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Battery Analysis in Off Grid Solar Power Plant as A Power Source for AC Motor Automatic Coffee Roaster Machine Capacity 20 Kg

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Abstract: Solar power plants that utilize solar energy to be converted into electrical energy have several advantages compared to other power plants, namely that they do not produce air pollution, are available continuously and are available everywhere. Coffee is a commodity in the world that is cultivated in more than 50 countries. Two species of coffee trees that are generally known are Robusta Coffee and Arabica Coffee. Processing coffee before consumption goes through a long process, namely from harvesting coffee beans that are ready to harvest. Then proceed with drying before roasting. Coffee roasting machine that uses an AC motor. The motor gets a DC power source from a solar power plant then the inverter changes the DC voltage to AC. This coffee roasting machine is equipped with IoT to control the motor rotation remotely and monitor the temperature. The battery has the function of storing electrical energy produced by solar panels in the form of direct current energy. The energy stored in the battery functions as a backup, which is usually used when the solar panels do not produce electrical energy. The greater the capacity of the battery used, the longer the battery can back up the load used.

Keywords: Solar Panels, Batteries, Coffee Beans

1. Introduction

Electrical energy is a very important requirement for the life of living things. The need for electrical energy continues to increase, so electrical energy is needed that can be used continuously. Utilizing solar energy into electrical energy is one of the renewable alternative energies, in Indonesia solar energy has very high potential. Indonesia's astronomical location is between 6° N (North Latitude) – 11° South Latitude (South Latitude) and 95° E (East Longitude) – 141° E (East Longitude), based on its astronomical location Indonesia is one of the countries traversed by the line equator and Indonesia is a country with a tropical climate so the sun continues to shine throughout the year. Based on this, Indonesia has great potential to be used as a location for building solar power plants. Solar power plants that utilize solar energy to be converted into electrical energy have several advantages compared to other power plants, namely that they do not produce air pollution, are available continuously and are available everywhere.

Solar panels are a medium for taking solar cells found in the sun and converting them into electrical energy. Semiconductor materials are the building blocks of solar panels, in the semiconductors that make up solar panels there are positive poles and negative poles, solar panels basically use the basic principle, namely the photovoltaic effect. The photovoltaic effect is the principle of converting solar energy directly into electrical energy, but the electricity produced is still direct current (DC) electricity. The electricity produced by solar panels can be directly used by electrical equipment that requires direct current (DC) electrical energy. If you want to use alternating current (AC) electrical equipment, you need an electric current converter, namely an inverter, so that the inverter will convert current electrical energy. Direct current (DC) produced by solar panels becomes alternating current (AC) electrical energy.

Coffee is a commodity in the world that is cultivated in more than 50 countries. Two species of coffee trees that are generally known are Robusta Coffee and Arabica Coffee. Processing coffee before it can be drunk is a long process, namely harvesting mature coffee beans either by machine or by hand. Then the coffee beans are processed and dried before they become coffee logs. The next process is roasting at varying temperatures and lengths of time using a coffee roaster. Some of the coffee roasting machines are use DC motors and some use AC motors, each motor gets its power source from a solar power plant. This coffee roasting machine is equipped with IoT to control motor rotation remotely and monitor temperature.

2. Methodology

The material that will be used as an object for comparing the power of the AC motor and DC motor of an automatic coffee roasting machine with a capacity of 20 kg can be seen in Figure 2.1 and the physical shape of the AC motor can be seen in Figure 2.3. The physical form of the AC motor can be seen in figure below.

Figure 2.1 Automatic coffee roaster with a capacity of 20 KG with an AC motor

2.1. Solar Panel

Solar cells, also known as photovoltaic cells, derive their name from the combination of the English term "photovoltaic," which, in turn, originates from the Greek word "photos" meaning light and "volt" derived from Alessandro Volta, the unit of electric current measurement. Photovoltaic technology serves the purpose of directly converting solar radiation into electrical energy. Solar cells, grouped into modules, constitute the means to transform solar energy into electrical power. Typically organized in series or parallel configurations, photovoltaics are packaged in units known as modules, each comprising numerous solar cells.

These solar cells incorporate semiconductor elements capable of converting solar energy into electricity through the photovoltaic effect. The operational mechanism involves the interaction of energy with photons in the semiconductor material. As a result, the energy is transferred to electrons within the atoms of the solar cell. The electrons, energized by the photons, break free from the semiconductor material's normal bonds, generating an electric current that flows through the connected electrical circuit. This liberation of electrons induces the formation of holes in the semiconductor material.

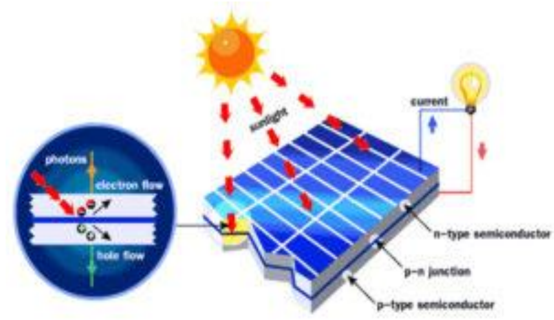

Figure 2.2 Solar Cells Convert Solar Energy Into Electrical Energy.

The primary instrument for capturing, converting, and generating electricity is the Photovoltaic system, commonly known as Solar Cells. These devices transform sunlight into electrical energy by facilitating the movement of negative and positive electrons within module cells, driven by electron differentials. The outcome of this electron flow is direct current (DC) electricity, which can be utilized to charge batteries based on the required voltage and amperage. Solar cell modules available in the market typically yield voltages ranging from 12 to 18 VDC and amperages between 0.5 to 0.7 amperes. Additionally, these modules come in various capacities, spanning from 10 WP to 200 WP, and are available in both monocrystal and polycrystal types.

Table 1. Specifications for 100 Ah battery in 450 VA Off-Grid Solar Power Plant

Battery Type	*Valve Regulated Lead-Acid Battery*
Capacity	100 Ah 12 V
25°C Floating Voltage	13.38 V
Torque Hardware Terminals	9-11 Nm
Charge Current Max	20 A

2.2. AC Electric Motor

An AC motor operates using Alternating Current (AC) voltage and comprises two essential components:

the stationary part known as the "stator" and the rotating part called the "rotor." The stator remains static, while the rotor rotates. These motors can be outfitted with variable frequency drives to manage speed and reduce power consumption. The primary role of an AC electric motor is to transform electrical energy from AC current into mechanical energy, specifically in the form of rotational energy generated by the rotor shaft. This function contrasts with that of an AC generator, which converts mechanical energy into AC electrical energy.

Figure 2.3 AC Motor

2.3. Battery

Batteries play a crucial role in storing and transforming energy, functioning on the principles of electrochemistry. Essentially, a battery serves as an electrochemical cell, comprising one or more cells where chemical energy undergoes conversion into electrical energy, serving as a means of electrical energy storage. The absence of batteries would limit the utilization of solar energy to periods with sunlight, as there would be no energy storage mechanism.

In Photovoltaic Solar Power Systems, batteries are integral components, providing backup storage for electrical energy. Their primary purpose is to store the DC current energy generated by solar panels. This stored energy acts as a backup, particularly useful during times when solar panels are not producing electrical energy, such as during the night or cloudy weather. Additionally, the energy stored in the battery contributes to system stability by ensuring a more consistent output voltage. Batteries play a crucial role in storing electrical energy generated by solar modules during sunlight hours, releasing it when the solar modules are inactive. Typically, batteries are utilized during nighttime, cloudy weather, or overcast conditions. In cases of excess energy demand from consumers during the day, batteries can supplement the solar module output. The inherent characteristic of batteries lies in their ability to store and discharge energy through chemical reactions, measured in watt hours (Wh) of electricity. This expended energy is replenished during the charging process facilitated by the solar module.

A battery comprises a series of elements or cells, with a lead-acid battery being an example featuring two lead electrodes immersed in a solution of water and sulfuric acid. Commonly used in solar photovoltaic applications, batteries are available with nominal voltages of 2 Volts, 12 Volts, and 24 Volts. For a 12 Volt battery, it typically consists of 6 cells arranged in series.

Figure 2.4 100 Ah Battery Solar Power Plant Off-Grid 450 V

Circuit on Battery

a. Series Circuit

Connecting solar modules in a series circuit results in an increase in output voltage, while the electric current (measured in Amperes) remains constant. Figure 2.5 illustrates a direct current source series electrical circuit, where four batteries each generate the same electric current capacity as a single battery, but the combined voltage is four times that of an individual battery. In electronics, voltage refers to the disparity in electrical potential between two points within an electrical circuit, and it is quantified in volts.

As illustrated in the provided diagram, when four batteries, each with a voltage of 1.5 Volts and a current capacity of 1,000 milliamperes per hour (mAh), are connected, the total voltage will be 6 Volts, while the electric current capacity (Current) will remain constant at 1,000 milliamperes per hour (mAh).

Figure 2.5 Battery Series Circuit

Vtot = Vbat1 + Vbat2 Vbat3 + Vbat4 + ……Vn ………………………….. **(2.1)**

Where:
Vtot = total voltage
Vbat1 = battery voltage 1
Vbat2 = battery voltage 2
Vbat3 = battery voltage 3
Vbat4 = battery voltage 4
Vn = nth battery voltage

b. Parallel circuit

In a parallel configuration of batteries or solar modules, the electric current (measured in Amperes) increases, while the output voltage remains unchanged. Figure 2.6 depicts a parallel electrical circuit featuring a direct current source.

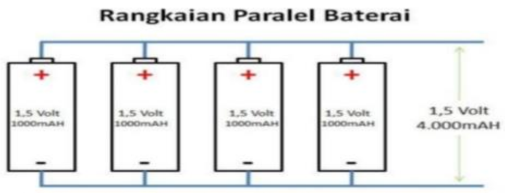

Figure 2.6 Parallel Battery Circuit

In the provided image with four batteries, the parallel circuit yields a consistent voltage of 1.5 Volts across all batteries. However, the total electric current capacity produced is 4,000 milliamperes per hour (mAh), combining the individual capacities of all the batteries in the circuit.

Itot = Ibat1 + Ibat2 + Ibat3 + Ibat4 + …In ……………………………………. **(2.2)**

Where:

Itot = total current strength
Ibat1 = battery current strength 1
Ibat2 = battery current strength 2
Ibat3 = battery current strength 3
Ibat4 = battery current strength 4
In = current strength of the nth battery

3. Discussion

➢ **Testing and Calculations with AC Motors**

Table 2. AC Motor Measurement Results

No.	Mass (Kg)	Voltage (V)	Current (I)	Cos ϕ	Rpm (N)
1	5	222.71	2.18	0.42	917
2	10	224.11	2.24	0.43	500
3	15	225.68	2.28	0.43	370
4	20	226.27	2.31	0.46	285

Where :
M = Weight of load applied to stop motor rotation (Kg)
V = Voltage given or received by the motor (Volts)
I = Current absorbed by the motor (Ampere)
Cos ϕ = Power factor on the motor under load (Cos ϕ)
N = Rotations that occur on the motor (Rpm)

First experiment with a coffee load of 5 kg:

- P_{Input} = V. I . Cos ϕ
  = 222,71 . 2,18 . 0,42
  = 203.91 Watts

- P_m Calculation

  Known: M = 5 Kg
  g = 9.8 m/s2
  r = 3.5 cm = 0.035 m
  n = 917
  Asked: P_m?
  Answer:

$$T = F\ x\ I$$
$$= M\ x\ g\ x\ r$$
$$= 5\ x\ 9{,}8\ x\ 0.035$$
$$= 1{,}71\ Nm$$

$$\omega = \frac{2\pi n}{60} = \frac{2\ x\ 3{,}14\ x\ 917}{60} = 95{,}97\ \frac{rad}{s}$$

$$P_m = T\ x\ \omega = 1{,}71\ x\ 95{,}97 = 164{,}1\ watt$$

Second experiment with a coffee load of 10 kg:

- P_{Input} = V. I . Cos ϕ
  = 224,11 . 2,24 . 0,43
  = 215,86 Watts

- Pm Calculation

  Known: M = 10 Kg
  g = 9.8 m/s2
  r = 3.5 cm = 0.035 m
  n = 500
  Asked: P_m?
  Answer:

$$T = F\ x\ I$$
$$= M\ x\ g\ x\ r$$
$$= 10\ x\ 9{,}8\ x\ 0.035$$
$$= 3{,}43\ Nm$$

$$\omega = \frac{2\pi n}{60} = \frac{2\ x\ 3{,}14\ x\ 500}{60} = 52{,}33\ \frac{rad}{s}$$

$$P_m = T\ x\ \omega = 3{,}43\ x\ 52{,}33 = 179{,}49\ watt$$

Third experiment with a coffee load of 15 kg:

- P_{Input} = V. I . Cos ϕ
  = 225,68 . 2,28 . 0,43
  = 221,25 Watts

- P_m Calculation

Known: M = 15 Kg
g = 9.8 m/s2
r = 3.5 cm = 0.035 m
n = 370
Asked: P_m?
Answer:

$$T = F\ x\ I$$
$$= M\ x\ g\ x\ r$$
$$= 15\ x\ 9{,}8\ x\ 0.035$$
$$= 5{,}14\ Nm$$

$$\omega = \frac{2\pi n}{60} = \frac{2\ x\ 3{,}14\ x\ 370}{60} = 38{,}72\ \frac{rad}{s}$$

$$P_m = T\ x\ \omega = 5{,}14\ x\ 38{,}72 = 199{,}02\ watt$$

Fourth experiment with a coffee load of 20 kg:

- P_{Input} = V. I . Cos ϕ
= 226,27 . 2,31 . 0,46
= 240,43 Watts

- P_m Calculation
Known: M = 20 Kg
g = 9.8 m/s2
r = 3.5 cm = 0.035 m
n = 285
Asked: P_m?
Answer:

$$T = F\ x\ I$$
$$= M\ x\ g\ x\ r$$
$$= 20\ x\ 9{,}8\ x\ 0.035$$
$$= 1{,}71\ Nm$$

$$\omega = \frac{2\pi n}{60} = \frac{2\ x\ 3{,}14\ x\ 285}{60} = 29{,}83\ \frac{rad}{s}$$

$$P_m = T\ x\ \omega = 3{,}43\ x\ 29{,}83 = 204{,}63\ watt$$

➢ **Current and Voltage Measurement Results During Loading**

This research is a step to find out how much voltage and current is released when discharging (charging) the battery and how many hours it takes. Discharging (loading) this battery uses a 20 KG Capacity Automatic Coffee Roasting Machine AC Motor load with 370 Watt.

Table 3. Battery discharge (loading) data using an AC

No.	Burden (%)	Mass (Kg)	Current (A)	Voltage (V)
1.	25	5	2.18	12.76
2.	50	10	2.24	12.44
3.	75	15	2.28	11.32
4.	100	20	2.31	10.37

Table 4. Battery Charging Data On Monday 14 June 2022 At Sriwijaya State Polytechnic

O'clock	Current (Amp)	Voltage (V)
07.00	1.19 A	9.83 V
08.00	2.35 A	10.08 V
09.00	2.44 A	10.39 V
10.00	2.54 A	10.75 V
11.00	4.30 A	11.27 V
12.00	6.02 A	11.80 V
13.00	5.32 A	12.23 V
14.00	3.46 A	12.48 V
15.00	2.61 A	12.51 V
16.00	2.23 A	12.62 V
17.00	0.83 A	12.70 V

➢ **Calculation Of Battery Usage Time On A Loaded AC Motor**

The electrical energy stored in a battery can be recharged or charged if the energy stored in the battery is used up/almost used up by the load. In this study, the load used was the AC motor on an automatic coffee roasting machine with a capacity of 20 kg. Calculation of how long the battery can back up an AC motor with a load of 5 Kg, 10 Kg, 15 Kg and 20 Kg is then calculated using the following formula:

P = V x I ………………………………………….. **(2.3)**

Where :
P = Load/Power (Watts)
I = Current Strength (Ampere)
V = Voltage (Volts)

- Calculation of AC motor power for a load of 5 kg
P = V x I x Cosϕ
= 222.71 x 2.18 x 0.42
= 203.91 Watt
So, the battery usage time at a load of 5 Kg can be seen from the calculation results:

$$I = \frac{P\ beban}{V}$$
$$= \frac{203{,}91\ W}{12\ V}$$
= 16.99 A

Usage time $= \frac{\text{Battery Capacity}}{Current}$
$$= \frac{100\ Ah}{16{,}99\ A}$$
= 5,885 Hours
20% Battery Efficiency = 1,177 Hours
Total Usage = 5.885 – 1.177
= 4,685 (4 Hours 41 Minutes)

- Calculation of AC motor power with a load of 10 kg

P = V x I x Cosϕ
= 224.11 x 2.24 x 0.43
= 215.86 Watts

So, the battery usage time at a load of 10 kg can be seen from the calculation results:

$$I = \frac{P\ beban}{V}$$
$$= \frac{215{,}86\ W}{12\ V}$$
= 17.98 A

Usage time $= \frac{Battery\ Capacity}{Current}$

$$= \frac{100\ Ah}{17{,}98\ A}$$
= 5,561 Hours

20% Battery Efficiency = 1,112 Hours
Total Usage = 5.561 – 1.112
= 4,449 (4 Hours 26 Minutes)

- Calculation of AC motor power with a load of 15 kg

P = V x I x Cosϕ
= 225.68 x 2.28 x 0.43
= 221.25 Watts

So, the battery usage time at a load of 15 kg can be seen from the calculation results:

$$I = \frac{P\ beban}{V}$$
$$= \frac{221{,}25\ W}{12\ V}$$
= 18.43 A

Usage time $= \frac{Battery\ Capacity}{Current}$

$$= \frac{100\ Ah}{18{,}43\ A}$$
= 5,425 Hours

20% Battery Efficiency = 1,085 Hours
Total Usage = 5.425 – 1.085
= 4,340 (4 Hours 20 Minutes)

- Calculation of AC motor power with a load of 20 kg

P = V x I x Cosϕ
= 226.27 x 2.31 x 0.46
= 240.43 Watts

So, the battery usage time at a load of 20 kg can be seen from the calculation results:

$$I = \frac{P\ beban}{V}$$
$$= \frac{240{,}43\ W}{12\ V}$$
= 20.03 A

Usage time $= \frac{Battery\ Capacity}{Current}$

$$= \frac{100\ Ah}{20{,}03\ A}$$
= 4,894 Hours

20% Battery Efficiency = 0.978 Hours
Total Usage = 4.894 – 0.978
= 3,916 (3 Hours 54 Minutes)

➢ **Analysis of Battery Usage Length Based on Load Used**

Based on the results of calculating the length of use of the battery used, the results shown in table 4.4 are obtained as follows:

Table 5. Calculation Results of Battery Usage Time

Load (Kg)	Battery Energy Consumption		Battery Deficiency (20%)	Usage Time (Hours)
	Power (W)	Current (A)		
5	203.91	16.99	1,177	4,685
10	215.86	17.98	1,112	4,449
15	221.25	18.43	1,085	4,340
20	240.43	20.03	0.978	3,916

Based on the calculation results table above, a graph of battery usage time based on the load used is obtained as follows:

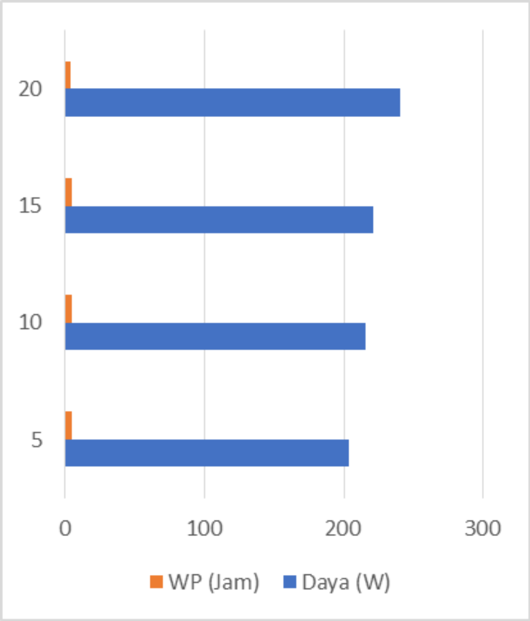

Figure 3.1. Graph of Battery Usage Time

Based on the graphic data above, it is known that the heavier the load used, the greater the power on the motor. When the power used increases, the electrical energy stored in the battery will run out more quickly. This can be seen when the motor load is 5 Kg, the power on the motorbike is 203.91Watt, so the battery usage time can reach 4 hours 41 minutes. During the second experiment, the load was 10 kg, the motor power was 215.86 Watts, so the battery usage time could reach 4 hours 26 minutes. Furthermore, in the third experiment, the load was 15 Kg, the motor power was 221.25 Watts. This causes the battery usage time to decrease more quickly to 4 hours 20 minutes. In the fourth experiment, the load used was 20 kg, the motor power was 240.43 Watts, and so the battery usage time could reach 3 hours 54 minutes.

4. Conclusion

Based on the results of the research that has been carried out, it can be concluded as follows:

1. From the calculations that have been made, the larger the battery capacity used, the longer the battery can back up the load used. The larger the battery capacity used, the longer it will take to charge the battery.
2. If the battery capacity is smaller, the battery charging will be faster. The smaller the battery capacity used, the faster the battery can back up the load.

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