Faculty of Electrical Engineering

PERFORMANCE AND DEGRADATION EVALUATION OF GRID-CONNECTED PHOTOVOLTAIC SYSTEMS AT UTeM

Hayder Salah Mohammed

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PERFORMANCE AND DEGRADATION EVALUATION OF GRID-CONNECTED PHOTOVOLTAIC SYSTEMS AT UTeM

HAYDER SALAH MOHAMMED

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DECLARATION

I declare that this dissertation entitle "Performance and Degradation Evaluation of Grid-Connected Photovoltaic Systems at UTeM" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ……..

Name : Hayder Salah Mohammed

Date : …….

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

Signature	:	…….
Supervisor Name	:	Associate Prof. DR. Gan Chin Kim
Date	:	…….

DEDICATION

To my family who has supported me significantly, a special feeling of gratitude to my great parents Salah Mohammed and Ahlam Ahmed who have supported me through my life. I will always appreciate their sacrifices for me. Their encouragement had a main role in achieving my goals and wishes throughout my career. I am extremely proud of them.

To my beloved country, Iraq, which has a special place in my heart.

ABSTRACT

Four grid-connected solar Photovoltaic (PV) systems were installed at Universiti Teknikal Malaysia Melaka (UTeM), namely Thin-Film (TF), Heterojunction with intrinsic thin layer (HIT), Poly crystalline, and Mono crystalline with the total capacity of 24 kW_p since October 2013. Hence, it is important to evaluate the performance and the degradation of UTeM's PV systems. In this regard, this research aims to evaluate the performance and the degradation of three of the four grid- connected PV systems located at UTeM, Melaka. The analysis presented in this study consists of the data recorded at 5 – minute intervals between January 2014 and December 2015. Meteorological parameters such as solar radiation and ambient temperature, module temperature, and solar generation were obtained from research laboratory of solar PV systems, smart grids, UTeM. The annual performance of the PV systems had been evaluated in terms of capacity factor, availability factor, reference yield, array yield, final yield, performance ratio, system losses, and array capture losses. The annual degradation rates of the PV systems were calculated using Power-Irradiance (P-G) technique. The average performance ratio of Thin-Film PV system for 2014 was 93.6% and 89.2% in 2015, while the average performance ratio of HIT PV system in 2014 was 85% and 82.3% in 2015, and the average performance ratio of Mono crystalline PV system in 2014 was 81.3% and 78.7% in 2015. The average degradation rates for two years of operation of Thin-Film, HIT, and Mono crystalline PV systems were 5.32%, 5.1%, and 3.65%, respectively. This study provides the insight for the system installer and investor in relation to the performance and degradation of various types of PV module technologies installed under Malaysia environment.

ABSTRAK

Empat sistem Photovoltaic (PV) sambungan grid telah dipasang di Universiti Teknikal Malaysia Melaka (UTeM), iaitu Thin-Film (TF), Heterojunction dengan lapisan nipis dalaman (Heterojunction with intrinsic thin layer/ HIT), Poly crystalline, dan Mono crystalline dengan jumlah kapasiti sebanyak 24kW$_p$, semenjak Oktober 2013. Maka, adalah penting untuk menilai prestasi dan tahap degradasi sistem PV UTeM ini. Dengan itu, kajian ini bermatlamat untuk menilai prestasi dan degradasi tiga daripada empat sistem PV sambungan grid yang terletak di UTeM, Melaka. Analisis yang dibentangkan dalam kajian ini merangkumi data yang direkod dengan jarakmasa 5 minit, di antara Januari 2014 dan Disember 2015. Parameter-parameter meteorological seperti pancaran solar dan suhu persekitaran, suhu modul, dan janaan solar adalah didapati dari makmal penyelidikan solar sistem dan, grid pintar, UTeM. Prestasi tahunan sistem PV ini telah dinilai dari aspek faktor kapasiti, faktor ketersediaan, hasil rujukan, hasil pelbagai, hasil akhir, nisbah prestasi, kehilangan sistem, dan pengambilan semula kehilangan pelbagai. Kadar degradasi tahunan sistem PV ini telah dikira menggunakan teknik Power-Irradiance (P-G). Purata nisbah prestasi sistem PV Thin-Film pada tahun 2014 adalah 93.6%, dan 89.2% pada tahun 2015, dan purata nisbah prestasi sistem PV HIT pada tahun 2014 adalah 85%, dan 82.3% pada tahun 2015, dan purata nisbah prestasi untuk sistem PV Monocrystalline pada tahun 2014 adalah 81.3%, dan 78.7% pada tahun 2015. Purata kadar degradasi selama dua tahun pengoperasian sistem PV Thin-Film, HIT dan Mono crystalline masing-masing adalah 5.32%, 5.1%, dan 3.65%. Kajian ini boleh menjadi rujukan kepada pemasang sistem dan para pelabur, berkenaan prestasi dan degradasi pelbagai jenis teknologi modul PV bersesuaian dengan persekitaran Malaysia.

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LIST OF ABBREVIATIONS

AC	Alternative Current
I_{sc}	Short Circuit Current
FF	Fill Factor
HIT	Heterojunction with Intrinsic Thin layer
TF	Thin-Film
NOCT	Nominal Operating Cell Temperature
PR	Performance Ratio
PV	Photovoltaic
DC	Direct Current
PID	Potential Induced Degradation
DNI	Direct Normal Irradiance
FKE	Fakulti Kejuruteraan Elektrik
IEC	International Energy Commission
R_D	Degradation Rate
CF	Capacity Factor
AF	Availability Factor
STC	Standard Test Conditions
UTeM	Universiti Teknikal Malaysia Melaka
RES	Renewable Energy System
BOS	Balance of System

AM	Air Mass
SEDA	Sustainable Energy Development Authority Malaysia
MPP	Maximum Power Point
Y_a	Array Yield
Y_r	Reference Yield
Y_f	Final Yield
L_s	System Losses
L_c	Array Capture Losses
G_{STC}	Total Solar Radiation under Standard Test Conditions
V_{oc}	Open Circuit Voltage

CHAPTER 1

INTRODUCTION

1.1 Research Background

In recent years, the side effects of traditional power resources have become more severe, affecting our lives. Depletion of natural sources, increasing CO_2 content ratio in the air and climate change have made the need for new alternative sources of power more urgent. Much attention is now focused on renewable energies such as solar and wind energy. The average solar radiation reaching the earth atmosphere is 1366 watts per meter square, and has an average total solar power of 173000 TW striking the earth. Since sunshine is scattered and reflected after penetrating the atmosphere, the average solar radiation on the sea level on a clear day is approximately 1000 watts per square meter (Wang & Zeng 2012). According to the consultation firm Enerdata, the world electricity consumption in 2013 was around 20000 TWh (Enerdata 2014). Approximately, 20000 TWh is needed to satisfy the global electricity demand; requiring 36.5 billion PV panels with 15% efficiency, and occupying a land area of approximately 20 million acre, based on the existing most efficient technology.

Solar power has significant features which make it attractive as research subject for alternative energy. Although the cost of installing solar power system is greater than that of traditional power plant, its operating and maintenance costs are much lesser, besides being environmentally friendly. As a result, many governments in the world have defined the exploitation of solar energy in a large scale, with the intention of identifying incentive program to guarantee continuous growth of solar power in their country. For example, solar

power production in Europe has gained more attention than in other countries. In 2007, the European Union set a target that 6% of the European Union electricity requirement will be produced using solar power by 2020, to meet the demand of 84.4 GW (Pearsall 2011). The most productive country of solar power is Germany, which produces a major portion of its energy demand using solar power, and already met 6% of electricity consumption in 2012. At certain hours in 2012, the solar power plants contributed 40% of the power demand in Germany. Germany now sets the target to reach the expected capacity of solar power in 2020 around 51.75 GW, meeting 7.4% of power needs (von Appen et al. 2013).

The peak electricity demand in west Malaysia is approximately 16562 MW, in which 45.5% of the total energy is generated by TNB using fuel gas, followed by coal at about 40.5%, and hydropower at around 11.7% and distillates 2.0% (Tenaga National Berhad 2016).

Recently, solar power is given more attention in Malaysia, which is evident from government subsidies and incentives dedicated to encourage PV installation. Malaysian government aimed for a significant step toward enhancing renewable energy in 2011, by issuing Renewable Energy Act 2011 (Tam 2013). The Sustainable Energy Development Authority Malaysia (SEDA) was established under this Act to promote, stimulate, facilitate and develop sustainable energy. Some recommendations have been introduced such as policies of laws, promoting sustainable energy by introducing Feed-in Tariff law, and carrying out related researches, assessments, and studies. At the end of 2012, the total renewable energy capacity connected to the Malaysian grid was 98.52 MW, in which 25 MW of them was produced by solar power (SEDA 2012). SEDA targets a total expected renewable energy (RE) capacity of 2080 MW by 2020; 175 MW of which shall be produced by solar power. The expected targets of Renewable Energy development in Malaysia by 2050 are shown in Figure 1.1.

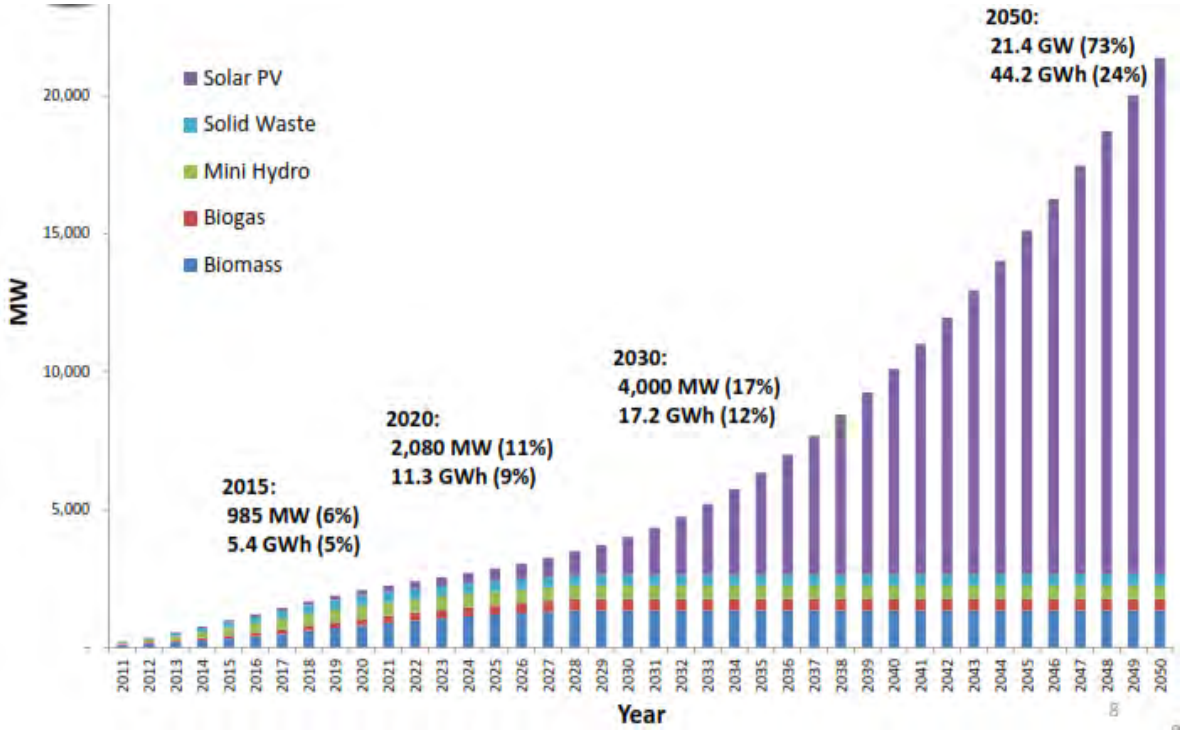

Figure 1.1: The expected target of Renewable Energy Development in Malaysia by 2050 (Chen 2012)

The PV applications can be generally divided into two categories: off-grid applications and grid-connected. Off-grid PV system is a system that is not connected with the utility grid, and it is considered a stand-alone system. This system normally contains storage unit to supply energy when needed, and it is used in small scale applications.

Grid-connected PV system is a system connected to the utility power grid, and it supplies the power directly into the grid, thus any onsite load is fed by combination of power generated by the PV system and power by the grid utility. Grid-connected system does not require storage unit because there is no extra power after feeding the public grid (Kumi & Brew-Hammond 2013). Grid-connected PV systems currently dominate the PV market, especially in Europe, Japan and USA. For example, in 2000, 90% of the cumulative installed PV capacity was connected to the grid, but by the end of 2013, this percentage increased to