

**DESIGN OF SYNCHRONIZED PHOTOVOLTAIC
AND WIND HYBRID POWER GENERATION
SYSTEM FOR STREET LIGHTING APPLICATION**

SUWARNO

UNIVERSITI MALAYSIA PERLIS

2016



**DESIGN OF SYNCHRONIZED PHOTOVOLTAIC
AND WIND HYBRID POWER GENERATION
SYSTEM FOR STREET LIGHTING APPLICATION**

By

**SUWARNO
(1040910536)**

A thesis submitted
in fulfillment of the requirement for the degree of Doctor of Philosophy

**SCHOOL OF ELECTRICAL SYSTEM ENGINEERING
UNIVERSITI MALAYSIA PERLIS**

2016

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name : SUWARNO
Date of birth : 17 April 1961
Title : Design of Synchronized Photovoltaic and Wind Hybrid Power
Generation System for Street Lighting Application
Academic Session : 2010-2016

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)
- RESTRICTED** (Constains restriced information as specified by the organization where research was done)
- OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy or no-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a priod of _____ years, if so requested above).

Certified by:



SIGNATURE

SIGNATURE OF SUPERVISOR

A4412623
(NEW IC NO. / PASSPORT NO.)

DR. LEONG JENN HWAI
NAME OF SUPERVISOR

Date : _____

Date : _____

ACKNOWLEDGMENTS

Alhamdulillah, Allah has given me health and enjoyment of very much, so today I was able to finish the study. The research project will not be completed without the support and assistance in the form of material and the spirit of many people. First, thanks to the supervisor Dr. Leong Jenn Hwai and co-supervisor Dr. Indra Nisja, who has provided input and guidance, so that this thesis can be completed. Moreover, I also say thank you very much for the help and support of all parties, especially Prof. Dr. Ismail Daut, Dr. Muhammad Irwanto, Mr. Muhammad Fitra Zambak, Mr. Tan Yee Chyan and all parties that I can not mention one by one.

Furthermore, thanks to all parties and members and technicians Centre of Excellence for Renewable Energy (CERE) for sharing in the literature and others.

Special thanks to my wife Elva Rosidah. Amd. children I love so much Resha Nurfitriani Addini, Bahana Qolbi Annaufal, Fariz Bagaswara, Taqif Andhika Putra, Naura Alandra Auini and whole family has given motivation and support to the success in completing the study.

TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLE	vii
LIST OF FIGURE	viii
LIST OF SYMBOLS	xi
LIST OF ABBREVIATION	xii
ABSTRAK	xiv
ABSTRACT	xv
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	4
1.3 Research Objectives	6
1.4 Thesis Scope	7
1.5 Thesis Organization	8
CHAPTER 2 LITERATURE REVIEW	9
2.1 Introduction	9
2.2 Wind Speed Prediction	10

2.3	Cumulative and Probability Density Function of Wind Speed	11
2.4	Solar Radiation	14
2.4.1	Solar Irradiance on Tilt Angle of PV Module	15
2.4.2	Solar Radiation Estimation	18
2.4.3	PV Module Performance	19
2.5	Solar Radiation on The Angle of PV Modules	19
2.6	Solar Radiation Estimation	20
2.6.1	Hargreaves Model	21
2.6.2	Annandale Model	22
2.6.3	Proposed Model	23
2.7	PV Power Generation Capacity	23
2.8	Photovoltaic Module Performance	24
2.9	Mathematical Modeling of PV Module Performance	26
2.9.1	Temperature Effect	29
2.9.2	Solar Irradiance Effect	30
2.9.3	Module Performance and Characteristic	31
2.10	Topology Buck-Boost DC-DC converter	32
2.10.1	Hybrid Buck-Boost DC-DC Converter	34
2.10.2	Synchronizing Buck-Boost Converter	34

2.11	Microcontroller Atmega16	39
2.12	Charging and Discharging Rechargeable Batteries	39
2.12.1	Battery Charging	40
2.12.2	Discharging Battery	42
CHAPTER 3 RESEARCH METHODOLOGY		45
3.1	Research Framework	45
3.2	Wind Speed Potential for Power Generation	48
3.2.1	Wind Speed Analysis	49
3.3	Potential of Solar Radiation as Power Plant	51
3.3.1	Solar Irradiance and PV Array Voltage	51
3.3.2	Measurement Set-up of Solar Radiation at Solar Panels	55
3.6	Estimation of Solar Radiation Using the Annandale, Hargreaves and Proposed Method	57
3.7	Hybrid Systems Wind Power and Photovoltaic	58
3.8	PV and WP Hybrid Generation	61
3.9	Synchronization indicator PV and WP Using LCD	62
3.10	Buck-Boost Converter Design	65
3.11	Implementation of Buck-Boost Converter Design	66
3.12	Testing Buck-Boost Converter	68
3.13	Proposed Buck-Boost Converter	71
3.14	Implementation of Buck-Boost Converter Design	74
3.15	Programming Language	75

CHAPTER 4 EXPERIMENTAL RESULTS AND DISCUSSION	77
4.1 Potential for Wind Power Generation	77
4.2 Daily Wind Speed in 2011 in Perlis	77
4.3 Cumulative Distribution of Wind Speed at 2011	79
4.4 Probability Density Function of Wind Speed at 2011	79
4.5 Monthly and annual wind speed at 2011-2014 in Perlis	80
4.6 Daily and Monthly Solar Radiation	87
4.7 Temperature and humidity of air in 2011 and 2012 in Perlis	91
4.8 Solar Irradiance Effect of PV module Performance at Different Tilt Angle	97
4.9 Wind Power and Phovoltaic Hybrid System	104
4.10 Analysis of Buck-Boost Converter	105
4.11 Testing Buck-Boost Converter and System Synchronization	109
4.11.1 Simulation Program and Implementation of the Synchronization	116
4.12 Charging and Discharging of Battery	127
4.12.1 Charging of Battery	127
4.12.2 Discharging of Battery	130
 CHAPTER 5 CONCLUSSION AND RECOMMENDATION	 133
5.1 Conclusion	133
5.2 Recommendation	134

REFERENCES	135
APPENDIX A (Publications)	141
APPENDIX B (Award)	144
APPENDIX C (List program for microcontroller by BASCOM)	146
APPENDIX D (Component of the XL6009, TIP2955, LM7815 and microcontroller)	147

©This item is protected by original copyright

LIST OF TABLE

NO.		PAGE
3.1	Electrical characteristics of the solar panel module	52
4.1	Comparison of the measured solar radiation and	90
4.2	Temperature and humidity in Kangar, Perlis	91
4.3	Comparison of the measured and estimated solar radiation	95
4.4	Comparison of error between the measured solar radiation and estimation	95
4.5	Statistical models of solar radiation	96
4.6	Results of statistical of PV modules	99
4.7	Performance of PV module at different solar irradiance and tilt angle	103
4.8	Measurement of the voltage on the buck-boost converter on the output of XL6009	109
4.9	The output voltage of the LM7815	111
4.10	The output voltage of the buck-boost converter loaded with 11W,12 V DC	113

LIST OF FIGURE

NO.		PAGE
2.1	Two diode model	26
2.2	Buck-boost converter topology	33
2.3	System block diagram of the synchronization between the WP and PV	35
2.4	Topology DC-DC boost converter	36
2.5	Topology DC-DC buck converter	36
2.6	Topology buck-boost converter circuit	36
2.7	Charging and discharging the battery (source internet: Model EL12030C)	44
3.1	Research framework	47
3.2	Methodology analysis of wind speed in 2011-2014	50
3.3	Estimation methodology of solar irradiation in 2011-2014	54
3.4	Solar irradiation set-up, temperature and solar module analyzer meter	55
3.5	Methodology analysis of solar irradiance throughout the year 2011-2014	56
3.6	Methodology of synchronize DC-DC converter	59
3.7	Module system hybrid wind power and photovoltaic	60
3.8	Panel box on hybrid plants	61
3.9	PV array and wind power generation are installed in front of CERE station, Malaysia Perlis	62
3.10	Synchronize system of microcontroller	63
3.11	Design circuit blocks buck-boost converter	64
3.12	Track buck-boost converter circuit	66
3.13	The layout of the buck-boost converter components on PCB	66

3.14	Wiring components buck-boost converter	67
3.15	Oscilloscope portable type ISDS205A	68
3.16	Track synchronization circuit, PV and WP	68
3.17	Layout hybrid system component on the PCB	69
3.18	Wiring synchronization system	69
3.19	Complete system of buck-boost converter and synchronization	70
3.20	Duty cycle of the waveform	71
4.1	Daily wind speed in 2011	77
4.2	Cumulative distribution of wind speed function at 2011	78
4.3	Probability density function and wind speed at day of the 2011	79
4.4	Daily wind speed in 2014	80
4.5	Probability density function of the year 2014	81
4.6	The cummulative distribution function of wind speed in 2014	82
4.7	Wind speed for monthly of the year 2014	83
4.8	Wind energy density (kWh/m^2) average monthly wind 2014	84
4.9	Wind power density (W/m^2) for monthly of the year 2014	85
4.10	Relation between power and energy density to tower height	86
4.11	Daily solar radiation throughout the year of 2011	87
4.12	Monthly solar radiation in 2011	87
4.13	Comparison of solar radiation minimum, average and maximum in January 2011	88
4.14	Solar radiation estimation by using the proposed method	89
4.15	Comparison of the measured solar solar radiation and proposed	89

4.16	Temperature throughout in Perlis 2011	92
4.17	Temperature throughout in Perlis 2012	92
4.18	Comparison of the measured solar radiation and proposed models	93
4.19	Comparison Annandale and proposed models	94
4.20	Comparison Hargreaves and proposed models	94
4.21	PV module characteristic curve type YL 75	97
4.22	Short circuit current simulation results using MATLAB	97
4.23	Power simulation results using MATLAB	98
4.24	Power to changes in solar irradiance	98
4.25	Short-circuit current to changes in solar irradiance	99
4.26	Performance power of PV moduls at 440 W/m ² and title 41.6 ⁰	101
4.27	Performance power of PV moduls at 425 W/m ² and title 40.8 ⁰	102
4.28	Hybrid system WP capacity and sunshine	104
4.29	PWM waveform as the switch is 'On' and 'Off'	108
4.30	V _{in} and V _{out} relation to buck-boost converter	110
4.31	Input and output voltage at LM 7815	112
4.32	V _{in} and V _{out} at loaded 11 W, 12 V	114
4.33	Simulation conditions unsynchronization	116
4.34	The PV and WP voltage the synchronous conditions	117
4.35	Synchronization between PV and WP	118
4.36	Block diagram of the measuring points	118
4.37	Waveforms of inductor (L)	119
4.38	Waveforms on diodes at cathode	120

4.39	TIP2955 waveform at each Pin	122
4.40	Waveforms on LM7815	123
4.41	Voltage and charging current and time	126
4.42	Voltage and discharge currents of the time	129

©This item is protected by original copyright

LIST OF SYMBOLS

ω	Sunset hour angle for the tilted surface for the mean day of the month
ϕ	Latitude
β	Tilted surface.
δ	Declination angle
n	Day number, with January 1 as day 1 and December 31 being day number 365.
ω_s	Mean sunrise hour angle
%	Percent
A	Area sweep of wind turbines
a	Empirical coefficient
A_i	Area of orientation surface
b	Constants obtained by fitting data.
$E_{solar,i}$	Available solar radiation on different orientation surfaces
f	Utilization factor
L	Latitude of the site
$^{\circ}$	Degree
η	Efficiency
η_{pv}	Efficiency of PV modules
μ	Location parameter
v	Wind before past the wind turbine
φ	Ground albedo
ρ	Density of air
σ	Deviation

Σ Total tilt angle of PV modules

©This item is protected by original copyright

LIST OF ABBREVIATION

A	Ampere
AC	Alternated current
ACF	Autocorrelation function
ADC	Analog to Digital converters
AhB	Capacity of the battery
AhC	Ampere hour charger
BASCOM	Basic Compiler
C	Capacitor
CDF	Cumulative distribution function
CERE	Centre of Excellent for Renewable Energy
CF	Cumulative probability
CP	Conditional probability
DACs	Digital to Analog converter
DC	Direct current
DF	Eccentricity correction factor of the earth's orbit
DSC	Duration of the speed curve
F	Frequency
FF	Fill Factor
I	Current
I_0	Current at $t=0$
IC	Integrated Circuit
I_L	Load current
I_{mp}	Maximum Power Current
I_{ph}	Photogenerated current
I_s	Reverse saturation current

I_{sc}	Short Circuit Current
JS	Saturation current density.
k	Boltzmann's constant
L	Inductor
L_{min}	Minimum inductor value
MCB	Mini Circuit Breaker
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
P	Power
PCB	Printed Circuit Board
PDF	Probability distribution function
P_{in}	Power input
P_{max}	Maximum Power
P_m	Mechanical power
P_{out}	Power output
P_r	Theoretical power
PV	Photovoltaic modules
q	Elementary charge
R	Load resistance
RAM	Read Access Memory
RISC	Reduce Instruction Set Computer
ROM	Read Only Memory
R_s	Series resistance
R_{Sest}	Solar radiation estimation
R_{sh}	Shunt resistance
R_{Smea}	Measured value measurement
SC	Solar constant
T	absolute temperature

T_e	Battery Discharge time (hours).
T_h	Total time (hours)
V	Voltage source
V_f	Provision MOSFET types of silicon (0.7)
$V_{i(\min)}$	Input voltage
V_{mp}	Maximum Power Voltage
V_o	Output voltage
V_{oc}	Open Circuit Voltage
WE	Wind energy
Z	Rainfall transform
ΔI_L	Ripple current of the inductor
V_{dc}	Direct current voltage
V_{rms}	RMS voltage
X_C	Capacitance impedance
X_L	Inductance impedance

©This item is protected by original copyright

Reka Bentuk Disegerakkan Hibrid fotovoltaik dan Angin Sistem Penjanaaan bagi Kegunaan Lampu Jalan

Turun naik dalam tenaga angin dan sinaran suria yang tidak selaras menjadi cabaran utama bagi membina loji kuasa alternatif. Ketidak-pastian ke dua sumber tenaga ini menjadi permasalahan dalam membuat penyegerakan. Untuk membina satu loji, terlebih dahulu dilakukan ujian potensi tenaga yang boleh digunakan. Ujian potensi tenaga angin menggunakan kaedah Weibull dan anggaran tenaga sinaran suria menggunakan model Annandale, Hargreaves dan model yang dicadangkan serta ke tiga model ini diuji statistik menggunakan simulasi MATLAB. Tenaga angin dan sinaran suria yang berubah-ubah dan ketidakselarasan berakibat pada voltan yang dibangkitkan tidak malar. Untuk voltan yang tidak malar boleh diatasi menggunakan buck-boost penukar. Buck-boost penukar merupakan penukar dc-dc yang dapat menaikkan dan menurunkan voltan. Reka bentuk dan pembangunan buck-boost penukar dengan menggabungkan komponen elektronik seperti Peraruh, Kapasitor, Diod, XL6009, TIP2955 dan LM7815. Suatu kesusahan untuk menggabungkan kedua-dua loji secara langsung dengan voltan tidak malar. Penggabungan tenaga angin dan sinaran suria menggunakan mikropengawal, yang berkhidmat untuk menyambung atau memutuskan kepada dua sumber tenaga kepada sistem tenaga elektrik, jika salah satu atau ke dua sumber tenaga mempunyai voltan lebih kecil atau lebih besar daripada voltan yang ditentukan, maka mikropengawal bekerja untuk memutuskan sumber tenaga ke bateri. Apabila salah satu atau ke dua sumber tenaga mempunyai voltan sama dengan voltan yang ditentukan, maka mikropengawal bekerja menghubungkan sumber tenaga kepada bateri. Berdasarkan simulasi MATLAB bahawa potensi tenaga angin dan sinaran suria di Perlis menunjukkan bahawa, tenaga angin rendah iaitu kelajuan angin maksimum 1.10 m/s pada PDF 0.44 (Tahun 2011) dan kelajuan angin maksimum 1.11 m/s pada PDF 0.51 (Tahun 2014), sedangkan hasil anggaran dan uji statistik (CRM, RMSE dan e%) untuk sinaran suria menggunakan MATLAB diperolehi bahawa model yang dicadangkan (gabungan Hargreaves dan Annandale model) lebih baik daripada dengan model Hargreaves dan Annandale dan tenaga sinaran suria sangat baik dengan sinaran suria rata rata 1,316 wh/m² (diatas nilai standard iaitu 1,000 wh/m²). Reka bentuk dan pembangunan buck-boost penukar dengan penambahan komponen Peraruh 35.5 μ H dan Kapasitor 220 μ F dapat menaikkan dan menurunkan voltan dari sumber tenaga angin dan sinaran suria. Pelaksanaan buck-boost penukar pada sistem penyelarasan tenaga boleh angin dan Suria sinaran digunakan untuk pengisian batere. Masa pengecasan bateri 5-6 jam dan masa menyahcas batere 28 jam.

Design of Synchronized Photovoltaic and Wind Hybrid Power Generation System for Street Lighting Application

Fluctuation of wind energy and solar radiation that is inconsistent become a major challenge to build alternative power generation. The uncertainties to two energy sources is a problem in synchronizing. To build a plant, first performed testing the potential energy that can be harnessed. Testing the potential of wind energy using Weibull distribution methods and estimation of solar energy radiation using a model Annandale, Hargreaves and the proposed model as well as to these three models were tested statistically using MATLAB simulation. Wind energy and solar radiation are fluctuating and inconsistent results in the voltage generated are not constant. For the voltage is not constant can be fixed using a buck-boost converter. Buck-boost converter is a dc-dc converter that can increasing and decreasing the voltage. Design buck-boost converter uses a combination of electronic components such as inductors, capacitors, diodes, XL6009, TIP2955 and LM7815. Of a difficulty to combine the two plants directly with a voltage are not constant. Merger of wind energy and solar radiation using a microcontroller, which serves to connect or disconnect the two energy sources to the electrical power system, if one or two sources of energy have a voltage less than or greater than the voltage is specified, then the microcontroller works to break source energy to the battery. If one or both energy sources have the same voltage with the voltage specified, then the microcontroller to work connecting the energy source to the battery. Based on MATLAB simulation that the potential for wind energy and solar radiation in Perlis show that wind energy is low at maximum wind speed of 1.10 m/s in PDF 0.44 (in 2011) and a maximum wind speed of 1.11 m/s in PDF 0.51 (2014), while the results of estimation and statistical tests (CRM, RMSE and e%) for solar radiation using MATLAB shows that the proposed model (combination Hargreaves and Annandale model) is better than model Hargreaves and Annandale and energy of solar radiation is very good with solar radiation average 1,316 wh/m² (above the standard value of 1,000 wh/m²). Design and development of buck-boost converter with the addition of components Inductors 35.5 μ H and capacitors 220 μ F can increasing and decreasing the voltage of the source of wind energy and solar radiation. Implementation buck-boost converter in the synchronization system wind energy (WP) and photovoltaic (PV) is used for charging batteries. The battery charging of 5-6 hours and discharging the battery of 28 hours.

CHAPTER 1

INTRODUCTION

1.1 Background

In this era, the rapid economic growth and industrial development in all parts of the world resulted in growing energy demands. The primary energy sources in the world is still dominated by fossil energy, whilst alternative energy is only contributing a small portion of the world energy market (Alam & Manfred, 2010). High dependency in non-renewable energy like fossil fuels causes the energy crisis due to dwindling fossil energy availability besides causing damage to the environment. One of the solutions is to develop the technologies to harvest the alternative energy such as energy from sunlight and wind efficiently and economically.

Wind is the movement of air caused by the rotation of the earth and because of the pressure difference in the surrounding air. Wind moves from high pressure areas to low air pressure. Changes depending on the pressure of the surrounding air, so it will affect the speed of the wind. Wind speed near the equator faster than those far from the equator, while the higher places, the wind is blowing too fast (Barbie Bischof et al, 2003).

Modeling and prediction of the wind speed characteristics and the potential of wind energy can be done by using Weibull distribution function (Odo et.al, 2012). Wind

speed estimation based on sensorless maximum wind power with tracking control is able to extract the maximum energy from the wind power for variable speed wind turbine generator (Qiao et al, 2008). Evaluation of wind energy potential in Lagos, Nigeria, showed that an annual average wind speed of more than 5 m/s (with a theoretical capacity factor of 0.09) can generate electrical energy of 512.11MWh (Sanusi and Abisoye, 2011).

Wind speed characteristics consist of daily, monthly and yearly average is analyzed using the Weibull distribution function is used to calculate the potential for wind power generation. The potential of wind power plants is observed and analyzed for 24 hours (March 9, 2011). The results of the analysis of monthly average wind power and energy density indicates that the early (January-March) and end (December) years have high power wind and energy potential, but in mid-they are very low, it is necessary to develop a wind power plant specifically capable of utilizing resources little wind power available in Perlis (I. Daut et al, 2011).

To determine the feasibility of solar and wind energy generation in Perlis, it is necessary to study the potential of both solar and wind estimation in advance before building the alternative power generation plant. Many models, such as Annandale and Hargreaves models, can be used to estimate the solar radiation. (Almorox, J, 2009; Al Riza et al, 2011; Oliveira et al, 2014), whilst the wind speed can be predicted by using the Weibull distribution (Sarkar, 2011; Ahmeda & Mahammeda, 2012).

Perlis is the northern states of Peninsular Malaysia and is known as the hottest country in Malaysia with an average of 12 hours of sunlight received per day. Solar

radiation average year, in Ulu Pauh, Perlis. From the overall observation and discussion, it was concluded that the Ulu Pauh area known as the potential for harvesting solar energy. It is the support by the methods used in the equations and data collected from weather stations. Some of the parameters and the necessary modifications to take into greater detail before developing as a center for solar energy harvesting in Perlis (Syafawati A.N et al, 2011).

Solar and wind energy both suffer fluctuations, resulting in inconsistent output voltage produced. Due to this drawback, it can not be used directly as a source of power generation (Leavey and Hild, 2012). To counter this problem, voltage stabilizer is needed. One of the circuit topologies that can be used for this purpose is the buck-boost converter.

In 2013, Surendra et al. designed a full-bridge DC-DC converter using zero voltage switchings (ZVS) of the active switches in the entire range of conversion. In which the ZVS operation over a range of conversions can be achieved without significant increase in conduction loss, making the full-load converter suitable in applications where high efficiency output is needed.

The buck-boost converter proposed in this thesis consists of XL6009, TIP2955, LM7815, inductor (L), capacitor (C) and ATmega16 microcontroller. XL6009 is a type of DC-DC converter which can increasing and decreasing the voltage. Increasing and decreasing the voltage depending on the magnitude of the duty cycle (D) of the PWM wave. If D is less than 0.5, then XL6009 work as a step-down the voltage, if D is greater than 0.5, it works as a step-up voltage. TIP2955 is a type of PNP transistor that function