Faculty of Electrical Engineering

DESIGN AND PERFORMANCE EVALUATION OF SOLAR PV SYSTEM IN MALAYSIA

Tan Pi Hua

Master of Science in Electrical Engineering

2016

DESIGN AND PERFORMANCE EVALUATION OF SOLAR PV SYSTEM IN MALAYSIA

Tan Pi Hua

A thesis submitted
in fulfillment of the requirements for the degree ofMaster of Science
in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this thesis entitled "Design and Performance Evaluation of Solar PV System in Malaysia" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature ofany other degree.

.

Signature	:…………………….
Name	: Tan Pi Hua
Date	: 5 February 2016

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature	:………………………
Supervisor Name	: Assoc. Prof. Dr. Gan Chin Kim
Date	:5 February 2016

ABSTRACT

The technical design and performance evaluation of solar PV system are gaining increasing attention nowadays. This is to maximize the economic benefits and to shorten the investment payment period, particularly under the Feed-in Tariff incentive scheme. In light of this, this thesis presents a comparison between the performance of Thin Film (tandem junction- micro-amorphous), Heterojunction with Intrinsic Thin layer (HIT) and Mono-Crystalline (Mono) photovoltaic (PV) module technologies between estimated and real measurement data for the grid-connected PV system installed at the Research Laboratory of PV System and Smart Grid, UTeM. The respective system performances were analysed in terms of total energy yield. In addition, the rooftop and ground mounted PV system installation conditions were also considered in the study. The respective system performances were compared in terms of total energy generated, specific yield and Levelized Cost of Energy (LCOE) for PV grid parity analysis in Malaysia. The FiT degradation rate of solar PV system has been taken into consideration. The key findings suggest that under the Malaysian climate environment, the Thin Film PV system has the highest energy yield, which is mainly driven by its lower module temperature losses and minimum module fluctuation response. Moreover, under the current Feed-in Tariff scheme in Malaysia, the rooftop thin-film PV system installation has the highest economic benefit for the utility scale PV power plant. Apart from the PV system performance evaluation, the installation of an external lightning protection system is crucial for power plants to minimize PV system damages.This is because Malaysia is also one of the countries withthe highest occurrences of lightning activities in the world. Thus, it is essential for PV power plants to have adequate protection from damage and power generation losses. In this regard, two different lightning systems were considered to two different PV technology Power Plant systems. The respective system performances were compared in terms of total energy yield. The key findings suggest that the air termination lightning pole is suitable for a solar power plant particularly a Thin Film or Crystalline PV power plant system that will result in lower losses compared to the Early Streamer Emitter lightning pole for the PV Power Plant system.

ABSTRAK

Rekabentuk dan penilaian prestasi teknikal sistem PV solar semakin mendapat perhatian pada masa kini. Ini penting untuk memaksimumkan manfaat ekonomi dan untuk memendekkan tempoh pulangan pelaburan, terutamanya di bawah skim insentif Tarif Feed-dalam. Dengan itu, tesis ini membentangkan perbandingan antara prestasi filem nipis (selaras junction-mikro-amorfus), Heterojunction dengan lapisan nipis intrinsik (HIT) dan Mono-Kristal (Mono) fotovoltaik (PV) modul teknologi antara data pengukuran anggaran dan sebenar. Sistem masing-masing persembahan telah menganalisis dari segi jumlah tenaga hasil dari PV modul teknologi dan analisis ekonomi sistem PV. Penemuan-penemuan penting mencadangkan bahawa keadaan iklim Malaysia, sistem PV filem nipis mempunyai hasil tenaga yang tertinggi, yang didorong terutamanya oleh kerugian modul suhu yang rendah dan maklum balas naik-turun modul minimum. Atas bumbung dan tanah dipasang pemasangan sistem PV syarat-syarat yang telah dipertimbangkan dalam kajian ini. Prestasi sistem masing-masing telah dibandingkan dari segi jumlah tenaga yang dihasilkan, hasil tertentu dan Levelized kos daripada tenaga (LCOE).Di bawah skim Feed-in Tariff ini semasa di Malaysia, pemasangan sistem PV nipis-filem di atas bumbung mempunyai faedah ekonomi yang tertinggi untuk loji janakuasa skala PV utiliti. Kadar kemerosotan patut solar PV sistem telah diambil kira. Gabungan struktur pelekap dan konsep struktur BIPV dianggap Universiti Teknikal Malaysia Melaka Reka bentuk loji janakuasa solar. Analisis tekno-ekonomi adalah untuk mengetahui dalam projek yang menjadi bankability yang tempoh bayar balik pelaburan dengan suapan yang terendah dalam skim tarif yang dicadangkan oleh pihak berkuasa pembangunan tenaga lestari (SEDA) pada tahun 2015. Pemasangan sistem perlindungan kilat luar adalah penting bagi loji-loji janakuasa untuk meminimumkan kerosakan sistem PV.Dua sistem berbeza kilat telah dipasang untuk dua PV teknologi loji kuasa sistem yang berbeza. Prestasi sistem masing-masing telah dibandingkan dari segi jumlah tenaga yang dijana dan hasil tenaga. Penemuan-penemuan penting mencadangkan bahawa tiang kilat penamatan Penyaman sesuai untuk loji janakuasa solar terutamanya filem nipis atau Kristal PV loji kuasa sistem yang akan mengakibatkan kerugian yang lebih rendah berbanding dengan kutub kilat awal Streamer Emitter untuk sistem loji kuasa PV. Ini adalah disebabkan oleh bayang-bayang tiang kilat yang jatuh pada modul PV untuk meningkatkan suhu sel solar dan mengurangkan penjanaan kuasa. Malaysia mempunyai salah satu ulangan aktiviti kilat tertinggi di dunia. Oleh itu, adalah penting bagi loji-loji janakuasa PV untuk mempunyai perlindungan yang mencukupi dari kerosakan dan kuasa generasi kerugian.

TABLE OF CONTENTS **PAGE**

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

I	Solar Irradiation
d	Distance between the sun and the earth
d_0	Yearly mean earth-sun distance (1.496 x 10^{11}m).
n	Number of day from 1 January.
AI (t)	Cosine Effect
I_g	Global irradiation
I	Extraterrestrial irradiation
Θ_z	Solar zenith angles.
A	Altitude of the location in kilometres.
P_{mp}	Maximum power of the systems' capacity, kW
γ_{coef}	Temperature coefficient, %/ °C
T_{module}	PV module cell temperature, °C
T_{stc}	Temperature at standard test condition, 25 °C
G	Solar Irradiance W/m^2.
E_{total}	Total energy production kWh
P_{mp}	Total PV installation capacity

PSH	Peak Sun Hour, h
PR	PV System Performance Ratio, %
E_{yield}	Energy yield, kWh/kW_p
P_{mp}	PV system installation peak capacity, kW_p
f_{temp}	Temperature correction factor
T_{cell}	PV module cell temperature (^0C)
T_{stc}	Temperature at standard testing condition, 25 ^0C
$V_{corrected}$	Corrected voltage
$I_{corrected}$	Corrected current
$P_{corrected}$	Corrected Power
CAPEX	Capital expenditures (RM)
O&M	Operation and maintenance cost (RM),
α	Capital recovery factor.
T	Economic lifetime of the PV system (year).
R_p	Radius protection coverage area
V	Assumed to be 1m/µs
D	Protection level, where D = 20, 30, 45, or 60 m
H	Height (m)
ΔT	Gain in sparkover time (µs) of the upward leader
S	Separation distance

k_i Factor that depends upon the chosen lightning protection level.

k_c Factor that depends upon the number of down-conductors.

L Length of down-conductor from the point being considered to the closest equipotential bonding point.

V_{max_oc} Maximum Open Circuit Voltage

V_{max-mp} Maximum Load Connected Voltage

V_{oc_stc} Open Circuit Voltage

V_{min_mp} Minimum Load Connected Voltage

V_{mp_stc} Load Connected Voltage

γ_{voc} Temperature Coefficient for Open Circuit Voltage

γ_{vmp} Temperature Coefficient for Load Connected Voltage

$N_{max\_base\_on\_Voc}$ Number of maximum PV module lower than 1000V.

$N_{max\_base\_on\_Vmp}$ Number of maximum PV module connected in series

$N_{min\_base\_on\_Vmp}$ Number of minimum PV module connected in series

$V_{max\_in\_win}$ Maximum input voltage to inverter connected to load

$V_{min\_in\_win}$ Minimum input voltage to inverter connected to load

$N_{parallel\ max}$ Maximum parallel PV array connection.

$I_{dc\_max\_inv}$ Maximum of current inverter

I_{sc_stc}	Short circuit current at STC.
$P_{nominal}$	Nominal PV array capacity
η_{inv}	Inverter efficiency
$V_{min\_win\_inv}$	Minimum voltage window at inverter.
P_{array_stc}	PV array capacity at STC
f_{tem_energy}	Factor of temperature lost at PV array
f_{dirt}	Factor of dirt and dust lost
f_{mm}	Factor of PV array mismatch lost
$f$cable	Factor of cable resistance lost
f inv	Factor of PV inverter efficiency
V_{drop_dc}	DC voltage drop
L_{dc_cable}	DC cable length
I_{mp}	PV system load current
ρ	Resistivity of conductor
A_{dc_cable}	Surface area of DC cable
V_{drop_ac}	AC voltage drop
L_{ac_cable}	AC cable length
cos Ø	Power factor

V_{drop} % Voltage drop factor

V_{drop} Voltage drop

$V_{min\ load}$ Minimum load voltage

Loss% Cable loss factor

$V_{min\_mp\_string/array}$ Minimum of string or array voltage.

P_{drop_dc} DC power drop

$P_{dc\ losses}$ % DC power loss factor

I_{sc_string} PV array string current

I_{trip} Tripping current

ΔCB Annual change in carbon stocks in biomass on land convertedto another land-use category.

ΔC_G Annual increase in carbon stocks in biomass due to growth on land converted to another land-use category (i.e., 2.25 metric tons C/hectare)

$C_{Conversion}$ Initial change in carbon stocks in biomass on land converted to another land-use category.

ΔC_L Annual decrease in biomass stocks due to losses from harvesting, fuel wood gathering, and disturbances on land converted to other land-use category (assumed to be zero)

$\Delta C_{Mineral}$ Annual change in carbon stocks in mineral soils

SOC_0 Soil organic carbon stock in last year of inventory time period (i.e., 40.83 mt/hectare)

$SOC_{(0-T)}$ Soil organic carbon stock at beginning of inventory time period (i.e., 62 mt C/hectare)

D Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values (i.e., 20 years for cropland systems)

LIST OF PUBLICATIONS

Journal Articles

[1] C. Y. Lau, **P. H. Tan**, C. K. Gan, , June 2014 "Evaluation of Solar Photovoltaic Levelized Cost of Energy For PV Grid Parity Analysis in Malaysia," International Journal of Renewable Energy Resources Vol 4, No. 1, pg. 28-34.

[2] N. M. Nawawi C.K. Gan, **P.H. Tan**, 2015. "Comparison of Different Options to Transport Energy in Photovoltaic Power Plant using Centralized Inverter," Applied Mechanics and Materials Vol. 785 pp.596-600.

Conference Proceedings

[3] C. K. Gan, **P. H. Tan**, and S. Khalid, 18-20 Nov 2013."System Performance Comparison between Crystalline and Thin-Film Technologies under Different Installation Conditions," 2013 IEEE Conference on Clean Energy and Technology, Langkawi, Malaysia.

[4] **P. H. Tan**, C. K. Gan,Dec 2013. "Methods of Lightning Protection for the PV Power Plant," IEEE Student Conference on Research & Development, Putrajaya, Malaysia.

[5] H. S. Liew, **P. H. Tan**, C. K. Gan, May 2014. "The Performances of UTeM Solar PV Systems: An Evaluation," The Power and Energy Conversion Symposium (PECS), Melaka, Malaysia.

[6] C. Y. Lau, **P. H. Tan**, C. K. Gan, May 2014. “PV Grid Parity Analysis for Residential Sector in Malaysia,” The Power and Energy Conversion Symposium (PECS), Melaka, Malaysia.

[7] **P. H. Tan**, C. K. Gan, K.A. Baharin, Nov 2014.“Techno-Economic Analysis of Rooftop PV System in UTeM, Malaysia,” 2013 IET Conference on Clean Energy and Technology, Kuching, Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Background

The Malaysian government is committed in the development of renewable energy with particular emphasis on solar Photovoltaic (PV). The Malaysia Renewable Energy (RE) Act 2011 was gazette in June 2011 with the introduction of the Feed-in Tariff (FiT) scheme (RE Act, 2011). Sustainable Energy Development Authority (SEDA Act, 2011) is then established to facilitate the development of RE in the country. Starting from 2013, 1.6% of the total electricity bills is collected from the consumers with monthly energy consumption exceeding 300kWh to support RE development under the FiT scheme. Amongst the RE technologies, the PV system received the most encouraging take up by the public and investors (SEDA, 2014). This is mainly driven by the FiT scheme for the Solar PV project to become economically attractive.

Researches on PV in Malaysia weremainly focusing on solar radiation prediction (K. Sopian, 1992; K.A. Baharin, 2013), PV module performance (N. Amin, 2009), cell materials (R. Daghigh, 2011) and inverter (N.A. Rahim, 2011). However, it is equally important to understand the cost and technical implication of PV installation in the Malaysian context. This is because technical implications and cost components of the PV system, as it will directly affect the investment return duration and the PV system performance. In addition,