Solar Panel Performance Monitoring System Using Arduino Uno for Energy Optimization

Daniel Wiranata, Haris Gunawan, Rahmaniar

Abstract

This study designs and tests an Arduino Uno-based solar panel performance monitoring system to support energy optimization in small to medium-scale solar power plants. The system measures DC voltage and DC current, calculates output power, and records panel temperature and air quality indicators as supporting parameters for interpreting performance changes. Data is collected periodically every 60 seconds and sent via Wi-Fi to a server for time series storage, enabling remote monitoring. Calibration is performed by comparing sensor readings against a multimeter and DC clamp meter under several operating conditions. The calibration results show an average voltage error of 0.6 percent to 1.2 percent in the range of 12 V to 21 V, and an average current error of 1.5 percent to 4.5 percent in the range of 2 A to 6 A. Field testing on an off-grid configuration using a 100 Wp module showed that the system was capable of generating daily performance data and calculating daily energy of 0.46 kWh on a sunny day, 0.27 kWh on a cloudy day with short rain, and 0.41 kWh on a sunny day with higher air quality indicators. Communication performance showed a recording latency of 1 to 4 seconds and a packet loss of 1 percent to 3 percent per day. A disturbance test with approximately 30 percent shading of the module for 10 minutes reduced the power from a range of 75 W to 80 W to 55 W to 58 W and returned to near normal after the disturbance was removed. These results indicate that the system can be used for operational monitoring, energy recording, and data-based performance change detection.

Keywords : Solar Panels , Arduino Uno, Internet of Things, Performance Monitoring, Daily Energy

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Introduction

Solar Power Plants (PLTS) change radiation sun become energy electricity through module photovoltaic . In the Indonesian context , a monitoring study of grid- connected rooftop solar power plants reported mark intensity radiation daily average approximately 4.8 kWh per square meter per day as base calculation potential production energy and evaluation performance system [26]. Potential value the No automatic compared straight with true energy Correct distributed to burden or network , because output module determined by a combination condition operation electrical , condition meteorology , and conditions surface environment module .

Electrical parameters the main determining factor energy output daily solar panels is voltage , current , and power generated at each condition operation . Variation temperature cell is factor key Because IV module characteristics shift to temperature . Review performance module show that increase temperature cell lower voltage and lower Power output module , so that measurement temperature become important For separate decline Power consequence temperature from decline Power consequence other factors [3]. In operation field , temperature cell No only influenced by radiation , but also the speed wind , temperature environment , and installation module , so that monitoring consistent temperature required For analysis reason change performance from time to time [3].

Besides temperature , quality atmosphere and cleanliness surface module influence energy that can converted . Study about urban smog show decline radiation surfaces that impact PV output, with estimate subtraction insolation annual that can reach around 11.5 percent in Delhi and around 2 percent in Singapore in the period analyzed , thus location with pollution different produce impact different energies [6]. Other studies show that efficiency generation solar decrease globally because contribution of atmospheric aerosols and pollution panel surface , so that both of them need treated as source lost measurable energy , not assumptions general [7]. At the module level , soiling triggers decline transmittance glass and lower current connection short , so that energy yield down and pattern decline often nature accumulative until happen Rain or cleaning [8], [9].

Loss energy documented soiling effects wide in various climate and type particle . Review yield loss due to deposition dust show decline significant energy in conditions certain , as well as emphasize that rate decline influenced by character dust , period without cleaning , and condition weather [12]. Study field and experiments also confirm that deposition dust in the atmosphere can lower performance module , good Because accumulation on the surface and Because change spectrum and attenuation radiation [14]. Factors design installation like corner slope participate influence rate deposition , so that tilt and policy selection cleaning should data-based , not habits [15], [16]. On a scale operations , temporal soiling modeling shows that impact energy and impact economy can changed between city and season , so that the need for regular monitoring become base For decision cleaning and maintenance [18]. Research on PV glass also evaluated mitigation strategies and placed soiling monitoring as a prerequisite before choose method mitigation , because character dirt and mechanisms adhesion different between location [22], [23].

On the side performance monitoring practices , standards and guidelines necessary for the data to be collected Can compared and followed up . Arduino -based data logger device designed for PV monitoring can arranged to meet need measurement that refers to practice standard , so that better data quality support evaluation performance and search disturbance [1]. Without adequate data structure , reduction energy daily can visible on the display power , but root problem difficult isolated whether originate from temperature cells , decreased irradiance, soiling, aging module , or disturbance system Power .

In many installation scale small until intermediate , monitoring often stop reading voltage and current moment , or recording local that is not connected to system warning . Implementation recording based on Arduino Uno and SD Card has shown in research national

, including recording current , voltage , and power in a way automatic periodically , for example 15 minute intervals , but data access is of a nature local and analysis done after the data is taken from storage media [27]. Models such as This help documentation performance , but not enough support action fast when happen decline Power suddenly , for example consequence disturbance connection , temporary shading , or decline performance Because condition environment .

Another limitation is delay information to manager when system be on site different . IoT -based monitoring system on on-grid PLTS with application message instant show that the current and voltage data can sent distance distance and results sensor readings can approach manual measurement . In the study said , the average error between multimeter and DC sensor readings are reported around 0.14 percent , so that IoT approach has potential give adequate monitoring accurate For supervision operational daily [28]. These results relevant For design notification early , because warning based threshold limit only beneficial if the sensor data is stable and error measuring under control .

IoT approaches are also evolving For enter variables meteorology and variables electric at the same time . IoT systems are cost-effective low monitoring voltage continuous , current continuous , AC power , and a number of variables meteorology show that integration data acquisition , synchronization time , storage local and cloud, as well as real time access possible achieved on the system scale micro and mini, which during This often No accessible by the system commercial [25]. Integration of multi-parameter monitoring such as This important Because decline Power without irradiance and temperature context can misleading decision maintenance .

Need optimization energy on solar panels means minimize time No productive and minimize losses that can occur prevented . Review of pollution air and soiling stress that part decline generation can prevented through capable monitoring differentiate attenuation atmosphere and surface soiling , as well as through the selected mitigation strategy in accordance condition local [4]. In the realm of device , an Arduino -based monitoring prototype that measures temperature , irradiance, PV voltage and current , as well as provide web interface for monitoring distance Far show direction practical implementation , including use Wi Fi module and monitoring continuous For support management system [5]. When monitoring is capable detect deviation Power maximum in a way fast , action like inspection connector , cleaning surface , or evaluation control filling can done before lost energy continues .

Based on need said , research This place Arduino Uno as controller main For system monitoring solar panel performance that measures electrical parameters main , plus the most relevant environmental parameters with efficiency conversion , namely temperature and indicators quality air as proxy condition particulates in the surroundings location . Arduino Uno selected Because sensor and module ecosystem communication wide , and has used on the PV data logger costs low and device recording national , so that design can replicated and maintained by users of large-scale solar power plants small until intermediate [1], [27]. IoT integration and notification designed so that data can be real time access and alerts early can sent when happen deviation from pattern normal operation , so that optimization energy No rely on periodic manual inspections which are risky late .

1.1 Research Objectives

As for the purpose writing This is :

1. Create and implement system monitoring solar panel performance using Arduino Uno for monitor parameters such as voltage , current , and output power in real-time.
2. Develop feature notifications that can give warning early when happen anomaly or decline performance on solar panels .
3. Integrate system This with IoT technology for allows monitoring distance Far and monitoring conditions relevant environment , such as temperature and quality air .

Literature Review

2.1. Photovoltaic System and Module Output Characteristics

Photovoltaic modules produce DC output that follows a current-to-voltage (I - V) characteristic at a given irradiance and temperature. Irradiance variations primarily change the current, while cell temperature variations primarily change the voltage, so that the maximum power point changes according to operating conditions [3]. Consequently, monitoring voltage, current, and power at consistent time intervals is required to construct daily operating profiles and distinguish output changes due to weather from output changes due to system disturbances.

In rooftop systems, daily output patterns typically show power starting to increase in the morning, peaking during high radiation, and then decreasing in the afternoon. Monitoring studies of a grid- connected 1.25 kW rooftop solar power plant show that output can occur approximately between 7:00 and 18:00 during sunny weather, while during rainy conditions, power decreases and the production period can be shortened [26]. This type of data is relevant for establishing a site operational baseline , so that power drops that deviate from the normal pattern can be detected early.

2.2. Monitoring Standard Framework

Assessing the performance of solar power plants that support energy optimization requires energy-based indicators, not just instantaneous power. Daily energy (kWh) and irradiance-normalized indicators allow for comparisons between days in different weather conditions [31]. The IEC 61724-1 framework defines monitoring parameters , data quality requirements, and performance metrics such as reference yield , final yield , and performance ratio [31]. This metric helps identify whether the energy decrease is due to radiation loss or due to additional losses in the system.

As an illustration of the use of metrics, reference The yield (YR) can be derived from the module field irradiance (kWh per square meter) normalized to 1 kW per square meter. The final yield (YF) is expressed as the output AC energy divided by the installed DC power under standard conditions. The performance ratio (PR) is calculated as PR = YF divided by YR [31]. If a 1.25 kW system experiences 5 equivalent hours of YR on a given day, then the expected AC energy at a given PR can be calculated from EAC = PR x 1.25 x 5. The PR value must be derived from correct measurement data, so the need for monitoring irradiance, energy, and data quality is key.

2.3. Effect of Temperature on Voltage, Power, and Operational Stability

Cell temperature is the dominant variable affecting module voltage and power. A temperature correlation study shows that increasing cell temperature lowers the open-circuit voltage and reduces module power, while the current changes less than the voltage changes [3]. Without temperature measurements, daytime power drops can be misinterpreted as indicating damage or interference.

In field operations, cell temperature is affected by radiation, air temperature, wind, and installation configuration. Therefore, integrating temperature sensors into a monitoring system enables cause-and-effect analysis. A practical example is when radiation conditions are relatively stable but cell temperature increases due to poor air circulation under the module, followed by a drop in power. This pattern would be difficult to detect if the system only monitors voltage and current.

2.4. Impact of Air Quality, Aerosols, and Soiling on Energy Output

Air quality affects the radiation reaching the module through aerosols and atmospheric particles. Urban haze studies in Delhi and Singapore reported annual reductions in insolation received by silicon PVs. The estimated reduction was approximately 11.5 percent plus or minus 1.5 percent, or approximately 200 kWh per square meter per year in Delhi during the analyzed period, while the estimate for Singapore was approximately 2.0 percent [6]. These figures demonstrate that air quality indicators are relevant in the context of decreasing daily energy production.

In addition to atmospheric attenuation, soiling on the module surface decreases optical transmittance and current, resulting in decreased energy yield . The literature describes soiling as particle deposition influenced by particle size, surface properties, humidity, and local conditions [9], [12]. Experiments on airborne dust deposition on PV modules show measurable performance degradation in electrical parameters, particularly current and power, under comparable irradiation conditions [14]. Module tilt also influences deposition characteristics . Studies have shown that particle size and tilt angle influence dust buildup characteristics, resulting in varying energy loss rates between mounting configurations [15], [16].

Temporal modeling shows that the energy and economic impacts of soiling vary across cities and seasons, so efficient cleanup decisions require regular monitoring and evaluation data [18]. Rain can reduce soiling but results vary, so scheduled cleaning is required in some locations [19]. Dew conditions have also been reported to exacerbate soiling by increasing particle adhesion, so repeated periods of dew can accelerate the formation of contaminant layers [24]. Mitigation studies include self-cleaning approaches , evaluation of PV glass types, and the consequences of surface abrasion due to cleaning or environmental exposure, so mitigation strategies need to consider monitoring of losses and risks of surface degradation [17], [22], [23].

2.5. Monitoring System , Data Logger , and Implementation Practices

monitoring systems consist of sensor data acquisition, signal processing, derived quantity calculation, storage, and monitoring interface. Instrumentation software-based approaches such as LabVIEW have been used for monitoring and modeling, but device and licensing requirements can increase costs in small systems [2]. Therefore, microcontroller platforms are widely used as the basis for low-cost data loggers .

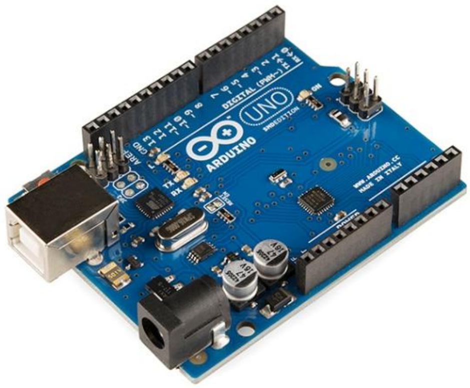

Figure 1. Arduino Uno

an Arduino-based PV data logger that emphasizes accuracy and compliance with monitoring requirements has been demonstrated through a low-cost autonomous device for PV monitoring, including attention to data quality and suitability of monitoring practices [1]. In a national context, the design of a monitoring system Arduino Uno-based solar panel output and data recording with SD Card is used to record current, voltage, and power as historical data for analysis [27]. This model is effective for post-event evaluation, but is not always adequate for rapid response when a disturbance occurs.

Implementation of monitoring online monitoring on a 1.25 kW rooftop solar power plant using voltage and current sensors processed by a microcontroller and displayed on an application, accompanied by real- time recording for further analysis [26]. The study reports testing of the ZMPT101B voltage sensor and the ACS712 current sensor. After calibration on a multimeter, the average error reported was approximately 1.058 percent for voltage and 6.96

percent for current [26]. This finding confirms that monitoring designs must include calibration and evaluation of sensor errors to ensure data is reliable enough for early notification.

2.6. IoT and Cloud -Based Real- Time Monitoring

IoT in PV monitoring adds data communication, centralized storage, and remote access. A low-cost IoT system that monitors electrical and meteorological variables has been designed to provide an alternative to more expensive commercial systems, with real -time monitoring of voltage, current, power, and climate variables for smart applications. grid [25]. An IoT prototype for PV monitoring was also developed with a focus on web-based remote monitoring and sensor integration into the PV system [5].

IoT architectures need to manage sampling intervals, transmission intervals, local buffering mechanisms in case of internet connection loss, and time synchronization. These settings allow consistent daily energy and performance metrics such as PR to be calculated, and performance degradation trends can be analyzed from historical data.

2.7. Voltage, Current, and Environmental Sensors for Performance Monitoring

Voltage and current measurements are the core of a solar panel performance monitoring system . Voltage sensors can use signal conditioning and isolation for safety purposes, while common current sensors use the Hall-effect sensor . National implementation literature indicates the use of the ZMPT101B for voltage measurements and the ACS712 for current measurements, with calibration required to control errors [26]. In addition to selecting the sensor, the design needs to consider the string voltage range , maximum current range, ADC resolution, filtering noise , and reading stability.

Temperature measurements are relevant because the relationship between temperature and voltage and power changes is well documented [3]. Air quality indicators are relevant in the context of aerosol changes that can reduce insolation and contribute to energy production losses during certain periods, including in urban areas [6]. Integration of these environmental parameters helps isolate the causes of power losses. Examples that can be identified with the data are a decrease in current during normally stable hours, accompanied by an increase in particulate indicators or a decrease in air quality, leading to the hypothesis of atmospheric attenuation or an increase in soiling rates .

2.8. Early Notification and Anomaly Detection Based on Performance Data

Early notification can be built from threshold-based rules and deviation detection from baseline . Commonly used parameters include DC power, daily energy, PR, current changes under comparable irradiation conditions, and voltage anomalies indicating connection or converter problems [31]. Soiling literature shows that losses can be accumulative and change over time, so trend indicators such as a decrease in daily PR over several days without extreme weather changes can be used as a trigger for inspection and cleaning [9], [18].

On system on grid , the power curve can also be affected by inverter operating conditions and interactions with the grid, so notification rules should consider operating hours, synchronization status, and weather context to reduce irrelevant alerts [26]. For small to medium systems, a practical approach is to combine absolute thresholds, daily pattern-based thresholds, and consistency checks between parameters, for example, power drops along with current drops but voltage remains constant, or power drops without temperature changes and without changes in irradiance, so that field check priorities can be determined.

Research Methodology

3.1. Types and Approaches Study

Study This use method design get up with orientation implementation system . Focus mainly is produce prototype system monitoring solar panel performance based on Arduino Uno which can working on conditions operation real . Stages study covers design device hardware and sensor selection , design device soft For data acquisition and processing , integration module communication For monitoring distance far , and testing For evaluate accuracy measurement and stability system . Approach evaluation done through comparison sensor results on tool measuring comparison and observation response system moment happen change condition panel operations.

3.2. Object Research and Test Locations

Object study is solar panel system operated on load real , good off-grid systems as well monitored system on the DC side . Tested unit covers module solar , path DC output , as well as point The measuring instrument is equipped with a voltage sensor and a current sensor . The test location is in an open area that receives radiation sun directly , with appropriate panel placement practice installation general so that the data obtained represent condition field . Testing done on several day operation For catch variation weather , variations temperature , and changes condition air around the panel, so that monitoring system is assessed No only on one condition a moment .

3.3. Variables Study

Variables study shared become variables measurable main and variable measurable environment . Variables measurable main is DC panel voltage (V) and DC panel current (I) which become base calculation power (P). Power counted directly by Arduino using P = V x I for each measurement interval , then used as base calculation energy . Variable monitored environment is panel temperature (Tpanel) as indicator condition thermal modules that influence characteristics voltage and power , as well as indicator quality air (AQ) as a relative parameter For see change condition air around the panel. AQ in study This treated as trend data For support interpretation decline Power daily , not as measurement standard concentration pollutants .

3.4. Tools, Materials , and Instruments

Device main study is Arduino Uno as controller data acquisition and processing . DC voltage sensors are used For read voltage panel output in the appropriate range with system , so that reading safe For Arduino analog input . A hall-effect based DC current sensor is used For read current output without cut off series , with election adjustable sensor range current maximum panel resolution reading still OK . The panel temperature sensor , for example the DS18B20, is mounted on the side behind module For record change the temperature that follows cell heating . Quality sensor air , for example the MQ-135 or class , placed in the area around the panel to get change indicator condition air . For IoT communication , used Wi-Fi module such as ESP8266 or device other communications available at the test site .

Instrument comparator prepared For ensure validity of sensor data. A digital multimeter is used as reference measurement voltage . DC clamp meter or ammeter is used as reference measurement current . Thermometer contact can used For verify temperature sensor reading If available . Instruments comparator This used at the stage calibration and validation For count error measurement system .

3.5. Design Systems and Data Flow

System designed in channel data acquisition , processing , transmission , and presentation . Voltage sensors, current sensors , temperature sensors , and quality sensors air send signal to Arduino Uno. Arduino does reading periodic according to the specified interval , then apply alignment simple For reduce analog reading noise . Power counted from results reading voltage and current at the same interval , then every data package is given marker time . Data then sent to the server or cloud via module communication in order to be able to monitored from distance remote . On the server side , data is stored in the database so that can displayed as chart trend daily and historical .

If the internet connection is not stable , design can enter storage local as reserves , for example recording to storage media . With mechanism this , measurement data No is lost moment connection disconnected , and can used For analysis energy daily or evaluation performance after testing completed . The data flow is also structured so that the core parameters, namely V, I, and P, are always available For analysis , whereas Tpanel and AQ play a role as variables supporters interpretation .

3.6. Procedure Data Collection and Testing

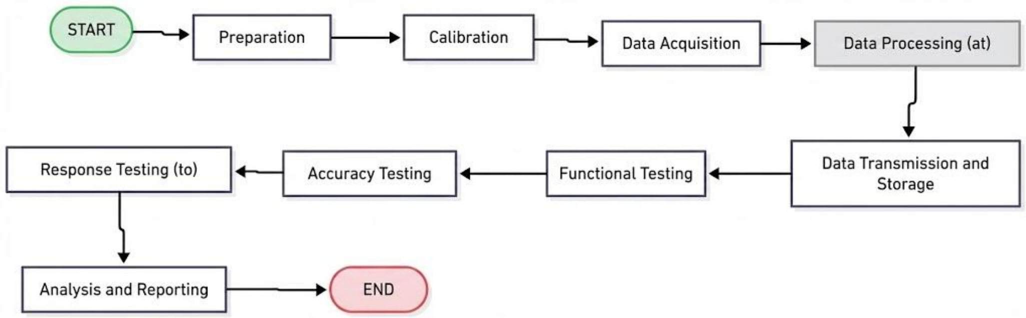

Figure 2. Flowchart Diagram

1. Stage First is calibration sensor start . Voltage and current sensor readings compared to with a multimeter and clamp meter on several condition operations , for example when the panel produces Power low in the morning day , power currently moment cloudy , and power tall moment afternoon . From the comparison This obtained factor correct simple ones that are applied to Arduino programs, including zero offset correction on current sensor when required .
2. Stage second is operational data retrieval daily . System run under normal conditions and record the V, I, P, Tpanel , and AQ parameters automatically. periodic , for example every 1 minute . Data is collected during a number of days to be obtained variation condition weather and variations sufficient load . Data collection several day required For build pattern normal operation and for see whether system capable record trend decline or relevant fluctuations .
3. Stage third is a functional test system . Testing ensure all sensors are read , power counted true , data can be sent to the server, and display monitoring distance Far update data according to intervals. Stage this also checks stability system moment long walk , including stability supply Arduino power and stability connection module communication .
4. Stage fourth is an accuracy test . Error measurement voltage and current counted to instrument comparator in form percentage average error in a number of sample . This result used For evaluate whether system adequate for operational monitoring and for support taking decision maintenance .
5. Stage fifth is a response test to disturbance . Disturbance simulated in a way controlled , for example with close part panel surface for produce shading, or change load on the DC side . Changes This observed in the V, I, and P data for ensure system capable catch decline performance and change pattern output . Disturbance test result data Then compared to with normal conditions at the same time For evaluate sensitivity system to deviation performance .

Results

4.1. Implementation Results System Monitoring

System monitoring succeed implemented using Arduino Uno, DC voltage sensor, hall-effect based DC current sensor , DS18B20 temperature sensor, quality sensor air MQ type as indicator relative , and Wi-Fi module for data transmission . Data is recorded periodic every 60 seconds . Each record contains time , voltage (V), current (I), power (P), panel temperature (Tpanel), and indicators quality air (AQ). Power calculated on the device with P = V x I. Data sent to the server and saved as series data time .

4.2. Voltage and Current Sensor Calibration Results

Calibration done with compare sensor readings against a multimeter for DC voltage and clamp meter for current in some condition operation .

1. Figure 3 shows the voltage linear relationship between voltage multimeter and voltage reference measured sensor in the range of 12 V to 21 V. Regression results produce equality Vsensor = 0.998 Vref + 0.02 with R^2 = 0.9995. The data points are located near the ideal line y = x, so sensor response to change voltage can considered linear in the range linear testing and correction can implemented For get consistent reading .
2. Calibration Current current done with the same procedure using a DC clamp meter as reference . Zero offset correction and offset correction scale applied to sensor readings so that changes current measurable follow mark reference to the range current Work system . Calibration results current reported through chart calibration current and used as base determination reading current during testing field .

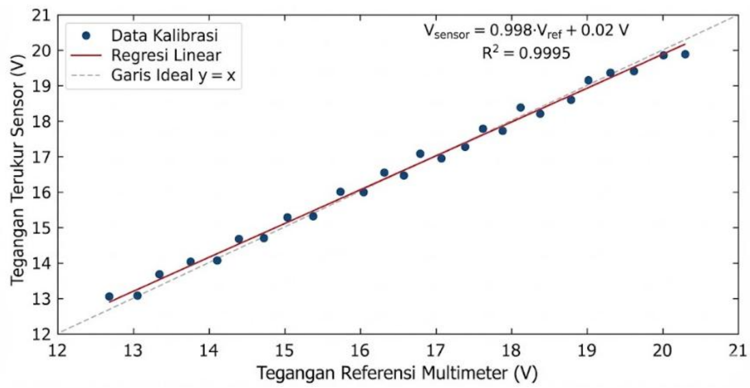

Figure 3. Chart DC voltage sensor calibration against multimeter

4.3. Monitoring Results Daily Voltage , Current , Power , Panel Temperature , and AQ

Testing field conducted on off-grid systems on a large scale small use 100 Wp module , system 12 V battery , and a DC load of about 30 W at a given hour . Data collection was carried out for 3 days with summary value on the clock key as following .

Table 1. Recap panel measurements per time (Day 1–3)

Day	Condition weather	Time	V (V)	HE)	P (W)	Tpanel (°C)	AQ
1	Bright	08.00	17.6	1.20	21.1	34	185
1	Bright	10.00	18.4	3.10	57.0	46	190
1	Bright	12.00	18.1	4.40	79.6	58	205
1	Bright	14.00	17.9	4.10	73.4	62	215
1	Bright	16.00	17.2	2.30	39.6	49	200
2	Cloudy + rain short	08.00	16.9	0.90	15.2	33	180
2	Cloudy + rain short	10.00	17.8	2.10	37.4	41	185
2	Cloudy + rain short	12.00	17.2	2.60	44.7	45	190

2	Cloudy + rain short	14.00	16.8	1.40	23.5	40	188
2	Cloudy + rain short	16.00	16.5	0.80	13.2	36	182
3	Bright (AQ more tall)	08.00	17.5	1.00	17.5	34	240
3	Bright (AQ more tall)	10.00	18.2	2.80	51.0	47	265
3	Bright (AQ more tall)	12.00	18.0	4.00	72.0	57	295
3	Bright (AQ more tall)	14.00	17.8	3.70	65.9	61	310
3	Bright (AQ more tall)	16.00	17.1	2.10	35.9	50	275

4.4. Calculation Energy Daily and Production Patterns

Energy daily counted from addition discrete average power each minute multiplied by 1/60 of an hour. Energy yield daily during testing is :

Table 2. Energy daily generated

Day	Energy (kWh)
1	0.46
2	0.27
3	0.41

4.5. Data Delivery Test Results

Data transmission is done via Wi-Fi at 60- second intervals . During testing , data is recorded on the server automatically continuous during operating hours main . Latency data recording is in the range of 1 to 4 seconds from time measurement . Loss package occurs in conditions signal decreased , with range lost around 1 percent up to 3 percent per day .

4.6. Response Test Results to Disturbance

Disturbance test done with partial shading module around 30 percent for 10 minutes at approximately at 12.30.

1. Normal condition before shading
   Current is in the range of 4.2 A to 4.4 A and power in the range of 75 W to 80 W.
2. When shading is applied
   Current down to range 3.0 A to 3.2 A and power down to range 55 W to 58 W.
3. After the shading is removed
   Current return to range 4.1 A to 4.3 A and power return to range 73 W to 77 W.

Discussion

Test results show system capable record change solar panel output that follows condition weather and conditions operation load . Sunny day produce energy daily more tall compared to day cloudy , and decreasing energy especially seen in the decline current , in harmony with more PV characters sensitive to change radiation on components current compared to voltage .

Monitoring panel temperature helps give context decline power during the day day . Ascension temperature recorded during the period approach peak radiation followed trend voltage No increased , so that Power peak No always happen moment temperature highest . This data support need enter temperature as variables supporters interpretation performance to decrease Power No direct considered as disturbance system .

Indicator quality more air high on one day testing followed mark more current and power low at the same time compared to day bright others , although relative panel temperature similar . Because AQ is used nature indicator relative , results This treated as signal supporters who point to the allegations decrease radiation effective or increasing lost optics , so that For separation more causes firm required addition measurement irradiation or a special soiling sensor .

From the side reliability , latency delivery a number of seconds and loss small package show system adequate For monitoring based minutes . The shading test shows system sensitive to disorders that reduce Power in a way real , so that approach monitoring based series time can used as base notification early and maintenance based condition .

1. Conclusion

Study This produce prototype system monitoring solar panel performance based on Arduino Uno which is capable of record electrical and environmental parameters in a way periodic . Evaluation done through calibration to tool measuring comparison , testing data transmission and observation response system in condition normal operation as well condition disturbance .

1. System monitoring solar panel performance Arduino Uno based success implemented For measure DC voltage , DC current , calculate Power output , as well as record panel temperature and indicators quality air as a supporting parameter . Data can be recorded periodic every 60 seconds and saved as series data time .
2. Calibration results show system capable give adequate accuracy For monitoring operational . Average error measurement voltage is in the range of 0.6 percent up to 1.2 percent in the range 12 V to 21 V. Average error measurement current is in the range of 1.5 percent up to 4.5 percent in the range 2 A to 6 A.
3. System capable generate performance data daily that can used For evaluation energy . Energy daily calculated on testing three day is 0.46 kWh on the day sunny , 0.27 kWh on day cloudy with Rain short , and 0.41 kWh on the day bright with indicator quality air more tall .
4. Wi-Fi based data delivery at 60 second intervals walk stable during operating hours main , with latency 1 to 4 seconds recording and loss package around 1 percent up to 3 percent per day in conditions normal network .
5. Disturbance test show system capable record change performance in a way clear . Partial shading module around 30 percent for 10 minutes lower current from range of 4.2 A to 4.4 A to 3.0 A to 3.2 A and decrease Power from range of 75 W to 80 W to 55 W to 58 W, then return approach normal condition after shading is removed .

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