International Journal of Environmental Sciences
Vol. 6 No. 1 (January-June, 2020)

Received: 22nd October 2019 Revised: 24th November 2019 Accepted: 10th November 2019

Performance Evaluation of Solar Modules using Lucas-Nülle Emulator

EMIRUL AKBAR BIN SHA'ARI, R.T. NAAYAGI
Department of Electrical and Electronic Engineering
Newcastle University in Singapore
172A Ang Mo Kio Avenue 8, SIT@ NYP Building
SINGAPORE
naayagi.ramasamy@ncl.ac.uk,
https://www.ncl.ac.uk/singapore/about/staff/profile/naayagiramasamy.html#background

Abstract: - This paper investigates the performance of solar modules using the photovoltaic systems equipment Lucas-Nülle to perform solar module simulations. These simulations include the arrangement of solar modules in series and parallel combinations, analysing the performance by varying the irradiance and evaluate the effect of shading on the modules' output.

Key-Words: - Solar modules, Photovoltaic system, irradiance, shading, series and parallel, Lucas-Nülle emulator

1 Introduction

Today, conventional sources of energy such as fossil fuels and natural gas face several problems. The more prominent ones are limited supply and negative impacts on the environment. These sources pale in comparison to the sun because of its seemingly unlimited availability and "clean" nature. This has sparked the increasing interest in photovoltaics as a promising alternative to meet the increasing energy demand while reducing emissions that contribute to climate change.

Photovoltaic (PV) cells in a solar module are made of light-sensitive semiconductors that produce electricity via the photovoltaic effect i.e. the phenomenon of producing an electrical voltage in the presence of light. The amount of electricity produced is determined by the efficiency of the PV cells which in turn affects the performance of the entire module. PV technology is costly to install and have low energy conversion but due to improvements in mass production techniques and research to improve solar cell efficiency, solar energy has become a strong competitor in the energy sector [1].

In today's solar energy market, there are many types of PV modules readily available for purchase and installation. The amount of power produced by a solar module is heavily reliant on the efficiency of its solar cells. Different types of solar cells have different efficiencies. Monocrystalline silicon cells, easily distinguished by its dark uniform colour, have high efficiencies of 20% and above with the highest recorded lab efficiency of 26.7% [2]. This high efficiency is due to its fabrication process from extremely pure high-grade silicon which also causes it to have a long life. Compared to other types of solar panels with the same power rating, monocrystalline solar panels are smaller in size making them space-efficient. Applications can vary from large-scale solar installations to powering satellites. Polycrystalline silicon cells, unlike monocrystalline cells, do not have a uniform appearance and have lower efficiencies of 13%-16% with the highest in a lab of 22.3% [2]. Unlike monocrystalline cells, these are made by melting lower-grade silicon and poured into a wafer mould. The use of lower-grade silicon and almost no-waste manufacturing process make polycrystalline modules more cost-effective with a small efficiency drop. Thin-film solar cell technology is made up of several different types of PV cell technologies. The main similarity is that they are typically produced by applying thin layers of different semiconductor materials on top of one another. The efficiencies vary with the different types with the Gallium Arsenide (GaAs) cell being the highest out of all single-junction PV technologies with 28.8% lab efficiency. Other common thin-film technologies include Copper Indium Gallium Selenide (CIGS) at 21.7%, Cadmium Telluride (CdTe) at 21.0%, amorphous silicon (a-Si) at 10.2% [5]. Thin-film technology is a relatively new form of PV technology but is rapidly growing due to its low manufacturing cost and versatile applications. Thin film cells can be made flexible and transparent which open more possible applications. Furthermore, shading on cells and operation at high temperatures only have minor effect on the performance.

PV systems are usually classified into 2 types: stand-alone or grid-tied. A stand-alone, or off-grid, PV system usually includes a storage device, solar charge controller and an inverter in the system.

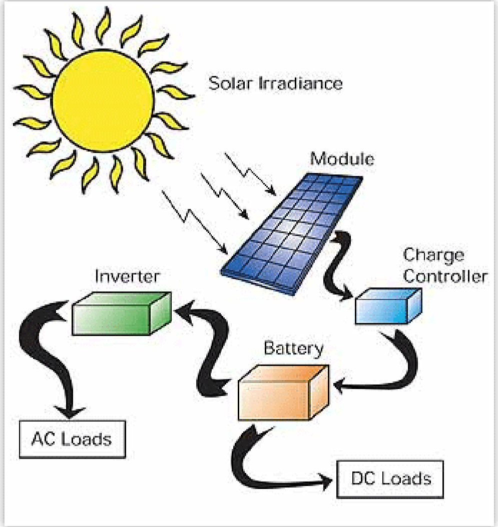

Fig. 1 Illustration of stand-alone PV system

As illustrated from Figure 1, the solar charge controller (SCC) is connected to the solar modules and a storage device such as a battery. A SCC is an electrical component that contains a program for maximum power point tracking (MPPT) is a major component in PV systems. It maintains the accurate charging voltage on the batteries and prevents it from damage due to over-charging or deep-discharging [3] [4]. The DC power is then converted to AC via an inverter for AC loads. As the name suggests, a grid-tied PV system is connected to the grid. A grid-connected system is like a stand-alone system except that grid-connected systems hardly includes a storage device. The main advantage of domestic users with grid-tied PV systems is that the excess electricity generated by the PV modules can be sold to the local electrical supplier. Other advantages include readily-available electricity and ease of installation compared to a stand-alone system [5].

In a PV system, there are additional factors that affect the performance such as the environment (incident irradiance, shading, etc) [6] [7] and system limitations (inverter efficiency, wiring losses, etc). Physical testing of a system may be costly, time-consuming and environmental conditions are uncontrollable [8][9][10]. Therefore, by using simulations, it is possible to evaluate the performance of a system by simulating ideal conditions and eliminating undesirable ones.

This paper presents the performance evaluation of solar modules present in the Lucas Nülle photovoltaic system emulator. Performance of solar modules in series and parallel configuration under different irradiances is evaluated. Also, the effect of shading in solar modules is discussed.

2 Lucas-Nülle Photovoltaic System Emulator

The Lucas-Nülle photovoltaic systems emulator shown in Figure 2 consists of various sub system equipment and can be connected to single and three phase mains. This provides a broad scope of possible simulations that may be conducted.

Solar module simulation CO3208-1A consists of 3 separate solar modules, each with adjustable irradiance and integrated voltage and current displays. Each module also has a bypass diode and a port for additional external solar module is available. Each module is rated at Open-circuit voltage approximately 23V and short-circuit current up to 2A and has short circuit protection to prevent damage.

Solar battery CO3208-1E is a maintenance-free lead-acid battery rated at 12V/7Ah with integrated analogue displays for voltage and current. It will be used as the storage element in this PV system.

Off-grid inverter CO3208-1F is a sinusoidal inverter for a stand-alone PV system and is rated at 12V/230V, 50hz. It also has protection against deep-discharge for batteries and reverse polarity on the DC connection side.

Load unit – 500W CO3208-1J is a potentiometer that can used to record characteristics of the solar modules.

Solar charge controller CO3208-1M is one of the main components for the stand-alone system experiments. It receives power from the solar modules and regulates the power flow to and from the battery. It has integrated displays for voltage and current levels on the load side and coloured LEDs to indicate its operation states. It also has protection against deep-discharge and overload of the battery.

Analog-Digital Multimeter CO5127-1Z will be used to record the data. It can display more than one data type at a time and has a USB port that connects to the PC. This allows the ‘Labsoft’ software in the PC to read the data and plot the graphs. Other instruments include circuit breaker CO3211-1A, three-phase AC meter CO3208-1T and industrial photovoltaics inverter CO3208-1S.

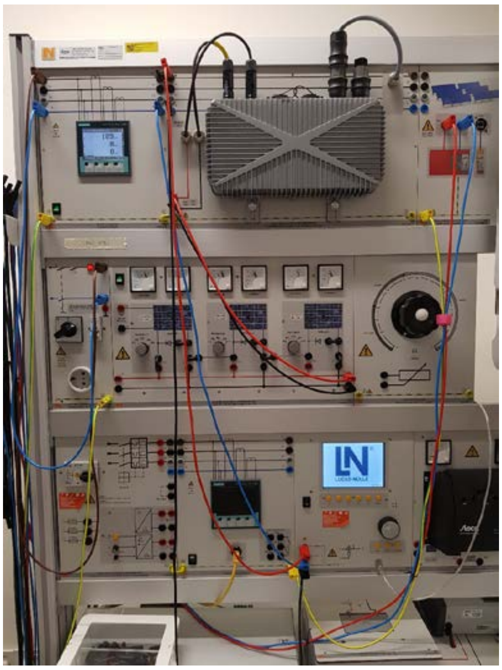

Fig. 2 Photograph of Lucas Nülle Emulator

3 Investigation of the Effect of Irradiance on Solar Module Output

Experimentation is performed to determine the open-circuit voltage and short-circuit current under various irradiance levels. The three solar modules in Lucas Nülle were connected in series and the irradiance was set to 200W/m^2. The open-circuit voltage and short-circuit current levels were recorded at 200W/m^2 and the irradiance is varied until 1000W/m^2. The experimental set-up was modified by adding the potentiometer CO3208-1J to plot the I-V and P-V curve for a specific irradiance level. The potentiometer is set to 0Ω and then slowly increased in steps of 1kΩ. The I-V/P-V curves are obtained from the Labsoft software in Lucas Nülle for different irradiance levels as shown in Figure 3 and 4.

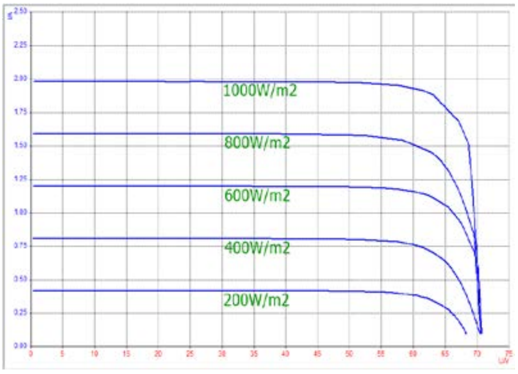

Fig.3 I-V curve for series connection

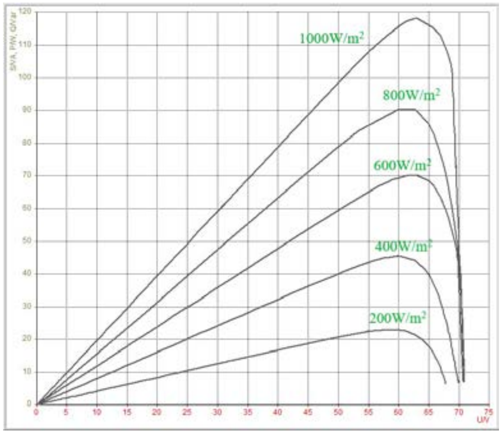

Fig. 4 P-V curve for series configuration

Later all the three solar modules were connected in a parallel configuration and their performance was evaluated for various irradiance levels and the I-V/P-V curves were obtained as shown in Figure 5 and 6 respectively.

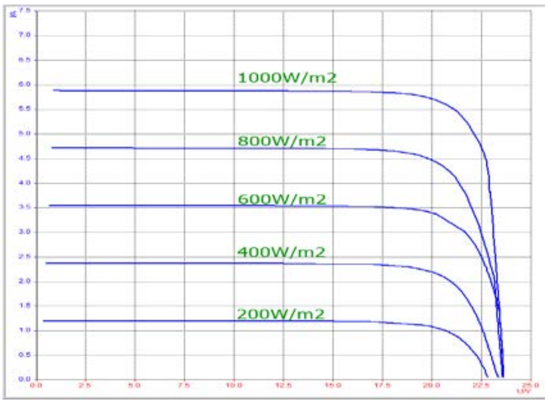

Fig. 5 I-V curve for parallel connection

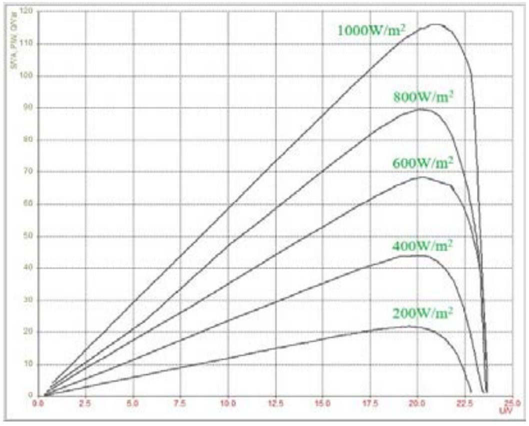

Fig. 6 P-V curve for parallel configuration

In the case of irradiance, output power of the system increases as irradiance increases. However, the difference in series and parallel arrangements provides different types of power. The series connection provides power that has a higher voltage level while the parallel connection provides power that has a higher current level. From the above results, it is evident that the amount of irradiance is directly proportional to the amount of output power for both module arrangements. There is significant increase in the current as the irradiance increases for both series and parallel configurations. This increase in current with respect to irradiance in turns affects the power produced by the modules i.e. the higher the irradiance, the higher the output power. Although voltage and current levels for series and parallel differ, output power is almost identical.

4 Investigation of Effect of Shading on the Solar Module Output

Shading is introduced on one of the modules to investigate the performance of the modules and to mimic real-world scenarios. For this, irradiance is fixed for two modules with the third module irradiance at a reduced level to mimic the shading effect. Shading greatly affects the electrical output of solar modules. For convenience, the modules are numbered as M1, M2 and M3. To investigate the effect of shading, the experimentation is performed with Module 1 and 2 irradiance fixed at 1000W/m^2 and Module 3 with 200W/m^2 and the results are shown in Figures 7 and 8. The module with lower irradiance reflects the shading of the module.

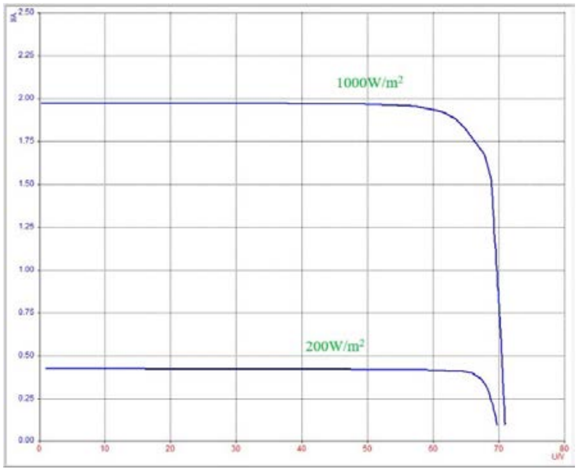

Fig. 7 I-V curve for SERIES connection with shading introduced in M3

Shading is a severe problem in photovoltaics. This problem is highlighted in the shading experiment when the modules are connected in series. Figure 8 demonstrates that when the irradiance at module 3 is lowered to 200W/m^2, the total output is equal to the sum of all the 3 modules at 200W/m^2 despite the other 2 modules at 1000W/m^2. From this observation, it can be deduced that for a series connection,

$$P_{out} = P_{\mathrm{lowest}} \times 3 \qquad (1)$$

Where P_{lowest} is the output power from the module of lowest irradiance.

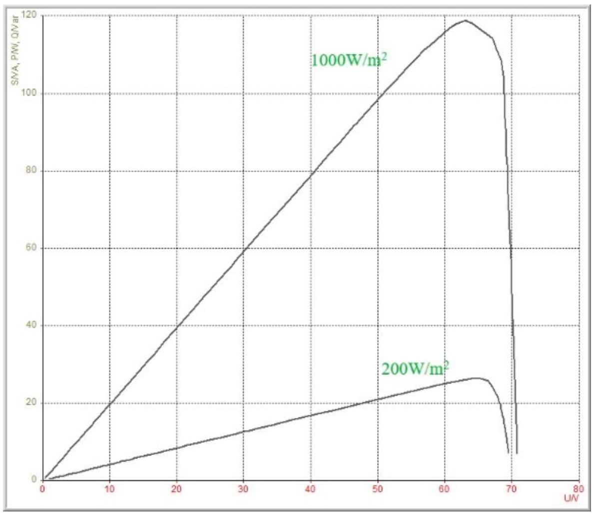

Fig. 8 P-V curve for SERIES connection with shading introduced in M3

However, in parallel connection the shading didn't have much effect as shown in Figure 9. When Module 3 is shaded, it only affects the output power of that module, leaving Module 1 and 2 unaffected. Output power will equal the sum of power produced by the individual modules as illustrated in Figure 10.

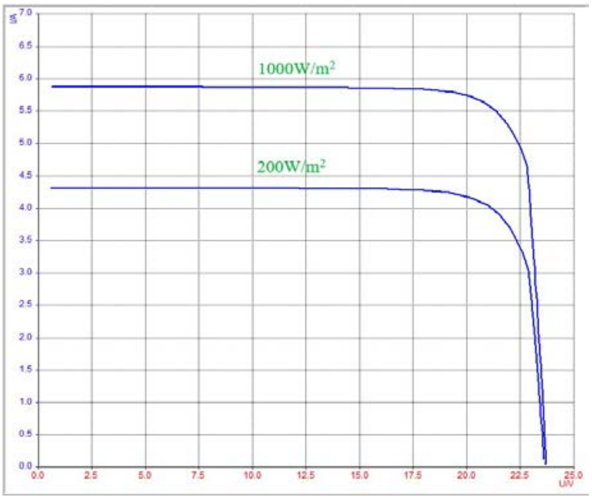

Fig. 9 I-V curve for Parallel connection with shading introduced in M3

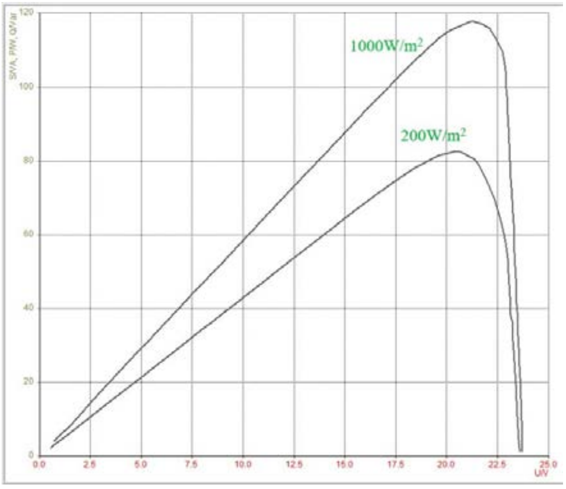

Fig. 10 P-V curve for Parallel connection with shading introduced in M3

Each solar module in the experimental set-up can provide approximately 40W of power under 1000W/m^2 of irradiance totalling approximately 120W. Under lower irradiances, power will decrease linearly. Shading has the most significant effect on series connection and can cause major power loss. In large-scale application where hundreds of modules may be involved, this is not practical as there will be an enormous power loss. To overcome this problem, a diode is connected in parallel with the module's internal wiring. Also known as a bypass diode, it allows power from unshaded modules to bypass the shaded module and prevent a major power loss. A bypass diode is usually included during the manufacturing of the module either one in parallel with the module or one for each PV cell in the module. This is particularly useful when the solar modules are placed on top of high-rise buildings.

4 Conclusion

This paper has presented the performance evaluation of solar modules present in the Lucas-Nülle photovoltaic system emulator. There were three solar modules of approximately 40W each which were connected in series and parallel configurations under different irradiance conditions and the performance was evaluated and their open circuit voltage and short circuit current levels were identified. Shading effect is introduced by minimizing the irradiance on any one of the modules in series and parallel configuration, and the I-V and P-V curves were obtained. It was observed that the effect of shading has not affected much the performance of solar modules connected in parallel. However, it severely affects the modules connected in series. Bypass diode would be useful to mitigate the effect of shading in solar modules.

References:

[1] M. Jazayeri, S. Uysal, K. Jazayeri, "*A simple MATLAB/Simulink simulation for PV modules based on one-diode model*," in 2013 High Capacity Optical Networks and Emerging/Enabling Technologies (HONET-CNS), 11-13 Dec. 2013, Magosa, Cyprus

[2] M. Green, Y. Hishikawa, E. D. Dunlop, D. H. Levi, J. Hohl-Ebinger, A. Ho-Baillie, "*Solar cell efficiency tables (version 51)*", in Progress in Photovoltaics: Research and Applications, Volume 26, Issue 1, 14 Dec. 2017.

[3] M. Pathare, V. Shetty, D. Datta, R. Valunjkar, A. Sawant, S. Pai, "*Designing and implementation of maximum power point tracking (MPPT) solar charge controller*", 2017 International Conference on Nascent Technologies in Engineering (ICNTE) 2017

[4] Mofakkharul Islam, Md. Abul Bashar Sarkar, "*An efficient smart solar charge controller for standalone energy systems*," in 2015 International Conference on Electrical Drives and Power Electronics (EDPE), 2015.

[5] Elhodeiby, A.S. Metwally, H.M.B Farahat, M.A, "*Performance analysis of 3.6kW rooftop grid connected photovoltaic system in Egypt*" in International Conference on Energy Systems and Technologies (ICEST 2011), Mar 2011, Pg. 151–157.

[6] A. Singla, K. Singh, V. K. Yadav, "*Environmental effects on performance of solar photovoltaic module*," in 2016 Biennial International Conference on Power and Energy systems: Towards Sustainable Energy, 2016.

[7] M. Hosenuzzaman, N. A. Rahim, J. Selvaraj, M. Hasanuzzaman, "*Factors affecting the PV based power generation*," 3rd IET International Conference on Clean Energy and Technology (CEAT) 2014.

[8] M. J. Mayer, "Comparison of different solar energy utilization methods: Photovoltaic systems and solar thermal power plants," in 2015 5th International Youth Conference on Energy (IYCE), 2015.

[9] Tan Hui Ying Felicia, R.T. Naayagi, T. Logenthiran, “Impedance Source Converter for Grid-connected Photovoltaic Applications,” *Proceedings of IEEE Region 10 Conference (TENCON)*, pp. 772-776, 2016, Singapore.

[10] Mariah Binte Marzuki, R.T. Naayagi, Van-Tung Phan, “Modelling and Simulation of Multilevel Inverter for Grid Connected Photovoltaic System,” *Proceedings of IEEE Region 10 Conference (TENCON)*, pp. 860-864, 2016, Singapore.