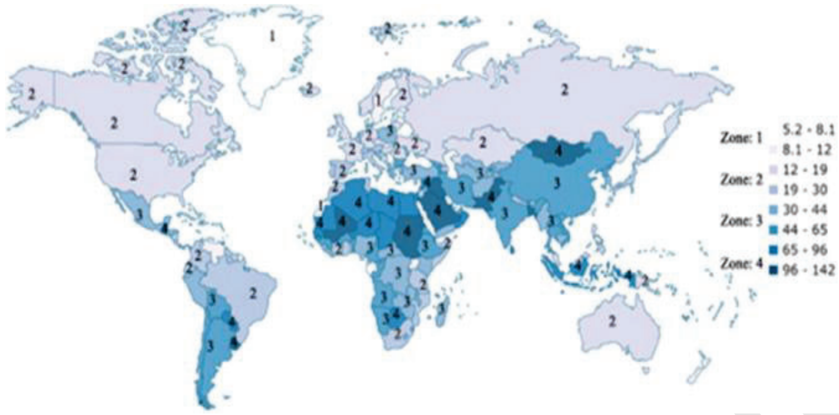

Figure 1.2 : Dust intensity around world (Maghami *et al.*, 2016)

Dust removal techniques for PV panels are one of the reasons which have an effect on PV performance (Ba *et al.*, 2017; Fouad *et al.*, 2017; Hassan *et al.*, 2017). However, the continuous cleaning of the photovoltaic collector surface to ensure continuity of good quality transmittance (Kebour *et al.*, 2017). Usually the recommended cleaning frequency is based on economic analyses of these techniques (Hammad *et al.*, 2017; Said *et al.*, 2018). Cleaning techniques involved usually falls into the major classification of active (mechanical and electrical) and passive techniques (natural) for dust removal (Said *et al.*, 2018) as shown in Figure 1.3. Dust removal techniques can be categorized briefly into three (3) categories: natural, mechanical and electrical. However, this study will focus on a mechanical wind powered dust removal technique for solar panel through an optimization method.

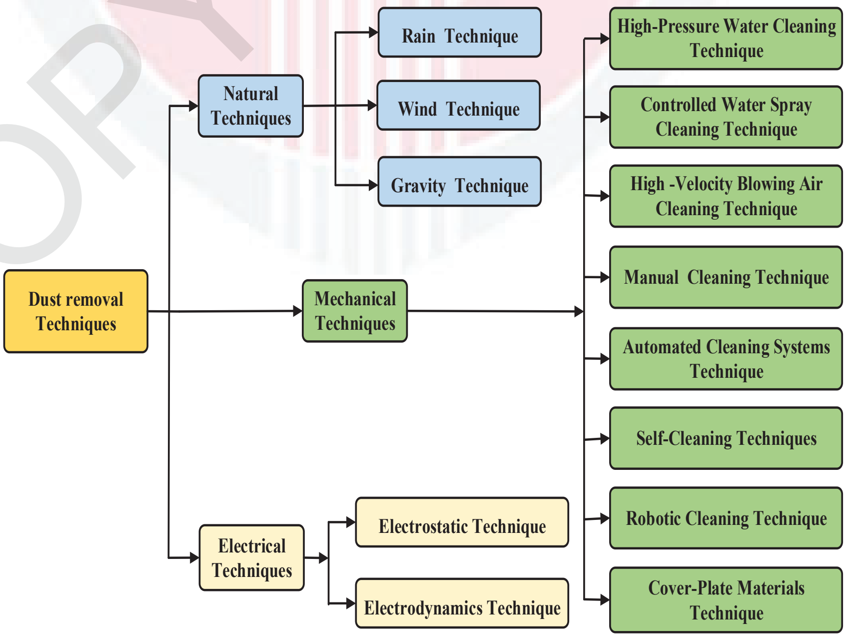

Figure 1.3 : Classification of dust removal techniques from solar panels

The optimization of the optimum conditions for the factors reaction variables using Response Surface Methodology (RSM) allows determining the optimal values in a defined range with a minimum set of experiments(Ghosal *et al.*, 2018). Design of experiments that is made by RSM is a large and well developed field for understanding and improving the performance of complex systems (Chaudhary *et al.*, 2018; Jaafari *et al.*, 2018). RSM allows an appropriate design of the experiments (Matias-Guiu *et al.*, 2018), and diminution the number of runs (Tyagi *et al.*, 2018). In addition, the modeling of the system facilitates the interpretation of multivariate phenomena and is valuable tool for scaling up (Malik and Pakzad, 2018) . In fact, RSM, can be used to estimate the relative significance of three or more affecting factors even in the presence of complex interactions between them using a lowest number of experiments (Anwar *et al.*, 2018; Chuahy and Kokjohn, 2017). It is important to fit a mathematical model equation in order to approximate a relationship between dependent and independent variables and determine the optimum settings of these variables that result in the maximum response (Bedin *et al.*, 2018). Based on the above another optimization method is Particle Swarm Optimization (PSO) was used under the verification procees for the empirical model acquired by RSM.

1.2 Problem statement

Solar panels(PVs) are usually installed in an open space such as deserts (Anglani *et al.*, 2017; Blakowski *et al.*, 2016), where a high solar irradiation exists. Moreover, dust accumulation on the surface of the solar panel significantly affects the PV efficiency (Alnaser, 2018; Piedra and Moosmüller, 2017). Therefore, this problem is an important area of research in solar system (Fouad *et al.*, 2017; Piedra and Moosmüller, 2017).

Dust accumulation which has been critical issues to the operation of PV (Chang and Lee, 2016; Mehmood *et al.*, 2017; Middleton, 2017; Walwil *et al.*, 2017), where in desert areas such as Middel- East countries, occurrence of dust storms are frequent (Boddupalli *et al.*, 2017). The accumulated dust must be cleaned regularly and directly after each dust storm (Said *et al.*, 2018); such as in Iraq (Chaichan *et al.*, 2018; Saidan *et al.*, 2016). Qatar (Javed *et al.*, 2017; Kawamoto and Guo, 2018), Iran (Gholami *et al.*, 2017a; Gholami *et al.*, 2017b), Jordan (Hammad *et al.*, 2017), Saudi Arabia (Jones *et al.*, 2016).

The weakness of many existing dust removal techniques has been demonstrated by various studies in last two decades. Many of these techniques are designed to consume power from the solar plant and without mention to the levels of affected parameters (Fouad *et al.*, 2017). The affected parameters are; tilt angle, dust size, dust quantity and wind speed (Elbreki *et al.*, 2016; Said *et al.*, 2018).The affected parameters have been not fully studied because of the huge number of experimental runs (3125 runs) for five levels and can be time consuming (Antil-Martini *et al.*, 2017). This issue can be solved by using response surface methodology (RSM) as an optimization method to produce an empirical model for the dust removal experiments (Chuahy and Kokjohn, 2017; Nazari *et al.*, 2017).

Although wind energy has potential energy to power a mechanical vibrator and can be used in significant way for dust removal, the following problems have been identified:

1 Evaluation of minimum required force that overcomes the adhesive force, i.e. prevent re-suspension of dust particle on the panel surface and hence proof of concept for vibrator to work for such application. Few studies have been carried out to evaluate the adhesive force (Debrincat *et al.*, 2008; Said and Walwil, 2014), but these studies consider only the effect of relative humidity on the adhesive force with no indication about minimum force value that can be added to dust particle for overcoming the forces acting on dust particle (Mazumder *et al.*, 2017). Thus there is a need to quantify the minimum force to make the average size dust afloat on the solar panel.
 Wind power, a renewable energy source, where the potential of wind could be derived many mechanical types of equipment (Dupont *et al.*, 2018). Therefore wind power can be used to power the mechanical vibrator which generated an excitation force for the accumlated dust particles and put these particles at free position to be removed from panel surface.
 Vibrating force which is generated via wind powered mechanical vibrator, as a sinusoidal excitation force has the capability to over come the ahasive force(Boddupalli *et al.*, 2017; Hudelson *et al.*, 2014), by producing the acceleration to the accumulated dust particles and increase in kinetic energy level for these particles (Aidara *et al.*, 2018; Sayyah *et al.*, 2017), to allow these particles to be removed away from panel surface. Hence, added as a fifth parameter under the test for the new concept and considered as an effected parameter for the test.

2 The current dust removal techniques provides no leveling (ranking) for effected parameters (Slocum *et al.*, 2011). Thus a comprehensive approach is required to consider the main factors that effect on the performance of vibrator and using optimization method can provide a comprehensive approach to produce reliable result without sacrificing sensitivity.

3 In desert environments which are widely existing between 15° and 35° N latitude, there will be some extreme weather events that require cleaning of all types of PV modules (Babatunde *et al.*, 2018; Fouad *et al.*, 2017). This information is transulated into focusing of solar panel tilt angle between 15° and 35° (Paudyal and Shakya, 2016).

4 There is no recommended constant frequency for cleaning PV unit, especially in dry areas (Chaichan and Kazem, 2017; Hassan *et al.*, 2017; Said *et al.*, 2018). A systematic approach is to determine an empirical model to optimize contributions of factors i.e. tilt angle, wind speed and dust character.

1.3 Study objectives

The main objective of this study is to optimize a wind powered of dust removal technique for solar panel that can provide an excitation force to overcome the adhesive force between dust particles and solar panel surface. The specific objectives are as follows:

1. To determine vibration response of the solar panel from mechanical vibrator to establish performing proof of concept.
2. To investigate the effect various levels for tilt angle, vibrating force, dust quantity, dust size and wind speed on dust removal index, with and without vortex generators using results from objective one.
3. To verify experimentally the effectiveness of the new wind powered vibrator to remove the dust from solar panel against electrical vibrator.
4. To propose an empirical relationship to estimate the dust removal from the solar panel using optimazation methods (RSM and verified by PSO techniques).

1.4 Significance of Research

Dust falling on the surface of the PV greatly affects the energy produced by this unit. Therefore, the dust removal process is important in generating electric power using solar system. The traditional dust removal techniques increase the cost of converting solar energy to electricity energy. This study is concerned to optimize and model for a new dust removal technique for PV powered by wind energy with contious operation. The optimization of the optimum conditions for the independent parameters using RSM allows us to find the optimal values in a defined range with a minimum set of experiments. The developed empirical model deals with the factors affecting this technique and the model can be used as a guide to engineering designers for the installation of PV plants. This model is experimentaly designed and optimized using RSM to find the optimal values of independent parameters and verified by PSO.

1.5 Scope of Study

The research approach followed in this study comprises of a literature survey, an extensive experimental program, theoretical analysis using rational model and numerical simulations. Figure 1.4, shows a schematic representation of the research approach adopted in this study to devlope a wind powered dust removal technique from solar panel. This development is optimized by two optimization methods; Response Surface Methodology (RSM) and Particle Swarm Optimization (PSO).

Nomination of effective parameters for this technique takes in consederation the most effective parameters on PV performance and accumulated dust on PV surface, which are tilt angle, wind speed, dust size and dust quantity, from previous study, according to the particular area between 15° and 35° N latitude angle as shown in Figures (1.1and 1.2), that corresponds to tilt angles of 15° - 35°, while the fifith parameter nominated from Proof of Concept (PoC) during the expermental rig ruuning with nominated wind speed values. The average values of wind speed at high accumulated dust areas are occure between 1 to 5 m/sec, especially in the Middle East countaries such as Baghdad (Kazem *et al.*, 2014), Tehran(Gholami *et al.*, 2018), Palestine (Goossens and Offer, 1995), Saudi Arabia(Chen *et al.*, 2018; Shaahid *et al.*, 2018), the northern area of Arabian Gulf (Al-Salem *et al.*, 2018). Dust sizes and dust quantity are different from site to another (Chaichan and Kazem, 2017; Elminir *et al.*, 2006; Fathi *et al.*, 2017b; Fraga *et al.*, 2018; Gholami *et al.*, 2018; Jordan *et al.*, 2010; Styszko *et al.*, 2018). Therefore, in current study nomination of these two parameters is according to previous studies; with range 1to 5 g/m^2 for dust quantity, and less than 20μm to 250μm dust size. These parameters are nominted by five levels for each one to be more accurate in evaluation the effect of each. While solar panel size (1050×540×2) mm, model BSP32-100 was used as it is a common size and available in the market.

The experimental and theoretical programs comprise proof of concept for the new technique. Also, the critical line between levitation and non-levitation zones according to dust particle size was evaluated with assumptions; that dust particles have a spherical shape(Style *et al.*, 2013), stable not reactive, uniformally distribution and a solid body, levitation mean that dust particle at this period is overcome adhesive force, whereas the particle in the transport period(Zhang *et al.*, 2018). Wind powered the mechanical vibrator which produced an excitation force for accumulated dust on PV surface, where the accumulated dust and solar panel is one rigid body. Therefore kinetic energy observed by solar panel transfer directly to dust particles, with a minimum capability of removing the accumulated dust more than 90% from the panel surface(Mazumder *et al.*, 2017).

Improvement of wind effect for dust removal by using vortex generators in the wind direction to added more energy for dust partcles that accumulated on PV surface. Others include the independent parameters screening to examine the performance of new dust removal technique with and without vortex generators.

Most importantly the evaluation of the performance of mechanical vibrator will provide a new concept in dust removing techniques, which is through applying an excitation force on the accumulated dust by converting the wind energy into vibration mechanical energy for solar panel. The experimental design is designed by using RSM which also attained an empirical model for the new dust removal technique. Also using optimization methods RSM to overcome the huge number of experimental runs (3125 runs), and constraint of time, while PSO is used to verify the empirical model which was formulated using RSM. Data for RSM are optained from experiments using experimental rig as shown in Figure 3.9.

The current study is limited to the ordinary indoor test; experimental data collected in sunny days then environmental parameters like relative humidity is excluded in the current study. Wind direction is fixed and the wind attack angle is zero at the front view. Life expentanacy of prototype, resonance, durability are ignored. However, during tests 6 mode shapes were conducted to ensure that natural frequency is never achived, where the simulation achieved the PV surface not including the supporting structure for it. Dust that used in experimental work is collected from local area of Universiti of Putra Malaysia (UPM).

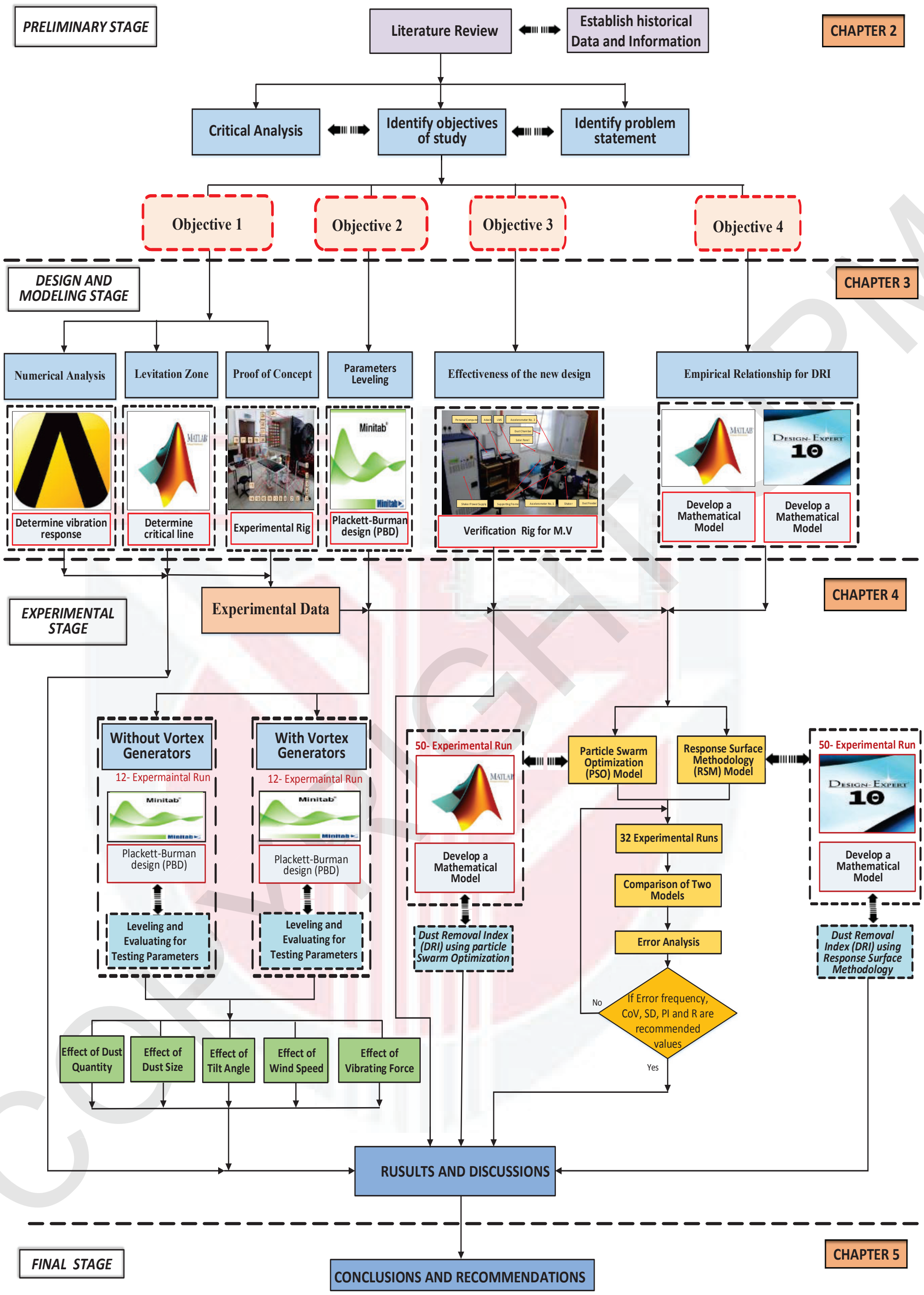

Figure 1.4 : Schematic representation of research approach

1.6 Thesis outline

This research was formatted with five chapters in accordance with the guidelines for thesis preparation, March 2004, provided by the School of Graduate Studies, Universiti Putra Malaysia.

Chapter 1 contains brief overview, statement of problem, objectives, scope of the current study and thesis outline.

Chapter 2 covers the background of the research regarding the dust removal techniques, dust accumulation on solar panel and its effect on panel performance, forces acting on dust particle, tilt angle, wind speed, Design of Experiment (DoE) and Particle Swarm Optimization (PSO) technique.

Chapter 3 presents the details of the methodology which was divided into parts i.e. experimental and numerical. The experimental program detailed out the testing procedure such as geometrical and material properties, test setup used and theoretical program. While the numerical part deals with the numerical analysis procedure for the achievement of stated objectives.

Chapter 4 presents the results and discussions of the experimental, theoretical and numerical findings.

Finally, Chapter 5 presents a general conclusion of the results obtained from the experiments and theoretical aspect with regard to the problems and observations. Recommendations for further studies were also stated.

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BIODATA OF STUDENT

Osam Hassan Attia was born on 1st of July 1972 in Baghdad, Iraq. He obtained his Bachelor's degree in Mechanical Engineering in 1994 from University of Technology, Baghdad, Iraq.

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LIST OF PUBLICATIONS

Accepted Papers

Osam H. Attia, Nor Mariah Adam, Azizan As'arry & Khairil Anas Md Rezali. Removal of Dust From the Solar Panel Surface Using Mechanical Vibrator. JMechE in 4 Jul 2018.

Osam H. Attia, Nor Mariah Adam, Azizan As'arry, Khairil Anas Md Rezali & Hanoon, A. N. Development of a Prediction Model for Output Power Reduction of PVSolar Panels Based on Environmental Parameters using Particle Swarm Optimization Technique. Journal of Engineering and Applied Sciences. April 04, 2018.

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Osam H. Attia, Nor Mariah Adam, Azizan As'arry & Khairil Anas Md Rezali. Removal of Dust From the Solar Panel Surface Using Mechanical Vibrator. NVC-03-2018 conference.

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Osam H. Attia, Nor Mariah Adam, Azizan As'arry & Khairil Anas Md Rezali. Systematic Review for Dust Removal Techniques from PV and Proposal of a New Sustainable Technique with Zero Power Consumption . IEEE journal of Photovoltaics in 16 October 2018. Under Review