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Analysis of The Impact of Temperature and Discharge Current on The Efficiency of LiFePO4 Batteries in Solar Charging Stations

Istiyo Winarno[1)*], Ach. Fathullah Pria Agung[2)], Belly Yan Dewantara[2)]
[1,2,3] *Department of Electrical Engineering, Faculty of Engineering and Marine Sciences, Hang Tuah University, Indonesia*
istiyo.winarno@hangtuah.ac.id
priaagung121@gmail.com

Abstract_ *The demand for electrical energy is increasing, along with technological advancements and population growth. Many countries still rely on petroleum, coal, and aerosol gasoline, exacerbating global warming. Electric vehicles offer a promising solution to reduce greenhouse gas emissions and dependence on fossil fuels, although their primary challenge is the availability of charging infrastructure. Solar-powered electric motor charging stations can help reduce electricity demand and global warming. An efficient charging system is needed to analyse the impact of temperature and discharge current on the energy produced to achieve this. Several load tests and temperature measurements over 5 days were conducted to cluster temperatures occurring throughout a full day. The tests using data acquisition showed energy losses caused by the effect of temperature on the charging station's storage battery. Energy efficiency graphs for each test case indicated a varied decrease in energy efficiency, with higher efficiency at lower temperatures and smaller energy losses compared to other temperatures. The load amount also affects the magnitude of energy losses. At a 500W load, the average energy loss was 46Wh, while at a 1000W load, the average energy loss was 52Wh per hour of testing the storage battery discharge. In summary, temperature and load amount can affect energy efficiency and the resulting losses.*

Keywords*: Charging station; energy efficiency; solar panel; data acquisition.*

Abstrak_ Kebutuhan energi listrik meningkat seiring dengan perkembangan teknologi dan pertumbuhan populasi. Banyak negara masih bergantung pada minyak bumi, batu bara, dan bensin aerosol, yang memperburuk pemanasan global. Kendaraan listrik menjanjikan solusi untuk mengurangi emisi gas rumah kaca dan ketergantungan pada bahan bakar fosil, meskipun tantangan utamanya adalah ketersediaan infrastruktur pengisian daya. Stasiun pengisian daya motor listrik tenaga surya dapat membantu mengurangi kebutuhan energi listrik dan pemanasan global. Untuk itu, diperlukan sistem pengisian daya yang efisien dengan melakukan analisis pengaruh suhu dan arus peluahan terhadap energi yang dihasilkan. Beberapa pengujian pembebanan dan pengukuran suhu selama 5 hari dilakukan untuk mengklaster suhu yang terjadi selama satu hari penuh. Pengujian yang dihasilkan menggunakan akuisisi data menunjukkan adanya losses energi yang disebabkan oleh pengaruh suhu terhadap baterai penyimpanan stasiun pengisian daya. Grafik efisiensi energi untuk setiap case pengujian menunjukkan adanya penurunan nilai efisiensi energi yang beragam, di mana efisiensi energi pada suhu rendah lebih besar dengan losses energi lebih kecil dibandingkan dengan suhu lainnya. Jumlah pembebanan juga mempengaruhi besarnya losses energi yang dihasilkan. Saat pembebanan 500W, rata-rata losses energi yang dihasilkan adalah 46Wh, sedangkan saat pembebanan 1000W, rata-rata losses energi adalah 52Wh setiap 1 jam pengujian peluahan baterai penyimpanan stasiun pengisian daya. Secara singkat suhu dan jumlah pembebanan dapat mempengaruhi efisiensi energi dan losses yang dihasilkan.

Kata Kunci: Stasiun pengisian daya; efisiensi energi; panel surya; akuisisi data.

I. INTRODUCTION

In the last decade, two major problems facing the world are the depletion of petroleum reserves and the increase in carbon emissions contributing to global climate change. According to CIFOR, global warming is caused by longwave solar radiation trapped by greenhouse gases, further exacerbated by fossil fuel use [1]. In Indonesia, the transportation sector is a major contributor to carbon emissions, with about 30% of the total national emissions coming from this sector, and 88% of them generated by land transportation. Awareness of the impacts of climate change has driven global efforts to find more environmentally friendly solutions in the transportation sector, including the adoption of electric vehicles to reduce greenhouse gas emissions [2].

In Indonesia, Presidential Regulation No. 55 of 2019 facilitates the use and development of electric vehicles. From 2018 to September 2023, approximately 70 thousand units of electric motorcycles have been used, according to Aismoli data [3]. However, a major challenge in this transition is the availability of adequate charging infrastructure. The use of solar power as a power source for electric vehicle charging stations offers an environmentally friendly and economical solution, especially in regions with limited access to electricity.

LiFePO4 (Lithium Iron Phosphate) batteries are becoming the top choice for solar charging stations due to several advantages, such as lower cost, high chemical stability, and minimal environmental impact. However, these batteries also have some limitations, including capacity imbalance and challenges in charge and discharge cycles [4]. Therefore, the use of a Battery Management System (BMS) is important to optimize battery performance, especially in regulating temperature and maintaining battery cell balance.

This study aims to analyze the impact of temperature and discharge current on the efficiency of LiFePO4 batteries in the context of solar charging stations. Optimal battery maintenance will greatly affect the efficiency and operational sustainability of solar-based electric motorcycle charging stations [5]. By understanding the influence of these operational conditions, it is expected that more effective strategies can be developed to maximize battery performance in renewable energy applications.

II. LITERATURE REVIEW

Energy efficiency analysis of storage batteries is an important step to understand how much energy loss occurs in the battery under the influence of temperature and discharge current. This study is usually done by observing how the battery performs when subjected to a certain load under discharge conditions. It is important to understand that environmental conditions, especially temperature, as well as varying discharge currents, can significantly affect battery performance and efficiency. In the context of solar charging stations, measurements of current, voltage, power, and energy on both the AC side (inverter output) and the DC side (battery output) become very important to get a comprehensive picture of the system efficiency [6]. In this research, focus is placed on the use of LiFePO4 (Lithium Iron Phosphate) batteries in solar charging stations. LiFePO4 batteries were chosen for their advantages in various aspects, including high thermal stability, long cycle life, and the ability to deliver consistent power. The high thermal stability of LiFePO4 batteries makes them more resistant to heat and less prone to the risk of fire or explosion compared to other types of batteries. This makes them a safe and reliable choice for applications in electric vehicles and energy storage systems at solar charging stations. In addition, these batteries can last longer as they are able to withstand repeated charge and discharge cycles without significant capacity loss, which is crucial for long-term applications [7].

The efficiency of LiFePO4 batteries is also better compared to other types of batteries due to their ability to provide stable and consistent power throughout their use. This allows them to be an efficient component in energy systems that require high reliability and performance, such as solar charging stations. With lower internal loads, LiFePO4 batteries also offer higher energy efficiency, meaning more of the stored energy can be effectively utilized, thereby reducing operating costs and extending battery life [8].

Solar charging stations themselves are part of renewable energy technology innovations that utilize solar energy to generate electricity. The system consists of several key components, including solar panels that convert sunlight into DC electricity, inverters that convert DC electricity into AC, and storage batteries such as LiFePO4 to store the generated energy. However, the efficiency of these solar charging stations is often affected by environmental factors, such as temperature and sunlight intensity. High temperatures can reduce the efficiency of solar panels and batteries, which means temperature plays an important role in the overall performance of the system [9].

As a country located in the tropics with abundant sunlight, Indonesia has great potential to utilize solar energy as a source of electricity. Solar charging stations can be used to charge electric vehicles, provide energy in remote areas, and as a backup energy source during power outages. With increasing awareness of the importance of using renewable energy to reduce carbon emissions and dependence on fossil fuels, the use of solar charging stations is increasingly relevant. Research and development continue to improve the efficiency of this technology, such as increasing the efficiency of solar panels and better energy storage systems, to optimize battery performance under various operating conditions [10].

The utilization of solar energy as a source of power generation has great potential in Indonesia due to its position in the tropics, which gets sufficient sunlight throughout the year. Solar charging stations have diverse applications, including for charging electric vehicles, providing energy in remote areas, and as a backup energy source during power outages. In addition, these stations help reduce carbon emissions and dependence on fossil

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fuels, in line with the growing awareness of the importance of renewable energy [11].

Research and development continue to improve the efficiency of this technology, both through the development of more efficient solar panels and more reliable energy storage systems. By understanding the factors that affect performance and efficiency, such as temperature and discharge current, this technology can be optimized for future applications [12].

Therefore, understanding factors such as temperature and discharge current that affect the efficiency of LiFePO4 batteries is critical. The findings of this research can contribute to the development of strategies to maximize the performance and reliability of solar charging stations, ensuring that these systems can function efficiently and sustainably in the long term.

III. RESEARCH METHODS

Pada simulasi Software dilakukan optimisasi menggunakan Software Mathlab sebagaimana flowchart simulasi perbaikan THD arus. Proses optimisasi pada rangkaian lampu LED untuk menghasilkan nilai THD arus terbaik menggunakan metode MQPSO dengan proses 100 kali iterasi. Sesudah dilakukan optimisasi pada rangkaian lampu LED untuk menurunkan nilai THD, didapatkan data tabel nilai komponen lampu LED, THD arus dan c-rms.

A. Research Flow

In this research, several stages will be carried out to test the effect of temperature and discharge current on the energy efficiency produced by the solar charging station, as shown in Figure 1.

[Figure 1 about here]

First, a literature study of previous research will be conducted on the theoretical basis of solar power plant planning, the theoretical basis of the effect of temperature and discharge current on battery durability. Then the planning of power requirements and observation of PV potential will be carried out to adjust the components to be used. After the power requirements have been calculated, the system design will continue. The system will be checked to ensure that all systems run according to function. If all systems have been confirmed to run according to function, several discharge experiments will be carried out with various test cases. The discharge becomes data that will be processed in the ANOVA test where it will be found how influential the temperature and current of the discharge are on the efficiency of the energy produced.

B. System Configuration

In this research the components that will be used are as follows: Solar panel (PV), LiFePO4 battery, Hybrid inverter, Data acquisition and battery management system (BMS). Figure 2 shows the detailed system configuration.

[Figure 2 about here]

Solar panels as a source of energy at the charging station and a Hybrid inverter is a system that controls the current and voltage produced by solar panels and converts the current that was originally DC from solar panels into AC. Then what will be the focus of this research is the battery as a storage medium for energy generated by solar panels at the charging station. BMS is a system that can manage the temperature on the battery and can be used as a battery feasibility measurement system the Bluetooth module is used to view data taken from BMS using a cellphone, then the electric motor is an object that will be charged at the solar charging station.

C. Discharge Test Conditioning

In research is inseparable from testing, it aims to see the characteristics of current, voltage, power, energy and energy efficiency. In this study, the testing mechanism was carried out by providing conditioning when carrying out the discharge. Where conditioning is carried out with various variations from each trial. In each trial, the data obtained is analyzed to determine patterns and trends that can provide valuable insights. These tests involving various variations not only help in understanding the characteristics of the system in depth but also in evaluating the performance of the system in various situations. This provides an important foundation for the development of more efficient and reliable technologies in the future. Overall, the testing process in this study was a crucial step that helped ensure that every aspect of the system was thoroughly tested. Thus, the research results are reliable and significantly contribute to the technology. The testing plan is outlined in Table 1.

[Table 1 about here]

Various variations of each conditioning will be charged at three different temperature ranges, namely low (28°C-32°C), medium (33°C-37°C) and high (38°C-42°C). This is done to see the amount of energy produced by the charging station when discharging with the influence of the temperature in the charging station box and the discharge current.

IV. RESULTS AND DISCUSSIONS

A. Research Location

The research location is a place or object for data collection by researchers to fulfill data in accordance with the formulation of the problem and the objectives of this research. The location that will be used by researchers in collecting data for this research is in the Surabaya City area, Sukolilo District, precisely on Jalan Arif Rahman Hakim with coordinates 7°17'31.6 “S 112°47'39.8 ”E shown in Figure 3. Researchers took this location because this location is an open area that avoids shading so this location remains exposed to sunlight and is suitable for charging station installation. The time taken by researchers to collect data takes several weeks to complete various conditioning variations.

[Figure 3 about here]

B. Daily Temperature Measurement in the Charging Box Panel

The temperature in a Panel charging box is affected by various external factors, including the temperature of the surrounding environment which determines the initial temperature baseline and the potential increase or decrease in temperature in the box. In addition, ventilation and air circulation around the box are instrumental in managing the heat generated from charging activities. Other factors such as exposure to direct sunlight can significantly increase the temperature, while environmental humidity can affect the effectiveness of cooling. Table 2 is the temperature measurement data for 5 days to determine the temperature range for conditioning.

[Table 2 about here]

These temperature measurements are taken for 24 hours to see the real temperature that will occur at the charging station. The above temperature measurements are taken when the sky conditions are clear. Data collection is not carried out or considered a failure when the sky conditions are cloudy because in this study, the charging station used uses renewable energy from solar heat. After measuring the temperature for 5 days, the lowest temperature was 28°C and the highest temperature was 42°C. The temperature measurement results are then divided into 3 parts, namely low, medium, and high with the range of each part being 5°C. This results in the categories of low (28°C-32°C), medium (33°C-37°C), and high (38°C-42°C).

C. Power Discharge Testing with System Condition Connected to Solar Panel

This conditioning is done to see the effect of solar panels on storage batteries during discharge conditions. Solar panels generate power based on the intensity of sunlight received. Variations in sunlight intensity, such as those caused by clouds, time of day, and weather conditions, can cause fluctuations in the power generated. The power going into the battery from the solar panel causes a chemical reaction inside the storage battery, which generates heat. This heat will affect the performance of the storage battery, thus affecting the efficiency of the energy produced by the battery during discharge conditions. The effect of each test case will be calculated using Equation 1.

$$Energy\ Efficiency(\%) = \frac{energy\ AC\ (after\ inverter)}{energy\ DC\ (after\ battery)} \times 100\%$$

This efficiency percentage calculation will be used in each experiment that has been carried out to see the energy efficiency value in each case. The test results in each case will be explained as follows:

1. Discharge Testing with No-Load Conditioning

This sub-section will discuss the amount of energy efficiency produced by the battery when the conditioning is connected to the solar panel without any load. Testing will be done three times to increase the accuracy of energy efficiency measurements. The test results will be displayed in the form of tables and graphs. Table 3 and Figure 4 are the results of three experiments, testing three times. Analysis of the results of this test will help in understanding the effect of no-load conditions on the energy efficiency produced by the battery and the following is one of the energy efficiency calculations from this test by Equation 1.

$$Energy\ Efficiency\ (\%) = \frac{4{,}2\ Wh}{22{,}3\ Wh} \times 100\% = 18\%$$

It can be seen in one of the energy efficiency calculations with no-load discharge testing, the energy obtained on the AC side (after the inverter) is 4.2 Wh and on the DC side (after the battery) 22.3 Wh, where after calculating the percentage of energy efficiency obtained is 18%.

[Table 3 about here]

Table 3 shows the results of reading the voltage, current, power, and energy values on the AC and DC sides to determine energy efficiency during no-load conditions. In the energy column on the AC side, there is no significant difference in value, where the value only ranges from 3.8Wh to 4.3Wh. This is due to the presence of indicator lights in each plug in the charging panel box. Furthermore, the energy column on the DC side also does not show a significant change in value. The value only ranges from 21.9Wh to 24.3Wh. This value is generated by the inverter load used in the charging box panel. And the following is the overall calculation, the difference in energy values on the AC and DC sides shows that the minimal load present in this system does not significantly affect energy efficiency.

[Figure 4 about here]

Figure 4 shows that in the experiments with no-load conditioning, the same energy efficiency values were obtained at temperatures of 28°C-32°C and 33°C-37°C. The dark green color represents the first experiment, the green color represents the second experiment, and the gray color represents the third experiment. The energy efficiency values obtained in each experiment were 18% for the first experiment, 19% for the second experiment, and 19% for the third experiment. At 38°C-42°C, all tested energy efficiency values decreased slightly compared to other temperatures, with values of 17%, 18%, and 17% in each experiment.

2. Discharge Testing with 500W Load

This sub-section will discuss the amount of energy efficiency produced by the battery when the conditioning is connected to a solar panel with a 500-watt load. The test will be carried out three times to increase the accuracy of

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the amount of energy efficiency. The test results will be displayed in the form of tables and graphs. Table 4 and Figure 5 are the results of three trials and the following is one of the energy efficiency calculations from this test following Equation 1.

$$Energy\ Efficiency\ (\%) = \frac{446\ Wh}{484\ Wh} \times 100\% = 92\%$$

It can be seen in one of the energy efficiency calculations with a discharge test with a 500W load, the energy obtained on the AC side (after the inverter) is 446 Wh and on the DC side (after the battery) 484 Wh, where after calculating the percentage of energy efficiency obtained is 92%.

[Table 4 about here]

Table 4 shows the results of the discharge test with a 500W load. In the energy column on the AC side, there is no significant difference in value, where the values only range from 446Wh to 448Wh. Then on the energy column on the DC side, the values range from 482Wh to 506Wh.

[Figure 5 about here]

Figure 5 shows that in experiments with conditioning with a 500W load, slightly different energy efficiency values are obtained at each temperature range, where at temperatures 28° C - 32°C the efficiency value in each experiment is different, namely 92%, 93% and 91%. At temperatures of 33°C - 37°C, the same energy efficiency value is obtained in each experiment, namely 90%. Then for temperatures 38°C - 42°C the value of energy efficiency has decreased slightly compared to other temperatures, namely 89%, 88% and 89% in each experiment.

6. Discharge Testing with 1000W Load

This sub-section will discuss the amount of energy efficiency produced by the battery when the conditioning is connected to a solar panel with a 1000W load. The test will be carried out three times to increase the accuracy of the amount of energy efficiency. The test results will be displayed in the form of tables and graphs. Table 5 and Figure 6 are the results of three trials. The following is one of the energy efficiency calculations from this test by Equation 1.

$$Energy\ Efficiency\ (\%) = \frac{845\ Wh}{899\ Wh} \times 100\% = 94$$

It can be seen in one of the energy efficiency calculations with a discharge test with a 1000W load, the energy obtained on the AC side (after the inverter) is 845 Wh and on the DC side (after the battery) 899 Wh, where after the calculation the percentage of energy efficiency obtained is 94%.

[Table 5 about here]

Table 5 shows the results of the discharge test with a 1000Watt load. In the energy column on the AC side, there is no significant difference in value, where the values only range from 842Wh to the highest 846Wh. Then on the energy column on the DC side the values range from 891Wh to 909Wh.

[Figure 6 about here]

Figure 6 shows that in experiments with 1000W loading conditioning, the same energy efficiency value is obtained at temperatures 28°C – 32°C and 33°C – 37°C, namely 94%, only at 28°C – 32°C during the second experiment the energy efficiency value is 95%. Then at temperatures 38°C – 42°C all tested energy efficiency values decreased slightly from other temperatures with values of 93%, 92% and 93% in each experiment.

D. D. Unconnected Solar Panel Discharge Testing

The discharge conditioning without connected solar panels is done to see the effect of discharge from the storage battery. In this condition, the battery does not receive power from the solar panel, so it is not affected by the intensity of sunlight. However, charging still causes a chemical reaction inside the storage battery, which generates heat. This heat will affect the performance and lifespan of the storage battery at the charging station when charging the electric motor. During this condition, charging will be divided into 3, namely charging without load, 1 load and 2 loads.

1. Discharge Testing with No-Load Conditioning

This sub-section will discuss the amount of energy efficiency produced by the battery when conditioning without connecting to solar panels without any load. Testing will be carried out three times to increase the accuracy of the amount of energy efficiency. Then the results of the test will be displayed in the form of tables and graphs. Table 6 and Figure 7 are the results of three tests and the following is one of the energy efficiency calculations from this test based on Equation 1.

$$Energy\ Efficiency\ (\%) = \frac{4{,}2\ Wh}{22{,}9\ Wh} \times 100\% = 18\%$$

It can be seen in one of the energy efficiency calculations with no-load discharge testing, the energy obtained on the AC side (after the inverter) is 4.2 Wh and on the DC side (after the battery) 22.9 Wh, where after calculating the percentage of energy efficiency obtained is 18%.

[Table 6 about here]

Table 6 shows the results of the discharge testing with no-load conditioning. In the energy column on the AC side, there is no significant difference in value, where the values only range from 4.1Wh to the highest 4.3Wh. Then on the energy column on the DC side the values range from 22.5Wh to 24.7Wh.

[Figure 7 about here]

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10.21070/jeeeu.v8i2.1700

Figure 7 shows that in experiments with no-load conditioning, the same energy efficiency value is obtained at temperatures of 28°C - 32°C and 33°C - 37°C, namely 18%. Then at temperatures of 38°C - 42°C all tested energy efficiency values decreased slightly from other temperatures with values of 16%, 17% and 17% in each experiment.

2. Discharge Testing with a 500-watt Load

This sub-section will discuss the amount of energy efficiency produced by the battery when conditioning without connecting to solar panels with a 500Watt load. Testing will be carried out three times to increase the accuracy of the amount of energy efficiency. Then the results of the test will be displayed in the form of tables and graphs. Table 7 and Figure 8 below are the results of three tests. The following is one of the energy efficiency calculations from this test based on Equation 1.

$$Energy\ Efficiency\ (\%) = \frac{448\ Wh}{482\ Wh} \times 100\% = 93\%$$

It can be seen in one of the energy efficiency calculations with no-load discharge testing, the energy obtained on the AC side (after the inverter) is 448 Wh and on the DC side (after the battery) 482 Wh, where after calculating the percentage of energy efficiency obtained is 93%.

[Table 7 about here]

Table 7 shows the results of reading the voltage, current, power and energy values on the AC and DC sides to determine energy efficiency under 500Watt loading conditions. In the energy column on the AC side, there is no significant difference in value, where the value only ranges from 443Wh-448Wh. Then on the energy column on the DC side, the value ranges from 482Wh to 497Wh.

[Figure 8 about here]

Figure 8 shows that in experiments with conditioning with a 500W load, the energy efficiency value decreases from low to high temperatures, where at temperatures 28°C - 32°C, the energy efficiency values are 93%, 92% and 91% in each experiment, temperatures 33°C - 37°C are 90%, 91% and 90% and at temperatures 38°C - 42°C, the energy efficiency value is the smallest of the other temperatures, namely 90%, 89% and 90% in each experiment.

3. Discharge Testing with 1000-Watt Load

This sub-section will discuss the amount of energy efficiency produced by the battery when conditioning without connecting to solar panels with a 1000W load. Testing will be carried out three times to increase the accuracy of the amount of energy efficiency. Table 8 and Figure 9 below are the results of three tests. The following is one of the energy efficiency calculations from this test under Equation 1.

$$Energy\ Efficiency\ (\%) = \frac{844\ Wh}{890\ Wh} \times 100\% = 95\%$$

It can be seen in one of the energy efficiency calculations with no-load discharge testing, the energy obtained on the AC side (after the inverter) is 844 Wh and on the DC side (after the battery) 890 Wh, where after calculating the percentage of energy efficiency obtained is 95%.

[Table 8 about here]

Table 8 shows the results of reading the voltage, current, power and energy values on the AC and DC sides to determine energy efficiency during 1000W loading conditions. In the energy column on the AC side, there is no significant difference in value, where the value only ranges from 841Wh to 846Wh. Then on the energy column on the DC side, the value ranges from 889Wh to 895Wh.

[Figure 9 about here]

1. Figure 9 shows that in experiments with 1000W loading conditioning, the same energy efficiency value is obtained at temperatures 28°C - 32°C and 33°C - 37°C, namely 95%, only at temperatures 34°C - 36°C during the second experiment the energy efficiency value is 94%. Then at temperatures 38°C - 42°C all tested energy efficiency values decreased slightly from other temperatures with a value of 94% in each experiment.

V. CONCLUSION

Based on the results of data collection from tests that have been carried out in the research Analysis of the Impact of Temperature and Discharge Current on the Efficiency of Lifepo4 Batteries on Solar Charging Stations using data acquisition shows that there are energy losses caused by the influence of temperature on the charging station storage battery. The energy efficiency graph of each test case also shows a decrease in the value of energy efficiency that varies, where the energy efficiency generated during discharge testing at low temperatures (28°C - 30°C) is always greater with smaller energy losses than the other two temperatures. The amount of loading can also affect the amount of energy losses generated. When loading 500W, the average energy losses generated are 46Wh, while when loading 1000W, the average energy losses are 52Wh every 1 hour of charging station storage battery discharge testing.

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*Corespondent e-mail address istiyo.winarno@hangtuah.ac.id
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LIST OF TABLES

Table 1. Test variation

Solar Panel Connected	Unconnected Solar Panels
Without loadings	Without loadings
500W Loadings	500W Loadings
1000W Loadings	1000W Loadings

Table 2. Temperature measurement and clustering

Time	Temp. H-1	Temp. H-2	Temp. H-3	Temp. H-4	Temp. H-5	Average Temp.	Temp. Cluster
06.00-06.30	28°C	28°C	28°C	28°C	28°C	28°C	Low
06.30-07.00	28°C	28°C	29°C	28°C	28°C	28°C	
07.00-07.30	29°C	29°C	29°C	29°C	29°C	29°C	
07.30-08.00	30°C	31°C	30°C	30°C	31°C	30°C	
08.00-08.30	32°C	32°C	31°C	31°C	32°C	32°C	
08.30-09.00	33°C	32°C	33°C	33°C	34°C	33°C	Medium
09.00-09.30	34°C	34°C	35°C	34°C	34°C	34°C	
09.30-10.00	35°C	35°C	35°C	36°C	35°C	35°C	
10.00-10.30	36°C	37°C	36°C	36°C	36°C	36°C	
10.30-11.00	38°C	38°C	38°C	37°C	38°C	38°C	High
11.00-11.30	39°C	39°C	39°C	39°C	39°C	39°C	
11.30-12.00	40°C	40°C	40°C	40°C	40°C	40°C	
12.00-12.30	41°C	42°C	40°C	41°C	41°C	41°C	
12.30-13.00	42°C	42°C	42°C	41°C	41°C	42°C	
13.00-13.30	40°C	40°C	40°C	39°C	40°C	40°C	
13.30-14.00	38°C	39°C	38°C	37°C	38°C	38°C	
14.00-14.30	36°C	36°C	36°C	36°C	36°C	36°C	Medium
14.30-15.00	35°C	35°C	35°C	35°C	35°C	35°C	
15.00-15.30	34°C	34°C	34°C	34°C	34°C	34°C	
15.30-16.00	34°C	33°C	33°C	34°C	33°C	33°C	
16.00-16.30	31°C	31°C	31°C	31°C	31°C	31°C	Low
16.30-17.00	30°C	30°C	30°C	30°C	30°C	30°C	
17.00-17.30	29°C	29°C	29°C	29°C	29°C	29°C	
17.30-18.00	29°C	29°C	28°C	29°C	29°C	29°C	
18.00-18.30	28°C	29°C	28°C	29°C	28°C	28°C	
…	…	…	…	…	…	…	
05.30-06.00	28°C	28°C	28°C	28°C	28°C	28°C	

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Vol. 8, No. 2, October 2024
10.21070/jeeeu.v8i2.1700

Table 3. Solar panel connected no-load discharge testing

Panel Temp. (°C)	Testing	AC				DC				Losses (Wh)
		V (V)	I (A)	P (W)	E (Wh)	V (V)	I (A)	P (W)	E (Wh)	
Low (28-32)	1	220,1	0,019	4,21	4,2	51,1	0,44	22,84	22,3	-18.1
	2	219,8	0,019	4,25	4,3	50,8	0,45	23,32	22,9	-18.6
	3	219,7	0,019	4,22	3,8	50,6	0,44	22,36	21,9	-18.1
Medium (33-37)	1	220,3	0,019	4,18	4,2	51,2	0,47	24,14	23,1	-18.9
	2	220,1	0,019	4,32	4,3	50,4	0,47	23,89	22,6	-18.3
	3	219,9	0,019	4,37	4,3	49,8	0,47	23,72	22,5	-18.2
High (38-42)	1	220,4	0,018	4,13	4,2	51,4	0,49	25,21	24,2	-20.0
	2	219,6	0,019	4,23	4,3	50,9	0,50	25,76	23,9	-19.6
	3	219,9	0,019	4,18	4,2	50,7	0,49	24,86	24,3	-20.1

Table 4. Discharge testing with 500W load connected to solar panel

Panel Temp. (°C)	Testing	AC				DC				Eff	Losses (Wh)
		V (V)	I (A)	P (W)	E (Wh)	V (V)	I (A)	P (W)	E (Wh)		
Low (28-32)	1	219,8	2,01	445,3	446	50,6	9,47	479,4	484	92%	- 38
	2	220,2	2,01	445,8	448	51,6	9,33	481,6	482	93%	- 34
	3	219,7	2,01	447,2	446	50,9	9,46	481,8	485	91%	- 39
Medium (33-37)	1	220,6	2,02	444,8	447	51,2	9,41	482,1	492	90%	- 45
	2	221,3	2,01	443,9	447	51,8	9,38	486,3	496	90%	- 49
	3	220,4	2,02	445,4	448	50,9	9,52	484,8	495	90%	- 47
High (38-42)	1	219,9	2,03	446,2	445	51,2	9,61	492,4	500	89%	- 55
	2	220,1	2,02	444,7	446	50,8	9,70	493,2	506	88%	- 60
	3	221,2	2,01	444,1	448	51,2	9,62	492,9	503	89%	- 55

Table 5. Discharge testing with 1000W load connected to solar panel

Panel Temp. (°C)	Testing	AC				DC				Eff	Losses (Wh)
		V (V)	I (A)	P (W)	E (Wh)	V (V)	I (A)	P (W)	E (Wh)		
Low (28-32)	1	222,1	3,75	834,7	845	51.8	17.2	893.2	899	94%	-54
	2	221,7	3,77	836,2	846	52.3	17.0	891.2	891	95%	-45
	3	221,1	3,78	835,2	844	51.7	17.3	893.3	898	94%	-54
Medium (33-37)	1	221,9	3,77	835,8	843	52.2	17.1	893.1	897	94%	-54
	2	222,3	3,76	836,4	845	52.1	17.1	893.4	899	94%	-54
	3	220,9	3,78	834,9	842	51.8	17.2	892.1	895	94%	-53
High (38-42)	1	221,7	3,77	836,3	843	51.9	17.3	896.3	907	93%	-64
	2	221,8	3,77	835,7	846	52.4	17.0	890.2	909	93%	-63
	3	220,9	3,77	833,9	843	52.4	17.1	896.9	906	93%	-63

Table 6. Solar panel connected no-load discharge testing

Panel Temp. (°C)	Uji Coba	AC				DC				Eff	Losses (Wh)
		V (V)	I (A)	P (W)	E (Wh)	V (V)	I (A)	P (W)	E (Wh)		
Low (28-32)	1	219,6	2,02	444,8	448	50,8	9,39	477,5	482	93%	- 34
	2	220,1	2,01	442,2	445	50,7	9,45	479,4	484	92%	- 39
	3	219,8	2,01	441,9	443	51,2	9,38	480,3	486	91%	- 43
Medium (33-37)	1	219,8	2,04	444,8	444	51,4	9,36	481,4	494	90%	- 50
	2	220,2	2,01	443,2	448	50,9	9,46	481,9	493	91%	- 45
	3	220,7	2,01	444,2	446	50,9	9,49	483,8	495	90%	- 49
High (38-42)	1	220,8	2,00	442,5	447	51,2	9,45	483,8	496	90%	- 49
	2	220,6	2,02	445,2	443	51,3	9,44	483,8	497	89%	- 54
	3	220,6	2,01	443,4	445	50,8	9,51	483,8	494	90%	- 49

Table 7. Discharge testing with 500W load connected to solar panel

Panel Temp. (°C)	Testing	AC				DC				Losses (Wh)
		V (V)	I (A)	P (W)	E (Wh)	V (V)	I (A)	P (W)	E (Wh)	
Low (28-32)	1	219,8	0,019	4,39	4,2	50,7	0,46	23,15	22,9	-18.7
	2	219,8	0,018	3,95	4,1	50,9	0,45	22,9	22,5	-18.4
	3	219,7	0,018	4,12	4,1	50,6	0,47	23,78	22,7	-18.6
Medium (33-37)	1	219,9	0,020	4,39	4,3	50,8	0,46	24,17	23,1	-18.8
	2	220,01	0,019	4,18	4,2	50,8	0,46	23,36	22,6	-18.4
	3	220,04	0,020	4,4	4,3	50,7	0,48	24,33	23,4	-19.1
High (38-42)	1	219,9	0,019	4,17	4,1	50,8	0,48	24,38	24,3	-20.2
	2	220,05	0,019	4,18	4,2	50,9	0.48	24,43	23,7	-19.5
	3	220,11	0,020	4,4	4,2	50,9	0,51	25,95	24,7	-20.5

Table 8. Discharge testing with 1000W load connected to solar panel

Panel Temp. (°C)	Testing	AC				DC				Eff	Losses (wh)
		V (V)	I (A)	P (W)	E (Wh)	V (V)	I (A)	P (W)	E (Wh)		
Low (28-32)	1	221,7	3,77	836,4	844	51,7	17,2	889,2	890	95%	- 46
	2	221,1	3,78	835,8	841	51,3	17,4	890,2	889	95%	- 48
	3	220,9	3,79	836,8	842	51,9	17,1	888,9	891	95%	- 49
Medium (33-37)	1	221,9	3,77	837,2	844	51,2	17,4	890,4	891	95%	- 47
	2	222,1	3,78	835,9	843	52,5	17	892,5	893	94%	- 50
	3	221,5	3,78	836,4	846	51,8	17,2	889,7	890	95%	- 44
High (38-42)	1	222,5	3,76	837,8	842	52,8	16,9	892,9	892	94%	- 50
	2	221,7	3,78	837,2	844	51,9	17,2	893,3	894	94%	- 50
	3	221,3	3,78	836,2	843	51,8	17,2	892,6	895	94%	- 52

Journal of Electrical and Electronic Engineering-UMSIDA
ISSN 2460-9250 (print), ISSN 2540-8658 (online)
Vol. 8, No. 2, October 2024
10.21070/jeeeu.v8i2.1700

LIST OF FIGURES

Journal of Electrical and Electronic Engineering-UMSIDA
ISSN 2460-9250 (print), ISSN 2540-8658 (online)
Vol. 8, No. 2, October 2024
10.21070/jeeeu.v8i2.1700

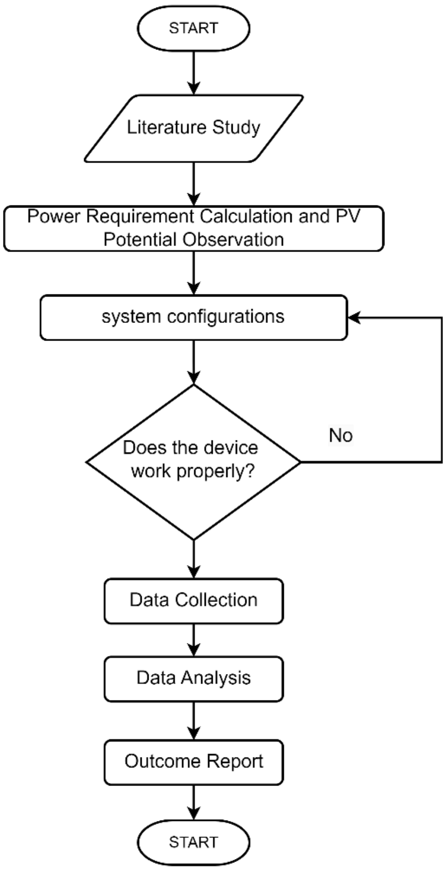

Figure 1. Research Flow

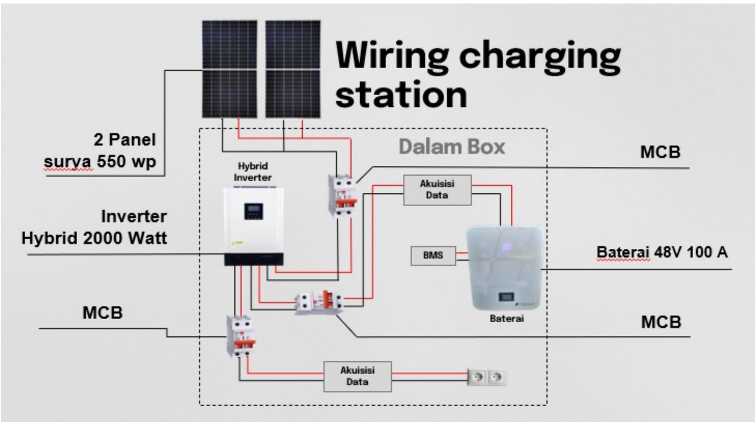

Figure 2. System Configuration

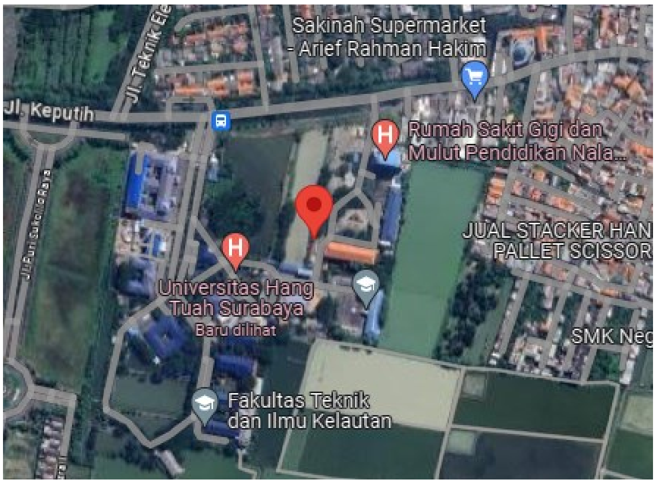

Figure 3. Coordinates of the research location in satellite view

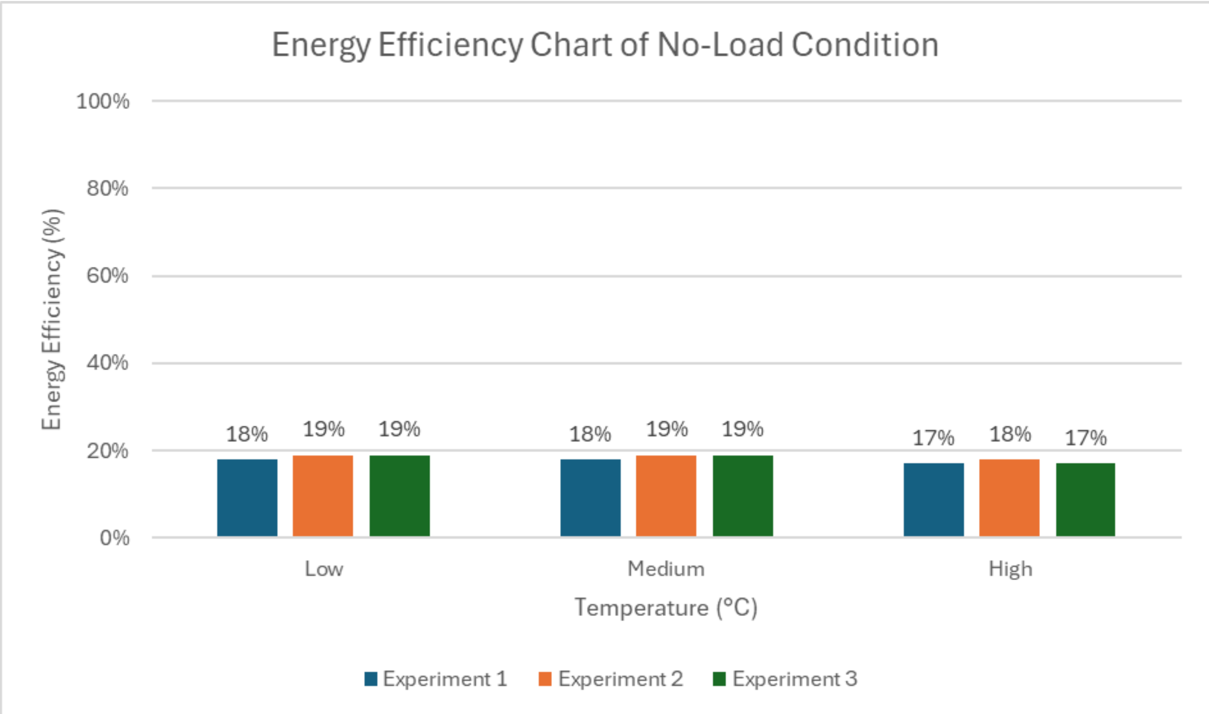

Figure 4. Chart of energy efficiency without loading

JEEE-U Journal of Electrical and Electronic Engineering-UMSIDA
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Vol. 8, No. 2, October 2024
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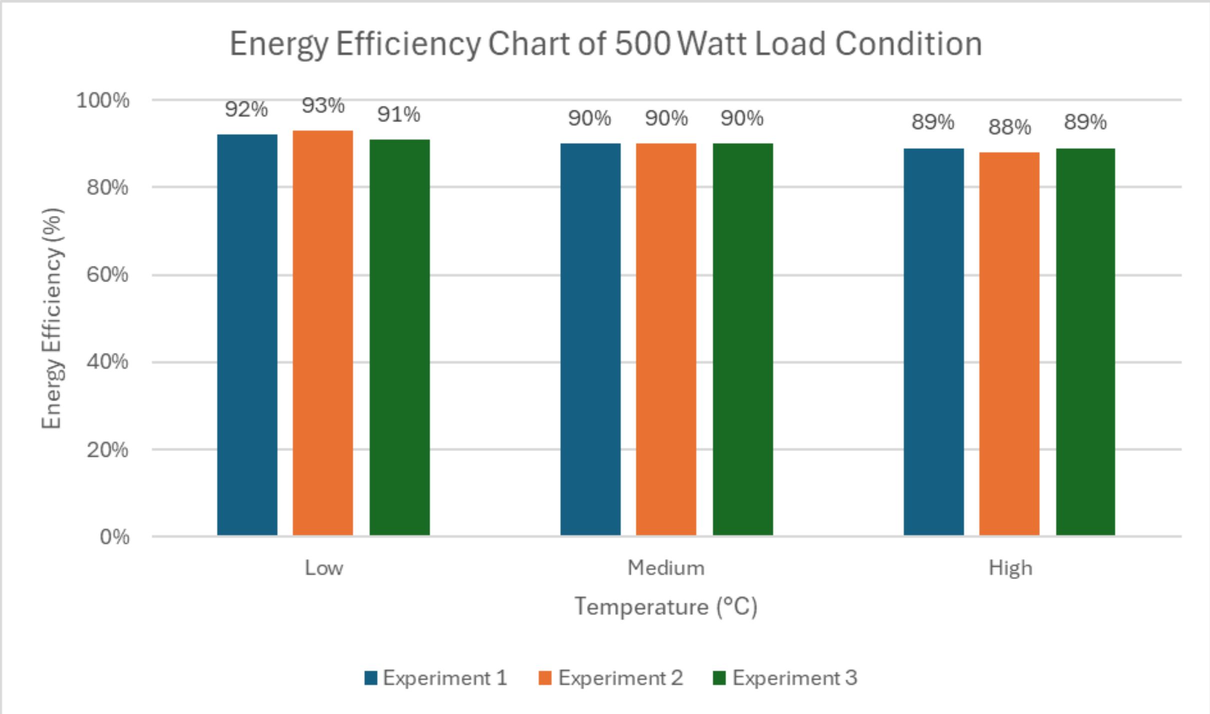

Figure 5. Energy efficiency chart of 500W load

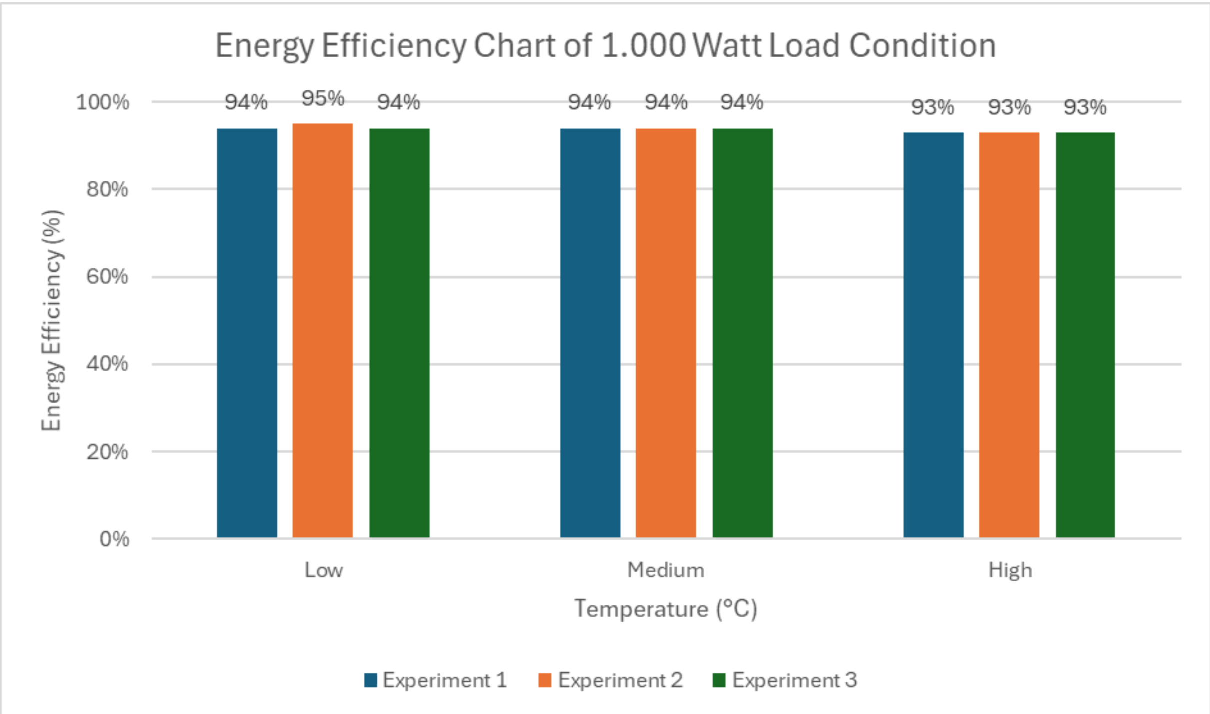

Figure 6. Energy efficiency chart of 1000W load

JEEE-U Journal of Electrical and Electronic Engineering-UMSIDA
ISSN 2460-9250 (print), ISSN 2540-8658 (online)
Vol. 8, No. 2, October 2024
10.21070/jeeeu.v8i2.1700

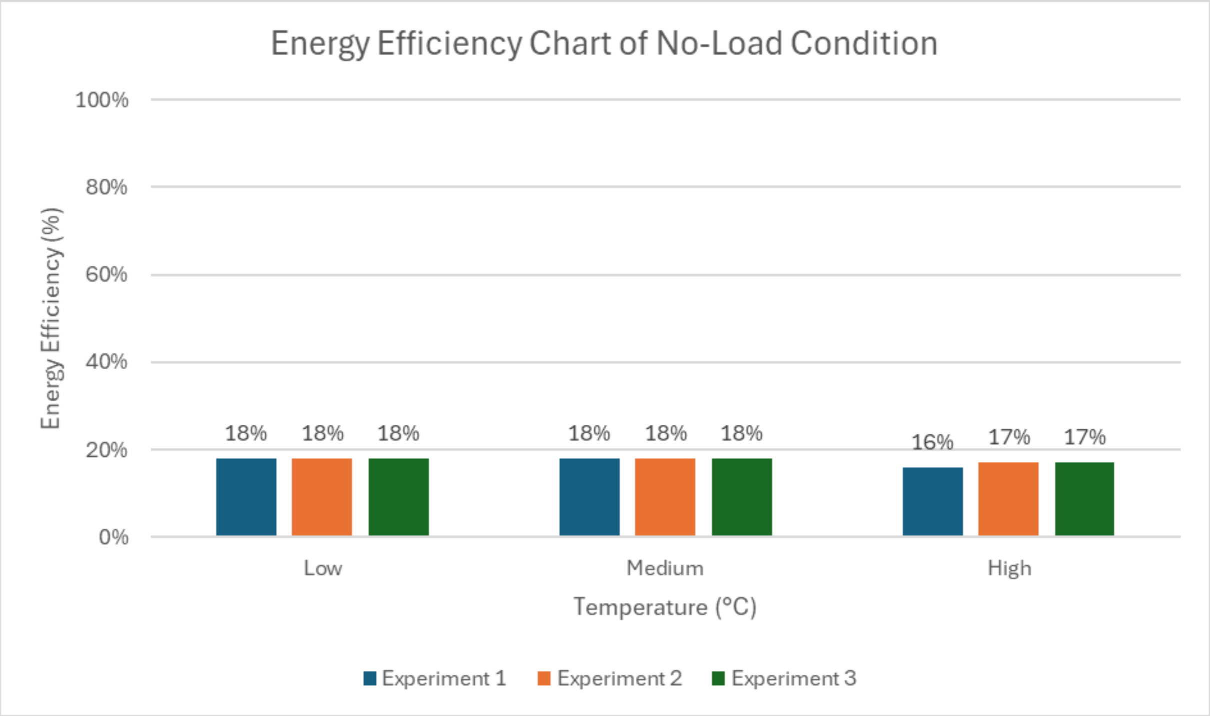

Figure 7. Energy efficiency chart without loading

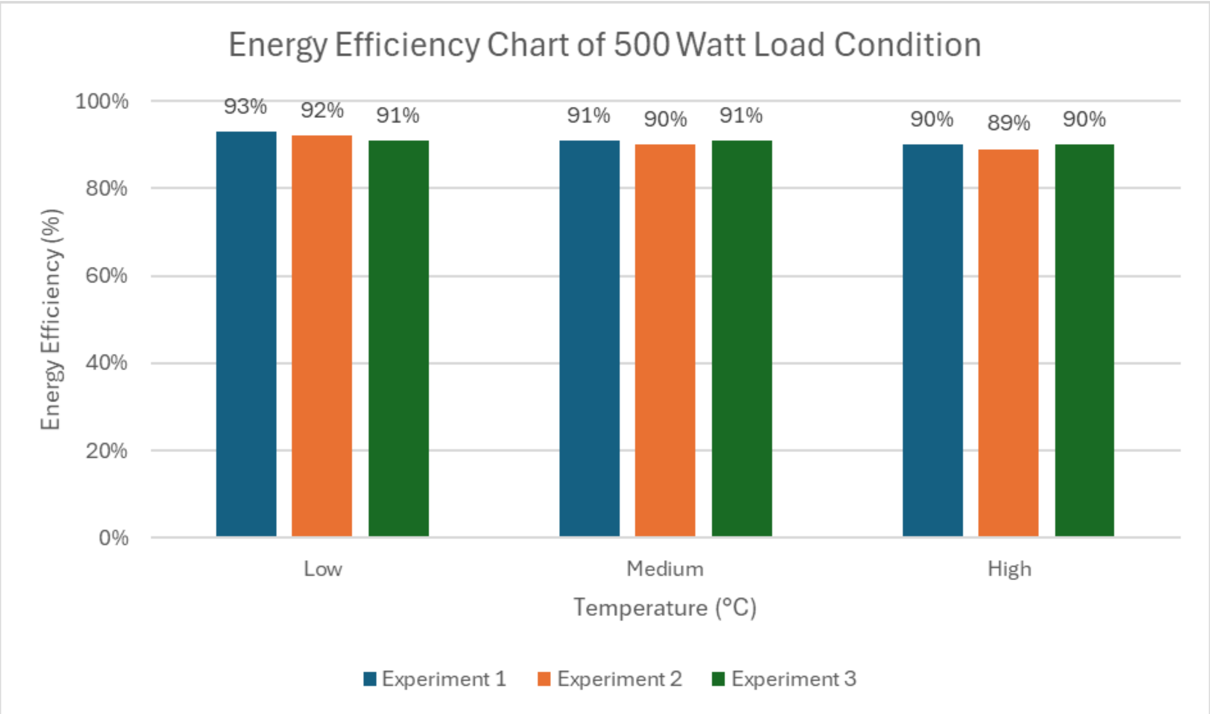

Figure 8. Energy efficiency chart of 500W load

Journal of Electrical and Electronic Engineering-UMSIDA
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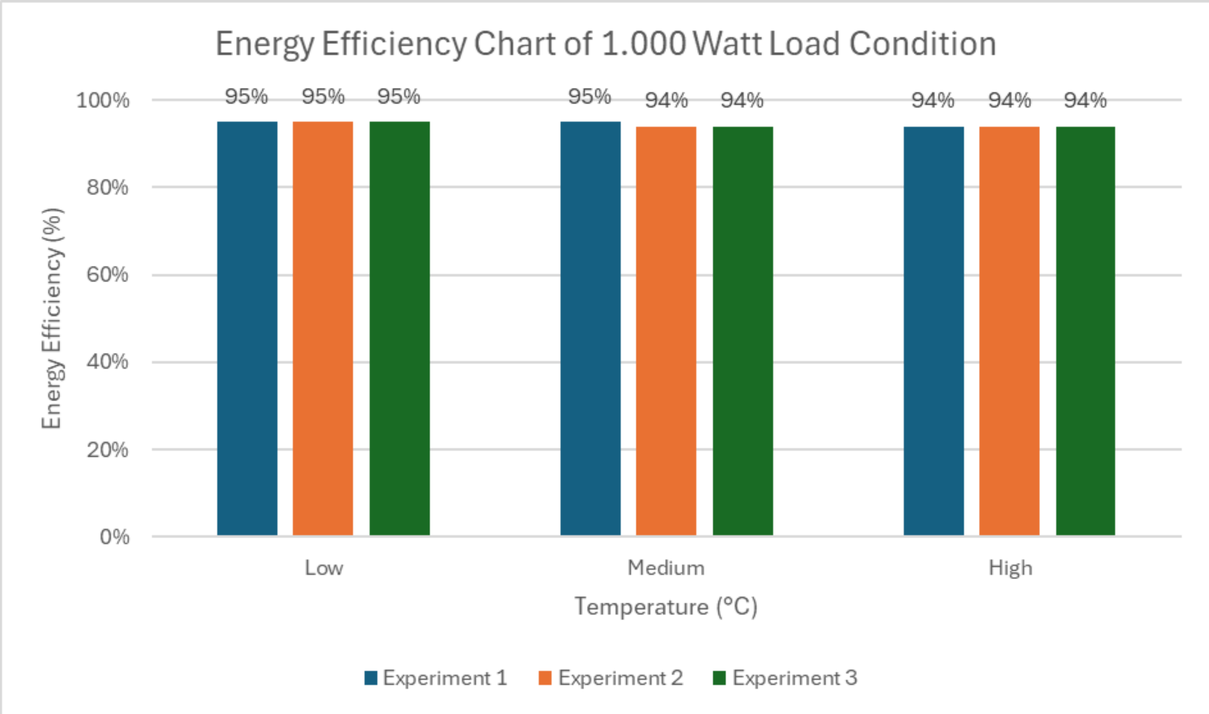

Figure 9. Energy efficiency chart of 1000W load