ANALYSIS OF WIND LOADING ON SOLAR PANEL AT DIFFERENT INCLINATION ANGLES IN MALACCA WEATHER CONDITION

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal- Fluids) with Honors"

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This Report Is Submitted In Partial Fulfillment of Requirement For The Bachelor Degree Of Mechanical Engineering (Thermal-Fluid) With Honors

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(MAY 2015)

DECLARATION

“I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged”

Signature: ____________________

Author: NURUL YASMIN BINTI MOKHTAR

Date: 28 MAY 2014

"Timothy Leroy Lincecum, for his pitching mechanic, the marvel of unorthodox engineering"

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ABSTRACT

The field of renewable energy has been widely growing topic of fascination by researchers, industrialist and the public alike. Solar technology is becoming increasingly popular for the past few decades and Malacca has become a home for solar energy harnessing where it houses 5MW solar farm owned by Kumpulan Melaka Berhad and a key project for Malacca to become a green technology state by 2020. Like any other structure, solar photovoltaic panels are subjected to wind loading and the effort to minimize the structural damages due to high wind has become the main interest for many. This study attempt to investigate the effect of wind loading on solar panel at different inclination angles using two common method ; CFD and wind tunnel testing. For computational fluid dynamics, Reynold Average Navier Stoke (RANS) equation of k-ε turbulent closure modeling is use. The result obtain from the simulation will be compare and validate with force measurement system in wind tunnel testing. The images of velocity contour generated from simulation managed to reveal the flow behavior such as flow separation, wake region and are compared with images captured using smoke generator in the wind tunnel experiment.

ABSTRAK

Bidang tenaga boleh dibaharui telah menjadi satu bidang yang menarik minat ramai penyelidik akademik, pihak industri, dan termasuk orang awam. Sejak beberapa dekad, teknologi solar telah menyaksikan peningkatan permintaan dan semakin mendapat tempat di pasaran. Negeri Melaka sendiri merupakan negeri pertama mempunyai ladang solarnya yang berkapasiti 5MW milik Kumpulan Melaka Berhad dan merupakan projek ulung bagi Melaka yang bercita-cita untuk menjadi negeri berteknologi hijau menjelang tahun 2020. Akan tetapi, seperti struktur lain panel solar juga tertakluk pada beban angin dan langkah untuk mengurangkan kesan beban angin telah menjadi satu fokus utama ramai pihak. Kajian ini bertujuan untuk mempelajari kesan beban angin pada panel solar jika dikenakan pada sudut condong yang berlainan dengan menggunakan dua kaedah iaitu simulasi CFD dan ujian terowong angin. Untuk CFD, persamaan *Reynold Average Navier Stoke* (RANS) jenis k-ε akan digunakan dan hasil dapatannya akan dibandingkan dengan hasil dapatan pengukuran daya daripada terowong angin.Imej kontur hadlaju yang terhasil dari simulasi dapat menunjukkan ciri-ciri bendalir tersebut seperti pemisahan aliran dan akan dibanding dengan imej yang diperoleh dari ujian terowong angin yang dijana menggunakan penjana asap.

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LIST OF ABBREVIATION

PV	Photovoltaic
CFD	Computational Fluid Dynamic
HVAC	Heating, Ventilation and Air Conditioning
RE	Reynold Number
RMS	Root-mean-square
LES	Large Eddy Simulation
NBCC	National Building Code of Canada
RANS	Reynold Average Navier Stoke Equation
RNG	Re-Normalisation Group
KMK	Kompleks Makmal Kejuruteraan
ASCE	American Society of Civil Engineer
SR EN	Asociatia de Standardizare din Romania
SIMPLE	Semi-Implicit Method for Pressure Linked Equation
2D	Two Dimensional
3D	Three Dimensional

NOMENCLATURE

δ	=	Boundary layer thickness (m)
V	=	Velocity (m/s)
ρ	=	Density (kg/m^3)
γ	=	Azimuth angle (°)
Π	=	Dependent variable
L	=	Characteristic length based on shape (m)
P	=	Pressure (Pa)
C_L	=	Lift Coefficient
C_D	=	Drag Coefficient
F_D	=	Drag Force (N)
F_L	=	Lift Force (N)
F_R	=	Summation of drag force and lift force (total force) (N)
ν	=	Kinematic viscosity (m^2/s)
τ_w	=	Shear stress boundary layer
A	=	Planform area (m^2)
θ	=	Momentum thickness of boundary layer
k	=	Turbulent kinetic energy
ε	=	Dissipation rate of k (eddy dissipation)
A_{ref}	=	Reference area of a structure (m^2)
F_w	=	Wind Force (N)
C_s, C_D	=	Structure Coefficient (Romanian Standard)
ρ	=	Atmospheric Air Density (kg/m^3)
μ	=	Air Viscosity (kg/ms)
Hz	=	Frequency

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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

Solar energy is the most considerable and abundant energy source in the world and emits approximately 1353W/m^2 on to the surface. The world receives 170 trillion kW of solar energy but in portion, 30% of this energy is reflected back to the space, 47% is transformed to heat energy, 23% is used for evaporation cycle, and 0.5% is used in the kinetic energy of the wind, waves and photosynthesis of plants. Photovoltaic system converts sunlight directly into electricity.

Solar photovoltaic system consists of cells which are the building block of the system. Module or panels are made up of multiple cells and array typically made up from multiple modules. Solar photovoltaic application can be found in spacecraft, commercial or domestic uses. Photovoltaic system has two types which is stand alone and grid connection. Wind is defined as air in moving motion. Any body that stop, deflects or change the kinetic energy of wind into potential energy creating a force called wind load. High velocity wind can be very destructive and dangerous thus wind load studies on structural integrity of the solar panel are very important.

1.1 PROBLEM STATEMENT

The evaluation and understanding of wind load applied on solar photovoltaic panels are crucial for design purpose as extreme wind event especially cyclone and monsoon season give challenges in designing solar panel. Concerns about structure strength of solar panel to withstand high wind loads has become a priority as aerodynamic forces acting on solar panel can cause serious mechanical damage to the structure which can lead to reduced efficiency. The consumer may subject to unreasonable, costly maintenance and unnecessary replacement.

In the past years, varies of solar-related technologies in the market but number of study exist regarding aerodynamic subject on solar panels especially Malaysia can be considered miniscule. As stated by the Building Research Establishment Digest for British Standard, “there is very little information and no authoritative guidance about wind loads on roof based photovoltaic systems” [Blackmore 2004] .Lack of clear guidelines on wind loading forces the engineers to do assumption of wind load coefficient when designing solar panels using standard that were made for structures like carport, fences, billboard and heating, ventilation and air conditioning (HVAC) units. It resulted in poor safety and uneconomical design.

1.2 OBJECTIVE

I. To investigate the aerodynamic feature on ground mounted solar panel system at different inclination angle.
II. To compare the wind load studies on solar panel between wind tunnel and by computational fluid dynamics simulation.

1.3 SCOPE

The focus of this study is mainly about wind loading on solar PV panels at different inclination angle. Investigation of wind flow, drag force, lift force and pressure distribution will be determines and how the aerodynamics load affects the solar photovoltaic panels. For experimental method, wind tunnel testing will be perform using small scale models of panels with atmospheric boundary layer flow representing open terrain condition with tilt angles of 10°,15° and 20°. For simulation case, CFD ANSYS FLUENT will be employ to examine the fluid flow.

CHAPTER 2

LITERATURE REVIEW

2.0 BACKGROUND

This chapter is a summary of fluid flow concept and previous studies on wind loading on solar panels. Malaysia's wind conditions in the year of 2014 were introduced in the first section. The fluid mechanics concept of boundary layer and their characteristic also described. Wind tunnel testing and computational fluid dynamics are briefly explained alongside the studies itself which is the wind effect on solar panels are written in the last section of this chapter.

2.1 MALAYSIAN WEATHER CLIMATE

Malaysia is a blessed country located between 1° and 7° North Equator, with its own characteristic of wind speed, cloud, rain distribution and humidity level. There is a plentiful rainfall that happens due to the convection of air and thunderstorm can occur nearly everyday. Malaysian temperature is high all year with the exception of wet season and high altitude places. Conclusively, Malaysia, a tropical place experienced two seasons only and that is wet and dry. However, places that located near the Equator are wet and humid throughout the year depending on certain factor such as the distance from a place to the ocean. The abundant rainfall and humidity means that the tropical climate is not the hottest but still it receives considerable sunshine. **Table 2.1** show the annual solar radiation receives in major towns in Malaysia.

Table 2.1: Annual Solar Radiation for towns in Malaysia
(http://www.seeforum.net/sustainableenergyandenvironment)

Region/Cities		Annual average value (kWh/m^2)
1	Kuching	1470
2	Bangi	1487
3	Kuala Lumpur	1571
4	Petaling Jaya	1571
5	Seremban	1572
6	Kuantan	1601
7	Johor Bahru	1625
8	Senai	1629
9	Kota Baru	1705
10	Ipoh	1739
11	Taiping	1768
12	Georgetown	1785
13	Bayan Lepas	1809
14	Kota Kinabalu	1900

It has all these renewable energy resources in abundance, but most of these renewable energies are still in introduction phase. In Malaysia, the climate conditions are favorable for the development of solar energy due to the large source of solar radiation. With the average daily temperature of 27.5°C, 2228 hours of sunlight per year with an average of 6.1 hours of sunlight per day and range between 4.9 hours per day in November and 7.4 hours per day in February [Rosli, 2010] .The solar radiation ranging from 6.5kWh/m^2 in the months of January and drops lower to 6.0kWh/m^2 in the months of August. As a result, the solar radiation in Malaysia is high by world standards [Mohammad et al, 2006].

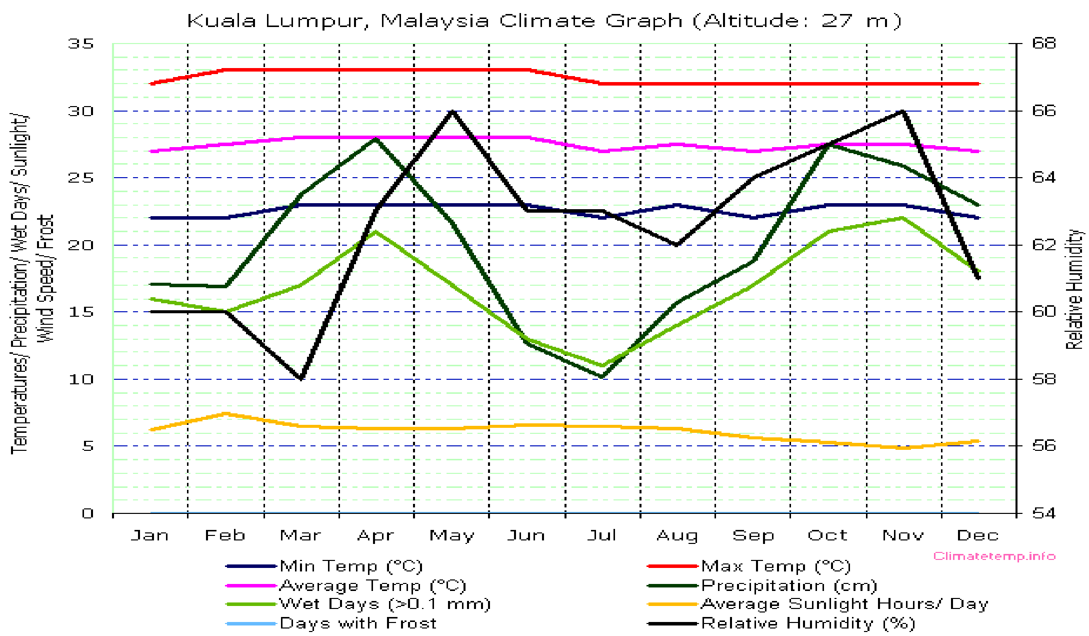

Figure 2.1: Malaysia climate change graph for 2010
(http://www.climatetemp.info/Malaysia, 2010)

Figure 2.1 shows the graph of climate change in 2010. The main wind direction is variable and the mean surface winds over peninsular Malaysia are generally mild, with the highest mean daily wind speed of about 3.8 m/s measured at Mersing, and a highest maximum wind speed ever recorded was 41.7 m/s at Kuching. Malaysia experienced four monsoon seasons throughout the whole year.

- The southwest monsoon season happens between May to early June and ends in September. The wind flow is generally southwesterly and light, below 15 knots (7.71 m/s)

- The northeast monsoon season occurs in November until March. During this season, steady easterly or northeasterly winds blows of 10 (5.14 m/s) to 20 knots

(10.28 m/s). The winds over the east coast of Peninsular Malaysia may reach 30 knots (15.42 m/s) or more.

However for the past few months in 2014, Malaysia has witnessed few violent wind and small scale tornadoes in multiple places such as Pandamaran, Klang and Kedah.

Figure 2.2: Aftermath of Violent Wind in Pandamaran, Klang 21 October 2014 (http://www.bharian.com)