UNIVERSITI PUTRA MALAYSIA

LIGHTNING PERFORMANCE ANALYSIS OF A ROOFTOP GRID-CONNECTED SOLAR PHOTOVOLTAIC WITHOUT EXTERNAL LIGHTNING PROTECTION SYSTEM

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FK 2019 60

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

November 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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The Sustainable Energy Development Authority of Malaysia (SEDA) received complaints on damaged components and distribution boards of PV systems due to lightning strikes. Permanent and momentary interruptions on distribution circuits may also occur from the disturbance. In this research, a solar PV Rooftop system (3.91 kWp) given by SEDA is modelled in the PSCAD/EMTDC. The Heidler function is used as lightning current waveform model to analyse the transient current and voltage at two different points under the influence of lightning events. These include different lightning current waveshape, standard lightning current and non-standard lightning current. The effect of the system components when lightning direct strikes at two different points of the installation are examined in this study. The two points lies between the inverter and the solar PV array and between inverter and grid. Extremely high current and voltage due to the direct lightning strike on a certain point at PV Rooftop system are also studied. The results of this case study are observed with the inclusion of surge protective devices (SPDs) and without SPDs. The parameters used were 31 kA peak current, 10 meters length of cable and the lightning impulse current waveshape of 8/20µs. The high current and voltage at P1 striking point are 31 kA and 2397 kV, respectively. As for the AC part, the current and voltage values were found to be 5.97 kA and 5392 kV, respectively. Therefore, SPD with suitable rating provided by SEDA were deployed. Results show that high transient current voltage is expected to clamp sharply at the values of 1.915 kV and 0 A at the P1 striking point. As for the AC part, the current and voltage values were found to be 0 kA and 0.751 V, respectively. Varying lightning impulse current waveshapes at striking point P2 showed that the highest voltage was obtained at waveshape 10/350 µsat 11277 kV followed by waveshapes of 2/70 µs, 8/20 µs and 0.7/6 µs. The high value of transient voltage was clamped at a lower level of 2.029 kV. Different lightning amplitudes were also applied, ranging from 2 – 200 kA selected based on the CIGRE distribution. It shows that the current and voltage at P1 and P2 are directly proportional. Therefore, the SPD will be designed at an acceptable rating and proper position of SPD installation at solar PV Rooftop will be proposed. The results obtained in this study can then be utilized to

appropriately assign a SPD to protect the PV systems that are connected to the grid. If SPDs are installed without consideration of the concept of lightning protection zones, the equipment to be protected are prone to damage despite the correct energy coordination of SPDs. Therefore, the simulation results serve as a basis for controlling the effects of lightning direct strikes on electrical equipment and power grids. Then provide proper justification on SPD coordination in ensuring the reliability of the system.

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

ANALISIS PRESTASI KILAT SOLAR FOTOVOLTAIK ATAS BUMBUNG GRID-SAMBUNGAN TANPA SISTEM PERLINDUNGAN LUARAN

Oleh

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SEDA menerima aduan mengenai komponen rosak dan papan pengedaran sistem PV akibat serangan kilat. Gangguan tetap dan seketika pada litar pengedaran juga boleh berlaku dari gangguan tersebut. Dalam kajian ini, sistem solar fotovoltaik atas bumbung (3.91 kWp) yang diberikan oleh SEDA dimodelkan dalam PSCAD / EMTDC. Fungsi Heidler digunakan sebagai model gelombang kilat untuk menganalisis arus dan voltan pada dua titik yang berbeza di bawah pengaruh situasi kilat. Ini termasuk gelombang arus kilat yang berbeza, gelombang kilat mengikut piawai dan arus kilat bukan mengikut piawai. Kesan komponen sistem apabila kilat menyambar pada dua titik berbeza pemasangan diperiksa dalam kajian ini. Dua titik terletak di antara: sumber dan inverter solar fotovoltaik dan antara inverter dan sumber kuasa. Arus dan voltan yang sangat tinggi disebabkan oleh kilat pada titik tertentu di sistem solar fotovoltaik atas bumbung juga dikaji. Hasil kajian kes ini diperhatikan dengan kemasukan alat perlindungan lonjakan (SPD) dan tanpa SPD. Parameter yang digunakan ialah 31 kA arus puncak, 10 meter panjang kabel dan gelombang kilat 8 / 20μs. Arus dan voltan tinggi pada titik P1 ialah 31 kA dan 2397 kV. Bagi bahagian AC, nilai arus dan voltan didapati 5.97 kA dan 5392 kV. Oleh itu, SPD dengan rating yang sesuai yang diberikan oleh SEDA telah digunakan. Keputusan menunjukkan bahawa voltan dan arus yang tinggi dijangka turun dengan ketara pada nilai 1.915 kV dan 0 A pada titik P1. Bagi bahagian AC, nilai semasa dan voltan didapati masing-masing 0 kA dan 0.751 V. Untuk gelombang kilat yang berbeza, titik pada P2 menunjukkan bahawa voltan tertinggi diperolehi di gelombang 10/350 μs iaitu 11277 kV diikuti oleh gelombang 2/70 μs, 8/20 μs dan 0.7 / 6 μs. Nilai voltan yang tinggi ditunkan pada tahap yang lebih rendah iaitu 2.029 kV. Amplitud kilat yang berbeza juga digunakan, dari 2 - 200 kA dipilih berdasarkan taburan CIGRE. Ia menunjukkan bahawa arus dan voltan pada P1 dan P2 adalah berkadar terus. Oleh itu, SPD akan direka bentuk pada kedudukan yang boleh diterima dan kedudukan pemasangan SPD yang sesuai di solar fotovoltaik atas bumbung akan dicadangkan. Keputusan yang diperolehi dalam kajian ini boleh digunakan untuk memberikan pengunaan SPD secara tepat untuk melindungi sistem PV yang disambungkan ke sumber kuasa. Sekiranya SPD dipasang tanpa mengambil kira konsep zon perlindungan kilat, peralatan yang

dilindungi adalah mudah rosak walaupun koordinasi tenaga SPD yang betul. Oleh itu, keputusan simulasi berfungsi sebagai asas untuk mengawal kesan pancaran kilat pada peralatan elektrik dan sumberkuasa. Kemudian, memberikan justifikasi yang betul mengenai koordinasi SPD dalam memastikan kebolehpercayaan sistem.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere and firm gratitude to honourable supervisor, Prof. Ir. Dr. Mohd. Zainal Abidin Ab Kadir for his great effort in guiding me towards successfully accomplishing this project. My grateful thanks to his moral support, technical and financial assistance as well. My full appreciation also goes to my co-supervisors Dr. Mahdi Izadi and Assoc. Prof. Dr. Mohd Amran Mohd. Radzi for their guiding the steps and ideas, patience, encouragements, and supports in many ways. In addition, a great deal, appreciated goes to all staffs and colleagues from the Center of Electromagnetic and Lightning Protection Research (CELP) and Department of Electrical and Electronic Engineering for all their support during my work. I owe thanks to my wife, Nur Alia Farina and my son, Iman Ar-Rayyan for their understanding and unconditional support during my pursuit of Master Degree. Last but not least, I would like to dedicate many thanks and love to my parents, Mohd Nasir Bin Hamid Saltan and Norsiah Binti Othman for their supporting and encouraging in moral and spiritual support from time to time which has motivated me to complete my Master degree.

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
BEEP	Building Energy Efficiency Programme
Biogen	Biomass Grid-Connected Power Generation and Co-Generation
DC	Direct current
FiT	Feed-in Tariff
GBI	Green Building Index
IEC	International Electrotechnical Commission
LV	Low voltage
LPS	Lightning Protection System
MIEEIP	Malaysian Industrial Energy Efficiency Improvement Project
MBIPV	Malaysia Building Integrated Photovoltaic
MPPT	Maximum Power Point Tracking
PV	Photovoltaic
PURPA	Public Utilities Regulatory Ac
RE	Renewable Energy
SPD	Surge Protection Device
SEDA	Sustainable Energy Development Authority Malaysia
SREPP	Small Renewable Energy Power Programme
TNB	Tenaga Nasional Berhad

LIST OF SYMBOLS

Uc	Maximum Continuous Operating Voltage
Up	Voltage protection level at In
I_n	Nominal Discharge Current
I_{imp}	Impulse current
I_p	Peak Current
α	Constants obtain lightning current waveform
β	Constants obtain lightning current waveform
$i(t)$	Impulse waveform for double exponential
η	current peak correction factor
τ_1	Time Constant to determine current rising
τ_2	Time Constant to determine current decay
U_{10}	Discharge voltage at 10 kA

CHAPTER 1

INTRODUCTION

1.1 Research Overview

Rapid growth for the energy developments and demands in renewable energy show that the implementation of renewable energy is vastly expanding. Compared to the other kinds of renewable energy, solar energy is prominently; an infinite resource; natural; ecological; friendly; and economical [1-3]. The amount of solar energy potential is considerably greater than the current worldwide energy demands. Solar energy has been developing more rapidly than the other renewable energy sources for the last few decades. The photovoltaic (PV) systems are used to convert the power of the sun from sunlight energy to electrical energy [1]. By the use In the future, solar power generation is crucial for a sustainable kind of energy. Moreover, solar irradiation is so abundant that the electricity demands of the world can be provided to a large extent by solar power technologies. The experts predict that by the year 2050, renewable energy could be generated over 50% of all the supply and 80% of all electricity system would come from it [2]. Therefore, the Malaysian government is keen to develop solar energy in the country as one of the important sources of energy [3].

The Sustainable Energy Development Authority Malaysia (SEDA) is a statutory body that was formed under the Sustainable Energy Development Authority Act 2011. This body was formed in order to ensure the effectiveness of growth for the RE sector in Malaysia. SEDA's role is to manage the implementation of Fit-in tariff (Fit) mechanism. Moreover, SEDA must ensure that sustainable energy are managed properly and part of important role in the development of nation's economic. The plan of FiT started by the Malaysian government under National Renewable Energy Policy and Action Plan (2010) facilitates the smoothness of RE contribution and fund besides ensuring the growth of the RE industry. Therefore, there was gazette on 2nd June 2011 by Renewable Energy Act 2011 that was published for this purpose [4].

Lightning is a major problem faced by TNB in Malaysia. Statistically in Malaysia, lightning causes over 70% of power failures. In Germany, statistical data shows 26% of the damages are caused by the lightning. It may cause permanent and momentary interruptions on distribution circuits. The rapid increase of sensitive loads, momentary interruptions is not acceptable and is a serious concern. Lightning can cause damage or malfunctioning of the electrical, communication or automation systems that approximately costs more than 250 million [4,5].

Photovoltaic (PV) systems are normally installed in wide open outdoor places such as on the rooftop or solar farm. This leaves the electrical or electronic equipment exposed to lightning strikes nearby. The operation of the electrical or electronic equipment power system placed outside or inside the building can be interrupted. The economical side of the power system operation would also be affected by this. Hence, a complete lightning protection in PV installation is very crucial and practically required in order to avoid the interruption of the system. Destruction as well as faults that could be lead to casualties can be avoided too [2,6].

1.2 Problem Statement

Direct and indirect lightning strikes have large potential in affecting the whole of a PV Rooftop system. The nature of its installation on rooftops, makes the panels easily exposed to a direct hit. The situation is made even worse if the installation was made in a high lightning density area. This will result in malfunction or destruction of the PV Rooftop system if it is drastically affected by lightning. Direct strikes can destroy PV panels, inverters, cables, and fuses due to its high current. On the other hand, indirect strikes would induce high voltages into the system. Subsequently, the conductors, PV panels and other components are affected. This will eventually emit sparks that would cause fire and explosion to the inflammable materials of the system. A sensitivity analysis is to for the development of lightning overvoltage in a Rooftop PV system, taking into consideration the effect of lightning striking spot, the lightning current amplitude, the building height, the soil resistivity and the distance between the solar arrays and the external protection system [1]. The PV Rooftop system is commonly located in high rise buildings which makes it very prone to lightning strike [7]. As far as Malaysia is concerned, there are no standards available on lightning protection for PV system, except for MS 1837:2010 which focuses on the PV installation. Thus; there were no studies imposed on lightning surge analysis prior to the solar PV installation for residentials, commercial buildings or solar farms.

There is no circuit model or test system for PV Rooftop system dedicated to lightning surge studies, especially in the aspects of: SPD placement; selections of suitable ratings; cable length and sizing; and number of SPDs required. Direct strikes may trigger fires and even explosion to the PV Rooftop system. In the case of indirect strikes, induced overvoltages may result in outages of the electrical and electronic components inside the building

Most of PV Rooftop systems installations are not properly protected from lightning especially when it comes to SPD installation, where no mandatory requirements are imposed. Thus, many concerns are raised on the safety and protection of the inverter. On the other hand, PV Rooftop systems may suffer from severe damage that comes from failure of the electrical and electronic parts at PV Rooftop system, interrupting their normal operation procedures. Therefore, it is clear that lightning protection system installation is crucial in determining the lifespan of a PV Rooftop system [6].

1.3 Research Aim and Objectives

This proposed project aims to investigate the performance of PV system under lightning impulse voltage conditions, with consideration of various conditions regarding the electrical performance of a PV system. The objectives of this research are:

1. To develop a model of PV Rooftop System by using the PSCAD/EMTDC software.
2. To investigate the effect of lightning impulse voltage and current on the electrical performance of PV Rooftop system under several design parameters.
3. To evaluate the effect of Surge Protection Device (SPD) placement on PV Rooftop Installation with special attention to the inverter protection.

1.4 Scope and Limitations of Work

The scope and limitations of this research work are:

1. The effect of a lightning impulse voltage and current on the electrical performance of PV Rooftop system
2. Analysing the electrical performance of Surge Protection Device (SPD) placement on PV Rooftop Installation with special attention to the inverter protection.
3. The PV Rooftop system section where acts as a distribution system.

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 improve the existing standards which are the IEC 62305 and MS 1837.
2. Technically, the findings of this study 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, this indirectly reduces the cost by not having to repair the damage caused by lightning strikes as well as succeeding in the long-term investment.

1.6 Thesis Outline

This thesis consists of five chapters: introduction; literature review; methodology; results and discussion; and conclusions and recommendations for future study.

Chapter 1 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 necessities for lightning protection.

Chapter 3 describes the research methodology that is carried out to achieve the objectives. This consists: research flow charts; the specifications of the PV system; and simulation of the model by using PSCAD software to search for an appropriate model by simulating different parameters to choose the most suitable arrangement. The optimal placement of SPD is also considered in this chapter.

Chapter 4 presents the results, discussion and the comparison of the results obtained from the analysis.

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

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LIST OF PUBLICATIONS

Journals

N. I. Ahmad, M. Z. A. AbKadir, M. Izadi, N. H. Zaini, M. M. Radzi, N. Azis and **M.S.M. Nasir**, "Lightning Protection on Photovoltaic Systems: A Review on Current and Recommended Practices," *Renewable and Sustainable Energy Reviews,* 2016. **(Accepted-In press) (Co-Author)**

Nur hazirahZaini, Mohd Zainal Abidin Ab. Kadir, Mohd Amran Mohd Radzi, Mahdi Izadi, Norhafiz Azis, Nor Izzati Ahmad and **Mohd Solehin Mohd Nasir**, "Lightning Surge Analysis on a Large Scale Grid-Connected Solar Photovoltaic System," *Energies*, 2017.**(Accepted – In press)(Co-Author)**

Conference Proceeding

N. H. Zaini, M. Z. A. AbKadir, M. M. Radzi, M. Izadi, N. I. Ahmad, and N. Azis,**M.S.M.Nasir** "On the Effect of Surge Protection Devices (SPDs) Placement for Grid-connected Solar PV Farm," *International Conference on Lightning Protection (ICLP)*, 2018. **(Accepted and to be Presented)(Co-Author)**

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