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DESIGN AND IMPLEMENTATION OF SOLAR-POWERED SUBMERSIBLE WATER PUMP FOR IRRIGATION SYSTEM IN SUBAK MUNDUK BABAKAN SANGEH, BALI

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Abstract:
This paper presents a comprehensive study on the design, implementation, and performance evaluation of a Solar-Powered Submersible Water Pump (SPSWP) system tailored for agricultural irrigation in Subak Munduk Babakan, Sangeh, Bali. With a focus on sustainable agriculture and water resource management, the system addresses the challenges of water scarcity during the dry season in the absence of natural irrigation sources. The SPSWP system, consisting of solar panels with pump controller, a submersible pump, and a water tank, harnesses solar energy to power the pump, eliminating the need for extensive infrastructure. The research encompasses site survey and mapping, analysis and design, installation, benefits beyond irrigation, and technical measurements. The implementation shows promising results in overcoming water scarcity issues. The system's advantages include minimal maintenance, cost savings, and enhanced reliability. Additionally, the SPSWP system serves as an educational site for renewable energy study and awareness. Performance metrics, including solar irradiance, voltage, current, solar panel temperature, and water discharge, are measured and discussed. The results indicate fluctuating solar energy availability, with voltage and current aligning with solar panel specifications. The system demonstrates a water discharge rate of 0.56 liters/second, showcasing promising outcomes in addressing water scarcity challenges for agricultural irrigation. Further research and monitoring are required to assess the long-term performance and sustainability of the system.

INTRODUCTION

As global concerns about sustainable agriculture and water resource management continue to grow, the integration of renewable energy technologies into irrigation systems has become a focal point of research (Rejekiningrum & Apriyana, 2020; Jibril et al., 2022; Ahmed & Iqbal, 2023; Kyeyune & Wanyama, 2023). This paper presents a comprehensive study on the design, implementation, and performance evaluation of a Solar-Powered Submersible Water Pump (SPSWP) system tailored for agricultural irrigation. The chosen study site is Subak Munduk Babakan, located in Sangeh, Bali, boasting an agricultural area of approximately 81,263.20 m^2. This traditional agricultural region predominantly relies on rainwater due to the absence of natural irrigation sources. However, the site features a well with a depth of 60 meters, presenting an opportunity for the implementation of the SPSWP system.

The necessity for irrigation is indispensable in agricultural systems. A water pump plays a crucial role in supplying clean water and facilitating irrigation for society. Depending solely on

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rainwater renders the land unproductive during the dry season. The absence of electricity in numerous remote areas in Indonesia poses a challenge for farmers seeking to establish drilled wells or extract water from rivers (Pratilastiarso et al., 2018). Despite Indonesia having extensive agricultural land, insufficient water occurs during the dry season. This challenge can be addressed by harnessing the abundant solar energy available during this period (Ali et al., 2022). The utilization of solar-powered irrigation systems significantly simplifies the irrigation process for farmers, reducing the user's exertion during irrigation activities (Sagala et al., 2022).

Current pumps in agricultural fields face limitations in reaching their maximum capacity due to interruptions in electric power supply. Solar water submersible pumps currently in use typically operate on DC power, distinguishing them from conventional pumps (Bhosale, 2022; Hariyanto, 2023). As sunlight fluctuates throughout solar hours or daytime, the power supplied to the pump changes (Bhattacharjee et al., 2021). In such instances, a pump controller is employed to regulate the voltage, eliminating the need for a battery and minimizing the cost. The selection of water pumps must be made with careful consideration to ensure optimal power consumption in the water pumping system (Ikrang et al., 2021). Additionally, factors such as the characteristics of water resources and daily water demand should be taken into account. The previous research also indicates that incorporating a water storage tank can enhance the effectiveness of solar-powered pumps.

In economic aspect, the previous study reveals that the initial investment for a solar PV pump per horsepower is eightfold greater than that of a diesel pump. However, it was observed that the operational and maintenance expenses for solar pumps are considerably lower compared to those associated with diesel pumps (Renjini et al., 2021). A comparable investigation also indicates that the initial investment cost for installing a solar pump is considerably higher than that of the conventional system (Choydhury et al., 2022). However, due to its lack of fuel requirements and minimal maintenance, the solar pump proves to be more economically viable in the long term. Over the 20-year lifespan of both systems, the cost of pumping one cubic meter of water using a solar pump is only PHP 1.35, whereas with gasoline, it amounts to PHP 5.44, making it approximately four times more expensive based on the prevailing costs during the study (Orpia et al., 2021).

After installation, the performance of solar-powered water pump system should be observed. Sontake et al. conducted a study to assess the effectiveness of a directly linked solar water pumping system under various pumping head (2 to 5 bar) and diverse PV array setups (3S×2P, 4S×2P, 5S×2P, 6S, 7S, and 8S) in the Vidarbha region in central India. Their findings indicated that the 4S×2P and 5S×2P configurations proved to be the most optimized arrays, delivering optimal energy output across all pumping heads (Salman et al., 2021). Meanwhile, Salman et al. investigated the performance of the direct-coupled PV water pumping system for agriculture in Iraq. The yearly results show pumping efficiency is increased up to 42.6%, used water need is achieved at 10950 m3, and unused energy is reduced by 48.8% (Sontake et al., 2020).

From the aforementioned contexts, this research encompasses five key aspects: (1) site survey and mapping, (2) analysis and design of the SPSWP, (3) installation of the system for irrigation, (4) benefits beyond irrigation, and (5) technical measurement of the SPSWP.

METHODS

The research activities unfold in sequential stages: (1) site survey and mapping, (2) analysis and design of a Solar-Powered Submersible Water Pump (SPSWP), (3) installation of the SPSWP for the irrigation system, and (4) technical measurement of the SPSWP. Fig. 1.a illustrates the

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geographical location of Subak Munduk Babakan in Sangeh, Bali, encompassing an agricultural area spanning approximately 81,263.20 m², as depicted in Fig. 1.b. This region, rooted in traditional agriculture, predominantly relies on rainwater due to the absence of natural irrigation sources. Notably, the site features a well with a depth of 60 m, strategically identified for the installation of the SPSWP.

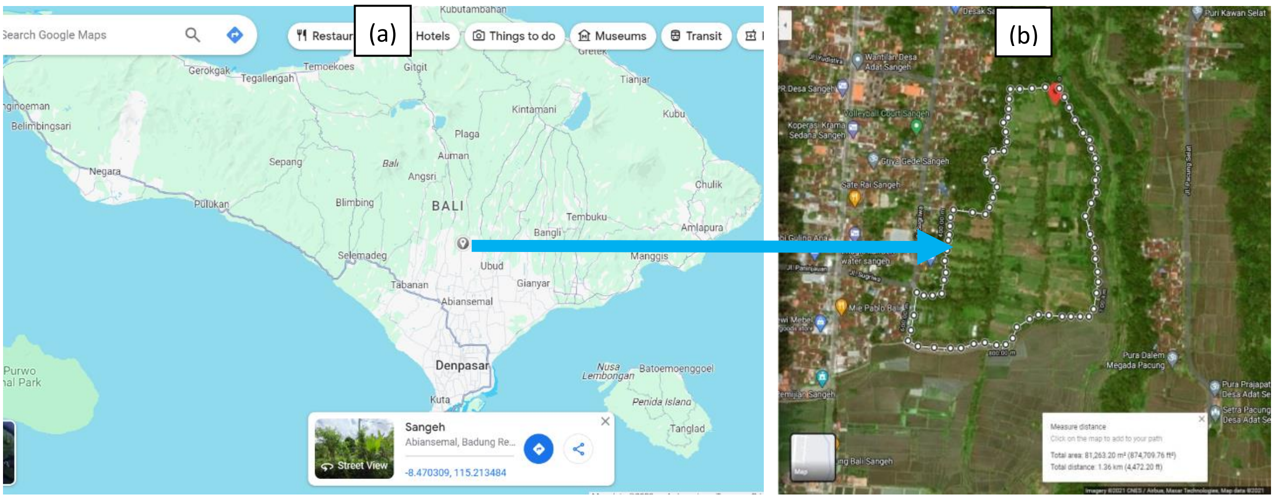

Figure 1. (a) Site Location on the Bali Map; (b) Subak Munduk Babakan Area

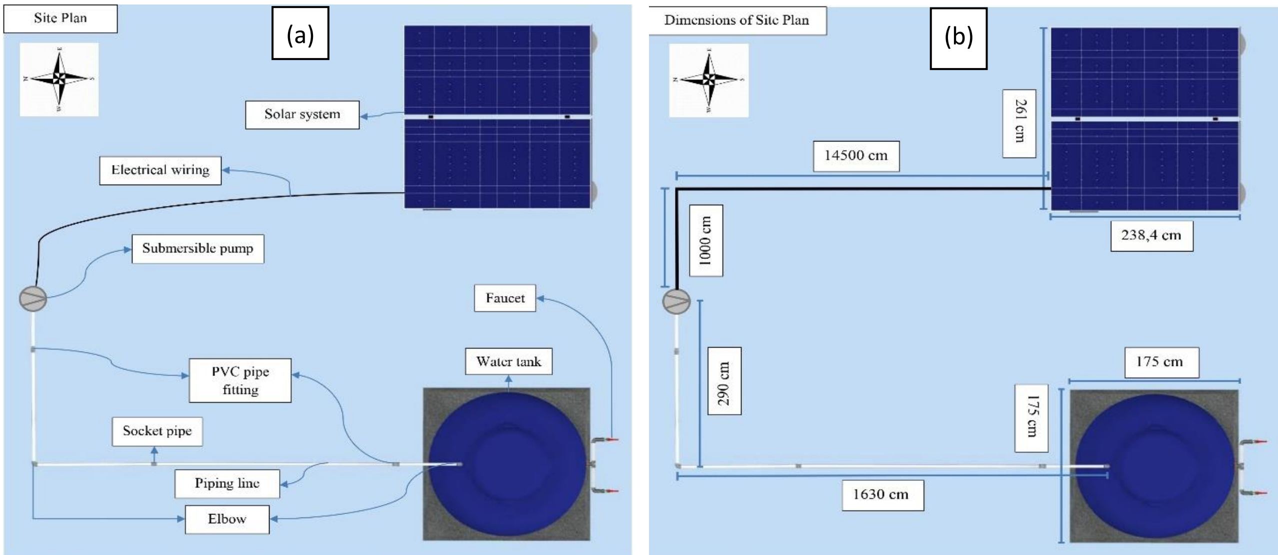

Figure 2. (a) SPSWP Site Plan; (b) Dimension of Site Plan

The proposed Solar-Powered Submersible Water Pump (SPSWP) comprises three primary components, namely the solar system, submersible pump, and water tank, as illustrated in Fig. 2.a. Solar panels serve as the means to capture solar energy, converting it into electrical power for the water pump. In this instance, the chosen pump is a submersible pump, a type of turbo pump intricately connected to an electric motor and fully submerged in water. The utilization of this pump eliminates the need for extended drive shafts and bearing housings in powerful turbo pumps,

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enhancing efficiency by expelling water outward without the necessity to draw it in. Subsequently, the water is directed through a pipe to a storage tank, as depicted in Fig. 2.b, showcasing the dimensions of the site plan and its integral components.

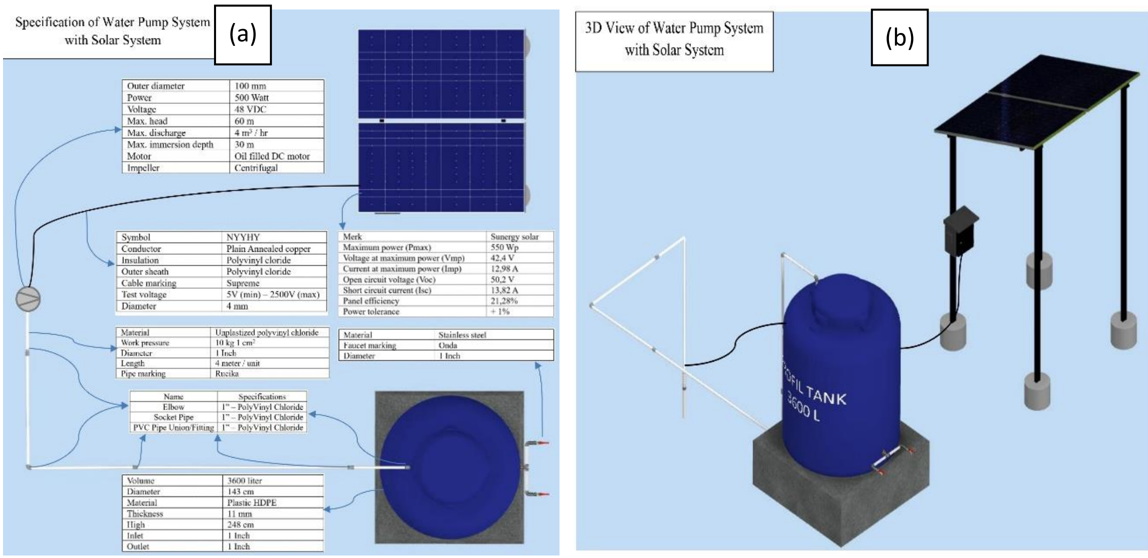

Figure 3. (a) Technical Specification of the System; (b) 3D View of the System

In Figure 3. a, the technical specifications of the proposed Solar-Powered Submersible Water Pump (SPSWP) system are presented. The system utilizes two 550 Wp solar panels connected in series, each featuring specifications such as 42.4 Vmp (voltage at maximum power), 12.98 Imp (current at maximum power), 50.2 Voc (open circuit voltage), and 13.83 Ioc (short circuit current). These specifications theoretically provide sufficient power to operate the pump. The submersible pump is equipped with a centrifugal impeller type, a motor with a 45 VDV oil-filled DC motor, and a power requirement of 500 Watts. Additionally, it has an outer diameter of 100 mm, a maximum head of 60 m, and a maximum immersion depth of 30 m. The pump can yield a maximum water discharge of 4 m^3/hour or 1.11 liters/second. The solar panels and the pump are connected using a 4 mm diameter NYYHY plain annealed copper cable, while the pump and the water tank are linked by a 1-inch PVC pipe. The water tank, constructed from plastic, has a capacity of 3600 liters. For a comprehensive view of the entire SPSWP system, refer to the 3D representation in Fig. 3.b.

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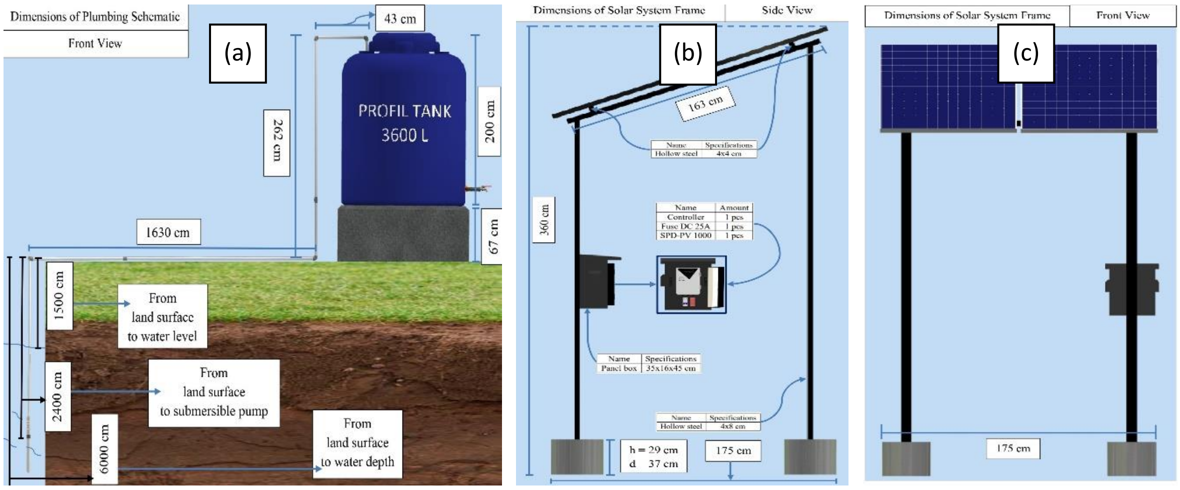

Figure 4. (a) Dimension of Plumbing Schematic; (b) Dimension of Solar System Frame Side View; (c) Dimension of Solar System Frame Front View

The well depth, measured as the distance from the land surface to the well's bottom, is crucial for the proposed SPSWP system. In this specific scenario, the well has a depth and diameter of 60 m and 15.24 cm, respectively, with a bore well casing of 6 inches. The water level from the land surface is 15 m, and the pump is strategically hung at a depth of 24 m from the land surface. The detailed dimensions of the plumbing system are illustrated in Fig. 4.a. The distance between the well and the water tank is 16.3 m, and the water tank boasts a substantial capacity of 3600 liters. Given the absence of a battery in the solar system, the water tank is filled exclusively when sunlight is available. The dimensions of the solar system frame are depicted in both Fig. 4.a and 4.b, providing side and front views, respectively. This frame, constructed with a hollow 4 x 4 cm design, stands at a height of 3.6 m and a width of 1.75 m. Additionally, the panel box housing the controller is strategically mounted on one of the frame poles beneath the solar panel.

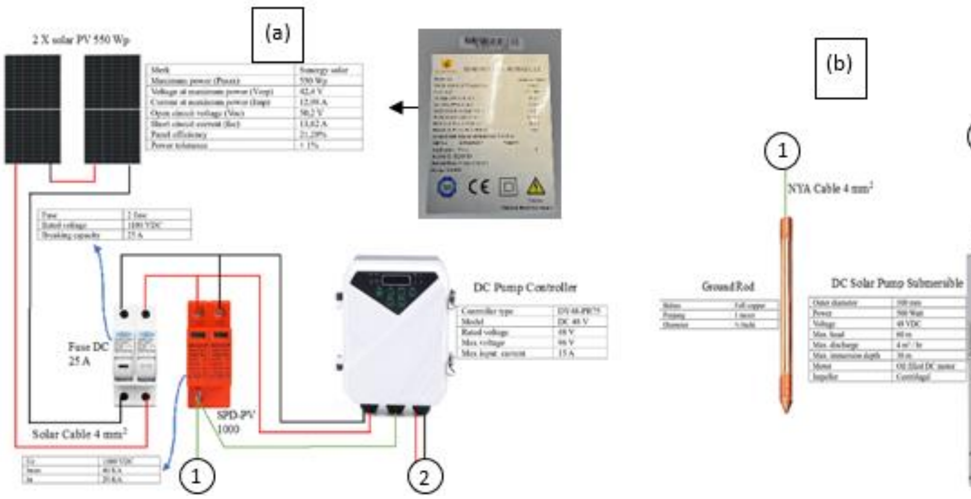

Figure 5. (a) Solar Panel and Controller Schematic and Specs; (b) Ground Rod and Submersible Pump Specs

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Fig. 5.a presents the schematic and specifications of the solar panel and controller, while Fig. 5.b details the ground rod and submersible specifications. The monocrystalline solar panel, boasting a 21.28% efficiency, is configured in series as a single string. This string is connected using a 4 mm^2 solar cable, linking to a 25 A fuse DC for protective measures. The purpose of this solar DC string fusing is to safeguard against reverse currents in the event of a fault condition, ensuring the wiring remains intact and secure without compromise. Moreover, Surge Protective Devices (SPDs) provide defense against electrical surges and spikes, whether triggered directly or indirectly by lightning. These protective measures are integrated with the ground rod and the DC pump controller. The controller exhibits advanced functionalities, including MPPT function, reverse polarity alarm, dry running protection, and automatic on/off functionality based on the water level. Further enhancing efficiency, the solar pump controller can enter sleep mode during low sunlight conditions and resume operation when sunlight levels increase. Also, it can autonomously adjust the rotational speed of the water pump motor.

RESULTS AND DISCUSSION

This section delineates and deliberates on the execution of the proposed SPSWP system design discussed earlier, situated in Subak Munduk Babakan, Sangeh, Bali. The process commences with the installation of the submersible pump within the existing well, succeeded by the setup of the solar panel and pump controller, along with the installation of the water tank and its corresponding pipes. The transfer of the SPSWP system to local farmers affiliated with Subak Munduk Babakan is detailed, and a site visit by students from a nearby elementary school is also highlighted. Finally, the section provides insights into the measurement of various system-related parameters and their corresponding results.

Figure 6. Installation of the Submersible Pump in the Well

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Figure 7. Installation of Solar Panel and Pump Controller

Figure 8. Installation of Water Tank and its Pipes

The fieldwork commences with the installation of the 48 VDC submersible pump in the existing well, depicted in Fig. 6.a – 6.c. The well, with a depth of 60 m and a diameter of 15 cm, features a 6-inch PVP pipe bore well casing. Utilizing a 2-inch pipe and a low-voltage cable with a 4 mm diameter, the submersible pump is attached with a length of 24 m from the land surface. It is imperative to ensure that the joint is waterproof since the cable joint will be submerged in water. Any excess cable length should be trimmed rather than coiled, ensuring a secure connection to the starter terminals to prevent loose connections. Simultaneously, the solar system installation is detailed in Fig. 7.a – 7c. Placed approximately 14.5 m away from the well and at a height of 3.75 m to avoid shading from nearby vegetation, the solar panels face north, given the southern hemisphere location of the site. Operating solely in daylight due to the absence of a battery to minimize costs, the system employs a pump controller to link the DC output of the solar arrays to the water pump. For DC water pumps, the pump controller integrates a Maximum Power Point Tracker (MPPT) for optimizing power extraction from the array, coupled with a DC motor pump controller. The final installation work involves the water tank and its pipes, as illustrated in Fig. 8.a – 8c. Water storage tanks, widely accessible, user-friendly, and easy to maintain, offer an economical solution for ensuring a continuous water supply through solar-powered irrigation systems. This tank presents a more advantageous design option compared to batteries, enhancing the reliability of the SPSWP for the irrigation system. Additionally, it proves useful for storing water in emergencies, such as pump failure or insufficient sunlight (low irradiance), particularly during mornings, evenings, or cloudy days.

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Figure 9. Handing Over of the SPSWP System to Farmers of Subak Munduk Babakan

Figure 10. Site Visit From Students of the Nearby Elementary School

Once all installation tasks have been successfully completed and the SPSWP operates seamlessly according to the proposed design, it is then handed over to the farmers of Subak Munduk Babakan. The implementation of this system raises hopes for addressing water challenges in irrigation, particularly during the dry season. In contrast to the traditional water pumps previously employed by farmers, solar water pumps demand minimal maintenance. The primary benefit of these pumps lies in their utilization of sunlight without any associated costs. By diminishing reliance on electricity or diesel, solar water pumps eliminate recurring expenses for electricity or fuel once they are installed. It has the potential to significantly decrease the labor and time required for crop irrigation. In remote regions facing less power availability, these pumps prove to be more reliable than traditional electric pumps.

Besides being beneficial for farmers, this system can also be a place to learn about the use of renewable energy. As the example shown in Fig. 10.a & 10.b, where students of the nearby elementary school visited the site. In this place, they can learn how solar energy can be converted into electrical energy to power the water pump, and how water can be stored and controlled for irrigation system. Renewable energy should be a subject that we should encourage them to engage with on an early academic level. It is not only the acknowledgment and significance of energy that

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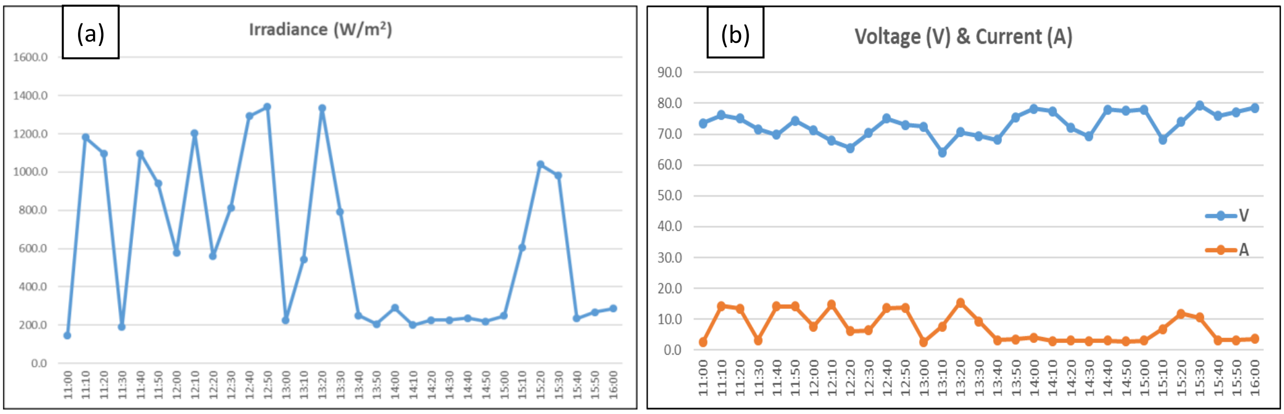
could be included in lesson plans, the value of renewable energy sources should also be emphasized in students' awareness.

To assess the system's performance, various parameters such as solar irradiance, voltage, current, solar panel temperature, and water discharge times are measured. Solar irradiance is gauged using a solar power meter (see Fig. 11.a-11.c). Voltage and current readings are obtained from the panel box. The recorded voltage corresponds to the output voltage generated by the solar PV entering the controller and is documented with a voltmeter. Concurrently, the measured current reflects the flow from the solar PV into the controller, identified through an ampere clamp. Also, the temperature of the solar panel's lower surface is measured with a thermogun (refer to Fig. 11.a-11.c).

Figure 11. Irradiance and Solar Panel Temperature Measurement

Irradiance serves as a measure of solar energy, indicating the rate at which solar energy reaches a particular area. The unit of power in this context is the Watt. Solar irradiance is typically quantified in W/m², representing power per unit area, with the measurement expressed as watts per square meter. As illustrated in Fig. 12.a, the results of irradiance measurements conducted at 10-minute intervals from 11:00 to 16:00 reveal a fluctuation in irradiation distribution, ranging from 200 to 1300 W/m², with an average of 608 W/m².



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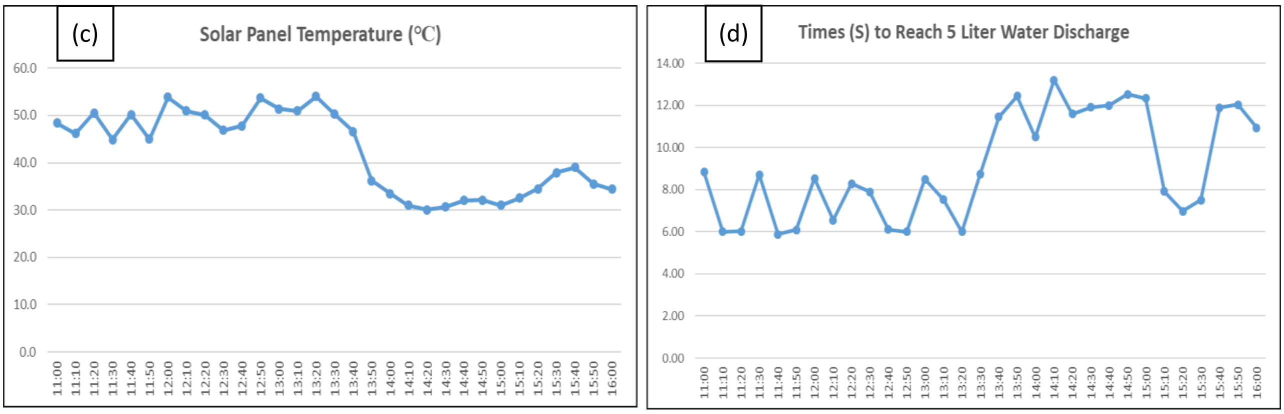

Figure 12. (a) Irradiance; (b) Voltage and Current; (c) Solar Panel Temperature; (d) Times of Water Discharge

The results of voltage and current measurements, depicted in Fig. 12.b, reveal that the average voltage generated by the solar PV is 73.1 V, with an average current flow of 7.35A. Both values fall within the specified range for solar panels connected in series. Concurrently, Fig. 12.c displays the temperature variation of the solar panel's bottom surface, ranging from 30 to 54 ℃, with an average of 43.2 ℃. Notably, these temperatures surpass the normal air temperature, highlighting the absorption of solar energy by the solar panel. To gauge water output from the pump, a 5-liter container is used to capture the water, and the time to fill is recorded with a stopwatch. As shown in Fig. 12.d, the average time to obtain 5 liters of water from the pump is 9 seconds, indicating a water discharge rate of 0.56 liters/second. Although this value is only half of the pump's maximum capacity of 4 m3/h or 1.11 liters/second, it signifies effective functionality.

CONCLUSION

This research outlines a comprehensive approach to address water scarcity for irrigation in the Subak Munduk Babakan, Sangeh, Bali, through the implementation of a Solar-Powered Submersible Water Pump (SPSWP) system. It involves site survey and mapping, analysis and design of the SPSWP, installation of the system, and technical measurements. The chosen site, characterized by an agricultural area dependent on rainwater and equipped with a well, serves as a suitable location for the proposed solution. The SPSWP system comprises solar panels, a submersible pump, and a water tank. The solar panels harness solar energy to power the submersible pump, eliminating the need for extensive drive shafts and bearing housings. Meanwhile, the pump delivers water to a storage tank for later use in irrigation. Upon successful installation, the system is handed over to farmers in the Subak Munduk Babakan, aiming to alleviate water scarcity issues during the dry season. The SPSWP system offers advantages such as minimal maintenance, cost savings, and enhanced reliability, particularly in areas with limited power availability. Moreover, the system serves as an educational resource for renewable energy, as evidenced by the visit of students from a nearby elementary school. It also presents and discusses the performance metrics of the SPSWP system, including irradiance, voltage, current, solar panel temperature, and water discharge. Irradiance measurements indicate fluctuating solar energy availability, while voltage and current readings align with the specifications of the solar panels. The solar panel's bottom surface temperature is higher than the air temperature, reflecting its absorption of solar energy. The water discharge rate from the pump is found to be 0.56 liters/second, half of the maximum capacity. Thus, the implementation of the Solar-Powered Submersible Water Pump system demonstrates promising results in addressing water scarcity challenges for agricultural irrigation. The system not only provides practical benefits for farmers but also serves as an educational tool for renewable energy awareness. Further research and monitoring are recommended to assess the long-term performance and sustainability of the system. We extend our gratitude to P3M PNB and Greenpeace Indonesia for supporting and funding this research and community service.

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