Journal of Applied Science, Engineering, Technology, and Education *ISSN: 2685-0591 (online)*
Vol. 5 No. 2 (2023)
https://doi.org/10.35877/454RI.asci2070

Analysis on The Influence of Sollar Irradiation And Rotational Speed of Centrifugal Submersible Pumps Efficiency in Solar Water Pump Systems Technology

Naura Shafa*, Damora Rhakasywi, & Fahrudin

Universitas Pembangunan Nasional Veteran Jakarta, Jalan RS. Fatmawati Raya, Kota Depok, 12450, Indonesia

Abstract

This study aims to analyze the effect of solar irradiation and rotational speed on the efficiency of centrifugal submersible pumps in solar water pump systems. The research was conducted using measuring instruments such as the PS2-4000 Controller on a PATS system with a capacity of 5940 Wp, Autodesk Inventor 2022, Microsoft excel, and Rstudio. The independent variables used were the level of solar irradiation and rotational speed obtained every day for two weeks from 07.00 – 17.00. The dependent variable is obtained from a literature study and the PATS system used. The PATS system uses a LORENTZ PS2-4000 C-SJ17-4 centrifugal submersible pump and a PLTS with a capacity of 5940 Wp with a static head design of 20 m. Data collection was carried out based on actual data taken at the installation location of the PATS system and the velocity triangle analysis approach based on pump geometry. Data collection at the location was carried out using the pump controller PS2-4000 and COMPASS software. Data processing is done using Excel and Rstudio software. The results of data processing will be presented in the form of a curve that explains the relationship between the two or three variables studied. Based on this curve, results and conclusions can be obtained regarding the effect of solar irradiation and rotational speed on the efficiency of centrifugal submersible pumps in solar water pump systems. Data processing is done using Excel and Rstudio software. The results of data processing will be presented in the form of a curve that explains the relationship between the two or three variables studied. Based on this curve, results and conclusions can be obtained regarding the effect of solar irradiation and rotational speed on the efficiency of submersible centrifugal pumps in solar water pump systems. Data processing is done using Excel and Rstudio software. The results of data processing will be presented in the form of a curve that explains the relationship between the two or three variables studied. Based on this curve, results and conclusions can be obtained regarding the effect of solar irradiation and rotational speed on the efficiency of submersible centrifugal pumps in solar water pump systems.

Keywords: Solar irradiation, Rotational speed, Rotate speed, Solar water pump system

Received: 1 October 2023 Revised: 29 November 2023 Accepted: 2 December 2023

1. Introduction

Solar energy is the main target in the use of New Renewable Energy (EBT) in Indonesia becausea very abundant potential and high ease of access. The rapid growth of a country depends on the availability of energy and water. Many water sources are located in hard-to-reach places, so it is necessary to use water pumps, most of which use electric or diesel-powered water pumps (Aliyu et al., 2018). Solar Water Pumps (PATS) have a target focus on meeting the needs of clean water. The use of a water pump with a diesel generator requires continuous fuel change and is not cost-effective, noisy and contributes to air pollution. On the other hand, PATS is economically superior, where diesel pumps are 2-4 times more expensive (Salilih et al., 2020). Variation of solar irradiation affects the overall PATS system efficiency and pump flow rate (Silambarasan & Belgacem, 2012). (Chahartaghi & Nikzad, 2021) conducting exergy research and evaluating PATS system performance using COMPASS software.

* Corresponding author.
E-mail address: xxxx@xxxxxx.edu

(Chahartaghi & Nikzad, 2021) Two experiments were carried out and at 900 W/m2 irradiation, the power and efficiency of the motor-pump, pump speed and water discharge were constant. (Chahartaghi & Nikzad, 2021) conducting exergy research and evaluating PATS system performance using COMPASS software. (Chahartaghi & Nikzad, 2021) Two experiments were carried out and at 900 W/m2 irradiation, the power and efficiency of the motor-pump, pump speed and water discharge were constant.Centrifugal submersible pumps have the ability to deliver water with a large discharge at a high head. In actual natural conditions where the water source is fluctuating, it is difficult to operate the pump at a predetermined head and discharge. This makes the efficiency of submersible pumps low (around 18-35%) compared to the efficiency of laboratory-scale products, which is 64% (Haque et al., 2019). The performance of solar water pumps mainly depends on flow rate which is one of the two main parameters of the pump, besides pressure . Studies regarding pump efficiency are not discussed in a comprehensive and thorough manner. Therefore, it is necessary to conduct research on the efficiency of submersible centrifugal pumps in the PATS system.

2. Theoritical Review

Based on SNI 8395:2017, Thermal Power Plantsa Solar (PLTS) is a power generation system whose energy comes from solar radiation, through the conversion of photovoltaic cells. Photovoltaic systems convert solar radiation into electricity. Solar photovoltaic is a technology that converts solar radiation into direct current (DC) electricity using semiconductors. When the sun hits the semiconductor in the PV cell, electrons are released and form an electric current. The higher the intensity of solar radiation that hits the photovoltaic cell, the higher the electrical power it produces (Indonesia Clean Energy Development II, 2020).

Solar radiation consists of electromagnetic waves that travel from the sun to the earth at the speed of light(Chalkias et al., 2013). Meanwhile, solar irradiation is the energy produced when sunlight hits a surface for a certain period of time and is expressed in kilowatt-hours per square meter in days or years.(Renewables Academy (RENAC) et al., 2020). The three main components of solar radiation are Direct solar radiation, Diffused solar radiation and Reflected solar radiation. Global solar radiation can be used in predicting the design of solar energy systems that require clean water. Solar Water Pumps (PATS) are pump systems based on photovoltaic technology that convert sunlight into electricity to pump water. The pump is configured with the PLTS system to carry out the solar energy conversion process. PATS is often used and is the best option in meeting the electricity needs for water pump systems in agricultural, livestock and fishery applications in remote areas. The PATS system has main components consisting of solar modules, motor pump units, inverters, controllers and storage units such as batteries or water storage tanks. In designing a PATS system, there are several parameters that must be considered. One *Dynaminc Head* (TDH) water source.

TDH is the total sum of the Static Head and the horizontal distance of the water source. Static Head is the distance between the lowest point of the water source which is commonly called drawdown and the location of the three storage tanks. The PATS installation location is needed to determine the amount of solar irradiation received at the location to determine the right PLTS capacity and be able to meet the water needs at the PATS system installation location. The solar module is connected to a DC motor or AC pump which converts the electrical energy supplied by the solar panels into mechanical energy which is then converted into hydraulic energy by the pump. The solar module is installed in a structure that matches the location where the PLTS system is installed with the appropriate tilt angle. Water is pumped when the sun is shining and then stored in a tank, so that the water can be used during the day, at night or when the sun conditions are not good, such as cloudy weather. The water tank acts as storage and generally batteries are not used for PV electricity storage as they are still expensive. The capacity of a solar pumping system to pump water is a function of three main variables: pressure, flow and power to the pump. For design purposes,

Direct coupled DC solar water pumps are simple and reliable, but cannot operate at the maximum power point of the PV generator because solar radiation varies during the day from morning to evening. Other components were added to increase the reliability of the PATS system in dealing with fluctuating sunlight, such as MPPT and pump controllers. Below are important parameters in the PATS system:

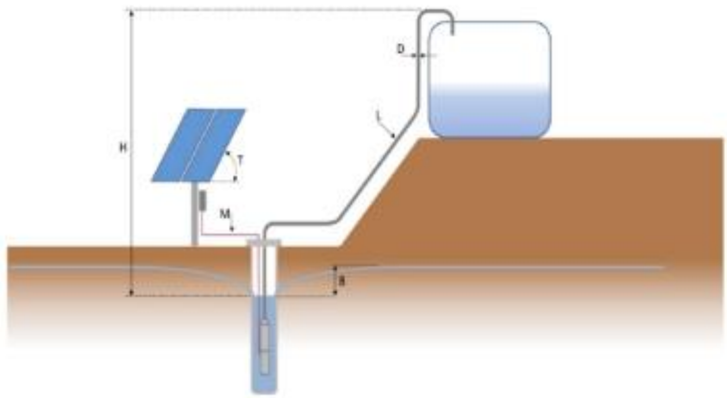

Figure 1. PATS System Terminology

Where H is*static head*, which is the vertical distance calculated from the dynamic water level to the highest water delivery point. B is the drawdown or decrease in water level depending on the flow rate and recovery time of the well, D is the inner diameter of the pipe, L is the length of the pipe from the pump to the water delivery point. M is the motor cable, namely the cable that connects the controller and the pump unit. T is the tilt angle of the solar module.

PATS systems usually consist of several components, namely: 1) solar photovoltaic modules, 2) controllers, 3) energy or water storage, 4) converters or inverters

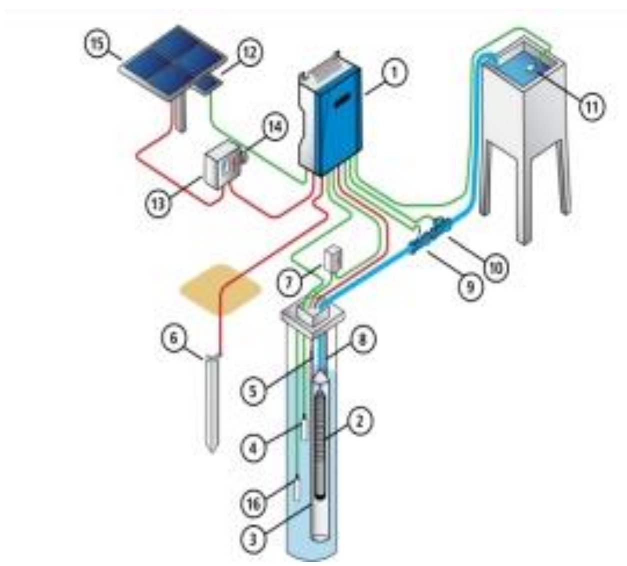

Figure 2. PATS system components

Centrifugal pumps are in the category of dynamic pumps. Centrifugal pumps are widely used for irrigation needs, drinking water supply plants, oil refineries, chemical plants, steel factories, food processing plants and various industries.(Journals, 2019). In a centrifugal pump, water is sucked in by the centrifugal force created by the impeller and the diffuser directs the water to the outlet as the impeller rotates. Pumps are machines designed to lift, convey and move various liquids. A pump can also be defined as a unit that transfers the mechanical energy of a motor or machine into the potential and kinetic energy of a fluid (Journals, 2019). Classification of pumps based on operating principles is divided into two categories: dynamic pumps and positive displacement pumps.

*Flow*is a parameter that states the amount of liquid that needs to be moved or transferred from one place to another. Neglecting possible losses, all input power will be used to drive the flow against the applied pressure.

$$Q = \frac{V}{t}$$

Q is the volume per unit time, which in pump parlance is called "flow", "capacity" or "delivery". Inside the pump, the fluid is driven under pressure by a piston, rotary gear, or impeller. Ideal power = fluid horsepower = FHP = p × Q × constant, because all input power is fluid horsepower if losses are assumed to be zero.

$$\text{psi x gpm} = \frac{\text{lbf x gal}}{\text{in}^2 \text{ x min}} \text{x} \left(144\ \frac{\text{in}^2}{\text{ft}^2}\right) \text{x} \left(\frac{\text{ft}^3}{7.48\ \text{gal}}\right) \text{x} \left(\frac{\text{min}}{60\ \text{sec}}\right)$$

$$= \frac{\text{lbf x ft}}{\text{sec}} \text{x} \left(\frac{144}{7.48 \text{ x } 60}\right) \text{x} \left(\frac{\text{HP}}{500\ \frac{\text{lbf x ft}}{\text{sec}}}\right) = \frac{\text{BHP}}{1714}$$

So,

$$FHP = \frac{p \times Q}{1714}$$

Where,

p= Pressure (psi)
Q = Flow rate (GPM)

In the application of the Solar Water Pump (PATS) system, centrifugal pumps have the ability to adjust to the output of solar modules in the PLTS system. The operation of such pumps lasts longer even at low insolation levels, and the load characteristics are close to the maximum power point of the PV (Maximum Power Point). Centrifugal pumps have relatively high efficiency, but decrease at lower speeds, which can be a problem for pumping systems at low insolations.

The pump has a performance curve in standard speed and fluid viscosity. The curve gives an indication of the correlation between the developed heads.

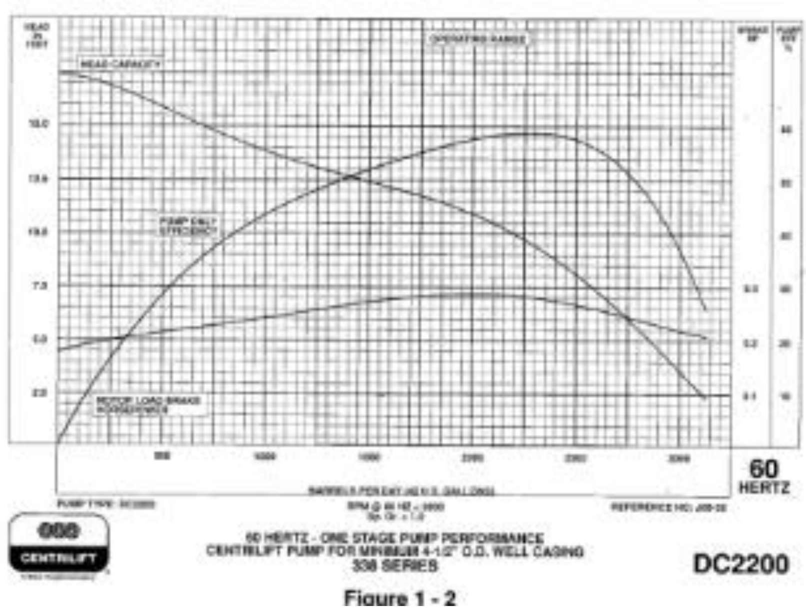

Figure 3. Curveshead-capacity

The head - capacity curve is formed by completeness of the actual pump performance data. Contrary to the figure, as capacity increases, the total head (or pressure) that the pump can reach decreases. Generally at highest head, the pump is continuously boosted up to the point where there is no flow through the pump and the discharge valve is fully closed. The Brake Horsepower (BHP) curve is formed with the actual performance test data which is the horsepower requirement by the centrifugal pump, based on the same constant factor to provide the hydraulic requirements. Brake horsepower (BHP) is the total power required by the pump to perform a certain work size, which can be determined as follows:

$$\text{BHP} = \frac{\text{p x Q}}{\eta \text{ x } 1714}$$

In the centrifugal principle, pressure is expressed in feet using specific gravity (SG) or specific gravity:

$$\text{H} = \frac{\rho \text{ x } 2.31}{\text{SG}} \text{ (feet of water)}$$

So that,

$$\text{BHP} = \frac{\left(\frac{\text{H x SG}}{2.31}\right) \text{x Q}}{\eta \text{ x } 1714} = \frac{\text{H x Q x SG}}{\eta \text{ x } 3960}$$

The efficiency of a centrifugal pump cannot be calculated directly without complete test data. Centrifugal pump efficiency formula:

$$\text{\% efficiency} = \frac{\text{H x Q x SG x } 100}{3{,}960 \text{ x BHP}}$$

Where,

Head = feet
Capacity =gallons/minute
BHP = Brake horsepower

*Hydraulic horsepower*or fluid horsepower is the energy output of the pump which is derived directly from the outlet parameters (flow rate and head). The fluid horsepower for water, specific gravity 1.0, can be determined by substituting equation (4) into equation (2):

$$\text{FHP} = \frac{\text{Q x H}}{3{,}960}$$

Where,

Q = gallons/minute (GPM)
H = feet

Efficiency can be expressed by the relationship between FHP and BHP:

$$\eta = \frac{\text{FHP}}{\text{BHP}}$$

When changing the centrifugal pump speed, the performance characteristics of the pump will change, but these changes are predictable. The law that governs the performance of a centrifugal pump, such as the change in speed that occurs, is known as the Afinity's Law. This law originates from non-dimensional analysis of rotating machines. The law of affinity indicates that under dynamically similar or relatively general conditions, certain dimensionless parameters remain constant. . Affinity's law simply connects points on a curve with different speeds.

- The submersible pump is a radial flow type multistage centrifugal pump.Stage is added to achieve higher lift capability by increasing the pressure(LORENTZ, n.d.). A pump in which the head is achieved by a single impeller is called a single stage pump. Often the total head to be achieved requires two or more impellers operating in series, each taking suction from the discharge of the previous impeller. For this purpose, two or more single-stage pumps can be connected in series or all impellers can be combined in one casing.

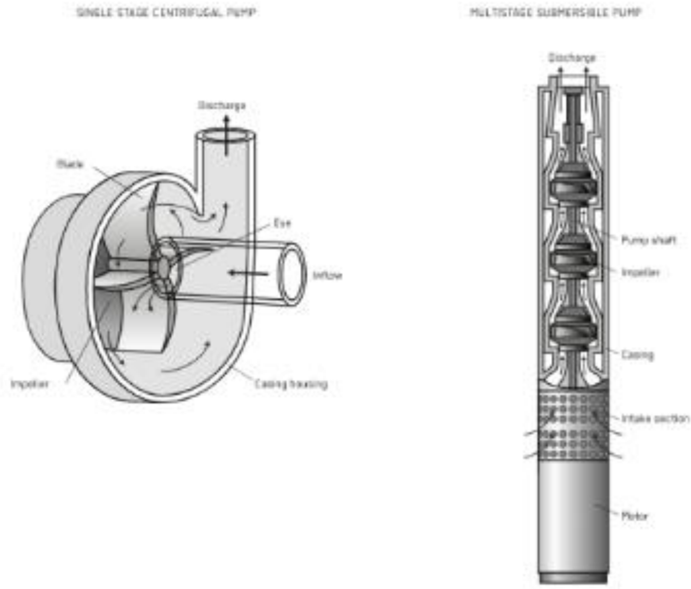

Figure 4. Single stage centrifugal pump and multistage submersible pump

Multistage submersible pumps operating in a vertical position are equipped with an airtight motor mounted on the pump body. The main advantage of this perfect immersion operation is avoiding the occurrence of pump cavitation (Alkarrami et al., 2020).

Figure 5. Submersible pump

Change *pressure-energy* achieved when the liquid being pumped passes through the impeller causing the impeller to rotate and create a rotary motion to the liquid. There are two components of motion imparted to the liquid by the impeller. One movement in the radial direction outward from the center of the impeller caused by centrifugal force. The other moves are tangential to the outer diameter of the impeller. The result of these two components is the actual flow direction. The function of the diffuser is to convert some of the high velocity energy into pressure energy. Submersible centrifugal pump designs fall into two general categories. Smaller flow pumps generally have a radial flow design.

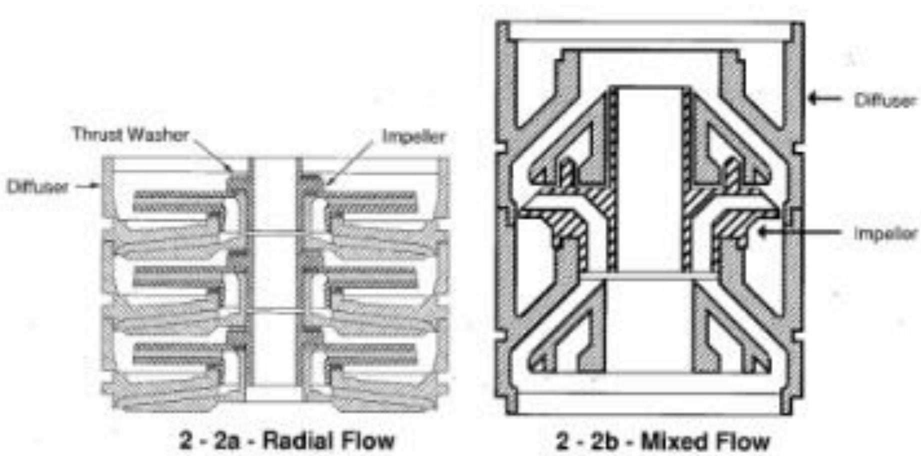

Figure 6. Submersible pump stages

The figure explains that the impeller expels liquid mostly in a radial direction. When the pump reaches a design flow of approx. 1900 BPD (300 m°/s) on the 400 and 3500 series pumpsD (550 m°/h) in larger diameter pumps, the design changes to mixed flow. The impeller in this stage design provides a direction to the fluid which contains a substantial axial direction as well as a radial direction (Baker Hughes, 1997).

The impeller is a fully enclosed curved vane design, the maximum efficiency of which is a function of the design and type of impeller and the efficiency of operation is a function of the percentage of design capacity at which the pump is operated. The mathematical relationship between head, capacity, efficiency and BHP is expressed as:

$$\text{BHP} = \frac{\text{Q x H x Specific Gravity}}{\text{Pump Efficiency}}$$

Where,

Q = volumes
H = Heads

The discharge rate of a submersible centrifugal pump depends on the rotational speed (rpm), the stage design, the dynamic head at which the pump operates, and the physical properties of the fluid being pumped. In centrifugal pumps, the water flow rate is targeted to be proportional to the speed of the motor to allow continuous and stable head operation (Alkarrami et al., 2020).*heads*(H), expressed in units of length is a normal practice used to determine the amount of useful mechanical energy delivered in units of weight under the acceleration of gravity. Head can be determined by measuring static pressure and velocity in the suction and discharge nozzles. Head is a unit of energy and corresponds to the total head between the suction and discharge nozzles as according to Bernoulli's law.

$$H = \frac{Y}{g} = \frac{P_d - P_s}{\rho \cdot g} + Z_d - Z_s + \frac{c_d^2 - c_{ds}^2}{\rho \cdot g}$$

Where,

$P_s, P_d =$ Static pressure on suction and discharge
$Z_s, Z_d =$ Reference height at suction and discharge
$C_s, C_d =$ Absolute speed on suction and discharge

Heads against which the centrifugal pump must work is known as the manometric head. Manometric head is expressed by the following equation:

$$H_{mano} = \left(\frac{p_2}{w} + \frac{V_2^2}{2g} + Z_2\right) - \left(\frac{p_1}{w} + \frac{V_1^2}{2g} + Z_1\right)$$

Where,

$\frac{p_2}{w}$ = pressure head at the pump outlet, or called Head discharge (H_d)

$\frac{v_2^2}{2g}$ = velocity head at the pump outlet, or $\frac{v_d^2}{2g}$ =

Z_2 = the vertical distance of the pump outlet from the datum line

$\frac{p_1}{w}, \frac{v_1^2}{2g}, Z_1$ is the same value at the inlet and suction.

Absolute velocity V and the relative velocity W of the fluid particle and the tangential velocity U formed by the impeller blades moving in a rotating flow trajectory form a velocity triangle.

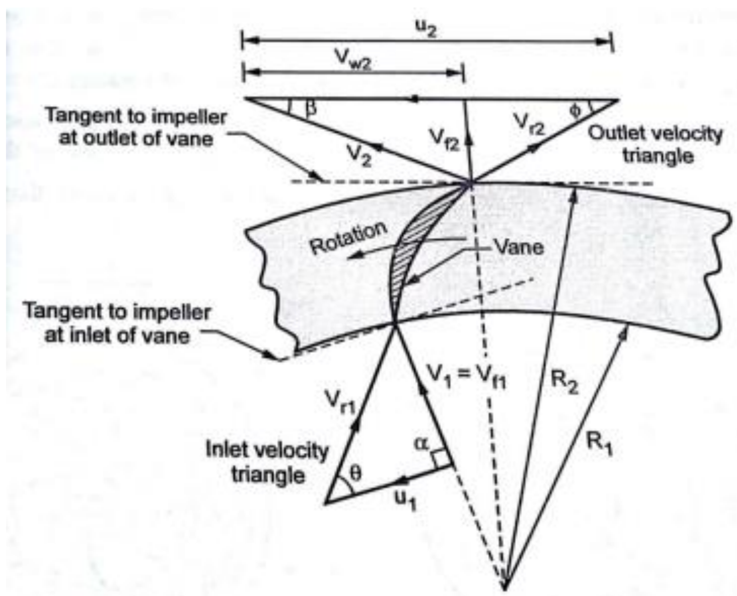

Figure 7. Velocity Triangles

Where,

D_1 = diameter of impeller at inlet (m)
N = speed of impeller (rpm)
u_1 = tangential velocity of impeller at inlet (m/s)
V_1 = absolute velocity of water at inlet
V_{w1} = velocity of whirl at inlet
V_{r1} = relative velocity of liquid at inlet
V_{f1} = velocity of flow at inlet
α = angle made by absolute velocity (V_1) at inlet with the direction of motion of vane
θ = angle made by absolute velocity (V_1) at inlet with the direction of motion of vane
$V_{w2}, V_{r2}, V_{f2}, \beta, \phi$ is the same value at the outlet.

Efficiency is how well a machine works in converting energy. Efficiency depends on the size of the small losses or losses produced, the smaller the loss, the greater the efficiency achieved. Engine efficiency is defined as the ratio of the power output of the engine to the power input into it. Centrifugal pumps have four types of efficiency, namely mechanical, volumetric, hydraulic and overall efficiency

3. Research Methodology

The research was conducted in the Bumiayu PATS system, Brebes, Central Java and in the Reading Room, Faculty of Engineering, UPN Veterans Jakarta from January 2023 – May 2023. The measuring instrument used in this study was the PS2-4000 Controller on the PATS system with a capacity of 5940 Wp, Autodesk Inventor 2022, Microsoft excel, and Rstudio. The independent variables used by the researchers were the level of solar irradiation and rotational speed obtained every day for two weeks from 07.00 – 17.00. The dependent variable is a variable whose data is not fully determined by the researcher, but the magnitude influences the independent variable. Several dependent variables were obtained from literature studies and the PATS system used. The PATS system uses a LORENTZ PS2-4000 C-SJ17-4 centrifugal submersible pump and a PLTS with a capacity of 5940 Wp with a static head design of 20 m. Literature study serves to understand the theoretical basis of the topic taken. At this stage, the process of collecting previous research data that has relevance to the research topic is carried out. Based on these studies, a formulation of the problem that deserves discussion can be obtained. This study focuses on the formulation of the problem which will be discussed regarding the analysis of the effect of solar irradiation and rotational speed on the efficiency of centrifugal submersible pumps in the PATS system and then associated with the flow rate generated by the pump. Data collection was carried out based on actual data taken at the installation location of the PATS system and the approach velocity triangle analysis based on pump geometry. The system uses energy sources from PLTS with a capacity of 5.9 kWp. Data collection at the location was carried out using a pump controller PS2-4000. The PS2-4000 controller records data in real time and is configured with the entire PATS system, which is also equipped with a sun sensor. Data retrieval using COMPASS software is carried out by inputting data on the installation location, TDH, and the required daily output or water requirements per day. Data processing is done using excel software. The results of data processing will be presented in the form of a curve that is processed using Rstudio. The curve will explain the relationship between the two or three variables studied. Based on this curve, the results and conclusions of the research can be obtained. Data retrieval using COMPASS software is carried out by inputting data on the installation location, TDH, and the required daily output or water requirements per day. Data processing is done using excel software. The results of data processing will be presented in the form of a curve that is processed using Rstudio. The curve will explain the relationship between the two or three variables studied. Based on this curve, the results and conclusions of the research can be obtained. Data retrieval using COMPASS software is carried out by inputting data on the installation location, TDH, and the required daily output or water requirements per day. Data processing is done using excel software. The results of data processing will be presented in the form of a curve that is processed using Rstudio. The curve will explain the relationship between the two or three variables studied. Based on this curve, the results and conclusions of the research can be obtained.

4. Results and Discussion

There are several related studies being examined, namely:

a) These results were found to be similar to the research (Suryana & Sari, 2018). The results of this study are designing, knowing and being able to test the quality of solar panels by comparing the voltage, current, and power produced by the panels. The parameters used as benchmarks in measurement are the temperature on the surface of the solar panel and the irradiation of sunlight to determine the performance and calculate the value of the efficiency of the solar panel. Based on the references and references used, the results of this design use two monocrystaline solar panels of 320 Wattpeak with a water pump load of ± 350 W. The greatest solar energy conversion efficiency obtained is 37.64% and the smallest conversion efficiency is 9.91 %. With an average energy conversion efficiency calculated between 18.46% to 20.62%. The efficiency of the submersible water pump supplied by the system is 77.3%.

b) Research conducted by (Harianti, 2022) entitled "Evaluation of the System for Selection of Submersible Pump Specifications Owned by PDAM Tirtauli in Siantar Selatan District, Pematangsiantar City in 2018" has implemented a submersible pump type pump with a capacity of 27.10 l/s and a head pump of 14.62 m based on calculations in the field. In this study, field measurements were carried out to determine the main parameters of the pump design, such as specific speed, pressure loss on the pipe wall, length, diameter and type of pipe, number and type of pipe accessories used. The measurement results show that the pipe diameter used is 6 inches, type Ci, and the length of the pipe is 1260 meters. Using the Hazen William formula and flow continuity,

Furthermore, the results of the research will be discussed as follows.

a. Solar Panel Production

Calculation of energy input produced by solar panels is obtained based on the number of panels, capacity and efficiency of the solar panels. The figure 8 shows the average irradiation received by the PATS system.

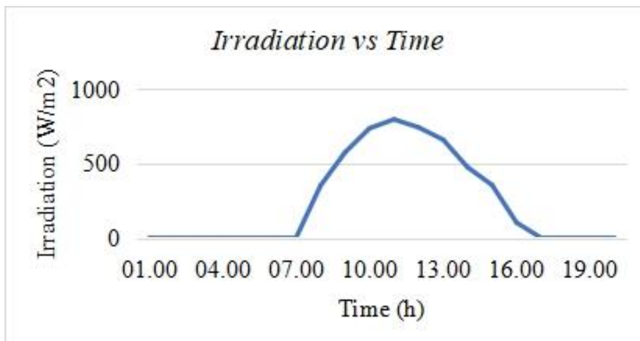

Figure 8. Irradiation curve against time

Solar irradiation recorded during the study period produced the highest irradiation number at 11.00, this is in accordance with the solar production curve which shows the maximum point atmidday. Therefore, the average irradiation on the system is 534 W/m^2. Irradiation below the pump irradiation requirement is not taken into account. The voltage and current numbers of the PV module are directly related to the irradiation variation. Thus, at higher radiation levels, an increase in this key parameter can be seen (Chahartaghi & Nikzad, 2021). Obtained hourly GHI results of 4,661 kWh/m2/day. Based on these data, the energy produced by PLTS at the maximum point is 4.7316 kWh. The PR of the system is known to be 45%. By calculating the effective area of solar panels, PV efficiency is obtained based on equation (1). Where is the effective area of the PV, calculated based on the stated configuration:

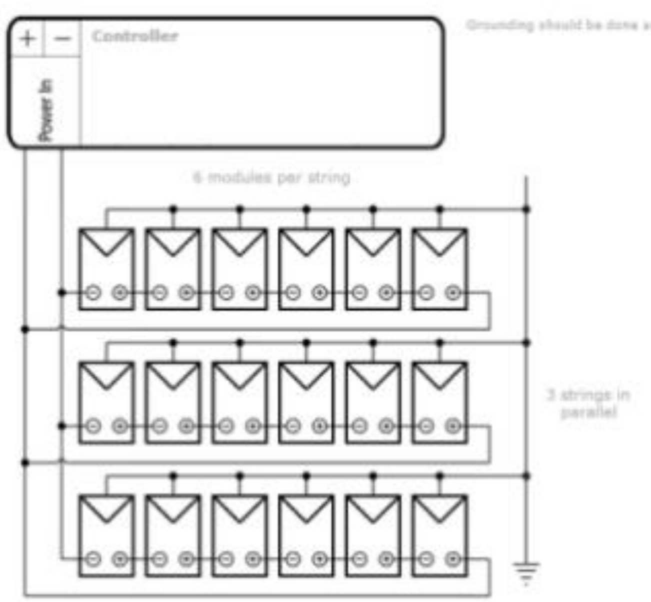

Figure 9. PV module configuration and wiring diagram

$A_{PV} = (6\ x\ lebar\ modul)\ x\ (3\ x\ panjang\ modul) = 32{,}31\ m^2$

Combining the effective area of PV with irradiation data for 14 days recorded by*sun sensor*, the efficiency graph is obtained as follows:

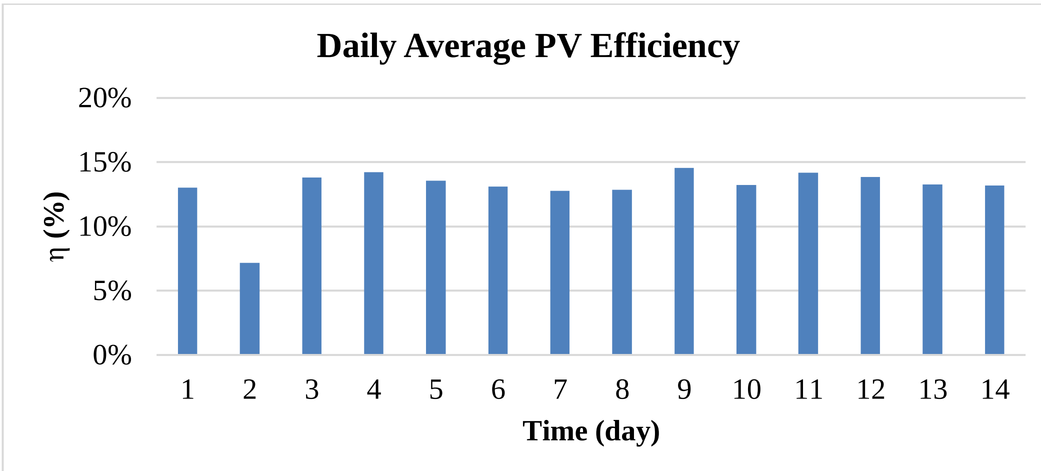

Figure 10. PV Efficiency (days)

Based on the figure 10, the highest daily efficiency during the test time is 14% with an average efficiency of 13%. Both were achieved within a span of 7 hours of irradiation. Efficient distributionThe hourly nsion corresponds to the trend of the system irradiation curve. However, there is a decrease in efficiency in mid-day (11.00 – 12.00), when efficiency should be at its peak.

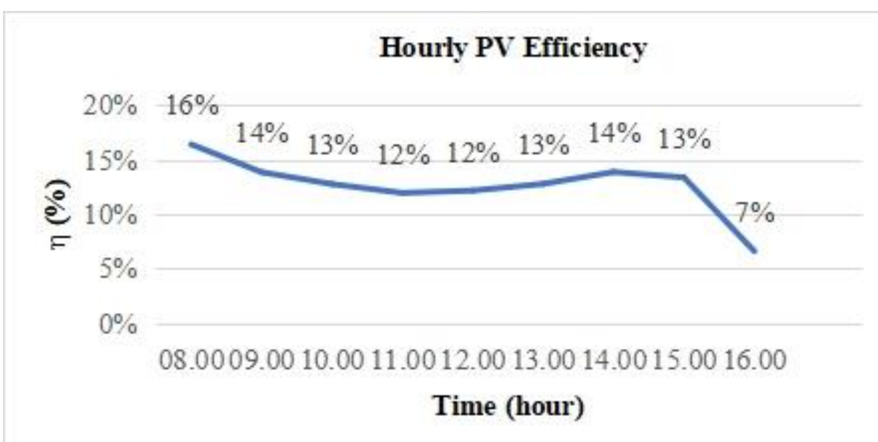

Figure 11. PVefficiency (h)

This is caused by *shading* generated by the existing pump house building near the PLTS system. In line with the research conducted by Research conducted by Rathore N, Panwar NL solar energy has become the ultimate solution to meet the ever increasing energy demands of a growing population. Solar photovoltaic technology is an efficient option for generating electricity from solar energy and reducing the impact of climate change. However, unused solar panels can become hazardous waste if not disposed of properly. Currently in India, it is estimated that around 200,000 tonnes of solar photovoltaic waste will be produced by 2030 and 1.8 million tonnes by 2050, by which time it could grow to 60 million tonnes globally.

Solar waste has recently been included in the category of waste electrical and electronic equipment to limit the negative impact of the ongoing development. However, recent progress has only focused on increasing the efficiency of solar photovoltaic panels without considering the environmental impact of solar panel waste and the issue of proper waste disposal. Effective and environmentally friendly methods for recycling final waste are rarely considered. Therefore, there is a need for critical investigation and management of the disposal and recycling of solar panel waste. This review article examines the handling and recycling of solar waste, which will be present in large quantities after 25 years. We review some of the technologies adopted for recycling solar waste and the technological advances achieved when recycling photovoltaic waste. In addition, the assessment of the life cycle of recycling technology is discussed.

b. Rotate Speed

The figure 12 shows the relationship between irradiation and pump rotational speed which is affected by time. The first and second weeks of irradiation peaked at 11.00 with pump speed of 3210 and 3221 RPM respectively.

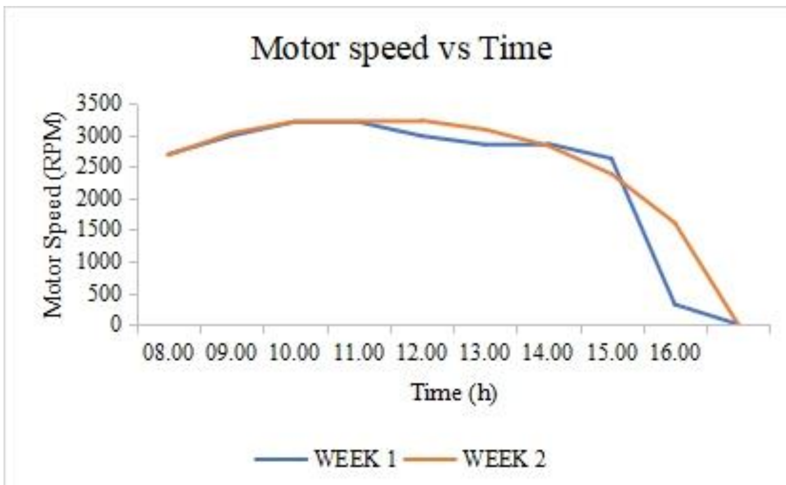

Figure 12. Irradiation VS RPM

Based on the results, it was found that it is important to know the rotational speed from the research review, namely:

a) Effect of rotational speed on pump efficiency: Centrifugal submersible pump rotational speed can affect pump efficiency. The higher the rotational speed, the higher the pump efficiency. Therefore, knowing the optimal rotational speed can help increase pump efficiency and reduce energy consumption (Arifin, et al., 2020).

b) Effect of rotational speed on system performance: Centrifugal submersible pump rotational speed can also affect the performance of the solar water pump system as a whole. If the rotational speed is too low, the pump may not be able to pump enough water to meet user requirements. Conversely, if the rotational speed is too high, the pump may wear out more quickly and require higher maintenance costs (Sevira, et al., 2019).

c) Effect of rotational speed on pump life: Centrifugal submersible pump rotational speed can also affect pump life. If the rotational speed is too high, the pump may wear out more quickly and require more frequent replacement. Therefore, knowing the optimal rotational speed can help extend the life of the pump and reduce maintenance costs (Kusuma, et al., 2020).

c. Pump Power Production

The following are several reasons why knowing pump power production is important in research, namely:

a) Effect of pump power production on pump efficiency: Pump power production can affect pump efficiency. The higher the pump power production, the higher the pump efficiency. Therefore, knowing the optimal pump power production can help increase pump efficiency and reduce energy consumption.

b) Effect of pump power production on system performance: Pump power production can also affect the performance of the solar water pumping system as a whole. If the power output of the pump is too low, the pump may not be able to pump enough water to meet user requirements. Conversely, if the power output of the pump is too high, the pump may wear out more quickly and require higher maintenance costs.

c) Effect of pump power production on pump life: Pump power production can also affect pump life. If the power output of the pump is too high, the pump may wear out more quickly and require more frequent replacement. Therefore, knowing the optimal pump power production can help extend pump life and reduce maintenance costs (Iqtimal, et al, 2018).

Pump power production is the amount of power generated by a solar water pump in pumping water. Pump power production can be measured using a power meter such as a wattmeter (Syukron, Imam, 2021). Here's how to measure pump power production:

a) Prepare a power meter such as a wattmeter.

b) Connect the wattmeter to the power source used to operate the solar water pump.

c) Turn on the solar water pump and let it run for some time until it reaches a steady state.

d) Read the number listed on the wattmeter. This figure is the production of pump power generated by solar water pumps in pumping water (Handoyo, et al., 2019).

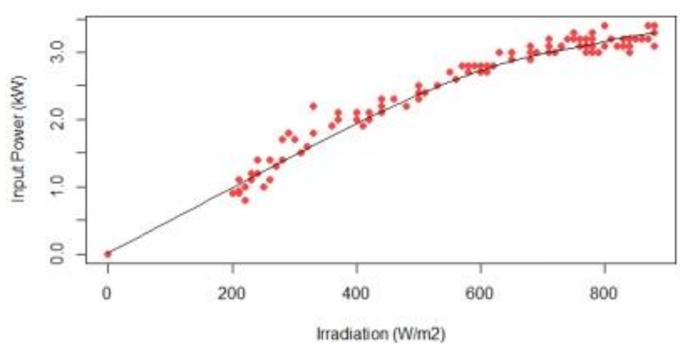

Figure 13. Smooth Scatter Plot Irradiation vs Input power

Power is directly correlated with the rotating speed of the motor. The figure 13 shows the relationship between solar irradiation and pump input power.

Therefore, knowing the optimal pump power production can help improve pump efficiency, system performance, and pump life. Therefore, measurement of pump power production is important in this study.

d. Flow RatePump

The figure 14 explains the relationship between irradiation and flow rate generated by the pump.

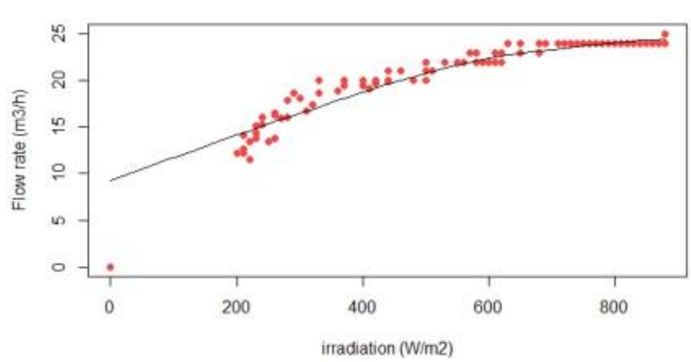

Figure 13. Irradiation vs Flo

5. Conclusion

Based on research and analysis of the effect of solar irradiation and rotational speed on the efficiency of centrifugal submersible pumps in the PATS system, the following conclusions can be drawn: one solar irradiation has a direct effect ton the performance of solar water pumps. The minimum and maximum irradiance received by the PV module as a source of pump energy is 210 w/m2 and 880 w/m2, respectively, and the average irradiation is 534 w/m2 two. 3221 RPM, with irradiation 800 w/m2 and the lowest production occurred at 16.00 with RPM 1609 three. The highest flow rate was achieved at 10.00 – 11.00 at the highest irradiation time, with a maximum Q of 24 m3/h. The lowest theoretical heads at 10 and 11 o'clock respectively are 15.3093 m and 15.3084 m. four Efficiencies are formed with constant RPM and flow rate variation achieved every hour. In the first week, the highest pump efficiency was 48% with N = 2640 RPM, and maximum Q, irradiation conditions of 795 w/m2. Second week at constant RPM N = 2811 RPM, at maximum Q and irradiation conditions of 799 w/m2 the pump efficiency is 42%. High flow rates are generated by large RPM, which are directly affected by the solar irradiation received by the energy source. The highest pump & motor efficiency was 52% and 48% achieved at 17.00 at 356 w/m2 irradiation with Q = 17 m3/h and 2507 RPM. The lowest efficiency was 34% and 31% achieved at 11.00 at 745 w/m2 irradiation with Q = 24 and RPM 3216.

Based on the conclusions, the authors can provide suggestions for further research as follows:

a) to add the capacity of the water storage tank so that it can determine the maximum efficiency without the pump being turned off because it is full, and so that it can discuss the losses that occur when the pump is turned off.

b) to conduct research with a longer period of time, so as to evaluate the system in different seasons and irradiation conditions.

References

Aliyu, M., Hassan, G., Said, S. A., Siddiqui, M. U., Alawami, A. T., & Elamin, I. M. (2018). A review of solar-powered water pumping systems. *Renewable and Sustainable Energy Reviews*, *87*, 61–76. https://doi.org/10.1016/j.rser.2018.02.010

Alkarrami, F., Iqbal, T., Pope, K., & Rideout, G. (2020). Dynamic Modelling of Submersible Pump Based Solar Water-Pumping System with Three-Phase Induction Motor Using MATLAB. *Journal of Power and Energy Engineering*, *08*(02), 20–64. https://doi.org/10.4236/jpee.2020.82002

Arifin, Z., Aries, J., Tamamy, N. I. (2020). Designing a Solar Water Pump Machine to Reduce Electricity Consumption on a Home Scale. *National Journal of Electrical Engineering, 9*(2).

Chahartaghi, M., & Nikzad, A. (2021). Exergy, environmental, and performance evaluations of a solar water pump system. *Sustainable Energy Technologies and Assessments*, *43*. https://doi.org/10.1016/j.seta.2020.100933

Handoyo, T. W., Hakim, A. R. (2019). Performance Test of a DC Refrigerator as an ES making machine using Solar Power. *Ministry of Maritime Affairs and Fisheries (Online)*, *18*(2), 51–60.

Harianti, D. (2022). Evaluation of the Selection System for Submersible Pump Specifications Owned by PDAM Tirtauli in South Siantar District, Pematangsiantar City in 2018. *ULIL ALBAB: Multidisciplinary Scientific Journal*, *1*(5), 984–991. https://journal-nusantara.com/index.php/JIM/article/view/221

Haque, A., Fernando, M., & Caputi, P. (2019). Responsible leadership, affective commitment and intention to quit: an individual level analysis. *Leadership and Organization Development Journal*, *40*(1), 45–64. https://doi.org/10.1108/LODJ-12-2017-0397

Iqtimal, Zian, Ira Devi Sara, and S. (2018). Application of Solar Power Systems as a source of Electric Power for Water Pumps. *Online Journal of Electrical Engineering (Online)*, *3*(1), 1–8.

Journals, I. R. E. (2019). *Performance Prediction of Centrifugal Pump 1, 2, 3*. *3*(2), 12–19.

Kusuma, K. B. & Partha C. G. I. (2020). Design of a DC Water Pump System with a 20 kWp Tianyar Tengah PLTs as a Power Supply to Meet the Water Needs of the Banjar Bukit Lambuh Community. *SPEKTRUM Journal*, *7*(2), 1–8.

Salilih, E. M., Birhane, Y. T., & Arshi, S. H. (2020). Performance analysis of DC type variable speed solar pumping system under various pumping heads. *Solar Energy*, *208*, 1039–1047. https://doi.org/10.1016/j.solener.2020.08.071

Sevira, R. H., Chairul, G., & Irianto, I. K. (2019). PLTS Systems for Agricultural Irrigation Water Pumps in the City of Depok. *Scientific Journal of Electrical Engineering*, *17*(1), 73–86.

Silambarasan, R., & Belgacem, F. B. M. (2012). Theory of natural transform. Mathematics in Engineering. *Science and Aerospace (MESA)*, *3*, 99–124.

Suryana, A., & Sari, R. (2018). Design of a Solar Power Generation System (PLTS) as a Submersible Water Pump Power Supply. *Journal of Electrical Engineering*, *11*(2), 1–10.

Syukron, Imam, R. (2021). *Use of the Blynk Application for Remote Monitoring and Control*. *15*(1), 2–11.