SINERGI Vol. xx, No. x, February 20xx: xxx-xxx
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.xxxx.x.xxx

Modeling of a Solar Electric Boat Power System using Matlab/Simulink

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Abstract
Malaysia's heavy reliance on fossil fuels, such as coal, oil, and natural gas, for its industrial and transportation sectors, has presented challenges in recent years, primarily due to the limited availability and increasing costs of these resources. Moreover, the continued use of fossil fuels contributes to greenhouse gas emissions and exacerbates environmental degradation. One of the industries that contribute to these causes is the fishing industry. Fishing vessels rely on fossil fuels such as diesel or petrol to power their engines. Therefore, this project proposes the modeling of a solar boat as a proactive solution to mitigate the growing challenges caused by the fishing industry as a solution to reduce diesel consumption and decrease gas emissions. The model comprises a DC-DC boost converter, an MPPT controller using Perturb and Observe (P&O), and an ideal switch with the power and voltage output of the system analysed using MATLAB/SIMULINK. Two case studies were carried out to assess how the system performed under various weather conditions. The results highlighted the impact of varying solar irradiance and temperature on the power and voltage output that is suitable to generate motor power for boats on a large scale. By leveraging solar energy, this project aligns with the United Nations Sustainable Development Goals (UNSDGs), specifically in preserving the environment for future generations and promoting Renewable Energy (RE). The successful implementation of this solar electric boat model can contribute to reducing Malaysia's dependence on fossil fuels, mitigating environmental impact, and fostering a sustainable energy future.

Keywords:
Solar electric boat, diesel consumption reduction,, renewable energy, sustainable development goals, MATLAB/SIMULINK Writing; Format;

Article History:
Received: May 2, 2019
Revised: May 29, 2019
Accepted: June 2, 2019
Published: June 2, 2019

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INTRODUCTION

Global warming and climate change present pressing challenges for our world today. Addressing these issues requires sustainable solutions, with solar energy emerging as a prominent option due to its environmentally friendly nature and lack of harmful emissions. By implementing renewable energy systems, particularly solar power, in industries, we can significantly reduce greenhouse gas emissions [1-

4]. The transition from traditional energy sources to renewable alternatives and the advancement of new technologies in industries are critical. Relying on fossil and nuclear fuels has resulted in adverse consequences such as air pollution, acid rain, resource depletion, and nuclear radiation hazards. Among various renewable energy sources, solar power has gained significant attention as a promising option for industrial use. It holds tremendous value [5] and has the potential to meet the increasing global energy demand in the coming decades. Malaysia, with its tropical climate characterized by high temperatures, humidity, and rainfall throughout the year, stands as an ideal location for solar energy utilization. The country maintains an average annual temperature of 25.4°C, with minimal monthly temperature variations ranging from 24.9°C in January to 25.9°C in May. The hottest months typically occur from April to June [6].

Solar radiation serves as the most vital natural energy resource, driving environmental processes on Earth's surface. The Sun provides an immense amount of energy, with the energy stored in the oceans helping maintain the planet's temperature equilibrium and supporting diverse life forms. In Malaysia, the monthly average of daily solar radiation ranges from 4000 to 5000 Wh/m^2 [7]. Additionally, the country experiences a monthly average sunshine duration of four to eight hours, equivalent to approximately 2200 hours per year [8].

Figure 1 displays a photograph highlighting the photovoltaic power potential across various locations in Malaysia, with daily totals surpassing 4.0 kWh/kWp. Direct Normal Irradiation (DNI), which refers to the solar radiation received per unit area by a surface held perpendicular to the sun's rays, serves as a crucial parameter for calculating energy yield and evaluating the performance of concentrating solar power (CSP) and concentrator solar photovoltaic (CPV) technologies. Photovoltaic modules capture the irradiation by tracking the sun's direction, utilizing DNI for measurement [9].

The solar energy industry can be classified into two main sectors: solar thermal and solar photovoltaic (PV). Solar panels, or photovoltaic (PV) panels, act as silent solar energy converters without rotating parts, making them an ideal solution for Malaysia given its high solar energy potential. The fishing industry in Malaysia heavily depends on fossil fuel-powered boats, leading to significant challenges. The limited availability and escalating costs of fossil fuels pose economic may be burdened for fishermen, while the continued reliance on these fuels contributes to greenhouse gas emissions and environmental degradation. Moreover, the combustion of fossil fuels in fishing boats results in environmental pollution, adversely affecting marine ecosystems and human well-being.

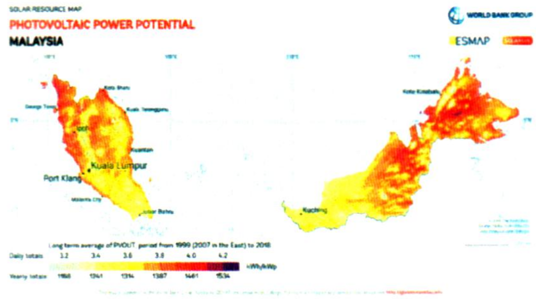

Figure 1. Photovoltaic Power Potential Map of Malaysia [10]

To address these critical issues, it is imperative to develop an innovative and sustainable solution that reduces the fishing industry's dependence on fossil fuels and mitigates its environmental impact. The purpose of this study is to model a solar electric boat using MATLAB software. Through this model, the aim is to analyze the power and voltage output of the boat under different operating conditions. By embracing solar electric boats, we aim to optimize their performance to decrease diesel consumption, minimize gas emissions, and foster a sustainable energy future for Malaysia's fishing industry.

METHOD

This section will comprehensively examine the various methods employed to carry out research on the maximum power point tracking (MPPT) technique using the perturb and observe approach. This section will delve into the specific techniques utilized in MPPT to effectively track the maximum power point, elucidating the anticipated outcomes of this analysis. Furthermore, it will explore the evaluation process of the data obtained from this research. Additionally, it will encompass a detailed discussion on the prediction of data related to irradiance and temperature, as well as an elaboration on the model employed in the photovoltaic (PV) cell. Notably, this chapter will also feature the inclusion of a flowchart depicting the perturb and observe algorithm.

The research commences by conducting an extensive exploration of various publications, journals, and credible sources relevant to solar electric boat power systems. The primary objective of this phase is to gather comprehensive information and knowledge essential for the successful execution of the project. Moreover, this phase facilitates the identification of potential challenges that may arise. Subsequently, the specific problem related to the design of solar-powered boats will be identified. Based on the problem statement, the objectives and scope of work will be established.

This project comprises three main simulation steps. The initial step involves modeling a photovoltaic (PV) module. Following this, two graphs representing Power versus Voltage (PV) and Current versus Voltage (IV) will be generated. The second step entails the modeling of a perturb and observe (P&O) maximum power point tracking (MPPT) controller. This algorithm utilizes voltage perturbation and power observation to incrementally increase power by raising the voltage. The final step involves integrating the MPPT controller with the PV module and a DC-DC converter, specifically a boost converter. The boost converter is employed to amplify the input voltage to a higher level required by the load. Figure 2 shows the flowchart of the project from the start to the end.

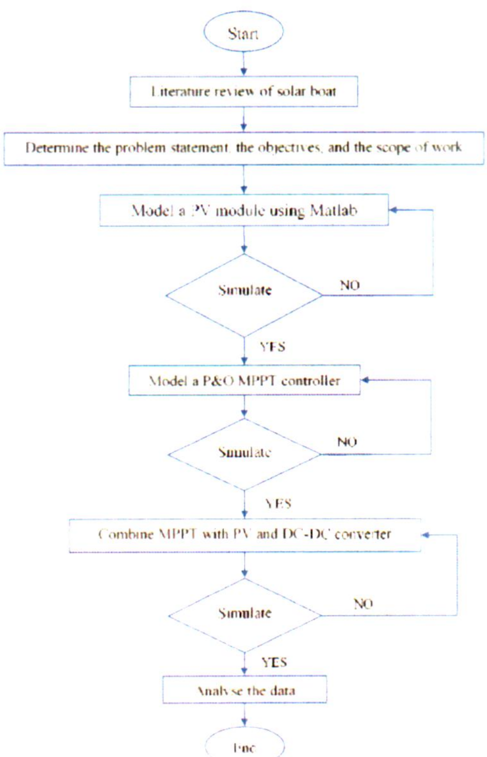

Figure 2. Overall flowchart of the project

Simulink Model of the Proposed System

The proposed system is implemented using MATLAB/Simulink. The system includes a PV array, MPPT controller, DC-DC converter, and Switching Relay for analyzing the performance of the system components. Figure 3 displays the Simulink model of the proposed system in MATLAB.

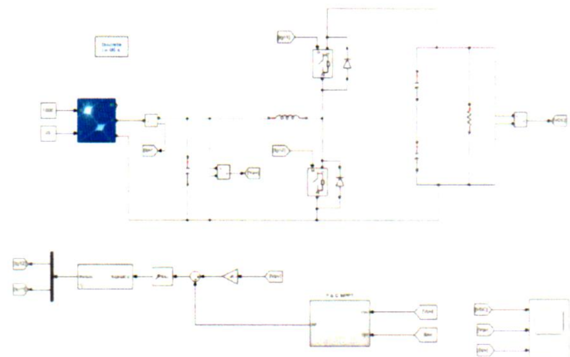

Figure 3. Simulink model of the proposed system in MATLAB

PV Array Design in Simulink

Figure 4 shows the block parameters for the PV array, which describe the input parameters in the Simulink PV block.

Figure 4. PV Array Input Parameter in the Simulink

Figure 5 and Figure 6 display the I-V and P-V characteristic curves, respectively, for the PV array under various solar irradiances.

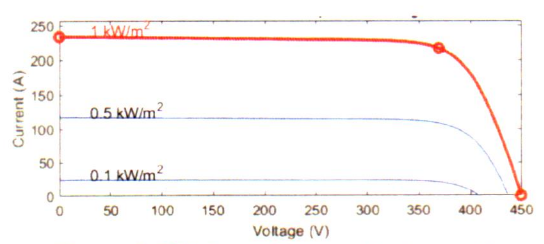

Figure 5. PV Array Current-Voltage (IV) Characteristic Curve for Various Solar Irradiance

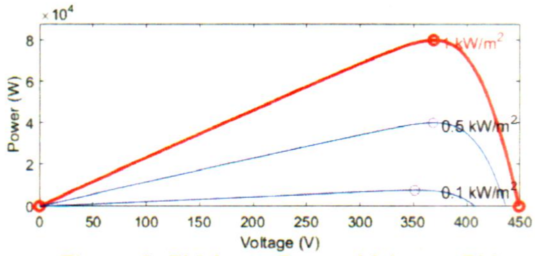

Figure 6. PV Array Power-Voltage (PV) Characteristic Curve Various Solar Irradiance

Maximum Power Point Tracking (MPPT)

To maximize the power output of solar PV modules, it is crucial to operate them near the maximum power point (MPPT). Various MPPT techniques have been proposed, with the Perturbation and Observation (P&O) method being chosen for this project due to its efficiency and widely known for its simple implementation on the PV system. The P&O method involves observing the PV array output power and perturbing the array operation current or voltage to optimize the power supply. The flowchart of the P&O algorithm operation is shown in Figure 7.

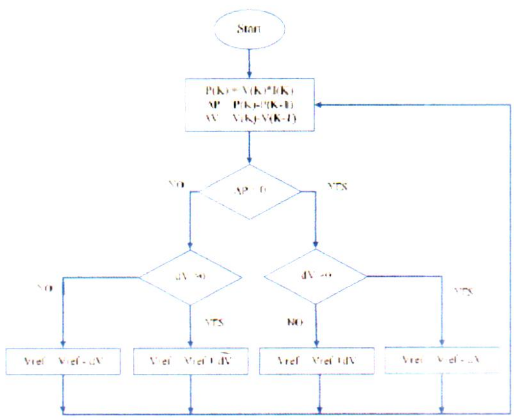

Figure 7. Flowchart of the P&O method

Proportional-Integral Controller

A PI controller is employed as a feedback control loop that calculates the error signal by comparing the system output with the reference voltage obtained from the MPPT. By adjusting the proportional gain (K_p), the PI controller achieves the desired response. The block diagram of the PI controller is presented in Figure 8.

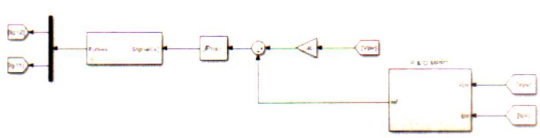

Figure 8. Block diagram of PI controller

Boost Converter

A DC-DC boost converter is utilized to regulate the PV voltage by stepping up the voltage based on the duty cycle received from the MPPT. The boost converter circuit consists of an inductor, diode, capacitor, load resistor, and an ideal switch, as illustrated in Figure 9.

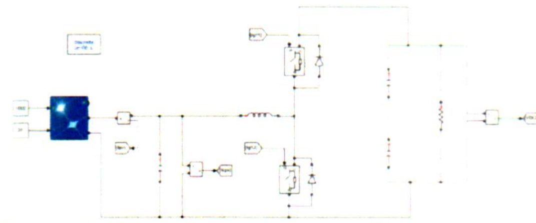

Figure 9. Boost Converter in the Simulink model

RESULTS AND DISCUSSION

Simulation Results with Boost Converter using MPPT (P&O)

The Perturb and Observe (P&O) method was employed in the simulation, and it achieved a maximum output power of 418 kW and an output voltage of 1.813 kV. These values represent the peak power (P_{max}) and maximum voltage (V_{max}) attainable from the PV module. Notably, the P&O algorithm reached this peak power level within a remarkably short timeframe of 0.5 seconds. The X-axes represent the time in seconds and the Y-axes represent power and voltage output. Figure 10 and Figure 11 show the P&O power and voltage under 1000 W/m^2 irradiance at 25°C. The power output is 418 kW, and the voltage output is increased from 200W to 1.813 kV.

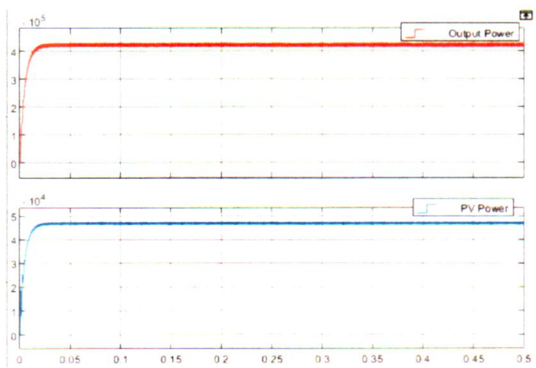

Figure 10. The P&O power under 1000 W/m^2 irradiance at 25°C

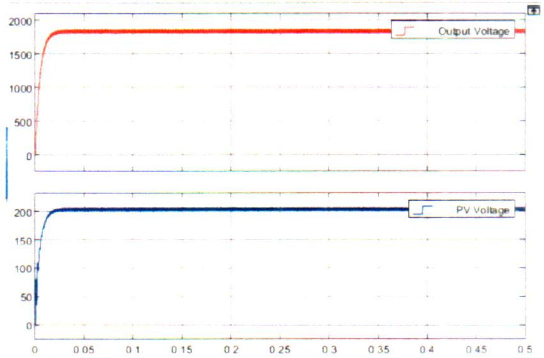

Figure 11. The P&O voltage under 1000 W/m^2 irradiance at 25°C

Case Study

Two case studies were conducted. The first case study involved simulating the PV module under different irradiance levels while maintaining a constant temperature of 25°C. The second case study simulated the PV module under constant irradiance levels at varying temperatures ranging from 10°C to 75°C.

Case Study I

The first case study examines the impact of irradiance levels on PV module performance while maintaining a constant temperature. This scenario mimics real-world conditions where the sunlight intensity may vary throughout the day, but the temperature remains relatively stable. The power and voltage output at the maximum power point were analysed for the PV module under 200 W/m^2, 400 W/m^2, and 800 W/m^2 irradiance levels at 25°C. Figure 12 and Figure 13 show the power and voltage output at the maximum power point under 200 W/m^2. The power output is 21.1 kW, and the voltage output is 0.4518 kV.

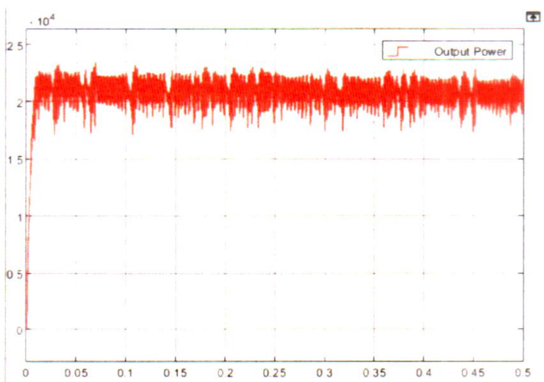

Figure 12. The P&O power output

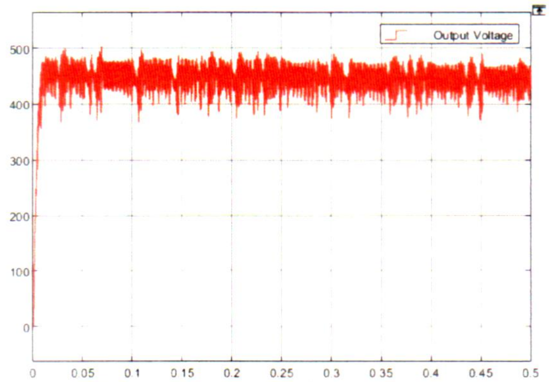

Figure 13. The P&O voltage output

Figure 14 and Figure 15 show the power and voltage output at the maximum power point under 400 W/m^2 with the value of power is 68.25 kW and voltage is 0.7327kV.

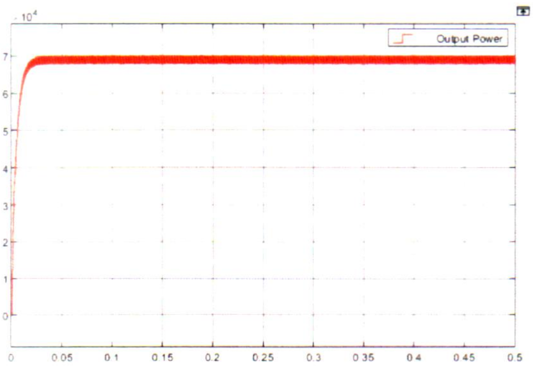

Figure 14. The P&O power output

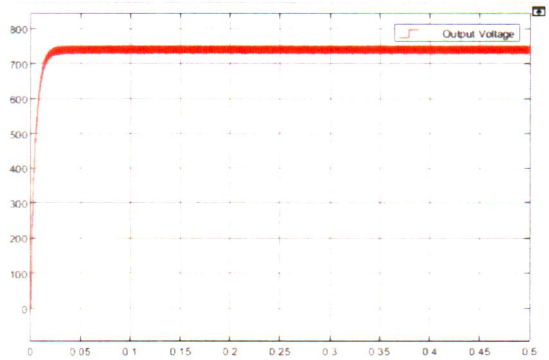

Figure 15. The P&O voltage output

Similarly, Figure 16 and Figure 17 illustrate the power, 269.3 kW, and voltage output, 1.455 kV at the maximum power point of the simulation respectively under 800 W/m^2 irradiance at 25°C.

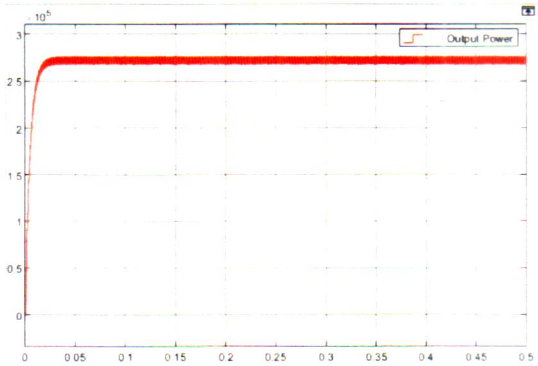

Figure 16. The P&O power output

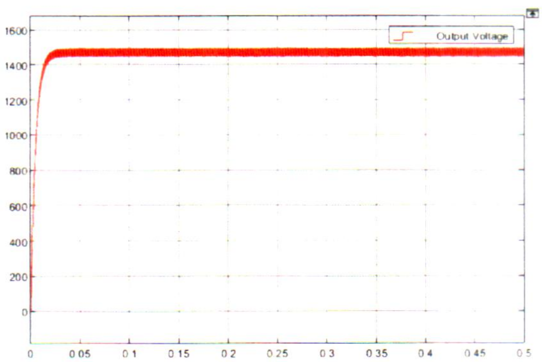

Figure 17. The P&O voltage output

Case Study II

The power and voltage output at the maximum power point were analyzed for the PV module under 1000 W/m^2 irradiance levels at 10°C, 50°C, and 75°C. Figure 18 and Figure 19 display the power and voltage output at 10°C respectively. The power output is 413.6 kW and the voltage output is 1.804 kV.

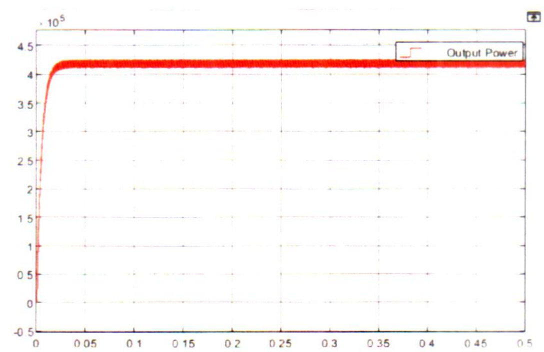

Figure 18. The P&O power output

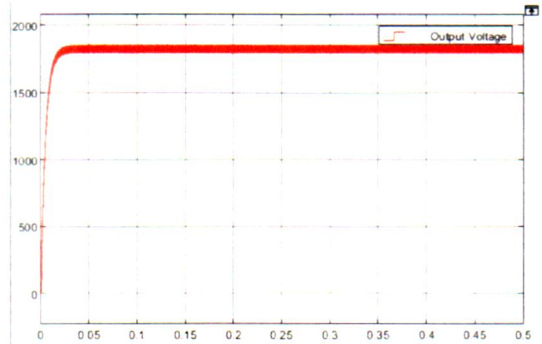

Figure 19. The P&O voltage output

Figure 20 and Figure 21 display the power and voltage output at 50°C respectively with the power output being 425.2 kW and the voltage output being 1.829 kV.

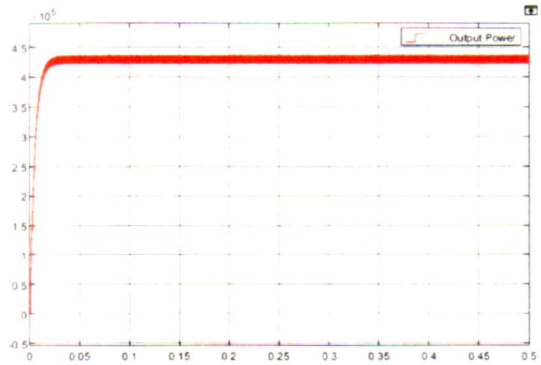

Figure 20. The P&O power output

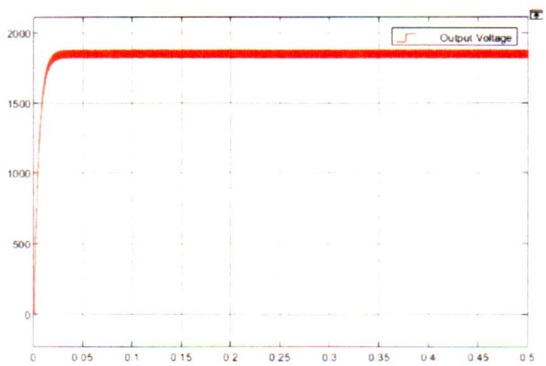

Figure 21. The P&O voltage output

Likewise, Figure 22 and Figure 23 present the power, 431.6 kW and voltage output, 1.843 kV at the maximum power point of the simulation respectively under the same irradiance at 75°C.

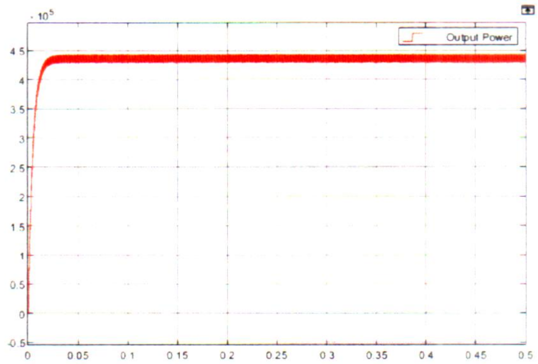

Figure 22. The P&O power output

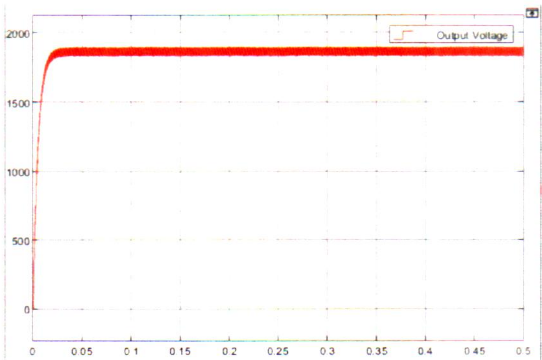

Figure 23. The P&O voltage output

Comparison Between Case Studies

A comparison between the two case studies is presented in Table 1, showcasing the power and voltage output under different weather conditions. The results demonstrate that the P&O algorithm consistently improves the PV module's efficiency by accurately identifying the maximum power point (PMPP).

Case study I showed that the PV module's power output varied under different irradiance levels, with larger oscillations observed at 200 W/m^2 compared to 400 W/m^2 and 800 W/m^2 as depicted in Figure 24, Figure 25, and Figure 26 respectively. In simpler terms, it means that the PV module generated more inconsistent or unstable power output when it received an irradiance level of 200 W/m^2 compared to when it received higher irradiance levels of 400 W/m^2 and 800 W/m^2.

Table 1: The comparison between power and voltage output

Weather condition	Output Power (kW)	Output Voltage (kV)
Fixed Irradiance G = 1000 W/m^2 Constant temperature T = 25°C	418	1.813
Case Study I		
Variable Irradiance G = 200 W/m^2 Constant temperature T = 25°C	21.1	0.4518
Variable Irradiance G = 400 W/m^2 Constant temperature T = 25°C	68.25	0.7327
Variable Irradiance G = 800 W/m^2 Constant temperature T = 25°C	269.3	1.455
Case Study II		
Fixed Irradiance G = 1000 W/m^2 Variable temperature T = 10°C	413.6	1.804
Fixed Irradiance G = 1000 W/m^2 Variable temperature T = 50°C	425.2	1.829
Fixed Irradiance G = 1000 W/m^2 Variable temperature T = 75°C	431.6	1.843

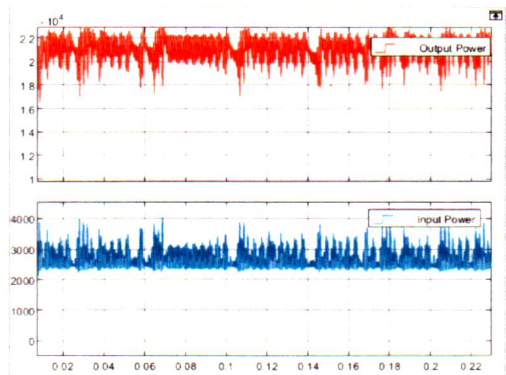

Figure 24. The power output under 200 W/m^2 at 25°C

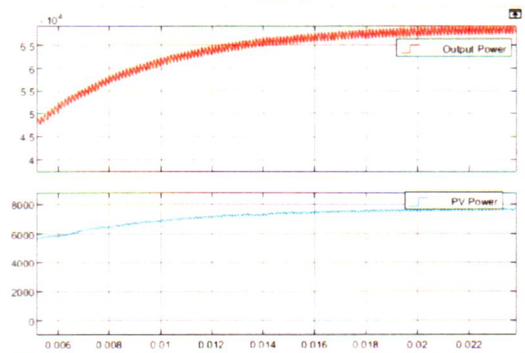

Figure 25. The power output under 400 W/m^2 at 25°C

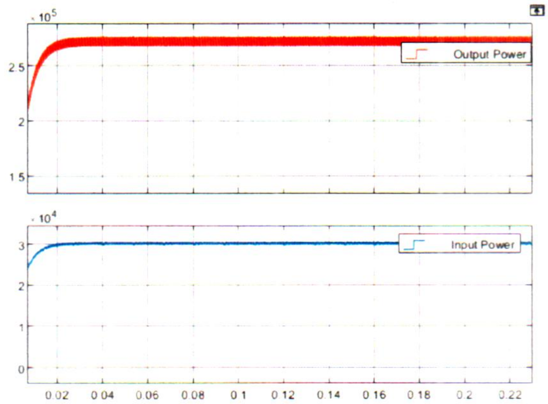

Figure 26. The power output under 800 W/m^2 at 25°C

It was observed that as the irradiance increased from 200 W/m^2 to 800 W/m^2, the output power and voltage demonstrated a consistent upward trend as shown in Figure 27. The output power increased from 21.1 kW to 269.3 kW, and the output voltage rose from 0.4518 kV to 1.455 kV. This indicates a strong positive correlation between solar irradiance and the system's performance, as higher irradiance levels provided greater power generation capabilities.

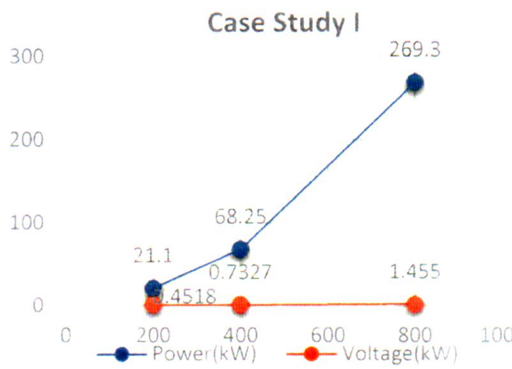

Figure 27. The P&O power and voltage at constant temperature, 25°C

In Case Study II, fixed irradiance of 1000 W/m^2 was paired with variable temperatures of 10°C, 50°C, and 75°C. The results indicate a marginal increase in output power and voltage as the temperature rose as illustrated in Figure 28. At 10°C, the system generated 413.6 kW of power with an output voltage of 1.804 kV. At 50°C and 75°C, the power output increased to 425.2 kW and 431.6 kW, respectively, with corresponding voltage levels of 1.829 kV and 1.843 kV. These outcomes suggest that higher temperatures can slightly enhance system performance but have a more limited impact compared to variations in irradiance.

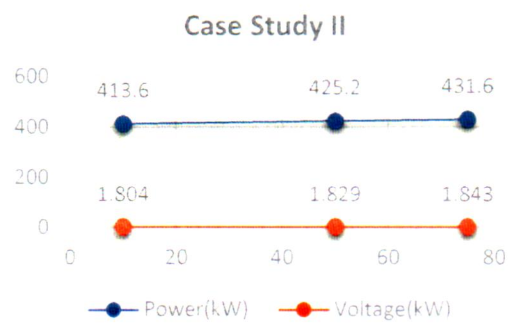

Figure 28. The P&O power and voltage at constant irradiance, 1000 W/m^2

CONCLUSION

The simulation results demonstrated the successful implementation of the P&O algorithm in achieving maximum power output and voltage from the PV module. The algorithm showed excellent performance in tracking the maximum power point under varying solar irradiance levels and temperature conditions.

Two case studies were conducted to evaluate the system's performance under different weather conditions. The results highlighted the impact of varying solar irradiance and temperature on the power and voltage output. The P&O algorithm exhibited greater tracking accuracy at higher irradiance levels, while the power output showed smaller oscillations.

In conclusion, this project successfully achieved its stated objectives, which were to study the current perspective on renewable energy, specifically solar energy development in Malaysia, propose a modeling of a solar electric boat power system, and analyse the power and voltage output of the system. The findings of the study revealed promising advancements in solar energy development in Malaysia, highlighting its potential as a viable renewable energy source. This knowledge serves as a solid foundation for further exploration and implementation of solar energy projects within the country.

The proposed modeling of a solar electric boat power system was successfully carried out. The results of the study have shed light on the significant influence of fluctuating solar irradiance and temperature on the power and voltage output required to effectively generate motor power for large-scale boats. Additionally, the power and voltage output of the photovoltaic (PV) system were thoroughly analysed. The PV voltage output was measured to be 200 V. After connecting the PV system to a Maximum Power Point Tracking (MPPT) mechanism and a boost converter, the voltage output was effectively boosted to boosted to 1.813 kV, which suitable to generate motor powerboat.

REFERENCES

[1] N. Heidari and J. M. Pearce, "A review of greenhouse gas emission liabilities as the value of renewable energy for mitigating lawsuits for climate change related damages," Renewable and Sustainable Energy Reviews, vol. 55, pp. 899–908, Mar. 2016, doi: 10.1016/J.RSER.2015.11.025.

[2] D. Bucher, R. Buffat, A. Froemelt, and M. Raubal, "Energy and greenhouse gas emission reduction potentials resulting from different commuter electric bicycle adoption scenarios in Switzerland," Renewable and Sustainable Energy Reviews, vol. 114, p. 109298, Oct. 2019, doi: 10.1016/J.RSER.2019.109298.

[3] K. Oehmichen and D. Thrän, "Fostering renewable energy provision from manure in Germany – Where to implement GHG emission reduction incentives," Energy Policy, vol. 110, pp. 471–477, Nov. 2017, doi: 10.1016/J.ENPOL.2017.08.014.

[4] F. Murphy, G. Devlin, and K. McDonnell, "Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry," J Clean Prod, vol. 92, pp. 134–141, Apr. 2015, doi: 10.1016/J.JCLEPRO.2015.01.001.

[5] E. Toklu, "Overview of potential and utilization of renewable energy sources in Turkey," Renew Energy, vol. 50, pp. 456–463, Feb. 2013, doi: 10.1016/J.RENENE.2012.06.035.

[6] "Malaysia - Climatology | Climate Change Knowledge Portal." https://climateknowledgeportal.worldbank.org/country/malaysia/climate-data-historical (accessed Dec. 15, 2022).

[7] N. Izadyar, H. C. Ong, W. T. Chong, J. C. Mojumder, and K. Y. Leong, "Investigation of potential hybrid renewable energy at various rural areas in Malaysia," J Clean Prod, vol. 139, pp. 61–73, Dec. 2016, doi: 10.1016/J.JCLEPRO.2016.07.167.

[8] S. T. Mohammad, H. H. Al-Kayiem, M. A. Aurybi, and A. K. Khlief, "Measurement of global and direct normal solar energy radiation in Seri Iskandar and comparison with other cities of Malaysia," Case Studies in Thermal Engineering, vol. 18, p. 100591, Apr. 2020, doi: 10.1016/J.CSITE.2020.100591.

[9] "Global Solar Atlas." https://globalsolaratlas.info/download/malaysia (accessed Dec. 15, 2022).

[10] "Malaysia's photovoltaic power potential map obtained from the Global... | Download Scientific Diagram." https://www.researchgate.net/figure/Malaysias-photovoltaic-power-potential-map-obtained-from-the-Global-Solar-Atlas-20-a_fig1_351752520 (accessed Dec. 16, 2022).

[11] K. Mahmud, S. Morsalin, and M. I. Khan, "Design and Fabrication of an Automated Solar Boat," International Journal of Advanced Science and Technology, vol. 64, pp. 31–42, 2014, doi: 10.14257/ijast.2014.64.04.

[12] H. Suryoatmojo, A. Kurniawan, F. A. Pamuji, N. S. MT, I. S. Wijaya, and H. Innah, "A Robust Frequency Control Approach in PV-Diesel Hybrid Power System," IPTEK Journal of Proceedings Series, vol. 1, no. 1, pp. 2354–6026, Dec. 2014, doi: 10.12962/J23546026.Y2014I1.208.

[13] S. Das, P. Kumar Sadhu, S. Chakraborty, N. Pal, and G. Majumdar, "New Generation Solar PV Powered Sailing Boat Using Boost Chopper," TELKOMNIKA Indonesian Journal of Electrical Engineering, vol. 12, no. 12, pp. 8077–8084, 2014, doi: 10.11591/telkomnika.v12i12.6677.

[14] A. Kurniawan, "A Review of Solar-Powered Boat Development," 2016.

[15] S. Das, P. K. Sadhu, and S. Chakraborty, "Green sailing of solar PV powered country boat using buck-boost chopper," in Proceedings of IEEE International Conference on Circuit, Power and Computing Technologies, ICCPCT 2016, Institute of Electrical and Electronics Engineers Inc., Aug. 2016. doi: 10.1109/ICCPCT.2016.7530283.

[16] M. L. Azad, S. Das, P. Kumar Sadhu, B. Satpati, A. Gupta, and P. Arvind, "P&O algorithm based MPPT technique for solar PV system under different weather conditions," Proceedings of IEEE International Conference on Circuit, Power and Computing Technologies, ICCPCT 2017, Oct. 2017, doi: 10.1109/ICCPCT.2017.8074225.

[17] S. Chakraborty, M. Mahedi Hasan, S. Das, and M. Abdur Razzak, "A novel MPPT-based synchronous buck converter for solar power system in fishing trawler; A novel MPPT-based synchronous buck converter for solar power system in fishing trawler," 2016 IEEE 7th Power India International Conference (PIICON), 2016, doi: 10.1109/POWERI.2016.8077296.

[18] W. Obaid, A.-K. Hamid, and C. Ghenai, "Hybrid Power System Design for Electric Boat with Solar Irradiance Forcasting; Hybrid Power System Design for Electric Boat with Solar Irradiance Forcasting," 2018 6th International Renewable and Sustainable Energy Conference (IRSEC), 2018, doi: 10.1109/IRSEC.2018.8702854.

[19] S. Salman, X. Ai, and Z. Wu, "Design of a P-&-O algorithm based MPPT charge controller for a stand-alone 200W PV system", doi: 10.1186/s41601-018-0099-8. 2018 4th International Conference for Convergence in Technology (I2CT). IEEE

[21] "Sci-Hub | Solar-powered boat design using standalone distributed PV system. 2018 IEEE International Conference on Applied System Invention (ICASI) | 10.1109/ICASI.2018.8394259." https://sci-hub.se/10.1109/ICASI.2018.8394259 (accessed Jun. 19, 2023).

[22] A. K. Hamid, "Design of Solar PV/Fuel Cell/Diesel Generator Energy System for Dubai Ferry; Design of Solar PV/Fuel Cell/Diesel Generator Energy System for Dubai Ferry," 2019.

[23] W. Obaid, A. Hamid, and C. Ghenai, "Hybrid PEM Fuel-Cell-Solar Power System Design for Electric Boat with MPPT System and Fuzzy Energy Management; Hybrid PEM Fuel-Cell-Solar Power System Design for Electric Boat with MPPT System and Fuzzy Energy Management," 2019 International Conference on Communications, Signal Processing, and their Applications (ICCSPA), 2019.

[24] W. Obaid, A. Hamid, and C. Ghenai, "Wind-Fuel-Cell-Solar Hybrid Electric Boat Power Design with MPPT System; Wind-Fuel-Cell-Solar Hybrid Electric Boat Power Design with MPPT System," 2019 8th International Conference on Modeling Simulation and Applied Optimization (ICMSAO), 2019.