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Hybrid Water Feedback Solutions Using Internet of Thing (Iot) Enabled Water Pumps Powered by Solar Panels

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Abstract.
Purpose: Renewable energy in Indonesia is very abundant, one of which is solar energy. With Indonesia's location on the equator, the abundant potential of solar energy can be utilized as an environmentally friendly source of electricity. To increase the potential of solar energy as a source of electricity, it is equipped with a battery storage system. The most widely used electrical energy storage system is the battery. The purpose of this study is the use of solar energy for DC water pumps. The proposed system is also equipped with power, voltage and current monitoring on the solar panel side and on the load side (water pump).
Methods: The method used is to conduct a literature review to study and find out the development of a power monitoring system using solar panels. The next step is to measure solar radiation, calculate PV capacity and SCC. Furthermore, designing, modeling, simulating, analyzing, and implementing the optimal topology for water pump control using solar panels.
Results: The results of the research are water pump control coordination devices using Sonoff with an IoT-based monitoring system. This device is capable of controlling PV and battery power flow. A prototype of a solar water pump has been produced which has been validated by experts in the field of appropriate technology with feasible results and received a positive response from farmers in Demak to be immediately implemented in the fields to help with the water crisis in agricultural land.
Novelty: The advantage of this solar water pump is that the product is equipped with the internet of things (IoT) which can control the use of water pumps in the fields with our android devices wherever we are, this makes it easy for farmers to apply them, then the water pumps also do not use electricity which makes this water pump not harmful to farmers, because in the past many farmers were electrocuted and died.

Keywords: Pump control, Monitoring power, IoT system, MPPT
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INTRODUCTION

Technological developments and population affect the availability of electrical energy. However, the availability of fossil fuels used by power plants is currently decreasing. Therefore, the development of renewable energy continues to be increased to reduce dependence on PLN electricity. One of the uses of renewable energy is solar energy as a source of electricity for water pumps, both for homes and for irrigation.

Various studies have been carried out for the use of water pumps. Researcher [1] uses a photovoltaic system as a power provider to operate a pool water pump in a villa in Bali. In this study, the Series and Parallel photovoltaic arrangement is used with a panel system that is integrated with PLN electricity. The tilt angle and placement direction chosen in this study was 15°.

Researcher [2] proposes a two-way power flow control from the grid and solar photovoltaic (PV), for a pumping system. Brushless DC (BLDC) motor drive without phase current sensor, used to run water pumps. This system allows consumers to operate the water pump at full capacity for 24 hours regardless of climatic

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conditions. Full utilization of the PV array and pump motor is made for increased reliability of the pumping system. Single-phase voltage source converter (VSC) for bi-directional power flow control between the DC grid and bus. Voltage source inverter (VSI) as a source for BLDC motors, which are operated at the basic frequency.

Researchers [3] designed a solar power plant capacity of 12.54 kWp using 33 units of solar modules and an 18.5 kW inverter. The pump can operate for 5 hours 30 minutes in sunny weather with a water discharge of 253 m3 or fulfills 17.5% of the water requirement for an area of 16 hectares. The investment cost for a solar power pump system is IDR 171,193,500. The operational cost of the new system (solar-powered) per hectare is IDR 6,495/day. Meanwhile, the operating cost of the old system (diesel-powered) per hectare is IDR 15,950/day.

Researcher [4] proposed a control strategy consisting of three control units. The first unit is a speed and hysteresis current controller for a BLDC motor pump. Maximum power point tracking (MPPT) is the second control unit, and the battery charge/discharge system is controlled by the third control.

Researcher [5] proposes an adaptive control strategy by considering the PV output power and load demand for inverter-controlled PV/battery. The proposed strategy can maximize the utilization of PV generation. Inverters are installed in a parallel configuration.

Researcher [6] proposed a VSG control strategy by considering coordinated energy management of battery and PV. Through real-time analysis of VSG output power and battery and PV state, dynamic adjustment of PV power output and VSG virtual characteristics is made to realize coordinated control of PV and battery. This strategy effectively increases VSG's dependence on battery capacity by favoring PV power adjustment and asymmetrical control of the battery SOC.

Researchers [7] proposed a single-stage and multi-stage water pumping system consisting of renewable energy and an AC motor. The review was carried out based on the type of motor, the power of the electronic interface and the control strategy used. The proposed system uses a PV-Wind turbine source.

Researchers [8] undertook a follow-up literature review on the design and performance of solar technologies for water pumping, as well as a transitional perspective for the energy needs of developing countries. In addition, the researcher intends to analyze perspectives on renewable energy technology that governs photovoltaic water pumping system technology. The aim is to identify key knowledge about water pumping design and research gaps about solar panels for water pumps. Researchers point out that the most commonly used water pumping technology configuration is a direct clutch system without battery storage. This system is simple and reliable, mainly used in small scale pumping for small irrigation and domestic use. The main variables that affect the performance of water pumping are: total dynamic head, amount of liquid extracted, variations in solar radiation levels, PV technology and pump motors. For large scale, PV can be used. However, the efficiency of PV and the whole system does not exceed 10% and 5%, so an optimal design is required.

Researcher [9] proposes an efficient brushless DC (BLDC) motor drive for a solar PV array (SPV) array in a water pump system. The zeta converter is used to extract the maximum available power from the SPV array. The proposed control algorithm eliminates the phase of the current sensor and adapts the base frequency switching of the source voltage inverter (VSI), thereby avoiding power loss due to high frequency switching. No additional controls or circuits are used for speed control of BLDC motors. Speed is controlled via a VSI variable DC voltage link. A zeta converter controls via incremental maximum conductance power point tracking (INC-MPPT) for soft starting BLDC motors.

Researchers [10] optimize the generated solar photovoltaic (PV) power using the maximum power point tracking technique (MPPT), the DC-DC conversion stage is usually required in solar PV water pumping driven by DC brushless (BLDC). This power conversion stage leads to increased cost, size, complexity and reduced efficiency. A simple control designed to operate the PV array at peak power using a voltage source inverter (VSI), for BLDC motor control. The proposed control eliminates the phase current of the BLDC motor.

Researcher [11]–[13] proposed a new model 'Semi-Modular Dual-Stack' (SMDS) Motor ST BLDC with 3D-FEM parameters. Photovoltaic (PV) powered submersible electric water pumps are becoming popular in remote areas, due to the unavailability of a PLN source. However, due to the high initial cost of a PV system, brushless dc (BLDC) permanent magnet (PM) motors are more efficient to use when compared to induction motors. Researchers propose a PV-based submersible water pump load from a 100 mm deep well.

Researchers [14]–[16] proposed a peak current detection algorithm based on wide speed range control without position sensors for PV arrays driven by PM BLDC motors for irrigation water pumping. This algorithm controls the exact initial turnover along with the peak viewing current. Eliminating the use of position sensors and current sensors for rotor position estimation makes drive implementation simpler and more cost effective for farms. Drive operation is tested by simulation and reliability is tested in laboratory prototypes as well as in industrial product prototypes.

In the end the researcher [17] designed a soft starter for a three-phase pump motor. The goal is to reduce the starting current when the pump is operated, but be able to generate sufficient torque to operate a three-phase induction motor. In this study a soft starter was developed using an Altera FPGA with a fuzzy logic controller, with a submersible pump power capacity of 5.5 KW.

The main focus of this research is to design a single-phase water pump control using solar panels and batteries equipped with an IoT-based monitoring system. By monitoring we can find out the electric power capacity available for the water pump and can turn on and turn off the pump remotely. After this introduction, we organize our work in section 2: Literature Review. Section 3: Methods. Section 4: Results and discussion. Section 5: conclusion of the work done.

PV models

Solar cell or PV is a non-linear component which can be shown in Figure 1 as a current source model. Iph is the cell current, ID is the intrinsic shunt current of the diode, Rsh is the shunt resistance, Rs is the series resistance of the solar cell, and Ish is the parallel current source. Rsh values are usually very large, and Rs values are very small, so the analysis can be neglected. PV cells are grouped into large units called PV modules which are also connected to form PV arrays or PV generators in series and parallel configurations [18]–[21].

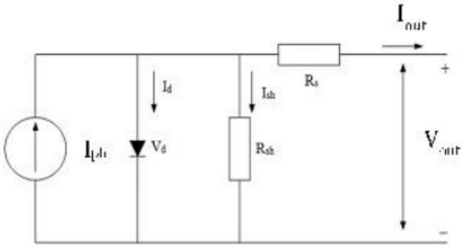


Figure 1. PV cell equivalent circuit model

Equation of the current voltage of a solar cell with the following equation

$$I = I_{ph} - I_s\left\{\exp\frac{(V+IR_s)}{(nV_tCN_s)} - 1\right\} - \frac{V+IR_s}{R_{sh}} \tag{1}$$

where I_{ph} is the photocurrent which depends on the cell and the operating temperature of the solar radiation as defined in equation 1.

$$I_{ph} = \frac{(I_{sc} + Ki(T_{op} - T_{ref}))\lambda}{1000} \tag{2}$$

The saturation current from temperature changes is expressed by the following equation:

$$I_s = I_{rs}\left\{\frac{T_{op}}{T_{ref}}\right\}^3 \exp\left\{\frac{qE_g}{nK}\left\{\frac{1}{T_{op}}-\frac{1}{T_{ref}}\right\}\right\} \tag{3}$$

$$I_{rs} = \frac{V+IR_s}{R_{sh}} \tag{4}$$

$$I_{sh} = \frac{V+IR_s}{R_{sh}} \tag{5}$$

$$I_d = \left\{\exp\frac{(V+IR_s)}{(nV_tCN_s)}-1\right\}I_sN_p \tag{6}$$

The PV circuit model for evaluating array currents, where N parallel (Np) and N series (Ns) cells are expressed as follows:

$$I = N_pI_{ph} - N_pI_s\left\{\exp\frac{\left(\frac{V_{pv}}{N_s}+\frac{IR_s}{N_p}\right)}{KT_{op}m}-1\right\} - \frac{\frac{N_pV_{pv}}{N_s}+IR_s}{R_p} \tag{7}$$

Where Is is the cell saturation current, Ns and Np are the number of PV panels in series and parallel, C is the number of cells in the PV panel, Rs is the series resistance, Rsh is the shunt resistance, Top is the operating temperature of the cell at 25°C, Voc is the circuit voltage open PV, m is the ideality factor, K is the Boltzmann constant (1.38 x 10 -23 J/ºK), and q is the electron charge (1.6 x 10-19C). The following parameters describe a solar cell [22]–[25]:

1. The highest current generated by the cell during the condition V=0 is determined by the short circuit current.
2. The open circuit voltage is due to the voltage drop across the diode when Iph is flowing, where ID = Iph and the resulting current is zero.

To ensure optimal system performance, certain system parameters must be considered in the design:

1. The efficiency of photovoltaic (PV) is low, this is due to the influence of internal series and shunt resistances and the effect of recombination on photovoltaics.
2. Since the performance of the PV module is affected by the surface temperature, the module temperature coefficient (TC) must be considered. For Silicon Modules, the temperature correction factor is around -0.5%/ºC, so it is safe to take a TC of 0.80 [26].
3. Efficiency of other parts of the device including the output of the charging controller, the performance of the DC-AC (inverter) and the output of the battery storage.

MPPT (Maximum Power Point Tracking)

There are two types of PV systems, isolated systems and grid-connected systems. An isolated PV system is designed to provide AC/DC electrical power to a load. MPPT (maximum power point tracking) is used between the PV array and the load to help obtain the maximum output power and also the mains impedance adjustment at the PV's maximum power output. A control method is used to increase PV system performance and to track the maximum power point. The MPPT algorithm calculates MPP (maximum power point) at any time for each radiation and temperature. MPP changes due to environmental conditions. There are several techniques for implementing MPPT and the most widely used methods are Perturbe and Observe which are known as P&O. This method is based on changing the PV output voltage and observing the power obtained by modifying the duty cycle of the DC/DC converter to achieve maximum power. Another control technique that is also used is the proportional and integral (PI) control method. This control is easy to implement by controlling the input voltage of the buck-boost converter according to the reference voltage, resulting in maximum power [27]–[29].

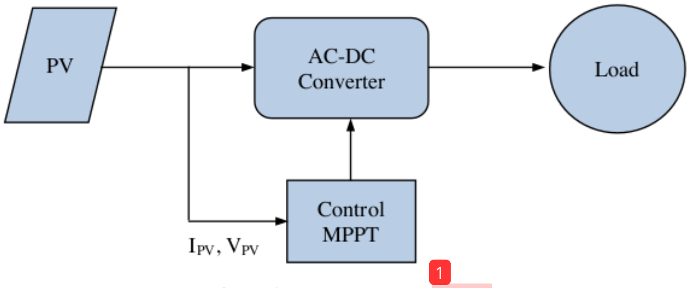


Figure 2. MPPT on a PV system

For any PV system the output power can be increased by tracking the MPP of the PV module using a controller connected to a DC-DC converter (usually using a boost converter). However, the MPP changes with radiation level and temperature due to the nonlinear characteristics of the PV module. Each type of PV module has its own specifications. In general there is a point on the V-I curve or V-P curve called the MPP, at which the PV system operates at maximum efficiency and produces its maximum output power. This point can be found with the help of MPPT. The PV system with MPPT control is shown in Figure 2 [30], [31].

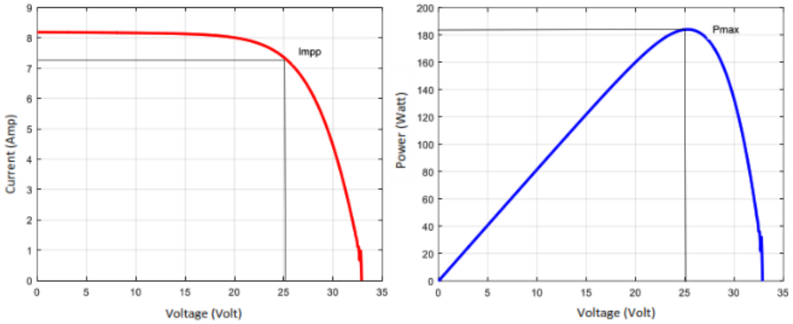


Figure 3. PV curve (PV and IV)

METHODS

The method used in the research on Water Pump Control with PV Sources and IoT-Based Batteries, through the following stages.

1. Measurement of solar radiation intensity.
2. Determination of PV capacity.
3. Determination of MPPT capacity.
4. Determination of battery capacity.
5. Monitoring system design
6. Measurement of power, voltage, and current in the system.

The first step is to measure the intensity of solar radiation as a research location, which serves to calculate the amount of PV capacity used. MPPT is used to extract the PV output power to the battery and load. The MPPT size depends on the PV used. For this study, no inverter was used, because the system uses DC electricity. The battery is calculated based on the duration of use of the water pump. Monitoring system using IoT. The end result is power, voltage, current on the PV side and on the load side (water pump). The study location d is at the PGRI University in Semarang and the system device testing location is in Demak. In this study, some of the main equipment used is as follows.

- Solar panels
- MPPT type SCC
- 100 Ah battery
- Son Off

- IoT

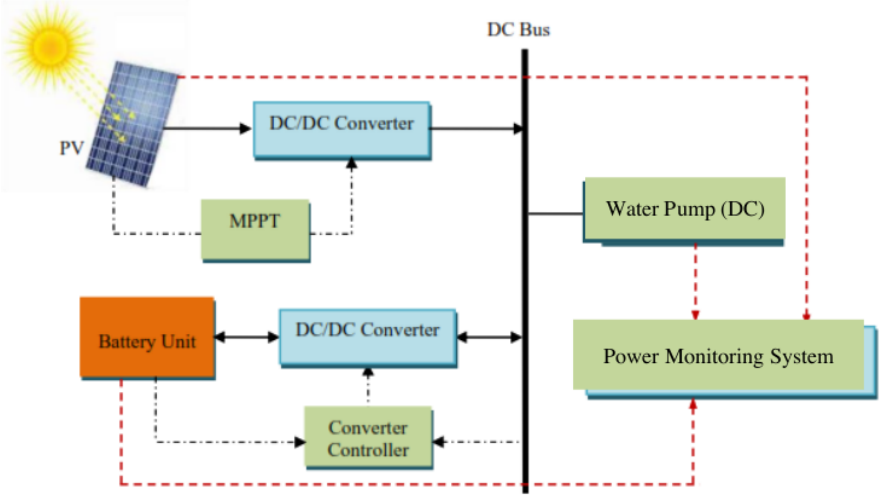
While additional equipment as follows

- Relay contactor.
- MCB.
- DC relays.
- Water pump.
- Overloaded.

To measure the PV output power, the measuring instrument is used as follows

- Watt meter (measuring power).
- Volt meter (measuring load voltage).
- Ampere meter (measures load current).

The capacity of the PV and battery is determined based on the duration of the water pump's energy use. In this study the water pump operated for two hours. The power capacity of the water pump is 250 watts, so the amount of electrical energy used is 250 Wh. The effective duration of sunlight exposure is five hours, resulting in four 100 Wp PVs and three 100 Ah batteries.



automatic solar radiation (measures the intensity of solar radiation) Description:

→ Power Flow

⇢ Control Flow

→ Power Monitoring

Figure 4. Block diagram of monitoring a water pump with PV Source and Battery.

RESULTS AND DISCUSSIONS

Measurement of solar radiation intensity

Measurement of solar irradiance is carried out to determine the length or duration of solar irradiation that occurs for one day in 12 hours, namely at 06.00 - 18.00 local time. Solar radiation measurements were carried out for one year from January to December 2022. Solar radiation measurement data is shown in Figure 5. The measurement locations were carried out on Campus I, Universitas PGRI Semarang. The location has a Latitude of -6.9833453 °, Longitude 110.44913884360147 °, Annual global irradiation 1920.7 kWh/m^2 and an average temperature of 28 °C. Meanwhile, the longest sunlight duration with a time range of 06.00–18.00 WIB will occur on November 22 2022 (8.4 hours) and the shortest sunlight duration will occur on November 11, 16 and 19 2022 (0.0 hours).

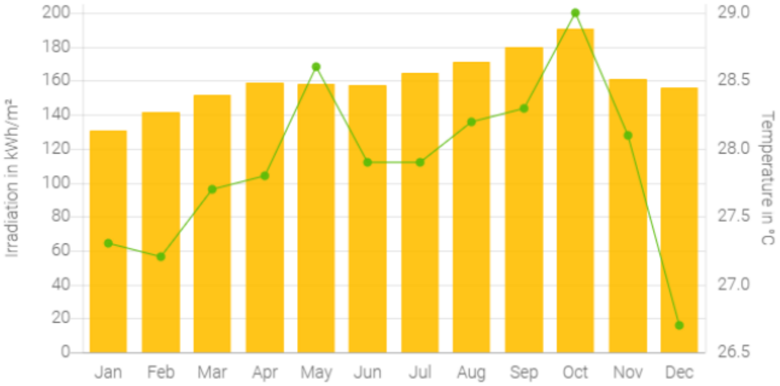


Figure 5. Solar radiation data for 2022

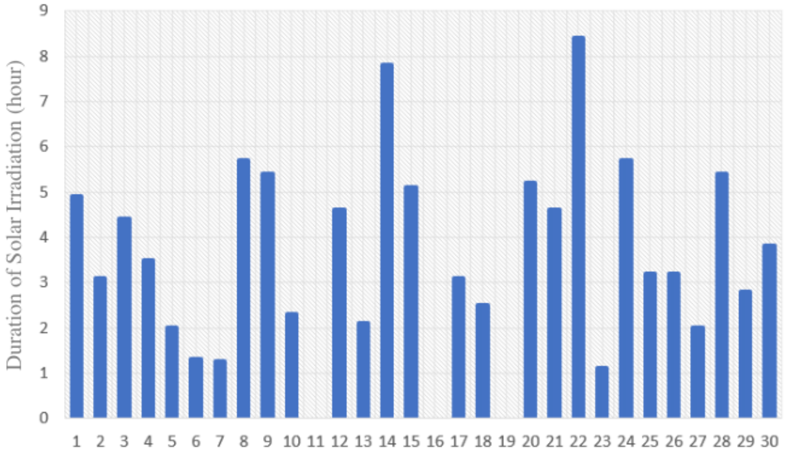


Figure 6. Graph of solar irradiation duration

PV output

The month with the highest PV output power in a year in Semarang City is August, with an average of 148.9 kWh. Meanwhile, the lowest PV output power occurred in February with an average of 96.5 kWh. In research on the development of educational game applications, it aims to make the application as a medium for learning to recognize attractive flat shapes, create easy-to-understand learning patterns so that it can improve the learning process about flat shapes, design and create educational games for Android-based flat shapes.

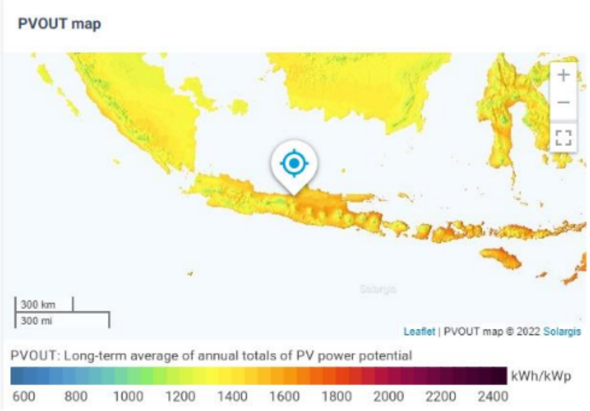


Figure 7. Average power of total PV potential power

Table 1. Total average hourly PV output power

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0-1	-	-	-	-	-	-	-	-	-	-	-	-
1-2	-	-	-	-	-	-	-	-	-	-	-	-
2-3	-	-	-	-	-	-	-	-	-	-	-	-
3-4	-	-	-	-	-	-	-	-	-	-	-	-
4-5	-	-	-	-	-	-	-	-	-	-	-	-
5-6	1	-	-	-	-	-	-	-	4	10	14	6
6-7	57	46	57	79	81	66	61	74	114	132	121	84
7-8	172	172	214	246	257	239	238	266	310	309	273	210
8-9	296	303	366	409	419	401	409	447	487	466	415	331
9-10	388	404	471	512	529	514	532	578	612	575	511	416
10-11	452	485	540	565	591	583	605	657	680	629	553	462
11-12	477	517	570	588	608	599	629	677	691	628	548	473
12-13	462	496	542	557	582	570	510	651	647	590	491	432
13-14	394	432	457	463	494	498	539	572	558	500	399	351
14-15	295	311	332	322	360	379	419	453	435	367	279	250
15-16	175	188	190	184	214	235	271	293	278	220	159	143
16-17	81	89	87	74	79	91	115	123	107	79	61	62
17-18	18	21	11	4	3	3	7	8	5	3	7	7
18-19	-	-	-	-	-	-	-	-	-	-	-	-
Sum	3268	3464	3837	4003	4217	4178	4335	4799	4928	4508	3831	3227

Calculating load and component needs

Calculation of load power is based on the required power consumption of the water pump used and how long (hours) it is used each day. The results of these calculations will produce power in units of Watt-hours/day. Next, the number of batteries needed is calculated according to the results of the calculation of the power used per day. The next step is to calculate the output power (Wp) of the solar panels needed to charge a number of batteries obtained from the calculation of the number of batteries. The pump is used with a power capacity of 250 watts with a usage time of 1 hour/day.

Calculating the number of batteries

The battery used in this study is 12V, 70 Ah. Battery requirements must also consider the time or day when sunlight cannot come out completely because of the weather, for example it is cloudy for 2 days in a row. In this study used as much as 1 battery.

Calculating solar panel needs

Research using 100 Wp solar panels. In Indonesia, the average maximum solar energy that can be absorbed by solar panels and converted into electrical energy is an average of 5 hours per day, from 09.00 to 14.00. Therefore, the number of needs for solar panels is 2, which has the specifications in table 2.

Tabel 2. Spesifikasi PV.

Description	Value
Solar Panel Type	Monocrystalline
Maximum power (Pmax)	100 W
Voltage at Pmax (Vmp)	17.2 V
Current at Pmax (Imp)	5.81 A
Short circuit current (Isc)	6.46 A
Open circuit voltage (Voc)	21.6 V
Maximum system voltage	1000 V dc

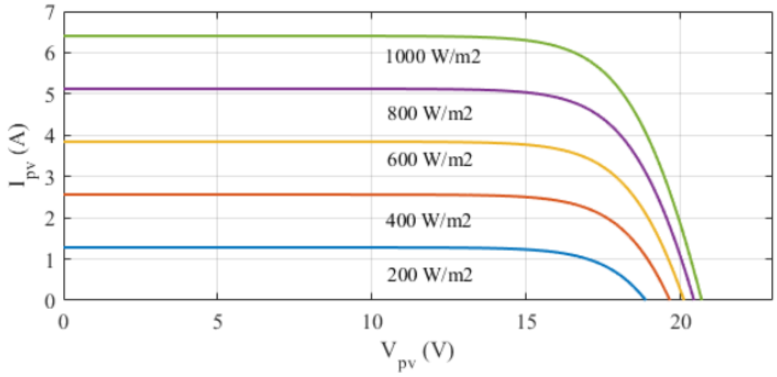


Figure 8. Characteristics of I-V PV

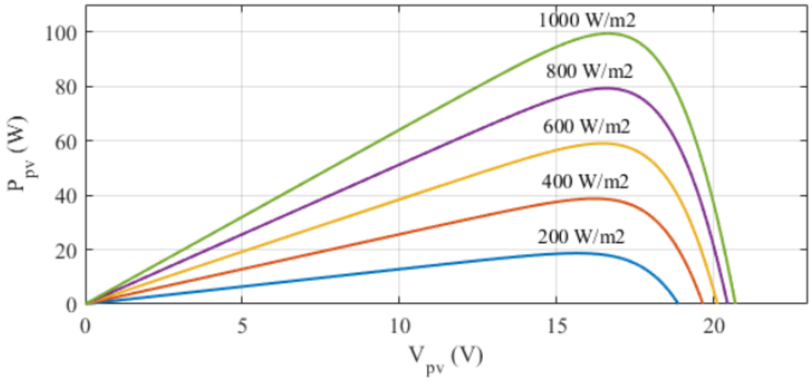


Figure 9. Characteristics of P-V PV

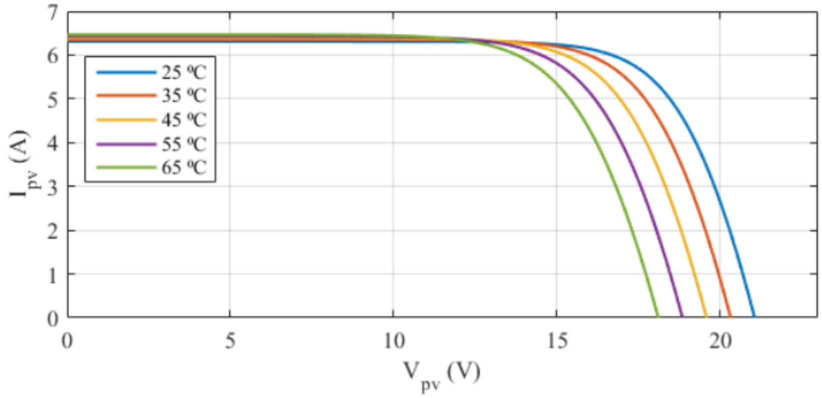


Figure 10. Characteristics of I-V with respect to temperature

SCC

The PV output power is basically a response to changes in the intensity of solar radiation and temperature, which are environmental factors. Tracking the Maximum Power Point of solar panels (PV) is very useful for use in PLTS. The intensity of solar radiation and temperature are the main factors that cause the electric power supplied using PV to change. Various MPPT techniques have been widely studied but the Perturb & Observe (P&O) algorithm is the most widely accepted. The P&O algorithm has also been proven to be able to provide good tracking of maximum power points with changes in solar radiation intensity. The P&O algorithm is widely used because it has a simple control structure and only IPV and VPV parameter measurements are needed for power point tracking. This method causes a loss of power that will increase according to each process step size pertubation. However, with a smaller pertubation step size, the power loss will turn out to be lower. This MPPT algorithm responds quickly to sudden changes in operating conditions. In this study a PWM type SCC with a capacity of 30 A was used, based on the specifications of the PV used.

Tools Testing

From Table 3 it can be concluded that when sunlight falls towards the maximum PV the highest average voltage reaches 18.43 V and the highest average current reaches 1.24 A at 12.00 WIB. The lowest average voltage is 11.13 V and the lowest average current is 0.06 A which occurred at 17.00 WIB. However, the PV voltage increased from 06.00 WIB by 14.93 V to 17.36 V at 07.00 WIB, then the voltage stabilized at 17.5 V until 15.00 WIB. The output voltage and current of the PV varies due to changes in the condition of the solar irradiance value captured by the PV surface. Table 3 shows the battery voltage rising from 11.86 V to 13.04 V during the charging process. The battery charging voltage to the clock is directly proportional. The longer the charging time, the higher the charging voltage generated from 07.00 WIB to 17.00 WIB an average of 13.81 V and the resulting charging current is an average of 1.33 A. In this test the charging process for a 12 V battery takes 10 hours from the state of the battery 11.86 V to 13.04 V. Fast or slow the charging process depends on the size of the current value and the capacity of the battery used. From table 4 it can be seen that battery energy can be used to supply a water pump for 1 hour with an average load current of 1.53 A.

Table 3. Battery charging test

Hour	Vo (SCC) (V)	Io (SCC) (A)	Vbattery (V)
06.00	13.55	0.15	11.86
07.00	13.70	0.92	11.93
08.00	13.74	1.37	11.98
09.00	13.86	1.39	12.00
10.00	13.94	1.57	12.05
11.00	13.97	1.64	12.15
12.00	14.00	1.79	12.33
13.00	13.95	1.78	12.49
14.00	13.87	1.61	12.67
15.00	13.77	1.54	12.89
16.00	13.72	1.40	13.00
17.00	13.62	0.86	13.04

Table 4. Water pump load.

Minutes to	Vi Inverter (V)	Vo Inverter (V)	I Load (A)
5	13.79	220	1.57
10	13.36	218	1.53
15	13.08	217	1.53
20	12.87	216	1.53
25	12.59	215	1.53
30	12.32	212	1.53
35	12.15	209	1.53
40	11.89	206	1.53
45	11.66	205	1.53
50	11.49	203	1.53
55	11.23	200	1.53
60	11.08	197	1.53

In this research a solar water pump has been produced which has been tested in a limited way in the village of Kuripan Karangawen Demak which is quite effective equipped with the internet of things, this confirms that using the Internet of Things helps farmers think smart without having to be in rice fields [32] , then the internet of things with 5G can increase the effectiveness of agricultural entrepreneurs in serving buyers of their products with fast access [33], then in Africa they are already using the internet of things which really helps farmers in checking their agricultural products online [34], then with IoT-based green house applications allow farmers to check PH levels inside the greenhouse so that the plants are safe and the results are maximized [35], then it is clarified that IoT products are also used in the world of architecture so that the design of home and building products can be controlled by prospective buyers anytime and anywhere. course [36], [37], then with the Internet of things for smar t agriculture: making Technologies practical as future technology [38], [39], further strengthened that with IoT making agricultural products there is a database of various kinds of content of agricultural products produced [40], [41], then with IoT makes [farmers understand the available water content in rice field areas online [42], then reinforced that with IoT it is able to manage and control water use in rice field areas quickly and accurately [43].

CONCLUSION

Solar energy in the cities of Semarang and Demak has the potential to be developed into power plants to power irrigation pumps. Based on the measurements obtained an average radiation intensity of 148.9 kWh. Meanwhile, the PV output power is the lowest with an average of 96.5 kWh. Therefore, research was developed on monitoring water pumps with solar energy sources. From the results of this study, the results of a monitoring system design for IoT-based water pump control were found. With this method the user can remotely monitor and control the irrigation pump. The system design also uses a battery storage system. The availability of the number of batteries used in the study is capable of supplying power to the load for one hour with an average load current of 1.53 A, according to the initial design.

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