Implementation of IC Mux-based data logger in off-grid PLTS

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ABSTRACT

Monitoring the performance of Solar Power Plants (PLTS), especially off-grid systems, requires an effective and efficient data logger solution to collect data from multiple measurement points. Commercial data loggers are often constrained by high costs, limited capacity, and lack of flexibility. This research aims to design and implement a low-cost data logger system based on the CD4051B Multiplexer Integrated Circuit (IC) integrated with an Arduino UNO microcontroller. This system is designed to measure key parameters such as current (ACS712) and voltage (voltage sensor) from eight different channels, as well as environmental parameters (DHT11 and BH1750 sensors). The use of the CD4051B MUX IC allows for significant expansion of the Arduino UNO's analog inputs. Time data accuracy is ensured by the DS1307 Real-Time Clock (RTC) module, and data is stored in an SD card for long-term analysis. This approach is expected to produce an economical, reliable, flexible, and scalable data logger solution to meet the monitoring needs of off-grid PLTS, overcome the limitations of commercial data loggers and support performance optimization and maintenance of renewable energy systems.

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1. INTRODUCTION

Renewable energy technologies, with solar power plants (PLTS) emerging as one of the most promising solutions [1]. Solar power plants (PLTS) are becoming a crucial renewable energy solution, especially for off-grid systems. Comprehensive monitoring of the performance of these systems is crucial for optimizing energy production and predictive maintenance, ensuring long-term operational reliability [2],[3].

Data loggers play a vital role in PV power plant monitoring by collecting key operational parameters. However, commercial data logger solutions are often constrained by high cost and lack of flexibility, particularly in accommodating multi-point measurement needs in large-scale systems [3]. Previous research has demonstrated the feasibility of using microcontroller platforms such as Arduino for low-cost data loggers [4]-[7]. While multiplexing techniques can overcome the limitations of analog inputs [8]-[10], challenges remain in measuring different parameters (voltage and current) simultaneously while maintaining adequate electrical isolation [11].

This study proposes an innovative data logger solution that integrates an Arduino UNO microcontroller, a CD4051B Multiplexer (MUX) IC, and a relay switching mechanism. This combination not only significantly expands the analog input capacity but also provides electrical isolation between measurement paths, improving system accuracy and safety [12],[13]. The system is designed to measure voltage and current from four solar panels, as well as environmental data, sequentially and on a schedule, with accurate timestamps from the DS1307 RTC and data storage on an SD card . The goal is to produce an economical, reliable, flexible, and scalable solar power plant monitoring system [14].

2. METHOD

This research uses a Research and Development (R&D) method with a prototyping approach to develop a data logger system that can comprehensively monitor the performance of off-grid solar power plants (PLTS) [15]. This approach was chosen because it allows the development of technical solutions that can be validated and optimized through a series of testing iterations [16]. The initial stage of the research involved an in-depth review of literature related to data logger technology, PV system characteristics, and multiplexing techniques to identify key parameters required for system monitoring [17]. This analysis will produce a functional system specification that includes the electrical parameters to be monitored, the required measurement resolution, and the optimal sampling interval [18].

Based on the results of the requirements analysis, a data logger system architecture will be designed that integrates an Arduino UNO microcontroller as the main processing unit, a CD4051B Multiplexer IC for analog input expansion, and a relay system for measurement isolation [19]. This stage produces a complete circuit schematic and specifications for the components to be used. The system was assembled according to the designed circuit diagram, including the integration of an ACS712 current sensor for four solar panels, a DC voltage sensor module, a DHT11 environmental sensor [11] for temperature and humidity, a BH1750 light intensity sensor [12], a DS1307 RTC module for time recording [6], and an SD card module for data storage [7]. Software development used the Arduino IDE with a focus on multiplexer control algorithms, relay switching coordination, sensor data acquisition, timestamp integration, and data storage management in CSV format [20]. Firmware was designed to optimize measurement accuracy and system energy efficiency [21].

System testing was conducted using four solar panels as monitoring objects. The data logger system will measure the electrical parameters (current and voltage) of each panel sequentially using a multiplexing mechanism, as well as environmental parameters (temperature, humidity, and light intensity) simultaneously [22]. The system will measure six main parameters: current and voltage from four solar panels (eight electrical parameters), ambient temperature and humidity using a DHT11 sensor, and light intensity using a BH1750 sensor [13]. Each measurement cycle will be accompanied by an accurate timestamp from the RTC module. The collected data will then be analyzed using descriptive statistics and trend analysis to evaluate the accuracy, reliability, and stability of the developed data logger system, following the principles of effective data logger design as outlined in previous research [23].

Multiplexer (MUX) is a key component in data logger system for monitoring Solar Power Plant (PLTS) which enables multi-point measurement with high efficiency [24]. The CD4051B Multiplexer IC is a CMOS integrated circuit that functions as a single 8-channel digitally controlled analog switch, allowing the selection of one of eight analog inputs to be forwarded to the output [25]. In this Arduino UNO-based data logger system research, the CD4051B Multiplexer IC functions as an 8-to-1 selector that allows one microcontroller to measure the electrical parameters of four solar panels sequentially [26]. By using three bits of control signals (S0, S1, S2), the system can select one of the eight data input lines to measure the voltage and current of each panel, overcoming the limitations of analog pins on the Arduino UNO while maintaining adequate electrical isolation between measurement lines [27]. Figure 1 shows the logic gates of the CD4051B Multiplexer IC.

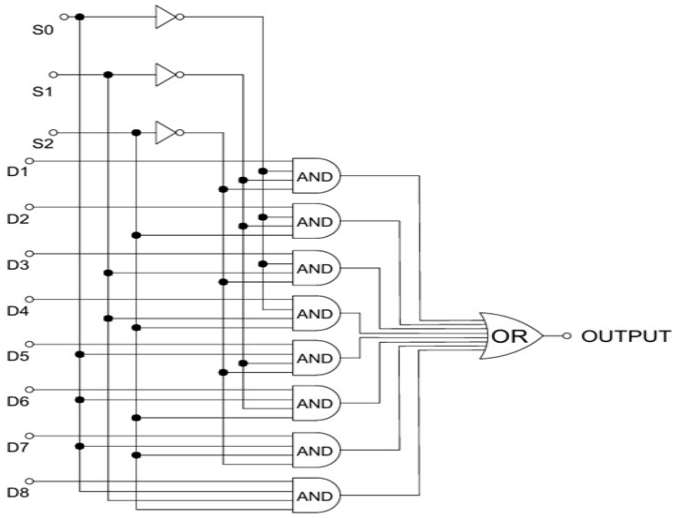


Figure 1. Multiplexer IC logic gate

Table 1. Truth Table of Multiplexer IC

ENABEL	S0	S1	S2	CHANNEL ON
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	X	X	X	None

In the context of designing this data logger system, a block diagram serves to provide a comprehensive overview of the system architecture and interactions between hardware modules, thus facilitating understanding of the workflow and overall structure of the system. This representation not only helps designers map the relationships between elements but also facilitates technical communication with stakeholders, such as engineers, technicians, or clients, in a simple yet informative manner.

The developed data logger system consists of several main, integrated blocks. Four solar panels are connected to their respective relays, which function as switches to switch the measurement path between the voltage and current sensors. Each panel has a voltage and current sensor connected to a CD4051B Multiplexer IC. This MUX IC acts as a connector between the various sensors and the Arduino UNO microcontroller. The system is also equipped with environmental sensors: a DS1307 RTC [6] for accurate time recording, a DHT11 sensor [11] for temperature and humidity measurements, and a BH1750 sensor [12] for light intensity measurements. All these components are connected to an Arduino UNO microcontroller which functions as a central processing unit, controlling the measurement flow, processing data, and saving it to an SD Card module [7]. The use of block diagrams in designing electronic systems, especially for data logger applications, has become standard practice in the industry.

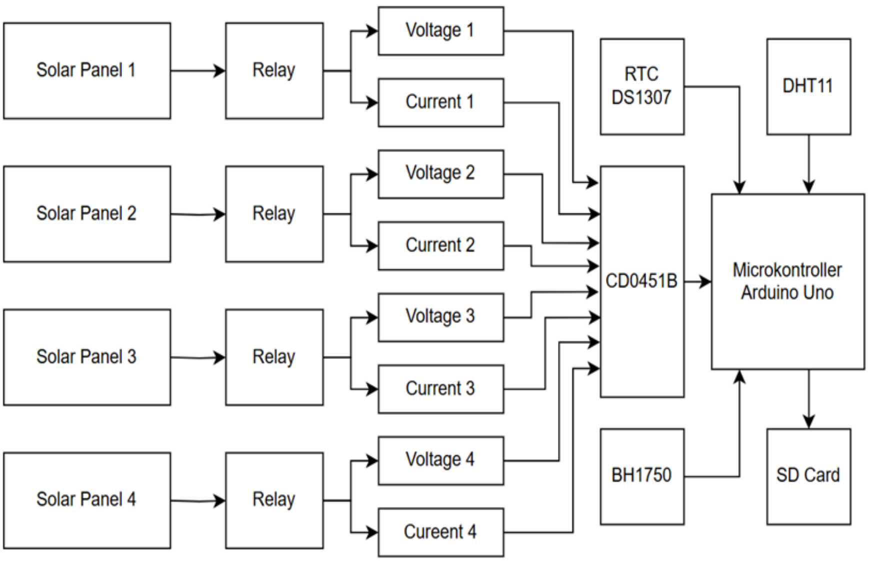


Figure 2. Diagram block ofproposed system

The flowchart begins with the START stage, followed by I/O preparation for initializing all hardware components, then enters the main loop that continuously reads the SD Card and RTC. The system will check the sampling time condition every 5 minutes at seconds 0 to 5, and if the condition is not met, the program will return to reading the SD Card and RTC to wait for the right time. When the time condition is met, the system will activate the relay, read data from the sensors (voltage, current, temperature, humidity, and light intensity), save the data to the SD Card in a predetermined format, then deactivate the relay to save energy before returning to the SD Card and RTC reading loop. This flowchart structure is very logical because it ensures the system works on schedule, is efficient in energy use, and has a good error handling mechanism through repeated checks of critical components such as the SD Card and RTC, making it suitable for data logger applications that require high reliability in the long term.

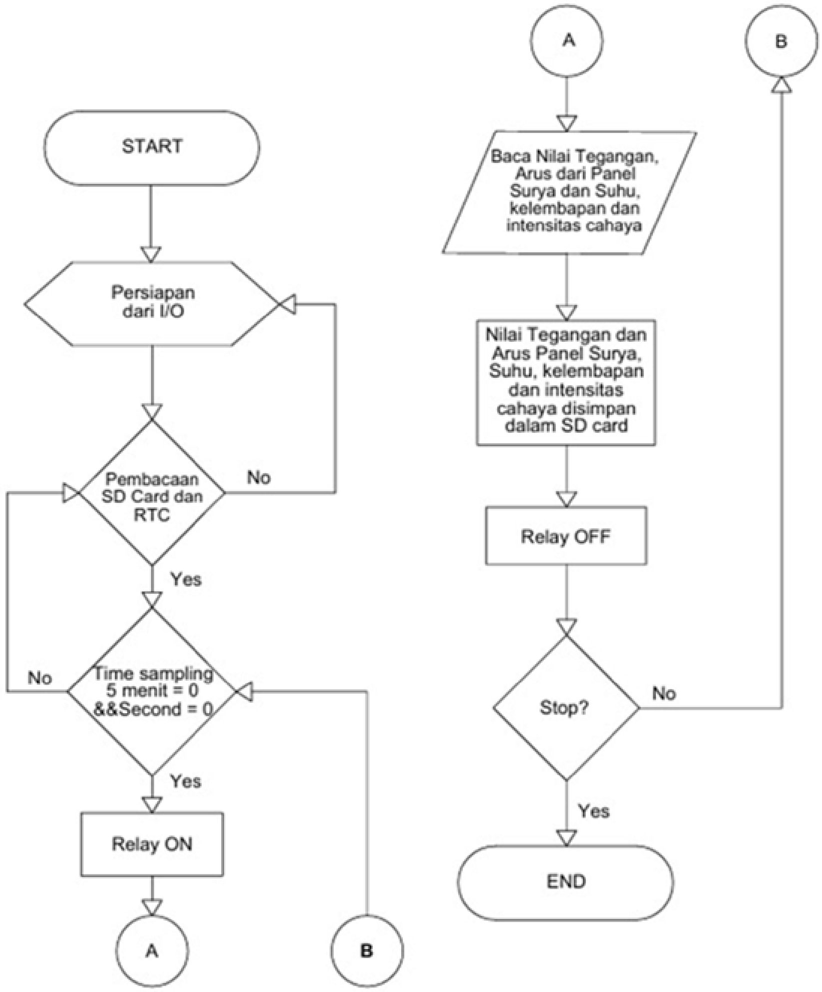
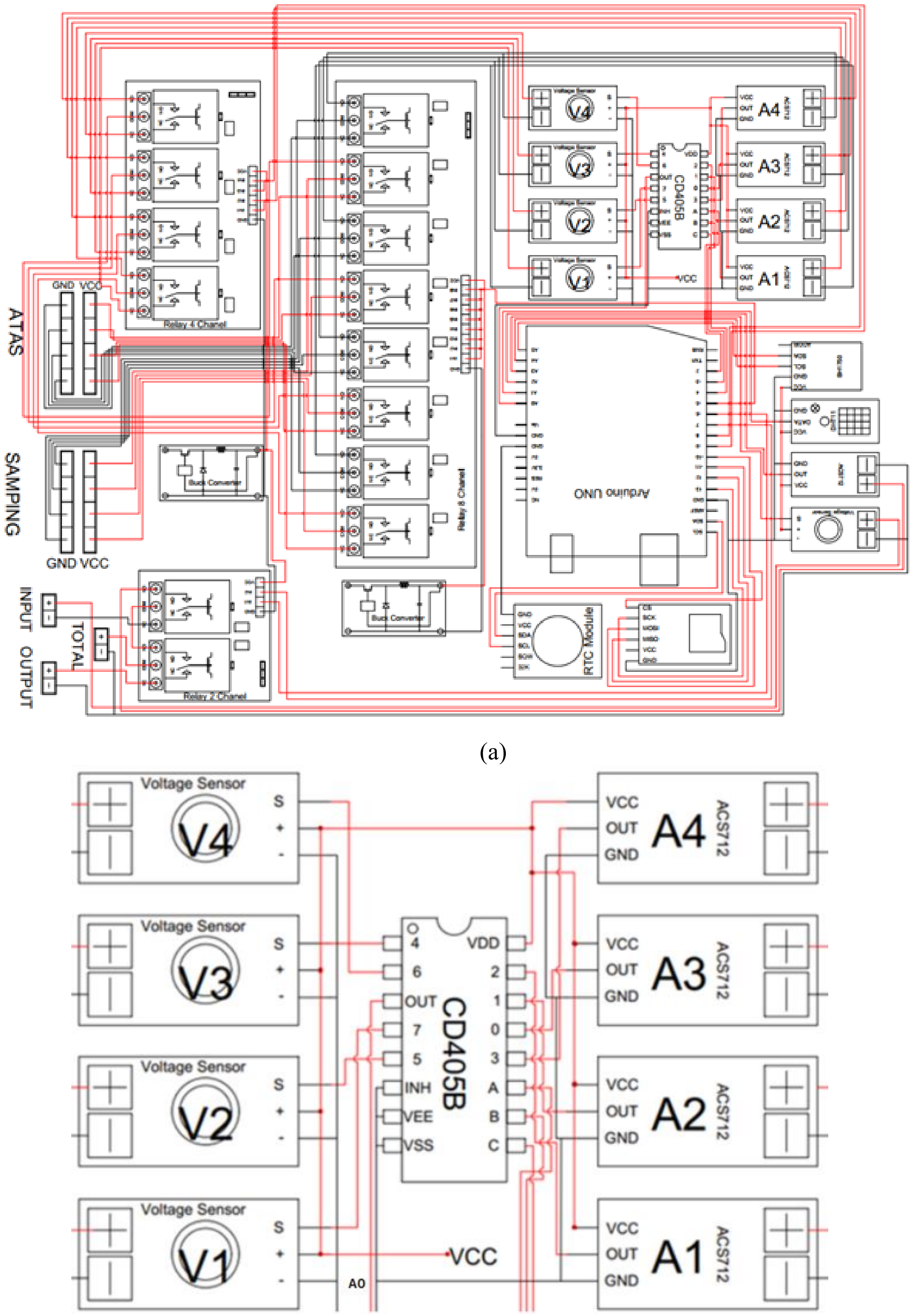


Figure 3. Flowchart of proposed system

The working principle of this data logger system is to work automatically and scheduled to collect data from the Solar Power Generation (PLTS) system using the Arduino UNO microcontroller as the main control unit. After the component initialization process which includes serial and I2C communication, DHT11 sensor for temperature-humidity, BH1750 sensor for light intensity, RTC DS1307 for time recording, and SD card for data storage, the system will continuously check the time and status of the SD card to ensure optimal operational conditions. Measurement will only start if the SD card is detected and the time shows the specified measurement interval, which is every 5 minutes at the 0th to 5th second, with all relays disabled first to ensure system safety during startup. When the timing conditions are met, the system initiates a scheduled measurement cycle by activating the appropriate relay to select the voltage or current measurement path. Then, it performs sequential measurements using the CD4051B multiplexer IC and a combination of 8-channel, 4-channel, and 2-channel relays to measure the voltage and current of four individual solar panels using ACS712 sensors. This is followed by measurements of the overall system output parameters and environmental conditions. The acquired data is then filtered to reduce noise, automatically calibrated for the current sensors, and saved in CSV format to an SD card along with an accurate timestamp from the RTC. Afterward, all relays are deactivated to conserve energy until the next measurement cycle.

The use of flowcharts is crucial to ensure structured and understandable program logic, as well as to facilitate communication and problem identification during system development [13]. In the context of complex systems such as solar power plant data loggers, flowcharts help identify the program execution flow, special conditions that need to be handled, and the overall logic structure.

In the electronic design, it includes the configuration of current sensors, voltage sensors, temperature and humidity sensors, light intensity sensors, RTC modules, SDCard modules, relays and Arduino UNO microcontrollers which are designed using AutoCAD.



(a)

(b)

Figure 4. Electronic circuit. a) Overall System Circuit, b) MUX IC Configuration with Sensors

In designing the software in this final project, the Arduino IDE (Integrated Development Environment) software is used, where the Arduino IDE is a compiler software specifically designed to translate, create and edit program languages so that they can be understood by the controller and can add library file extensions to make it easier for programmers to control the tools they create. In this study, there are several libraries used to run the functions of several sensors, RTC (Real Time Clock), current sensors, voltage sensors, DHT11, and BH1750. To program the RTC and other sensor components, programmers will be assisted by the libraries provided by the developer. This aims to allow programmers to focus on the working principles of the tools they will design.

```
#include "RTClib.h"
#include <Wire.h>
#include <SPI.h>
#include <SD.h>
#define sampling 1000
#include <BH1750.h>
#include <DHT.h>

//konfigurasi untuk sensor DHT11
#define DHTPIN2 A1
#define DHTTYPE DHT11

BH1750 lightMeter;
float Intensitas;
RTC_DS1307 rtc;

//buat variabel untuk sensor DHT
float humidity, temperature;
DHT dht11(DHTPIN2, DHTTYPE);
char daysOfTheWeek[7][12] = {"Minggu", "Senin", "Selasa", "Rabu", "Kamis", "Jumat", "Sabtu"};
double hasil1 = 0.0, hasil2 = 0.0, hasil3 = 0.0, hasil4 = 0.0, hasilOp = 0.0;
float arus1, arus2, arus3, arus4, arusOp;
float R1 = 30000.0;
float R2 = 7500.0;
```

Figure 5. Program Design

3. RESULTS AND DISCUSSION

Testing the tool starts from assembling all the sensors; Current, Voltage, Temperature and Humidity, Light Intensity, RTC module and SDCard module to the Arduino Uno microcontroller, for the current and voltage sensors for each solar panel configured with the IC MUX CD405B, make sure everything is connected properly

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Figure 6. Hadrware implementation

Next, testing is carried out by supplying the power source from the solar power plant with the assembled equipment to ensure measurements and proper system operation. The measured values are then stored on an SD card in the cvs format. The testing is carried out on Sunday May 25 2025 with result as shown in Table 2.

Figure 7. System Implementation

Table 2. Measurement Results

Time	V1	V2	V3	V4	I1	I2	I3	I4	Temp (°C)	Humidity	Radiation
07.45	20.07	19.92	20.00	20.00	0.51	0.47	0.54	0.49	27.69	75.86%	49.5W/m²
07.50	20.09	19.90	19.92	19.95	0.51	0.49	0.54	0.50	28.34	75.59%	25.55 W/m²
07.55	20.00	19.85	19.95	19.97	0.56	0.52	0.59	0.55	28.74	75.36%	39.36 W/m²
08.00	20.07	19.75	19.90	19.87	0.53	0.52	0.57	0.53	27.94	77.74%	42.42 W/m²
08.05	20.02	19.82	19.92	19.92	0.56	0.54	0.62	0.58	28.12	75.22%	32.23 W/m²
08.10	20.07	19.90	20.02	20.02	0.63	0.62	0.69	0.64	28.11	71.73%	48.26 W/m²
08.15	20.00	19.85	19.92	19.95	0.63	0.62	0.69	0.65	28.23	74.08%	50.6 W/m²
08.20	20.19	19.92	20.04	20.04	0.71	0.72	0.79	0.73	28.13	73.21%	42.33 W/m²
08.25	20.07	19.97	20.02	20.02	0.78	0.79	0.87	0.82	28.54	74.48%	52.15 W/m²
08.30	20,21	19.95	20.07	20.14	0.86	0.87	0.94	0.88	28.62	73.96%	53.88 W/m²
08.35	20.19	19.92	20.12	20.14	0.91	0.91	0.99	0.92	30.85	73.51%	50.04 W/m²
08.40	20.04	19.85	20.09	19.95	0.91	0.91	0.99	0.93	29.13	75.23%	54.45 W/m²
08.45	20.12	19.90	20.09	20.04	0.98	0.99	1.06	1.01	29.25	77.34%	63.66 W/m²
08.50	20.00	19.95	19.97	20.04	0.98	1.01	1.09	1.02	29.03	73.58%	62.31 W/m²
08.55	20.24	20.02	20.17	20.07	1.03	1.04	1.11	1.05	30.12	72.31%	53.58 W/m²
09.00	20.07	19.92	19.95	20.07	1.08	1.11	1.19	1.11	28.63	75.62%	68.06 W/m²
09.05	19.85	19.80	19.82	19.90	1.05	1.09	1.16	1.10	30.97	71.44%	75.9 W/m²
09.10	19.90	19.68	19.85	19.75	1.05	1.09	1.16	1.08	29.97	72.59%	81.89 W/m²
09.15	20.02	19.75	20.02	19.90	1.05	1.06	1.14	1.08	29.07	71.36%	61.59 W/m²
09.20	20.04	19.78	20.04	19.97	1.08	1.11	1.19	1.11	30.39	68.67%	103.72W/m²
09.25	20.14	19.82	20.02	20.00	1.13	1.14	1.24	1.15	30.03	67.1%	91.54 W/m²
09.30	20.24	19.92	20.14	20.02	1.25	1.29	1.36	1.27	29.95	67.15%	87.57 W/m²
09.35	20.12	19.78	20.09	19.97	1.30	1.34	1.41	1.34	32.27	70.01%	122.26W/m²
09.40	20.02	19.78	19.95	19.85	1.35	1.39	1.49	1.39	31.2	70.44%	96.22 W/m²
09.45	20.02	19.75	20.04	19.92	1.35	1.41	1.49	1.40	30.9	68.09%	99.24 W/m²
09.50	20.02	19.70	20.02	19.90	1.38	1.44	1.49	1.42	31.3	73.72%	107.24W/m²
09.55	20.04	19.75	20.02	19.82	1.33	1.36	1.46	1.36	31.66	70.21%	119.72W/m²
10.00	20.12	19.80	20.04	19.90	1.38	1.41	1.49	1.42	31.96	66.46%	89.54 W/m²
10.05	20.04	19.82	20.02	19.92	1.38	1.44	1.51	1.42	31.38	69.93%	84.33 W/m²
10.10	19.90	19.68	19.85	19.78	1.40	1.44	1.54	1.45	32.44	64.71%	107.58W/m²
10.15	20.00	19.73	19.90	19.87	1.38	1.44	1.51	1.43	31.66	66.72%	126.96W/m²
10.20	20.02	19.78	19.87	19.78	1.43	1.46	1.56	1.48	32.84	67.89%	80.88 W/m²
10.25	20.02	19.75	19.95	19.85	1.48	1.56	1.64	1.55	32.78	67.2%	210.53W/m²

Data obtained from the multiplexing system showed characteristics consistent with the normal operating parameters of solar panels. The voltage range of 18.8 to 21.0 V and the current range of 0.11 to 1.51 A are in accordance with the specifications of monocrystalline solar panels (Vmp: 18-21 V).

4. CONCLUSION

The implementation of the CD4051B Multiplexer IC has successfully proven that the limitations of the Arduino UNO analog pins can be overcome effectively. By using only 4 pins (3 digital pins + 1 analog pin for data), the system successfully expands the input capacity to 8 analog channels. This allows the measurement of 8 electrical parameters 4 voltage sensors, 4 current sensors and two environmental parameters sequentially with one microcontroller (temperature, humidity, and light intensity) with a sampling interval of 5 minutes. The integration of the CD4051B Multiplexer IC with a relay switching system has proven effective in overcoming the limitations of the Arduino UNO microcontroller analog pins. This system successfully implements data storage in CSV format on an SD card with an accurate timestamp from the DS1307 RTC module, providing an economical and scalable data logging solution. System testing shows that the data logger can operate automatically and on a schedule from 07:30 to 16:00 WIB, capturing variations in solar panel performance throughout the productive period. The noise filtering mechanism and automatic calibration of the ACS712 current sensor improve measurement accuracy, while the energy management strategy through controlled relay activation optimizes system power consumption. The developed data logger system offers several advantages over commercial solutions, namely; significantly lower cost, flexibility in configuring measurement parameters, ease of adding measurement points for system expansion, and local data storage capabilities that are independent of internet connectivity. This research proves that the Arduino microcontroller platform with the right supporting components can be an alternative for renewable energy system monitoring applications. The implementation of this system is expected to support the optimization of solar power plant energy production through real-time performance monitoring and historical data analysis, as well as facilitate predictive maintenance to ensure long-term operational reliability.

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