Journal of Engineering Science and Technology
Special Issue on ISCoE2023 Vol. 19, No. 4 (2024) 50 - 58

PERFORMANCE EVALUATION OF THE PHOTOVOLTAIC-THERMOELECTRIC GENERATORS (PV-TEG) TANDEM HYBRID POWER PORTABLE STOVE

DANIEL PARENDEN[1,*], H. HARIYANTO[1], NURJANNAH YUSMAN[1], CANDRA AGUS WAHYUDHI[1], S. SUPRIYADI[1, 2], ANDERIAS HENUKH[1, 2]

[1]Universitas Musamus, Merauke, Indonesia
[2]Universitas Pendidikan Indonesia, Bandung, Indonesia
*Corresponding Author: daniel@unmus.ac.id

Abstract

Solar energy is commonly recognized as a plentiful and ecologically friendly source of energy. This type of energy plays a crucial role in protecting the environment by reducing the increase of carbon emissions and air pollution. This study aims to evaluate the effectiveness and feasibility of a portable stove that operates using a combination of photovoltaic and thermoelectric generators (PV-TEG). This work utilizes a combination of experimental techniques and theoretical mathematical analysis. The experiment was carried out under full sunlight, with the sun's rays striking the surface of the solar panel at a 90-degree angle. During a continuous 30-day period, data was collected systematically within the geographical boundaries of Merauke Regency, which is situated in the province of Papua, Indonesia. The data collection started at 08:00 and ended at 15:00 WIT. The test results reveal that the average solar radiation value produced is 728.33 W/m^2. Furthermore, the photovoltaic (PV) system has an average power output of 283.73 W, the thermoelectric generator (TEG) has an average power of 0.974 W, and the battery's charge rate is 235.97 W.

Keywords: Hybrid, Performance, Portable, Power, PV, Stove, TEG.

1. Introduction

Solar energy has been researched [1-6]. One of the utilization of solar energies is solar thermal energy. Solar thermal energy can be harnessed for diverse purposes, including drying, air heating, and cooking [7-11]. Cooking stoves are essential appliances in houses, acting as the main method for preparing food. Nevertheless, the extensive pursuit of implementing stoves powered by renewable energy sources has not yet been widely undertaken [12]. The photovoltaic and thermoelectric generators (PV-TEG) Hybrid Portable Stove is a stove that harnesses solar energy as a renewable energy source. The main components consist of an electric stove, a photovoltaic (PV) system, and a thermoelectric generator (TEG). The integration of PV and TEG technologies has been developed to efficiently convert incoming light and heat energy into electrical power [13]. PV systems can harness solar radiation [14-18], but it is crucial to understand that not all absorbed solar radiation can be efficiently converted into electrical energy. Some of it is lost as waste heat. This waste heat can be utilized by employing TEG to generate additional electrical energy [19-21].

Extensive study has been carried out in the field of combined PV-TEG technology, including both theoretical [22-24] and practical [25-27] techniques, to observe the best possible performance of PV and TEG systems. However, the utilization of this method on electric stoves has been significantly restricted. The need for additional equipment, such as charging controllers, BTUs, batteries, and inverters, arises due to the inherent unpredictability of the intensity of sunlight. The Portable Hybrid PV-TEG electricity Stove primarily harnesses solar energy for electricity generation. The energy is subsequently allocated to a charging controller, inverter, and battery, yielding a portable device that is conveniently transportable and suitable for both indoor and outdoor use.

This research project aims to develop a Portable Hybrid PV-TEG Tandem Stove Technology that offers a significantly efficient and sustainable alternative to traditional stoves. This objective us accomplished by employing a methodical approach that encompasses completing an exhaustive examination of current literature, scrutinizing pertinent technologies, and formulating experiments for testing. This technology has been specifically engineered to prioritize the characteristics of portability, disassembly, and flexibility, rendering it suitable for use in both indoor and outdoor settings. This idea focuses on the underexplored field of portable solar cookers, providing an ecologically sustainable substitute for traditional stoves.

2. Literature Review

Solar energy is an unlimited energy source that is constantly being improved to meet future energy needs [28]. The generated light and heat can be utilized for everyday necessities [29]. The Merauke Regency Renewable Energy has the potential to be utilized to fulfil daily energy needs. The monthly average irradiation of solar energy is 5.38 kWh/m^2/day, with a peak value of 6.43 kWh/m^2/day occurring in October annually [30]. Solar thermal energy is used in drying, water heating, and cooking. Stoves are an essential requirement for cooking in households, however, the utilization of solar-powered stoves has not been extensively advanced. Historically, kerosene and gas have been the primary sources of energy utilized for culinary purposes [31-33]. Nevertheless, acquiring these two energy sources has become progressively challenging, and their costs persistently rise. They have conducted numerous experiments [34-36] on solar cookers, utilizing parabolic collectors to capture and reflect thermal energy. Nevertheless, the drawback of utilizing a parabolic model is that it necessitates outdoor usage and direct exposure to sunlight, requiring the removal and insertion of the cooking equipment.

The Portable Hybrid PV-TEG burner is a cutting-edge version of solar-powered stoves that combines an electric burner with a PV system and a TEG. PV and TEG devices are designed to convert light and heat, respectively, into electrical energy. PV systems can capture approximately 80% of solar radiation. Nevertheless, it is crucial to acknowledge that not all of this acquired radiation can be efficiently converted into usable energy. As a result, this lack of efficiency leads to the production of excess heat and a subsequent decrease in the overall effectiveness of the system [37-39]. Thermoelectrics can harness the surplus heat generated by rising temperatures. The TEG operates by turning thermal energy into electrical energy, utilizing temperature disparities between the hotter and colder sides [40].

3. Method

The research used is a type of experimental research that aims to determine the effect of sunlight intensity on the power produced by PV and TEG. In this research, direct testing was carried out on the prototype that had been created. The prototype is shaped like a cart with a solar panel roof equipped with wheels that make it easy to move anywhere. Measurements are carried out in real-time with a time lag of 10 minutes for 8 hours in 1 day for 30 days. The parameters measured include light intensity, current, and voltage. The data analysis used is an analysis method that involves collecting data parameters and calculating their quantity using power and efficiency equations.

4. Results and Discussion

4.1. Efficiency PV

The efficiency of a solar panel is measured by its ability to convert light energy into electrical energy with maximum output efficiency (η) [41-42]. Solar cells generate electric power by producing voltage under load, which enables the concurrent flow of current [43]. The efficiency value is expressed using Eq. (1) [44]:

$$\eta = \frac{P_{\max}}{P_{in}} \tag{1}$$

Solar cell efficiency (η) is found by dividing the power generated by the cell (P_{max}) by the power of the incident light (P_{in}). P_{in} is determined by the solar irradiance (I_r), which is the intensity of light (W/m^2), and the surface area of the solar cell (A). The power output of the solar cell (P_{out}) is calculated by multiplying the open circuit voltage (V_{oc}), short circuit current (I_{sc}), and Fill Factor (FF) of the PV cell.

4.2. Efficiency TEG

TEG Modeling is employed in semiconductor circuits to enhance comprehensibility. The electrical energy is derived from the disparity in temperature between the hot and cold sides [25]. The measurement of electric power at TEG can be characterized by the open circuit voltage (VOC) and the electrical resistance of the TEG. The Seebeck effect on a TEG produces an electric potential difference, commonly referred to as voltage. The amount of heat absorbed is represented by Eq. (2) [38]:

$$Q_H = \alpha I T_H + K(T_H - T_C) - 0.5RI^2 \tag{2}$$

Efficiency can be calculated by Eq. (3) [26]:

$$\eta_{TEG} = \frac{V_{TEG} I_{TEG}}{Q_H} \tag{3}$$

The technical elements of the system comprised PV panels, a TEG, a battery, a charger controller, an inverter, and an electric stove. The PV system converts solar energy into electrical energy, while the TEG harnesses the remaining thermal energy to provide extra electrical power. The aggregated electrical energy is regulated by a charger controller, stored in a battery, and subsequently transformed from direct current (DC) to alternating current (AC) by an inverter for optimal utilization in supplying power to the electric stove, as demonstrated by the results of the trial run presented in Table 1.

Table 1. Technology test results data.

Parameter	Value
Average Solar intensity	728,33 W/m^2
Average Power PV	283,73 W
Average Power TEG	0.974 W
Average power for battery charging	235,97 W

The experiment took place in the Merauke district on August 1, 2023, from 08.00 WIT to 15.00 WIT under gloomy weather circumstances. As a result, the efficiency of charging the battery using solar panels was suboptimal, with an average power of 235.974 W. Figure 1 illustrates average values for both current and voltage. The voltage shows slight variations, while the current remains steady. The generated voltage ranges from 34.33 to 36.67 V, while the current ranges from 7.84 to 8.24 A.

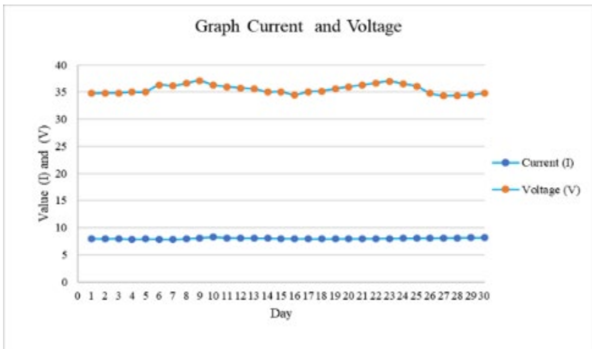

Fig. 1. Average values of current and voltage.

The representation in Fig. 2 depicts the variability in output power, which is subject to the influence of unstable solar intensity. The highest recorded value is 299.93 W, while the lowest recorded value is 274.62 W. Figure 3 shows the average value of efficiency that is measured but fluctuates. This fluctuating efficiency graph is due to the unstable power generated - a maximum efficiency value of 70.65% and a minimum percentage of 63.10%.

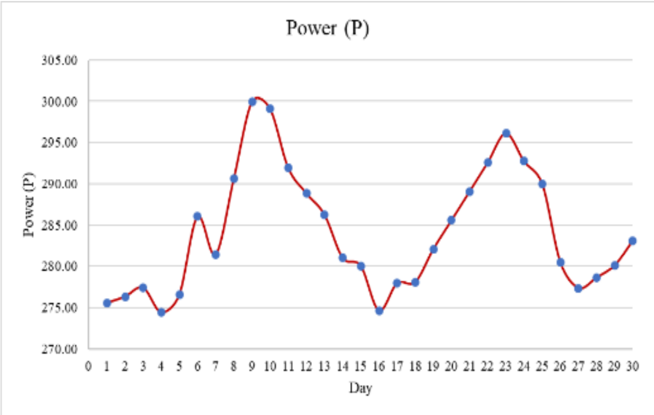

Fig. 2. Rated average output power.

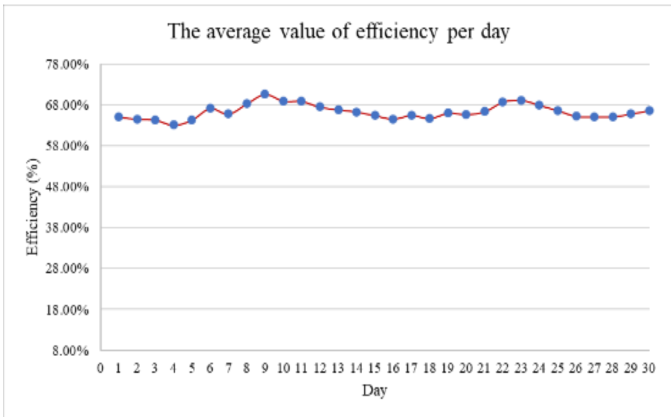

Fig. 3. The average value of efficiency.

5. Conclusion

According to the findings of this study, variations in solar intensity have an impact on the voltage, current, and output power of solar panels. As the sun intensity value increases, the voltage value also increases, while the current value falls. The magnitude of the current and voltage directly influences both the power output and the efficiency percentage achieved. Data was gathered over 30 consecutive days, starting from 08.00 to 15.00 WIT, in Merauke Regency, Papua, Indonesia. The test findings indicate that the mean solar radiation value generated is 728.33 W/m^2, the mean power generated by PV is 283.73 W, TEG generates 0.974 W, and the power achieved in battery charging is 235.97 W.

Acknowledgments

Thank you to the Directorate of Research, Technology, and Community Service (DRTPM) for supporting Basic Research in 2023. This was done through the Directorate General of Higher Education, Research, and Technology in the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia by the researcher.

References

1. Sutikno, T.; Pamungkas, A.; Pau, G.; Yudhana, A.; and Facta, M. (2022). A review of recent advances in metaheuristic maximum power point tracking algorithms for solar photovoltaic systems under the partial-shading conditions. *Indonesian Journal of Science and Technology*, 7(1), 131-158.
2. Wangsupphaphol, A.; Phichaisawat, S.; and Lengkayan, R. (2024). Alternative energy options for a thai durian farm: Feasibility study and experiments for the combination of solar photovoltaics and repurposed lithium-ion batteries. *Indonesian Journal of Science and Technology*, 9(1), 125-144.
3. Ahmad, F.; Qurban, N.; Fatima, Z.; Ahmad, T.; Zahid, I.; Ali, A., Rajppot, S.R.; and Maqbool, E. (2022). Electrical characterization of ii-vi thin films for solar cells application. *ASEAN Journal of Science and Engineering*, 2(2), 199-208.
4. Bhosale, S.K. (2022). Development of a solar-powered submersible pump system without the use of batteries in agriculture. *Indonesian Journal of Educational Research and Technology*, 2(1), 57-64.
5. Irawan, A.K.; Rusdiana, D.; Setiawan, W.; Purnama, W.; Fauzi, R.M.; Fauzi, S.A.; Alfani, A.H.F.; and Arfiyogo, M.R. (2021). Design-construction of a solar cell energy water pump as a clean water source for people in Sirnajaya village, Gununghalu district. *ASEAN Journal of Science and Engineering Education*, 1(1), 15-20.
6. Morales, A.; Lopez, E.J.; Manansala, J.; Intal, J.F.; Loria, M.C.; Mallari, S.; and Pampo, F. (2023). A multi-USB ports solar-powered charging station for mobile phones in duracurve sheds: From educational perspectives. *ASEAN Journal of Science and Engineering Education,* 3(2), 129-138.
7. Laaraba, A.; and Khechekhouche, A. (2018). Numerical simulation of natural convection in the air gap of a vertical flat plat thermal solar collector with partitions attached to its glazing. *Indonesian Journal of Science and Technology*, 3(2), 95-104.
8. Khamaia, D.; Boudhiaf, R.; Khechekhouche, A.; and Driss, Z. (2022). Illizi city sand impact on the output of a conventional solar still. *ASEAN Journal of Science and Engineering*, 2(3), 267-272.
9. Bellila, A.; Souyei, B.; Kermerchou, I.; Smakijk, N.; Sadoun, A.; Elsharif, N.; and Siqueira A. (2024). Ethanol effect on the performance of a conventional solar still. *ASEAN Journal of Science and Engineering,* 4(1), 25-32.
10. Kermerchou, I.; Mahdjoubi, I.; Kined, C.; Khechekhouche, A.; Bellila, A.; and Isiordia, G.E.D. (2022). Palm fibers effect on the performance of a conventional solar still. *ASEAN Journal for Science and Engineering in Materials, 1*(1), 29-36.

11. Bellila, A.; Khechekhouche, A.; Kermerchou, I.; Sadoun, A.; Siqueira, A.M.D.O.; Smakdji, N. (2022). Aluminum wastes effect on solar distillation. *ASEAN Journal for Science and Engineering in Materials*, 1(2), 49-54.
12. Pasha, A.F.; Ali, M.A.; Roy, H.; and Rahman, M.M. (2023). Designing a modified Tchar stove and evaluation of its thermal performance. *Cleaner Chemical Engineering*, 5, 100096.
13. Tyagi, K.; Gahtori, B.; Kumar, S.; and Dhakate, S.R. (2023). Advances in solar thermoelectric and photovoltaic-thermoelectric hybrid systems for power generation. *Solar Energy*, 254, 195-212.
14. Laaraba, A.; and Khechekhouche, A. (2018). Numerical simulation of natural convection in the air gap of a vertical flat plat thermal solar collector with partitions attached to its glazing. *Indonesian Journal of Science and Technology*, 3(2), 95-104.
15. Khamaia, D.; Boudhiaf, R.; Khechekhouche, A.; and Driss, Z. (2022). Illizi city sand impact on the output of a conventional solar still. *ASEAN Journal of Science and Engineering*, 2(3), 267-272.
16. Bellila, A.; Souyei, B.; Kermerchou, I.; Smakijk, N.; Sadoun, A.; Elsharif, N.; and Siqueira A. (2024). Ethanol effect on the performance of a conventional solar still. *ASEAN Journal of Science and Engineering*, 4(1), 25-32.
17. Kermerchou, I.; Mahdjoubi, I.; Kined, C.; Khechekhouche, A.; Bellila, A.; and Isiordia, G.E.D. (2022). Palm fibers effect on the performance of a conventional solar still. *ASEAN Journal for Science and Engineering in Materials*, 1(1), 29-36.
18. Bellila, A.; Khechekhouche, A.; Kermerchou, I.; Sadoun, A.; Siqueira, A.M.D.O.; Smakdji, N. (2022). Aluminum wastes effect on solar distillation. *ASEAN Journal for Science and Engineering in Materials*, 1(2), 49-54.
19. Strömberg, L.J.T. (2022). Models for elasto-electricity and photovoltaic material in the micropower plant. *ASEAN Journal for Science and Engineering in Materials*, 1(2), 67-70.
20. Ganthia, B.P.; and Praveen, B.M. (2023). Design and harmonic elimination of sinusoidal pulse width modulation (SPWM) based five level cascaded H-bridge multilevel inverter for photovoltaic system for educational purposes. *Indonesian Journal of Teaching in Science*, 3(2), 143-160.
21. Valera, Á.; Rodrigo, P.M.; Ceballos, M.A.; Almonacid, F.; and Fernández, E. F. (2023). Design, manufacturing and indoor/outdoor testing of a hybrid thermoelectric-concentrator photovoltaic mono-module at unprecedented ultra-high concentration levels. *Solar Energy Materials and Solar Cells*, 254, 112269.
22. Wen, X.; Ji, J.; Li, Z.; and Song, Z. (2022). Performance analysis of a concentrated system with series photovoltaic/thermal module and solar thermal collector integrated with PCM and TEG. *Energy*, 249, 123777.
23. Singh, D.; Chaubey, H.; Parvez, Y.; Monga, A.; and Srivastava, S. (2022). Performance improvement of solar PV module through hybrid cooling system with thermoelectric coolers and phase change material. *Solar Energy*, 241, 538-552.
24. Verma, S. K.; Kumar, R.; Barthwal, M.; and Rakshit, D. (2022). A review on futuristic aspects of hybrid photo-voltaic thermal systems (PV/T) in solar

energy utilization: Engineering and Technological approaches. *Sustainable Energy Technologies and Assessments*, 53, 102463.

25. Wen, X.; Ji, J.; Song, Z.; Li, Z.; Xie, H.; and Wang, J. (2021). Comparison analysis of two different concentrated photovoltaic/thermal-TEG hybrid systems. *Energy Conversion and Management*, 234, 113940.
26. Fini, M.A.; Gharapetian, D.; and Asgari, M. (2022). Efficiency improvement of hybrid PV-TEG system based on an energy, exergy, energy-economic and environmental analysis; experimental, mathematical and numerical approaches. *Energy Conversion and Management*, 265, 115767.
27. Yang, B.; Xie, R.; Duan, J.; and Wang, J. (2023). State-of-the-art review of MPPT techniques for hybrid PV-TEG systems: Modeling, methodologies, and perspectives. *Global Energy Interconnection,* 6(5), 567-591.
28. Nandiyanto, A.B.D.; Sofiani, D.; Permatasari, N.; Sucahya, T.N.; Wiryani, A.S.; Purnamasari, A.; Rusli, A.; and Prima, E.C. (2016). Photodecomposition profile of organic material during the partial solar eclipse of 9 March 2016 and its correlation with organic material concentration and photocatalyst amount. *Indonesian Journal of Science and Technology*, 1(2), 132-155.
29. Rabaia, M.K.H.; Abdelkareem, M.A.; Sayed, E.T.; Elsaid, K.; Chae, K.J.; Wilberforce, T.; and Olabi, A.G. (2021). Environmental impacts of solar energy systems: A review. *Science of The Total Environment*, 754, 141989.
30. Hariyanto, H.; Parenden, D.; Vincēviča-Gaile, Z.; and Adinurani, P.G. (2020). Potential of new and renewable energy in Merauke regency as the future energy. *In E3S Web of Conferences*, 190, 00012.
31. Kaushik, L.K.; and Muthukumar, P. (2019). Performance assessment of a porous radiant cook stove fueled with blend of waste vegetable oil (WVO) and kerosene. *Energy Procedia*, 158, 2391-2396.
32. Getnet, M.Y.; Gunjo, D.G.; and Sinha, D.K. (2023). Experimental investigation of thermal storage integrated indirect solar cooker with and without reflectors. *Results in Engineering*, 18, 101022.
33. Angappan, G., Pandiaraj, S., Alruabie, A.J., Muthusamy, S., Said, Z., Panchal, H.; Katekar, V.P.; Shoeibi, S.; and Kabeel, A.E. (2023). Investigation on solar still with integration of solar cooker to enhance productivity: *Experimental, exergy, and economic analysis. Journal of Water Process Engineering*, 51, 103470.
34. Coccia, G.; Aquilanti, A.; Tomassetti, S.; Comodi, G.; and Di Nicola, G. (2020). Design, realization, and tests of a portable solar box cooker coupled with an erythritol-based PCM thermal energy storage. *Solar Energy*, 201, 530-540.
35. Latupeirissa, S.; Sahupala, P.; Wullur, C.W.; Andriyono, A.; Rahangmetan, K.A.; and Bako, R. M. (2020). Pemanfaatan Energy Radiasi Matahari Untuk Kebutuhan Rumah Tangga. *Musamus Journal of Electro & Mechanical Engineering*, 2(02).
36. Djafar, Z.; and Piarah, W.H. (2018). A new hybrid of photovoltaic-thermoelectric generator with hot mirror as spectrum splitter. *Journal of Physical Science*, 29, 63-75.
37. Piarah, W.H.; Djafar, Z.; Hariyanto, H.; and Mustofa, M. (2019). A New Simulation of Photovoltaic and Thermoelectric Generator Hybrid System with

a Beam Splitter Cold and Hot Mirror for Low Intensity. *International Review of Mechanical Engineering (IREME)*, 13(9), 559.

38. Jouhara, H.; Żabnieńska-Góra, A.; Khordehgah, N.; Doraghi, Q.; Ahmad, L.; Norman, L.; Axcell, B.; Wrobel, L.; and Dai, S. (2021). Thermoelectric generator (TEG) technologies and applications. *International Journal of Thermofluids*, 9, 100063.
39. Khare, V.; Chaturvedi, P.; and Mishra, M. (2023). Solar Energy System Concept Change from Trending Technology: A Comprehensive Review. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, 100183.
40. Lv, Y.; Han, X.; Chen, X.; and Yao, Y. (2023). Maximizing energy output of a vapor chamber-based high concentrated PV-thermoelectric generator hybrid system. *Energy*, 282, 128882.
41. Tasnim, M.N.; Akter, S.; Shahjalal, M.; Shams, T.; Davari, P.; and Iqbal, A. (2023). A critical review of the effect of light duty electric vehicle charging on the power grid. *Energy Reports*, 10, 4126-4147.
42. Sidibba, A.; Ndiaye, D.; Kobor, D.; El Bah, M.; and Bouhamady, S. (2018). Energy and exergy analysis of a solar photovoltaic module performance under the Sahelian Environment. *International Journal of Physical Sciences*, 13(12), 196-205.
43. Hariyanto, H.; Mustofa, M.; Djafar, Z.; and Piarah, W.H. (2019). Mathematical modeling in combining photovoltaic and thermoelectric generator using a spectrum splitter. *EPI International Journal of Engineering*, 2(1), 74-79.
44. Kırbaş, İ.; Sözen, A.; Tuncer, A.D.; and Kazancıoğlu, F.Ş. (2020). Comparative analysis and forecasting of COVID-19 cases in various European countries with ARIMA, NARNN and LSTM approaches. *Chaos, Solitons and Fractals*, 138, 110015.