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Influences of Environmental Factors of a Hybrid Photovoltaic and Thermoelectric Generation System

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ABSTRAK

Saat ini, pemanfaatan sumber energi terbarukan menjadi salah satu pilihan dalam menjawab tantangan krisis energi. Sistem pembangkit listrik fotovoltaik-termoelektrik hibrida yang menggabungkan keunggulan konversi energi cahaya dan panas dari matahari perlu dikaji kinerjanya. Penelitian ini membahas peningkatan efisiensi pembangkit listrik tenaga surya hybrid panel-termoelektrik dan hubungannya dengan pengaruh faktor lingkungan. Akuisisi data berdasarkan analisis komputasi menganalisis statistik multivariat, seperti regresi, korelasi, boxplot, dan principal component analysis (PCA). Hasil penelitian menunjukkan daya masukan MPPT lebih tinggi dibandingkan daya keluaran, dengan efisiensi tipikal sebesar 99,66%. Peningkatan suhu udara membuat tegangan sedikit menurun, dan daya yang dihasilkan meningkat cukup besar seiring dengan naiknya suhu udara. Peda penelitian terlihat bahwa radiasi ultraviolet (UV) meningkat secara signifikan seiring dengan peningkatan suhu lingkungan.

Kata kunci: *efisiensi, faktor lingkungan, fotovoltaik, analisis statistik, termoelektrik*

ABSTRACT

Recently, using renewable energy sources is one option in answering the challenge of the energy crisis. The hybrid photovoltaic-thermoelectric power generation system is a solution that combines the advantages of converting both light and heat energy from the sun, which needs to be studied. This study discussed the increase in efficiency in a hybrid solar panel-thermoelectric power generation and its relationship to the influence of environmental factors. The data acquisition is based on the computational analyses of multivariate statistics, such as regressions, correlations, boxplots and principal component analysis. It showed the input power of the MPPT was higher than the output power, with a typical efficiency of 99.66%. The rising air temperature decreased the voltages and generated power considerably, increasing as the air temperature rose. Finally, the ultraviolet (UV) radiation increased significantly as the ambient temperature rose.

Keywords*: efficiency, environmental factor, photovoltaic, statistical analysis, thermoelectric*

1. PENDAHULUAN

Energy demand is increasing due to population growth and economic development. Generally, fossil fuel energy sources are gas, oil, and coal. The use of these fuels causes toxicity and climate change impacts **(Al-Waeli, 2024)(Dezfouli, 2024)(Mariprasath, 2024)(Narducci, 2018)**. The use of renewable energy sources as alternative energy is for the future **(Al-Waeli, 2024)(Mariprasath, 2024)(Narducci, 2018)**. Solar energy technology is one of the main roles in renewable energy generation because the price is relatively low, without emissions, mechanical movement and noise. The two main technologies are solar cells and thermal collectors, each converting solar energy into electricity and heat **(Al-Waeli, 2024)(Narducci, 2018)(Pawula, 2021)(Yazawa, 2021)**. Problem Formulation Solar energy is converted into electricity with the help of solar cells **(Waluyo, 2021).** Meanwhile, thermoelectric generation utilizes the heat of sunlight **(Khoiriyah, 2018).** Solar energy is also utilized by generating hybrid solar-thermoelectric cells **(Stefanie, 2021)(Habiburosid, 2019)(Tyagi, 2023)(Prapawan, 2019).**

This generation increases its efficiency (**Saseendran, 2023)(Matias, 2020)(Indira, 2022)(Rodrigo, 2019)(Yan, 2018)(Lorenzi, 2021)(Zhao, 2024)(Lorenzi, 2018)** also reduces waste heat **(Saleh, 2021)** and improves electrical and thermal performance **(Chen, 2023)(Sheikholeslami, 2023)(Sheikholeslami, 2023)(Wang, 2022).** The literature study shows that the hybrid solar-thermoelectric cell system increases efficiency and provides sustainable renewable energy. However, the increase in efficiency varies. Weather conditions affect performance, including efficiency and durability. So, the operation of hybrid systems in various weather conditions is a challenge in research. Based on this, research on the influence of the environment on increasing the efficiency of hybrid generation systems is necessary. The formulation of the research problem is (i) the design of solar-thermoelectric cell hybrid generation and its measurement, (ii) the effect of environmental factor fluctuations on the hybrid system, (iii) the range of power, energy and efficiency increases produced, (iv) the magnitude of the relationship between efficiency increases and environmental parameters, and (v) recommendations for optimizing performance. This study aims to develop solar-thermoelectric cell hybrid generation, analyze its efficiency increases and the effect of environmental factors on performance, and provide recommendations for optimizing performance. The environmental parameters in question are temperature, illumination, humidity, rainfall, pollution and solar radiation power. This research will make a significant contribution to the development of solar-thermoelectric cell hybrid systems. Problem-Solving Approach The problem-solving approach plan is (i) design and realization of solar-thermoelectric hybrid power generation and its measurement, (ii) observation and analysis of the influence of environmental factor fluctuations on daily performance, (iii) measurement and calculation of power, and energy and efficiency increases, (iv) analysis of the relationship between efficiency increases and environmental parameters, and (v) performance optimization. The problem-solving strategy is to measure the electrical quantities and environmental parameters of the solar-thermoelectric hybrid power generation implementation, calculate power fluctuations and efficiency, and calculate the relationship between efficiency increases and environmental parameters based on multivariate statistics and recommendations to optimize its performance. Completing the plan and problem-solving strategy uses primary means, such as electrical and environmental parameter measuring instruments, as well as multivariate statistics **(Durrheim,2004)**. State-of-the-art and novelty: The state-of-the-art efficiency improvements in solar and thermoelectric hybrid power generation can be seen in Table 1.

Table 1. The state-of-the-art of several efficiency improvements in solar and thermoelectric hybrid power generation

Ref.	Title
(Khoiriyah, 2018)	Characteristics of thermoelectric generators using solar thermal energy
(Lorenzi, 2018)	Efficiency of hybrid solar thermoelectric-photovoltaic generators
(Stefanie, 2021)	Characteristics of sensor-based hybrid solar cells
(Prapawan, 2019) **(Matias, 2020)**	Solar cell and thermoelectric hybrid generators
(Rodrigo, 2019)	Passively cooled hybrid thermoelectric generator-concentrator photovoltaic modules
(Yan, 2018)	MEMS-based thermoelectric–photoelectric integrated power generator
(Mahmoudinezhad, 2019)	Experimental and numerical study on the transient behavior of multijunction solar cell-thermoelectric generator
(Waluyo, 2021)	Implementation and evaluation of 3.3 kWp based photovoltaic microgrid-interactive configuration
(Stefanie, 2021)	Hybrid thermoelectric-solar cell Thin Film Sf 170-S Cis 170 Watt
(Saleh, 2021)	Evaluation of a PV-TEG Hybrid
(Lorenzi, 2021)	Practical development of thermoelectric – Photovoltaic hybrid
(Indira, 2022)	Novel hybrid concentrator photovoltaic/thermal and solar thermoelectric generator
(Tyagi, 2023)	Solar thermoelectric and photovoltaic-thermoelectric hybrid generation
(Saseendran, 2023)	Development, optimization, and testing of hybrid solar panel concept
(Chen, 2023)	potential evaluation of thermoelectric cooler driven by dye-sensitized solar cell
(Sheikholeslam, 2023)	photovoltaic-thermoelectric system for building units in the presence of helical tapes and jet impingement of hybrid nanomaterial
(Sheikholeslam, 2023)	photovoltaic cell using hybrid nanofluid confined jet and helical fins for improving electrical efficiency
(Wang, 2022)	PDLC Control with smart light intensity adjustment using photovoltaic-thermoelectric hybrid
(Zhao, 2024)	Synergizing perovskite solar cell and thermoelectric generator

Observing previous research, the generation of solar cells and hybrid solar-thermoelectric cells is a single parameter, namely increasing the efficiency of electricity generation. In reality, the generation is influenced by environmental factors in addition to internal factors. Therefore, it is necessary to conduct research using the latest approach, considering internal and external factors of environmental parameters and analyzing them with multivariate statistics. The novelty and innovation produced in the research are models, performance analysis and forecasting.

2. METHODS

Figure 1 shows the research scheme of the solar cell-thermoelectric hybrid system that was designed and tested. Some of the main components in the solar cell-thermoelectric hybrid system scheme include solar cell modules used in the generating system, thermoelectric modules, batteries, inverters and AC loads. There are several measurement parameters used in the design of this hybrid system, including current, voltage, and power measured at the inverter output.

Each of the two solar panels with a capacity of 150 Wp is connected in series. There are two series connections, so there are four solar panels in total. From the two series connections, they are then connected in parallel and enter the DC-watt meter (1). On the other hand, four thermoelectric packages are connected in series, which then enter the DC-watt meter (2). This thermoelectric circuit is connected in parallel with the solar panel circuit through a diode, where the combination results enter an MPPT (Maximum Power Point Tracking). The

MPPT is then connected to the battery and inverter, which ultimately supplies the AC load in the form of LED lights.

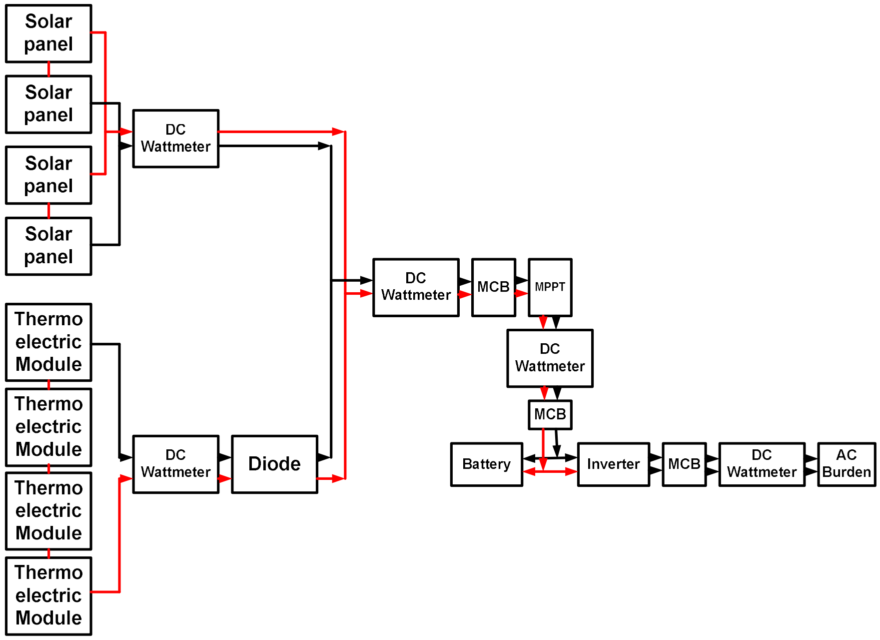

Figure 1. Research implementation system diagram

The measurement results in the solar cell-thermoelectric hybrid system test based on environmental parameters are then analyzed to determine the relationship between the influence of environmental parameters of temperature, humidity, rainfall, pollutants, light intensity and solar radiation power on the voltage and current of the solar cell-thermoelectric output. Analysis of measurement results using multivariate statistical methods (regression, correlation, principal component analysis), system performance analysis and forecasting. Meanwhile, the measuring instruments used are the ombrometer (rainfall), thermocouple (temperature), hygrometer (humidity), lux meter (illumination or light intensity), PM 2.5 (pollution concentration), and solar power meter (sunlight power).

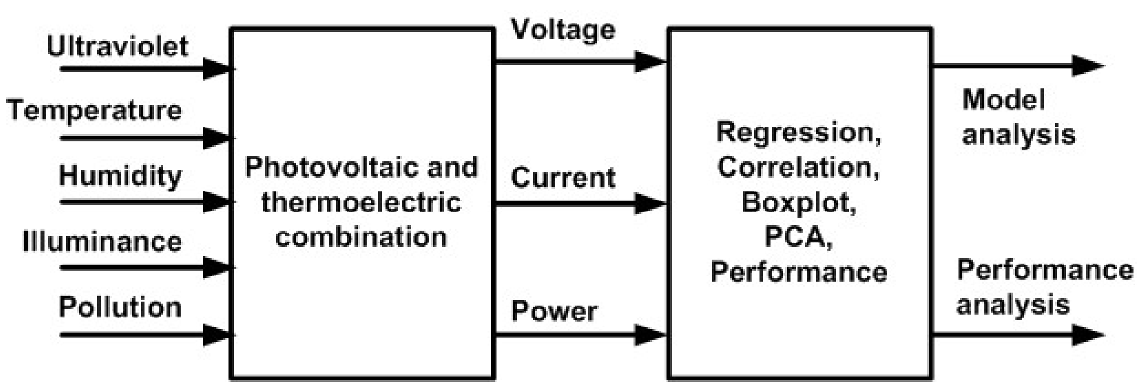

Figure 2. Scheme of acquisition, processing and analysis of measurement data

Figure 2 shows the process diagram of data acquisition, processing and analysis. First, data are obtained from environmental parameter measurements, such as daily time data, rainfall, temperature, humidity, illumination (light intensity), pollution and solar power on a relatively simultaneous basis. Furthermore, data on the hybrid generation system based on solar-thermoelectric cells, in the form of voltage, current and power, need to be obtained in the form of measurement results, to then be analyzed together with environmental parameter measurement data using several multivariate statistical tools, such as regression, correlation, box plot and principal component analysis (PCA) and performance. From the results of this analysis, a model of the relationship between the power generated and environmental parameters will finally be produced.

3. RESEARCH RESULTS AND DISCUSSION

Figure 3 shows several sub-systems of research implementation in the field. These sub-systems include solar panels and thermoelectric packages, where the position of the thermoelectric package is under the solar panel, a panel box containing the main MPPT components, inverters, measuring instruments and protection equipment, and system loads in the form of LED lights. This research system is implemented on the rooftop of Building 1, Itenas.

Figure 3. Several sub-systems of research implementation in the field

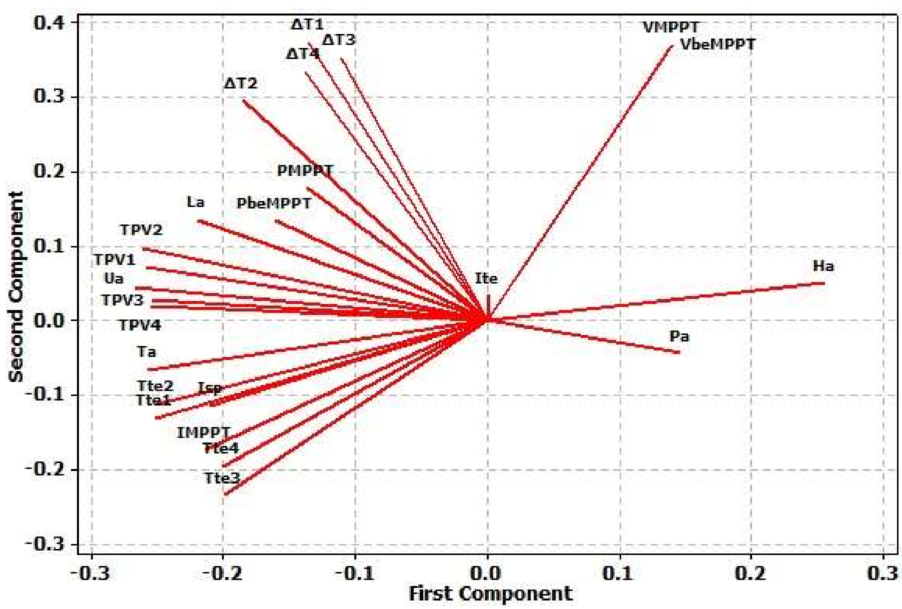

Figure 4. Results of principal component analysis of system and environmental parameters

Figure 4 shows the results of the principal component analysis of system and environmental parameters. In general, quantities of one type create groups. These groups include solar panel temperature (TPV), thermoelectric temperature (Tte), temperature difference (ΔT) between solar panel temperature and thermoelectric temperature, electric current, electric voltage and electric power. Solar panel temperature and thermoelectric temperature are directly proportional to the ambient air temperature. So is the intensity of light (illumination) and ultraviolet radiation (UV). At the same time, air humidity is inversely proportional to air temperature. While air pollution is somewhat proportional to air humidity.

Figure 5 shows the results of the boxplot analysis of system and environmental parameters, where each shows the median (typical) value of the quantity. The typical voltage value before entering the MPPT is 29.95 volts, while after passing through the MPPT it is 28.5 volts. The typical solar panel current is 14.65 amperes, while the typical thermoelectric current is 0.2 amperes. The typical temperatures of the four solar panels are close to each other, namely 51.05°C, 51.6°C, 49.4°C and 49.4°C respectively, for solar panels 1, 2, 3 and 4. While the typical temperatures of the thermoelectric package are 35.15°C, 34.35°C, 33°C and 33.9°C for the same thermoelectric sequence. The temperature difference between the two is 15.75°C, 17.65°C, 15°C, 14.4°C respectively. The typical MPPT current is 15.79 amps. Finally, typical temperature, humidity, pollution and ultraviolet radiation are 31.25°C, 22.45%, 19 µg/m³ and 6.47 mW/cm².

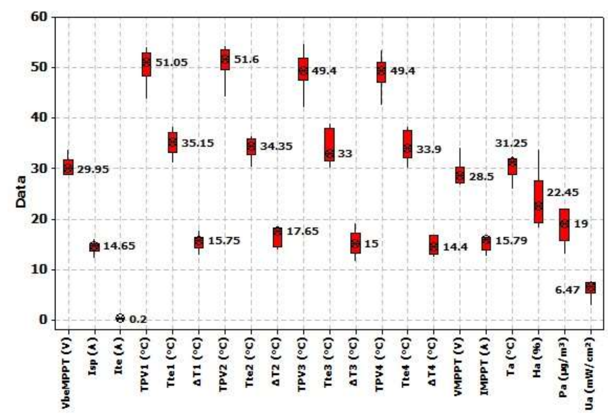

Figure 5. Boxplot analysis of system and environmental parameters

Figure 6 shows the boxplot analysis of power before and after MPPT. Each typical value is 441.5 watts and 440 watts. Thus, when taken from the typical value, the MPPT efficiency is 99.66%. In the power boxplot before MPPT, the first and third quartile show values of 420.6 watts and 468.9 watts. Meanwhile, in the power boxplot after MPPT, the first and third quartiles show values of 412 watts and 453.7 watts.

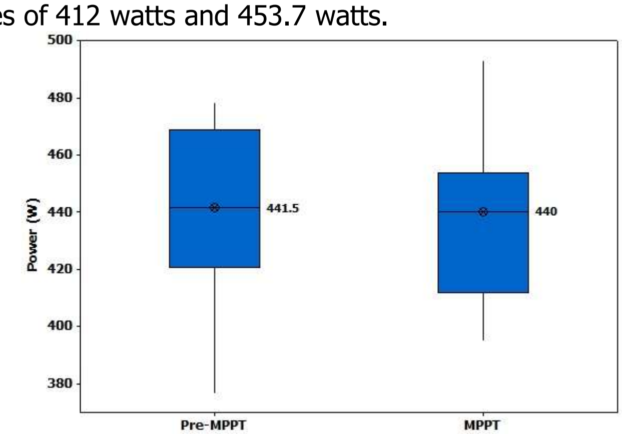

Figure 6. Power boxplot analysis before and after MPPT

Figure 7 shows the boxplot analysis of the illumination (lighting intensity) of the system's surroundings in kilolux (klux). This analysis shows the median (typical) value of 78.5 kilolux. Meanwhile, the first and third quartile values are 75.1 klux and 86.6 klux, respectively.

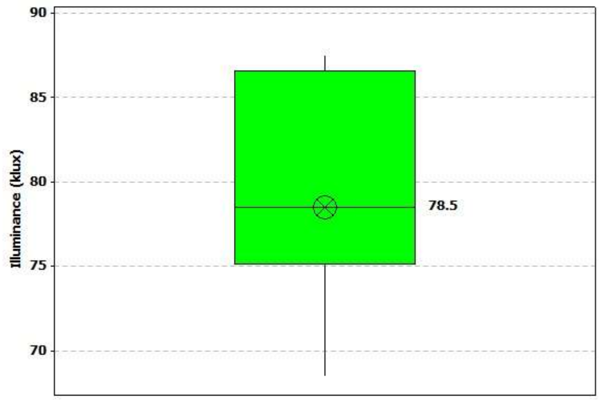

Figure 7. Boxplot analysis of the illumination (lighting intensity) of the system's surroundings

Figure 8 shows four solar panel temperatures as a function of ambient air temperature. In general, the temperature of the solar panel is higher than the ambient air temperature, ranging from 16°C-21°C. The gradient of increasing solar panel temperature to ambient air temperature is 1.37, 1.39, 1.5 and 1.37 times the temperature increase respectively, for solar panels 1, 2, 3 and 4. This is in accordance with research conducted by Prapawan **(Prapawan, 2019)**.

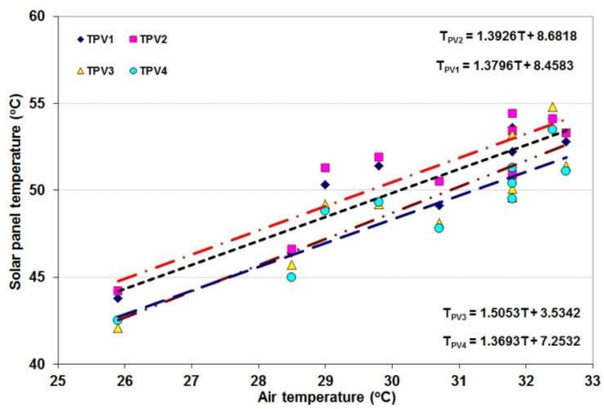

Figure 8. Solar panel temperature as a function of ambient air temperature

Figure 9 shows the thermoelectric temperature as a function of ambient air temperature. As the ambient air temperature increases, the thermoelectric temperature also increases. The rate of increase in thermoelectric temperature is around 1.097, 0.897, 1.15 and 1.08 times the ambient air temperature for thermoelectric packages 1, 2, 3 and 4. In addition, the thermoelectric temperature is usually 2°C - 3°C higher than the ambient air temperature. This is in accordance with research conducted by Prapawan **(Prapawan, 2019).**

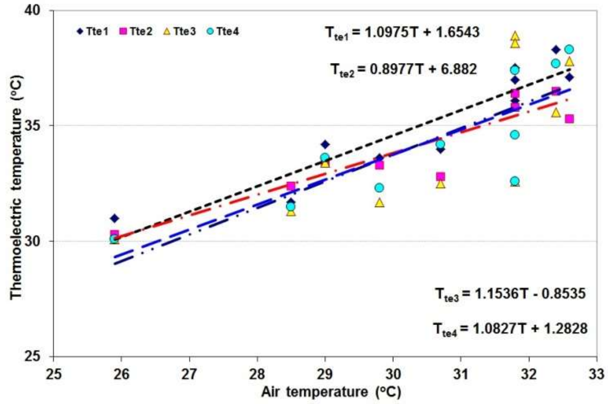

Figure 9. Thermoelectric temperature as a function of ambient air temperature

Figure 10 shows the function of the difference in solar panel and thermoelectric temperature to the ambient air temperature. The temperature difference will increase with increasing ambient air temperature. The increase rate of temperature difference is 0.28, 0.29, 0.35 and 0.28 to ambient air temperature. This is in accordance with the research conducted by Prapawan **(Prapawan, 2019).**

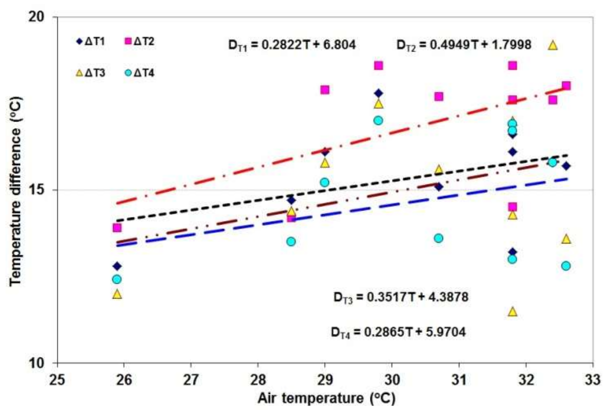

Figure 10. Difference in temperature of solar panels and thermoelectric functions of ambient air temperature.

Figure 11 shows the voltage and direct current magnitude as a function of the ambient air temperature. The solar panel current and MPPT current increase with increasing ambient air temperature; the respective increase rates are 0.4395 and 0.4887. Meanwhile, the voltage before and after MPPT tends to decrease with increasing temperature. This is most likely caused by the increase in current, which results in a voltage drop. Meanwhile, the thermoelectric current decreases very little. This is in accordance with research conducted by Bruno Lorenzi, et al. **(Lorenzi, 2021)**, Jiabin Yan, et al. **(Yan, 2018)** , Mohammed A. Qasim, et al. **(Qasim, 2022)**

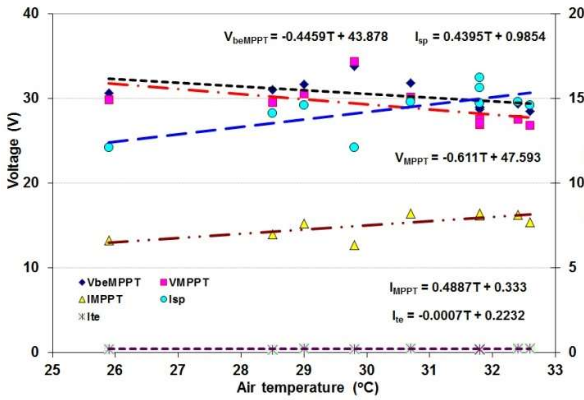

Figure 11. Voltage and current as a function of ambient air temperature

Figure 12 shows the magnitude of the power before and after MPPT as a function of ambient air temperature. Power will increase with increasing temperature. The rate of increase in power against temperature is 6.79 W/°C and 5.0 W/°C, respectively for, before and after entering MPPT. Thus, the increase in power before MPPT is greater than after MPPT. This is in accordance with research conducted by Prapawan **(Prapawan, 2019)**, Mohammed A. Qasim, et al. **(Qasim, 2018)**, Derrick Gharapetian, et al. **(Gharapetian, 2018)**, and Flávio Matias, et al. **(Matias, 2018).**

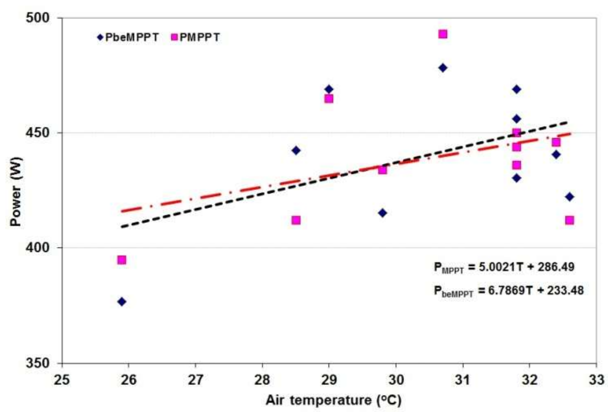

Figure 12. Functional power of ambient air temperature

Figure 13 shows the humidity, pollution, ultraviolet radiation and illumination values as a function of ambient air temperature. When the temperature increases, the illumination (light intensity) will also increase, with an increase rate of 2.03 klux/°C. Likewise, with increasing air temperature, ultraviolet radiation will increase at an increased rate of (0.686 mW/cm^2)/°C. While humidity and air pollution will decrease with increasing ambient air temperature, with a decrease rate of -2.397%/°C and -0.7496 ($\mu g/m^3$)/°C, respectively.

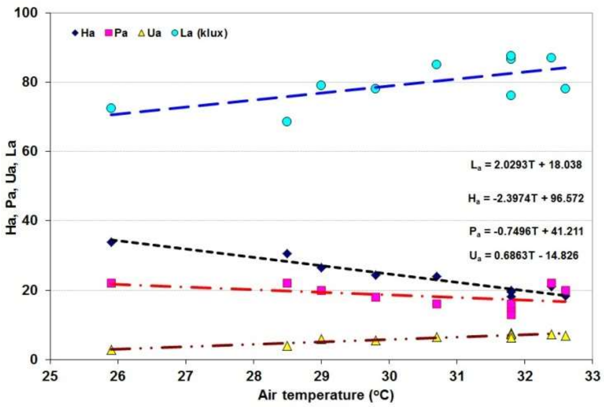

Figure 13. Humidity, pollution, ultraviolet radiation and illumination are functions of ambient air temperature.

4. CONCLUSION

Investigated prototype on a hybrid photovoltaic-thermoelectric, including measurements, has implemented. The temperatures and electrical current on the solar panels and thermoelectric were directly proportional to the surrounding air temperature and illuminance. These quantities were inversely proportional to the ambient air humidity and pollution. The input power of the MPPT was higher than the output power, with a typical efficiency of 99.66%. The temperature difference between the solar panels and photovoltaic modules slightly increased as the ambient temperature rose. The rising air temperature slightly decreased the voltage because the increasing electrical currents caused voltage drops. Of course, the generated power considerable increased as the air temperature rose. Finally, the ultraviolet (UV) radiation increased significantly as the ambient temperature rose.

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