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PERFORMANCE ANALYSIS OF DIRECT SOLAR WATER PUMPING SYSTEMS WITH VARIATIONS IN PANEL CAPACITY IN SOA, EAST NUSA TENGGARA

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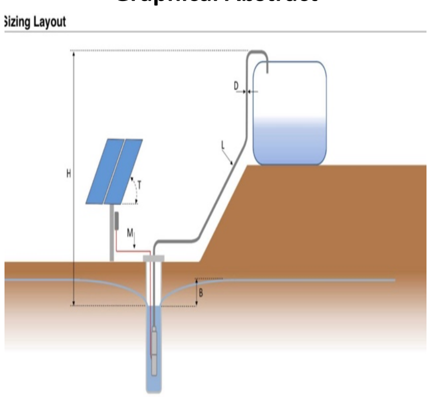
Graphical Abstract



Abstract

Limited access to water is still a major problem in Soa Ngada Regency, East Nusa Tenggara. This research aims to analyze the performance of solar water pumping systems with varying panel capacities of 400 Wp, 600 Wp and 800 Wp. The maximum power produced in each variation is during the day when the intensity of solar radiation is at its peak. Maximum power is recorded at 322 Watts in the 400WP variation, 554 watts in the 600Wp variation and 620 watts in the 800Wp variation. The percentage of power utilized by the pump varies, at 400Wp the average percentage of power utilized is 90.2%, at 600Wp 92.3% and at 800Wp the percentage is 85.2%. The decrease in power at 800Wp shows that the increase in power is not always directly proportional to the increase in system efficiency, this is caused by head loss, friction in the pipe which becomes greater as power increases and energy loss. Overall, the 600Wp variation shows more optimal performance in terms of the presentation of the power used, more efficient water discharge with the utilization of existing power and quite good efficiency. The system efficiency value obtained in the 400Wp variation is 22%, while in the 600Wp variation it decreases to 17% and in the 800Wp variation the system efficiency is 18%. The decrease in efficiency is caused by a mismatch between the panel power supply and the characteristics of the pump working point.

Key words: solar panels; panel capacity; system efficiency; water pumping system; power supply

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1. Introduction

The need for water for agricultural purposes in remote areas is still a problem in various regions of Indonesia, especially in areas where the electricity network does not yet reach. The dry season is a significant challenge for farmers, so far farmers have only depended on the rainy season [8]. For areas affected by climate change like Soa, it will be a problem for farmers in the dry season, this will cause the economic cycle to weaken due to local income decreasing with each dry season [1]. This condition encourages the need to implement appropriate technology that is able to provide water in the dry season.

To answer this challenge, solar energy offers an innovative solution, by simply utilizing sunlight it can produce electricity to drive the pump [2]. Solar water pumping systems utilize sunlight as an abundant and environmentally friendly renewable energy source [3]. This system is considered effective for areas with high intensity of solar radiation such as in the Soa area, Ngada Regency, East Nusa Tenggara [4].

Solar water pumping systems can generally be configured with batteries or without batteries (*direct system*). The direct system has the advantage of lower initial investment costs and simpler maintenance because it does not require batteries [5]. However, the performance of the direct system is greatly influenced by fluctuations in the intensity of solar radiation and the capacity of the solar panels used [6], [7].

Several previous studies have shown that increasing the capacity of solar panels can increase the electrical power produced and pump water flow [8]. However, increasing panel capacity is not always directly proportional to increasing overall system efficiency, especially in systems without batteries which are very dependent on the working characteristics of the pump and solar radiation conditions [9].

The Soa region, Ngada Regency has quite good solar energy potential, however the selection of optimal panel capacity for water pumping systems has not been analyzed comparatively much. Therefore, research is needed to evaluate the performance of direct solar water pumping systems without batteries with different panel capacity variations [10].

This research aims to analyze the effect of variations in solar panel capacity of 400 Wp, 600 Wp, and 800 Wp on electricity parameters, water discharge, power utilization, and efficiency of the water pumping system in Soa, Ngada Regency [11]. It is hoped that the results of this research can be a reference in determining the optimal solar panel capacity for water pumping systems in areas with similar characteristics.

Some limitations set in this study include:

1. The test time is carried out from 07:00 to 17:00 to find out at what time the sunlight intensity is best for the solar panels.
2. Measurements only include technical parameters, namely voltage (V), current (I) and power (W) produced by the solar panel, as well as the power used to drive the pump.
3. The pumping system studied uses a Lorentz PS2-1800 C-SJ5-12 type submersible pump, with pump discharge and efficiency according to manufacturer's specifications.
4. The solar panels are in good condition and clean to ensure maximum efficiency in absorbing solar energy during testing.

2. BASIC THEORY

2.1 Solar energy as an energy source

Solar energy is a new, renewable energy source that has great potential to meet electricity needs in a sustainable manner. The use of solar energy in water pumping systems is based on photovoltaic (PV) technology which converts sunlight into electricity to drive water pumps [12]. This system is very relevant for remote areas, especially in the Soa area, Ngada Regency.

Indonesia, as a tropical country, has great potential to utilize solar energy. Based on data from the Meteorology, Climatology and Geophysics Agency (BMKG), the average intensity of sunlight in Indonesia ranges from 4.5–5 kWh/m²/day, which is very supportive for the application of solar energy technology, such as photovoltaic panels.

2.2 Solar direct water pumping system

A solar water pumping system with a direct pump configuration without using batteries is an efficient choice to reduce initial investment costs. In this system, the energy absorbed from the solar panels is directly channeled to the MPPT (*Maximum Power Point Tracking)* controller and the power is directly distributed to the pump. This shows that this pumping system is very dependent on the intensity of the sun during its operating hours and causes the pump performance to change according to fluctuations in the power produced by the panels [13] [14]. A mismatch between panel capacity and pump power requirements can cause the system to work beyond its optimal point, which in the end can affect the water flow and efficiency of the entire system.

2.3 Water discharge and hydraulic power

Water flow is the main parameter for measuring the output produced by a pump by looking at the volume of water that is successfully pumped at each specified panel capacity. The relationship between the electrical energy utilized by the pump and the mechanical energy produced can be explained through the concept of hydraulic power. Hydraulic power describes the energy required to lift water to a certain height and can be calculated using the equation:

P_{hid} = $\rho . g . Q . h$ .... (1)
Where :
P_{hid} : Hydraulic Power (watts)
ρ : Density of the pumped liquid (kg/m³)
g : Gravitational acceleration (9.81 m/s²).
Q : Water discharge (m³/s).

This equation shows that the greater the water discharge produced and the total water head lifted, the hydraulic power required also increases proportionally. Therefore, increasing the capacity of solar panels to produce greater power has the potential to increase water discharge, but it still depends on the characteristics of the pump and the condition of the pumping system as a whole.

2.4 Pumping system efficiency

System efficiency shows how much electrical energy can be converted into hydraulic energy. Efficiency is an important indicator for evaluating the performance of a solar water pumping system, especially in direct pump systems without batteries, because pump performance is very dependent on the environmental conditions at that time. To measure system efficiency theoretically, the following equation is used:

$\eta_{system} = \frac{P_{hid}}{P_{in}}$ x 100% .... (2)

Where:
P_{hid} : Hydraulic Power (watts)
P_{in} : Power used by the pump (watts)

The efficiency value is influenced by several factors, such as energy loss, cable loss, head loss, friction force on the pipe, water back pressure when the water is pushed into the reservoir, and the system's working point on the pump performance curve [15]. In field results, efficiency does not always show results that are comparable to increasing panel capacity, this is because the system can experience a mismatch between the available power and the actual needs of the pump.

3. METHOD

3.1 Research description

The research was conducted in the Soa area, Ngada district, East Nusa Tenggara. This location was chosen based on geographical characteristics that really support the application of a solar water pumping system as well as topographic conditions that require a pumping system to distribute water from low elevations to higher reservoir points. Data collection was carried out in sunny to cloudy weather conditions with observation periods ranging from morning to evening. This aims to see the performance of the water pumping system against natural changes in the intensity of solar radiation.

The experiment was carried out by comparing three variations of solar panel capacity, namely 400 Wp, 600 Wp and 800 Wp, each of which was assembled using a 200 Wp capacity panel module. The independent variable in this research is the specified variation in solar panel capacity, while the dependent variable includes voltage, current, solar panel output power, power used by the pump and the resulting water discharge.

3.2 Design of pumping systems

The solar water pumping system used in this research is a direct pump type without batteries to store energy. In this system, the solar panel module is connected directly to the pump via an MPPT (*maximum power point tracking*) controller device, the electrical energy produced by the panel during the day is directly used to drive the pump.

The system configuration consists of a solar panel module, solar panel controller, submersible pump, piping network and reservoir.

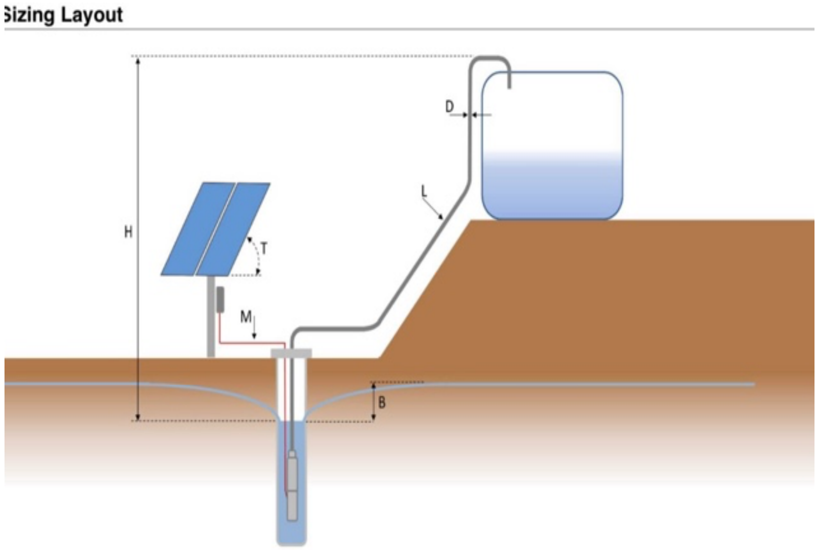

Figure 1. Solar water pumping system schematic

In this direct pump system, there is no battery which means the panel output power is very dependent on the intensity of daily solar radiation. When the intensity of the sun increases, the voltage and current increase along with the intensity of solar radiation, therefore this system is very suitable for filling storage tanks during the day when the sun's intensity peaks.

3.3 Solar panel capacity variations

This research uses three variations of solar panel capacity, namely 400 Wp, 600 Wp and 800 Wp, each variation is arranged using a solar panel module with a capacity of 200 Wp per unit.
Variation configuration is carried out as follows:

1. 400 Wp consists of two 200 Wp panel modules
2. 600 Wp consists of three 200 Wp panel modules
3. 800 Wp consists of four 200 Wp panel modules

Capacity changes are made by increasing the number of modules in the circuit configuration, while other components remain the same, only the panel module capacity changes according to needs. Thus, the difference in performance of a solar water pumping system really depends on the power capacity of the panels installed.

3.4 Panel circuit configuration and testing system

The solar panel circuit in this research uses a series configuration. In this configuration, each solar panel module is connected in series, so that the total voltage of this system is the result of the sum of the voltages of each solar panel [16][17]. The series configuration was chosen to obtain a working voltage that suits the input requirements of the controller and water pump, especially under conditions of varying solar radiation intensity.

Electric voltage (V) is measured using a multimeter by connecting the measuring probe directly to the positive (+) and negative (−) terminals of the solar panel output before entering the controller, without changing the solar panel circuit configuration. Electric current (I) is measured using a multimeter on the panel output cable before going to the controller.

The output electrical power of solar panels is obtained from the results of voltage and current measurements at each test time interval, so that it can describe changes in solar panel electrical power due to variations in the intensity of solar radiation during testing.

This test is carried out by maintaining all variables other than panel capacity constant. The pump used, pipe length and diameter, and total head did not change during the entire test series. So the independent variable in this research is the capacity of the solar panels, while the dependent variables include the panel output power, the power used by the pump, the water discharge, and the daily water volume or cubication.

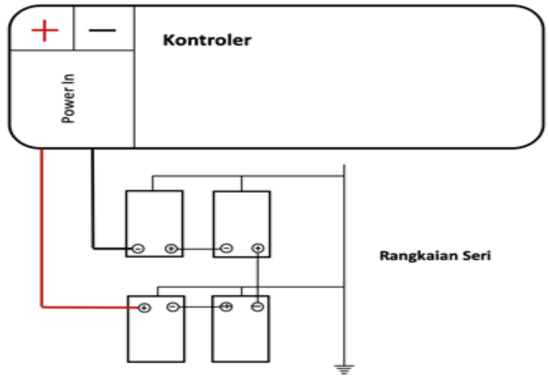

Figure 2. Solar panel circuit configuration

3.5 Data collection procedure

Data collection is carried out directly in the field for each variation of solar panel capacity that has been determined. Each variation tested was tested at the same time interval, starting from 07.00 to 17.00 WITA, to capture the overall system performance naturally according to the intensity of solar radiation at that time.

Data is recorded periodically at consistent time intervals in order to describe the pattern of changes in power and discharge over time.

Data collection is carried out with the following measurement tools:

1. Solar Radiation Intensity: Recorded using a Solar Power Meter every hour.
2. Solar Panel Electrical Power:The voltage (V) and electric current (I) are recorded using a multimeter, then the power is calculated.
3. Water Discharge:Measured using a flowmeter for each panel power configuration and operational time.

4. RESULTS AND DISCUSSION

4.1 Electrical parameter measurement results

Testing was carried out from 07.00 to 17.00 with observation time intervals every 15 minutes. However, for the purposes of analysis in this journal, the data is displayed in representative form in five time conditions. The parameters measured include panel output voltage (V), panel output current (I), power produced by the panel, and power that can be utilized by the pump. In general, changes in panel power are greatly influenced by changes in current, while voltage is relatively more stable. This is in accordance with the characteristics of photovoltaic panel modules where the current is directly proportional to the intensity of solar radiation.

Table 1. Electrical parameters variation 400 Wp

Time (WITA)	Voltage (Volt)	Current (Ampere)	Panel power (Watt)	Pump power (Watt)
07:00	64	0,2	12,8	10
09:00	68	3,2	217,6	210
12:00	70	4,6	322	310
15:00	60	3	180	170
17:00	60	0,4	24	10
Minimum	60	4,6	12,8	10
Maximum	70	0,2	322	320
Average	65,8	2,7	184,3	177,6

The system voltage is relatively stable in the range of 60-70 V throughout the day, the largest changes occur in the current, which increases significantly at 12.00 when the intensity of solar radiation peaks. This condition causes the panel power to reach the highest value of 322 Watts. The average power used by the pump is 177.6 watts. The power used by the pump is always lower than the panel power due to the loss system in the cable and the characteristics of the pump motor[18][19]. Overall, the percentage of power that can be used by the pump in the 400 Wp variation is 90.2%. This shows that most of the panel power can be used to drive the water pump.

Table 2. Electrical parameters variation 600 Wp

Time (WITA)	Voltage (Volt)	Current (Ampere)	Panel power (Watt)	Pump power (Watt)
07:00	100	0,2	20	15
09:00	100	2,2	242	240
12:00	100	4,2	420	400
15:00	100	0,6	60	50
17:00	60	0,1	6	5
Minimum	50	5,8	5	5
Maximum	110	0,1	554,4	540
Average	95,8	2,5	242,6	235

In the 600 Wp variation, the current increases significantly, the voltage remains stable in the range of 50-110 V, the current increases in the range of 0.1-5.8 A. The maximum power reached at 12.15 is 554.4 Watts and the power utilized by the pump is 540 watts. Overall, the percentage of power that can be utilized by the pump is 92.3%. A larger capacity allows the pump to work more stably, this variation shows that the pump can work at its optimal point so that most of the panel power can be utilized.

Table 3. Electrical parameters variation 800 Wp

Time (WITA)	Voltage (Volt)	Current (Ampere)	Panel power (Watt)	Pump power (Watt)
07:00	100	0,8	80	70
09:00	110	3	330	320
12:00	100	5,4	540	530
15:00	100	0,2	20	10
17:00	55	0,1	5,5	4
Minimum	55	6,4	5,5	3
Maximum	110	0,1	620,8	610
Average	96	2,3	224,4	213

In the 800 Wp variation, the increase in current is very significant because it is directly proportional to the incoming power in accordance with the increase in panel capacity. The maximum power reaches 620.8 watts at 11.15 and the power that can be used by the pump is 610 Watts. The percentage of power that can be utilized by the pump in the 800Wp variation is 85.2%. This power difference occurs due to system losses, such as loss in the conductor cable, power consumption by the controller, and the load characteristics of the pump during operation. However, the difference in power is relatively small compared to the total power produced by the panel, so it can be concluded that the direct pumping system in the 800 Wp variation is able to utilize panel power efficiently even though the percentage of power utilized by the pump is smaller.

4.2 System hydraulic performance and water discharge

The hydraulic performance of the system is evaluated based on the water discharge produced by the pump for each variation in solar panel capacity. Discharge is measured directly using a flowmeter in units of liters/minute.

Theoretically, the pump discharge is directly proportional to the electrical power received by the pump motor. The greater the power received by the pump, the greater the rotation of the motor on the pump and the greater the water flow produced. Variations in panel capacity are thought to have a direct influence on the hydraulic performance of the pumping system.

Table 4. Water discharge measurement results

Time (WITA)	Water Flow rate 400 Wp (L/minute)	Water Flow rate 600 Wp (L/minute)	Water Flow rate 800 Wp (L/minute)
07:00	3,3	5,1	9,6
09:00	29	27,3	39,7
12:00	36,4	35	47
15:00	24	9,9	4
17:00	2	1	2
Average	22,9	23,2	24

Overall, the test results show that the capacity of solar panels has a significant influence on the water discharge produced, but the stability of the discharge throughout the day is influenced by the intensity of the existing solar radiation.

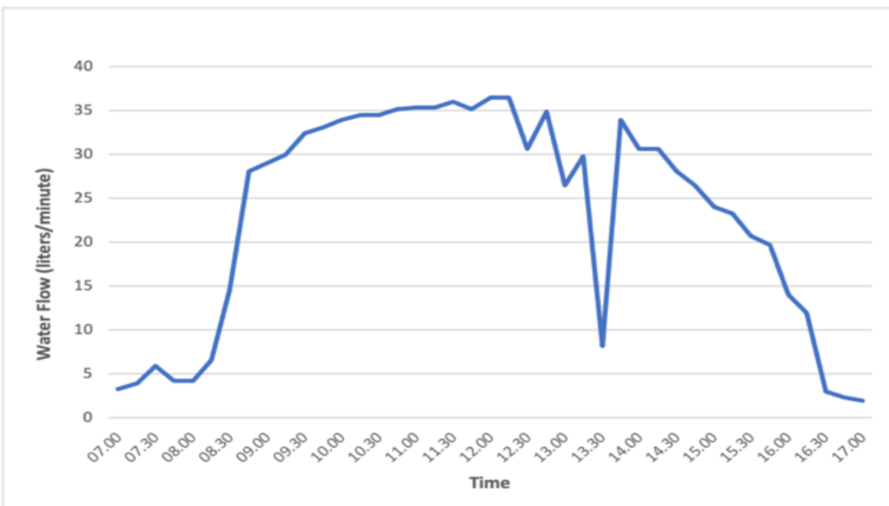

Figure 3. 400 Wp variation water flow graph

Figure 3 explains that at 07.00 WITA the water discharge was recorded at 3.3 L/minute. The water discharge then increased significantly starting at 08.15 WITA, along with the increase in electrical power received by the pump. A quite sharp increase in discharge occurred in the time period 08.30–10.30 WITA, where discharge increased from 14.6 L/minute to 34.5 L/minute. The maximum water discharge was recorded at 11.30 WITA at 36 L/minute. After midday, water levels tend to decrease gradually until the afternoon. At 17.00 WITA the water flow decreased again to 2 L/minute, following the decrease in available power from the solar panels.

Based on Figure 4. Water Discharge Pump with 600 Wp Solar Panel, it can be seen that the water discharge resulting from experimental measurements has increased as the testing time increases from morning to close to noon. At 07.00 WITA, the experimental water flow was still relatively low, namely around 5.1 L/minute. As the power used by the pump increases due to the greater intensity of solar radiation, the water discharge increases gradually and reaches a higher value in the range from 09.00–12.30 WITA. The maximum flow rate was recorded at around 42.5 L/minute at 12.30 WITA, which shows that the pump operating conditions are close to optimal.

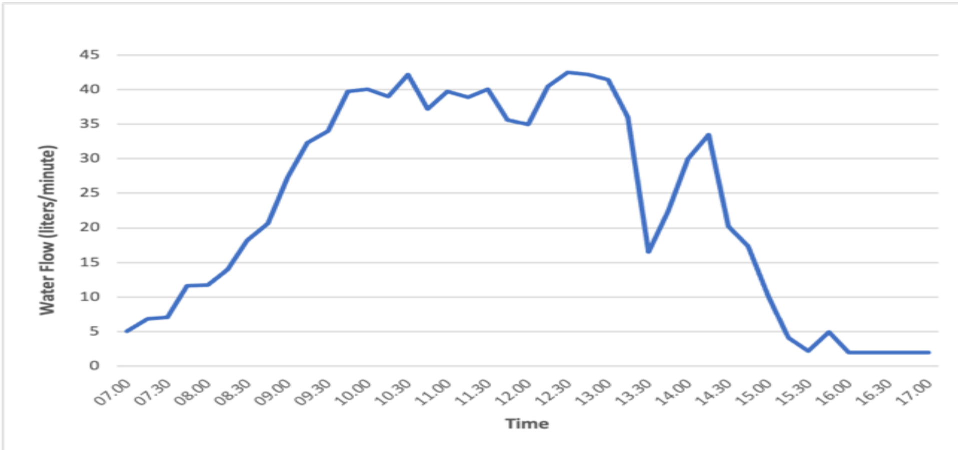

Figure 4. 600 Wp variation water flow graph

After midday, water discharge begins to fluctuate and tends to decrease. This decrease in discharge was clearly visible after 13.00 WITA, for example at 13.30 WITA the discharge fell to around 16.5 L/minute. This condition is in line with the decrease in electrical power used by the pump due to reduced solar intensity and changes in the angle of incidence of radiation on the surface of the solar panels. Towards the afternoon, the water discharge again decreased significantly until it reached a minimum value at 17.00 WITA of 1 L/minute.

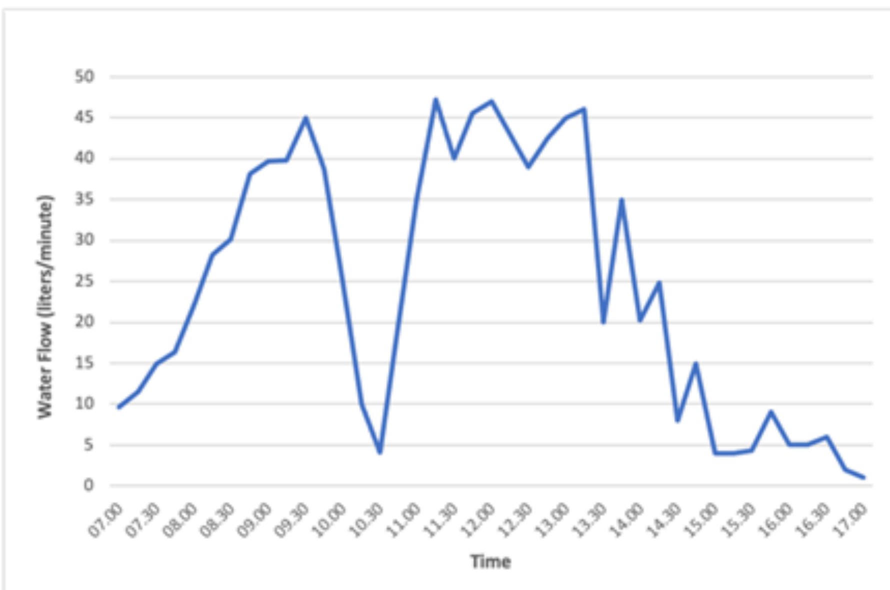

Figure 5. 800 Wp variation water flow graph

Based on Figure 5, the water discharge on the 800 Wp solar panel variation produces the highest water discharge compared to the 400 Wp and 600 Wp variations. In the morning (07.00–08.30 WITA), the experimental discharge was still relatively low, but was greater than the smaller panel variations due to higher power availability. Water discharge increases significantly in the period from midday to midday (around 09.00–13.15

WITA), with maximum discharge reaching the range of 45–47.2 L/minute. This condition shows that at maximum solar intensity, the pump works close to its optimal capacity[22][23]. After midday, the discharge decreases again as the intensity of solar radiation decreases.

4.3 Pumping system efficiency analysis

The efficiency of a solar water pumping system shows the system's ability to convert the electrical power used by the pump into hydraulic energy to circulate water. This efficiency value is obtained from the comparison between the hydraulic power produced by the pump and the electrical power used by the pump during the pumping process[24][25]. Hydraulic power is calculated from actual measurements of water flow and system head, whereas electrical power is derived from field measurements of the pump's power consumption. Hydraulic power is calculated using the following equation:

$P_{hid} = \rho . g .$Q.h

Example of efficiency calculation 400 Wp

The actual water discharge used in this calculation is the average water discharge throughout the test:

Q = 0,0003827m^3/s

So the hydraulic power obtained:

$P_{hid} = 1000\ x$ 9,81 x 0,0003827 *x 10 = 37,5 W*

The average electrical power used by the pump based on measurement data is 177 W, so the system efficiency:

$\eta_{sistem} = \frac{P_{hid}}{P_{in}}$ x 100%

$\eta_{sistem} = \frac{59,5}{320}$ x 100% = 22%

So the system efficiency in the 400 Wp variation shows 22%. This calculation method is also carried out for the 600 Wp and 800 Wp variations, and complete data is presented in table 5.

Table 5. Pumping system efficiency

Panel Variations	Average water discharge (L/Second)	Average power used by the pump (W)	Average system efficiency (%)
400 Wp	0,385	177	22%
600 Wp	0,386	235	17%
800 Wp	0,402	214	18%

Table 5 shows the results of calculating the efficiency of the water pumping system for variations in solar panel capacity. Efficiency is calculated based on a comparison between the hydraulic power produced and the average electrical power utilized by the pump.

In the 400 Wp variation the efficiency was 22%, in the 600 Wp variation the efficiency was 17% and in the 800 Wp variation the efficiency was 18%. Even though the power produced at 600 Wp and 800 Wp is greater, the efficiency does not show an increase that is proportional to the power produced. This condition occurs because the pump works at a certain optimal working point. In the 400 Wp variation, the available electrical power is relatively in line with the pump's needs to lift water at a head of 10 meters, so that the conversion of electrical energy into hydraulic energy takes place more effectively [26][27].

When the panel capacity was increased to 600 Wp and 800 Wp, the electrical power entering the system increased, but the increase in power was not fully accompanied by an increase in water discharge. As a result, some of the additional electrical energy is not converted into hydraulic energy, but is lost in the form of losses in the pump motor, controller and hydraulic system. This is what causes the system efficiency value to tend to decrease at larger panel capacities.

5. CONCLUSION

Based on the test results and performance analysis of the solar water pumping system, it can be concluded that increasing the capacity of solar panels from 400Wp to 800Wp significantly increases the electrical power produced, especially when the intensity of solar radiation is high. This increase in power has an impact on increasing the water flow produced, although the increase is not linear to the increase in panel capacity. This shows that system performance is not only influenced by the capacity of the solar panels, but also by the pump characteristics and system operating limits.

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