UNIVERSITI PUTRA MALAYSIA

ELECTRICAL PERFORMANCE OF MONOCRYSTALLINE AND POLYCRYSTALLINE PHOTOVOLTAIC PANELS UNDER LIGHTNING IMPULSE VOLTAGE CONDITION

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By

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Faculty: Engineering

Photovoltaic (PV), directly converts light from the sun into electricity and widely used in countries with high irradiation such as Malaysia. However, Malaysia is also recognised as a country prone area with lightning occurrences. Sustainable Energy Development Authority of Malaysia (SEDA) has received several complaints on damaged components and distribution boards of PV system installations and the chances of lightning strikes causing damage can be somewhat high since life span of PV systems could achieved up to 21 years or more. Therefore, this research aims to investigate the effect of lightning impulse voltage for monocrystalline and polycrystalline PV panels, the effect of temperature on the faulty PV panels and the estimation of the reduction factors of the PV panels.

In this research, there are twelve PV panels in total, six monocrystalline and polycrystalline PV panels each. A PV panel was selected from each type and labelled as healthy to be the base PV panels whilst the other five PV panels of each type were taken for the lightning impulse voltage test of 100 kV, 150 kV, 200 kV, 250 kV and 300 kV each, and all are labelled as faulty. The efficiency of the PV panels were analysed through the laboratory testing for open-circuit voltage, short-circuit current, and maximum power.

The findings indicated that the maximum power of healthy polycrystalline PV panel has affected about 2.88% (at 25°C) and 11.07% (up to 70°C) which is higher than healthy monocrystalline PV panel which only 1.84% (at 25°C) and 10.19% (up to 70°C). When the lightning impulse voltage is increased from 100 kV to 300 kV, the open circuit voltage and maximum power output gradually decreases for both types of PV panels demonstrating a non-linear trend for both. The percentage difference of maximum power for faulty monocrystalline is increased from 8.08% to 36.22% and for faulty polycrystalline it is increased from 0.77 % to 10.22%. Then, both types of faulty PV panels were taken for different temperature testings and the maximum power of the faulty PV panels is gradually reduced. For 300 kV (up to 70°C), the percentage difference is reduced from 9.84% to 7.11% for faulty polycrystalline PV panels. Whilst

for faulty monocrystalline it is 36.22% to 32.66%, at the same trend, which the temperature affects the maximum power of both types of faulty PV panels.

It was found that both healthy and faulty monocrystalline PV panels indicate the percentage difference more than 5% as stated in IEC 61215. This shown that the faulty polycrystalline PV panels performed better compared to the faulty monocrystalline PV panels. Overall, the higher the voltage stress, the degradation became severe and it becomes more serious as the faulty PV panels were exposed under high temperature. Thus, several proper forms of lightning protection system and planning for installation locations are able to be proposed in order to avoid excessive heat. Indirectly, it will reduce the cost by not having to repair the damage caused by lightning strikes as well as succeeding in investment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PRESTASI ELEKTRIK FOTOVOLTAIK PANEL MONOHABLUR DAN POLIHABLUR DIBAWAH DEDENYUT VOLTAN KILAT

Oleh

NOR IZZATI AHMAD

Disember 2016

Pengerusi: Mohd. Zainal Abidin B. Ab. Kadir, PhD
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Fotovoltaik (PV); terus menukarkan cahaya matahari kepada elektrik dan digunakan secara meluas di negara yang mempunyai penyinaran tinggi seperti Malaysia. Walau bagaimanapun, Malaysia juga diiktiraf sebagai kawasan terdedah negara dengan kejadian kilat. Lestari Pihak Berkuasa Pembangunan Tenaga Malaysia (SEDA) telah menerima beberapa aduan mengenai komponen rosak dan papan agihan pemasangan sistem PV dan peluang untuk kilat menyebabkan kerosakan boleh agak tinggi kerana jangka hayat sistem PV boleh mencapai sehingga lebih 21 tahun. Oleh itu, kajian ini bertujuan untuk mengkaji kesan kilat voltan dedenyut untuk panel monokristal dan polihabluran PV, kesan suhu ke atas panel PV rosak dan anggaran faktor pengurangan.

Terdapat dua belas panel PV dalam jumlah; enam panel PV monokristal dan polihabluran setiap satu. Satu panel PV telah dipilih dari setiap jenis dan dilabelkan sebagai sihat untuk menjadi panel asas PV manakala panel PV lain telah diambil untuk ujian kilat dorongan voltan 100 kV, 150 kV, 200 kV, 250 kV dan 300 kV setiap satu, dan semua dilabel sebagai rosak. Kecekapan panel PV dianalisis melalui ujian makmal untuk voltan litar terbuka, litar pintas semasa, dan kuasa maksimum.

Dapatan kajian menunjukkan bahawa kuasa maksimum polihabluran sihat telah memberi kesan kepada kira-kira 2.88% (pada 25°C) dan 11.07% (sehingga 70°C) daripada monoberhablur sihat yang hanya 1.84% (pada 25°C) dan 10.19% (sehingga 70°C). Apabila voltan kilat dorongan dinaikkan daripada 100 kV hingga 300 kV, voltan litar terbuka dan kuasa maksimum secara beransur-ansur berkurangan bagi kedua-dua jenis panel PV menunjukkan trend bukan linear untuk kedua-duanya. Perbezaan peratusan kuasa maksimum untuk monokristal rosak dinaikkan daripada 8.08% kepada 36.22% dan untuk polihabluran rosak ia meningkat daripada 0.77% kepada 10.22%. Kemudian, kedua jenis panel PV rosak telah diambil untuk ujian suhu yang berbeza dan kuasa maksimum panel PV rosak secara beransur-ansur dikurangkan. Untuk 300 kV (sehingga 70°C), perbezaan peratusan berkurangan daripada 9.84% kepada 7.11% bagi panel polihabluran PV yang rosak. Manakala bagi monokristal rosak adalah 36.22% kepada 32.66%, pada trend yang sama, bahawa suhu memberi kesan kuasa maksimum kedua jenis panel PV rosak.

Ia telah mendapati bahawa kedua panel PV monokristal sihat dan rosak menunjukkan perbezaan peratusan lebih daripada 5% sebagaimana di IEC 61215. Ini menunjukkan bahawa yang rosak panel polihabluran PV mencatatkan prestasi berbanding dengan panel PV monocrystalline rosak. Secara keseluruhan, semakin tinggi tekanan voltan, kemerosotan menjadi teruk dan ia menjadi lebih serius kerana panel PV rosak telah terdedah di bawah suhu yang tinggi. Oleh itu, beberapa sistem perlindungan kilat yang betul dan perancangan untuk lokasi pemasangan dapat dicadangkan bagi mengelakkan haba yang berlebihan. Dengan meningkatkan perlindungan sistem PV, secara tidak langsung mengurangkan kos dengan tidak perlu untuk membaiki kerosakan yang disebabkan oleh kilat dan berjaya dalam pelaburan.

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

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LIST OF ABBREVIATIONS

AC	Alternating current
AM	Air mass
DC	Direct current
FiT	Feed-In Tariff
I-V	Current-Voltage
IEC	International Electrotechnical Commission
kV	Kilo Voltage
LPMS	Lightning protection measure system
LCD	Liquid crystal display
MS	Malaysian Standard
PV	Photovoltaic
RE	Renewable energy
ROI	Return of investment
SPD	Surge protection device
SEDA	Sustainable Energy Development Authority Malaysia
STC	Standard Test Condition
TNB	Tenaga Nasional Berhad
UV	Ultra-violet

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LIST OF SYMBOLS

A	Area at working plane height
D	Diffusivity of the minority carrier
d	Diameter
E	Illuminance level required
F	Average luminous flux
H	Height
H_m	Mounting height
I_{sc}	Short Circuit Current
I_o	Reverse saturation current
I_{mp}	Maximum power current
K	Room index
L	Length
MF	Maintenance factor
N	Number of lamps
N_i	Intrinsic carrier concentration
N_D	Doping
P_{max}	Maximum power
q	Electronic charge
S	Distance
UF	Utilisation factor
V_{mp}	Maximum power voltage
V_{oc}	Open Circuit Voltage
V_{ref}	Reference temperature
W	Width
η	Efficiency

CHAPTER 1

INTRODUCTION

1.1 Research Overview

At present, solar energy is the most promising source of renewable energy (RE) [1, 2]. Photovoltaic (PV) technology directly converts sunlight into electricity through a solar cell which is usually mounted on the surface of a rooftop, facades, and generally in open areas [3]. It comprise several benefits such as economic advantages, it is clean and unobtrusive, environmentally friendly and require less maintenance [4]. PV systems are regarded as one of the best RE sources in terms of cost of installation, return of investment (ROI), incentive and benefit to the end users.

Malaysia as a tropical country enjoys abundant sunshine and solar radiation, as well as receives at least 6 hours of sunshine per day which enable a high potential to generate electricity by employing PV systems [5-8]. There is a statutory body formed under the Sustainable Energy Development Authority Act 2011 known as Sustainable Energy Development Authority of Malaysia (SEDA) [9]. Feed-in Tariff (FiT) system also has been implemented through SEDA where it would ensure RE to became practice as it can be a long-term investment in industries and also for individuals since it is guaranteeing access to the grid and setting a favourable price per unit of RE. Throughout this system, it would fulfil the RE policy where it would enhance the application of RE resources by contributing towards national electricity supply security and sustainable socioeconomic development.

However, since Malaysia is located in a region of high lightning density, lightning frequently occurs and can lead to severe damage to electrical systems including cause failure on power lines, substations and power outages to the customers[10]. Statistically, lightning cause the damage on power system distribution is about 35% where it is the major contributor whilst about 32% of damage cause by surge overvoltage to electronic devices [11].

SEDA also has received several complaints on damaged components and distribution boards of PV system installations where the main reason is due to the lack of knowledge and exposure on the necessity of protection of PV systems against lightning. However, the subject of lightning protection itself is wide and has to be understood through experience and exposure.

In fact, the chances of lightning strikes and surge overvoltage disturbance causing damage can be somewhat high due to life span of PV systems normally can be achieved up to 21 years or more. Therefore, a guideline covering lightning protection for PV systems is highly needed which will help to ensure in maintaining and prolong the life span of PV systems due to safety aspect.

1.2 Problem Statement

Lightning has potential in affecting the whole of PV system, by both direct and indirect strikes, and other surge overvoltage. Due to fully exposure to lightning strike, it can lead to malfunction or destruction of PV panels. Direct strikes would destroy PV panels, inverters, cables, and fuses. Indirect strikes would induce high voltages into the system and subsequently affect the conductors, PV panels and other components, eventually emit spark that could kindle inflammable material. Various studies to investigate direct lightning strikes on a PV panel have been carried out by considering [12-15];

1. The spark-over characteristics between a rod and a PV panel where direct lightning strike was applied to a PV panel.

2. The effect of lightning impulse voltages to the polycrystalline PV panel with considering the aging effect as well.

3. The effect of lightning impulse voltage with relatively lower magnitude to the polycrystalline PV panel.

However, considering on the previous studies [12, 14-19] there is still lacking as;

1. There is no significant study has been done on the effect of lightning impulse voltage for both monocrystalline and polycrystalline PV panels.

2. There is no significant study has been done on the effect of temperature on the damaged PV panels due to a lightning impulse voltage.

3. There is no significant study has been done on the estimation of the reduction factors. Several electrical parameters such as maximum power, short circuit current and open circuit voltage under different value of impulse voltages and temperature also need to be considered thoroughly for evaluation of the performance of a PV panel.

Consequently, the benefits of this study can form part of the requirement for PV installation and also to improve the existing standards which are IEC 62305 and MS 1837.

1.3 Research Aim and Objectives

This proposed project aims to investigate the performance of PV panels under lightning impulse voltage conditions, with consideration of other important conditions such as temperature and irradiance with regard to the electrical performance of a PV panel. The objectives of this research are:

1. To investigate the effect of lightning impulse voltage on the electrical performance of monocrystalline and polycrystalline PV panels.
2. To determine the effect of temperature on the electrical performance of damaged PV panels due to a lightning impulse voltage.
3. To estimate the reduction factors for both monocrystalline and polycrystalline PV panels parameters.

1.4 Scope and Limitations of Work

The scope and limitations of this research work are:

1. This research focuses on the effect of a lightning impulse voltage on the electrical performance of monocrystalline and polycrystalline PV panels.
2. This research considers only on positive impulse voltage on the electrical performance of monocrystalline and polycrystalline PV panels.
3. This research only focuses on analysing the electrical performance of monocrystalline and polycrystalline PV panels without considering the load.
4. This research assumes there is no insulation part (tempered glass) of monocrystalline and polycrystalline PV panels as our focus is only on electrical performance of solar cell itself.
5. Both the irradiance and temperature under this laboratory work are produced by a set of lamp in the PV panel tester.

1.5 Contribution of the Research

In this research, there are several contributions which are:

1. The benefits of this study can form part of the requirement for PV installation and also to improve the existing standards which are IEC 62305 and MS 1837.
2. Technically, it could assist designers to generate an idea to improve the protection of PV systems against lightning strikes by observing a correlation between the isolated and non-isolated LPS to select suitable surge protection elements.
3. By improving the protection of the system, indirectly reduce the cost by not having to repair the damage caused by lightning strikes as well as succeeding in investment.

1.6 Thesis Outline

This thesis consists of five chapters, which cover the introduction, literature review, methodology, results and discussion and finally conclusions and recommendations for future study.

This thesis starts with Chapter 1 which presents a general introduction to the subject and the problem statement. It also introduces the aims, objectives, scope and limitation of work, the contribution of the study and a brief summary of the structure of the thesis.

Chapter 2 provides a literature review of related fields to this study, which includes an overview of a PV and its characteristics. It also includes the lightning phenomenon and its effects and the necessity for lightning protection.

Chapter 3 describes the research methodology that is carried out to achieve the objectives. This consists of research flow charts, the specifications of the PV panel, construction of a PV panel tester, experimental setup and the selection of the equipment for data collection.

Chapter 4 presents the results, discussion and the comparison of the results by conducting laboratory tests to validate the proposed method which displays the efficiency of the PV panels.

Chapter 5 concludes the conclusion of this project and presents suggestions for future study.

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LIST OF PUBLICATIONS

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