Vokasi Unesa Bulletin of Engineering, Technology and Applied Science (VUBETA)
https://journal.unesa.ac.id/index.php/vubeta
Vol. 1, No. 2, 2024, pp. 26~37 DOI: 10.26740/vubeta.v1i2.34859
ISSN: 3064-0768

Off-grid Solar System Monitoring Based on ESP-32 and INA219 in Pesanggrahan Gordomulyo

Zufar Permana Muqorrobin[1*], Akhmad Nawawi[1], Achmad Aris Ardani[1], Singgang Putra Setia[1], Reza Rahmadian[1], Mazli Mustapha[2]
[1]Department of Electrical Engineering, Faculty of Vocational Studies, Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Mechanical Engineering Department. Universiti Teknologi PETRONAS, Persiaran UTP, 32610 Seri Iskandar, Perak, Malaysia

Article Info

Article history:

Received September 13, 2024
Revised October 6, 2024
Accepted November 14, 2024

Keywords:

PV Solar Panel
HT (Handy Talkie)
ESP 32
Monitoring
Innovation

ABSTRACT

The main problem in the highland area of Pesanggarahan Gordo Mulyo is the difficulty of monitoring and maintaining the solar power plant (PLTS) due to its remote location and lack of reliable communication signals. As a solution, this research developed a remote solar power monitoring system using ESP32 and HT (Handy Talkie) communication, which enables automatic data transmission without internet connectivity. This research contributes to the optimization of the monitoring system tailored to the environmental conditions surrounding the test. With 3 different test categories, the PV solar panel monitoring test obtained the highest voltage was 37.1 V, the highest current was 2.1 A, and the maximum power generated was 81 W. Error calculations were also carried out to see the performance of the INA219 sensor with a multimeter measuring instrument, testing voltage, current, and power were 0.3%, 1.8%, and 1.26% respectively. The last test is the transmission of data that has been managed, to be sent in the form of voice by HT, the results show five times the test, the data has the same status of the appropriate data content. Based on each test, this tool has a small error rate, so that it can become one of the innovations in the world of monitoring solar power plants.

1. INTRODUCTION

The Pesanggrahan Gordo Mulyo plateau is one area that has abundant solar energy potential. With high sunlight intensity throughout the day, this area is ideal for the development of Solar Power Plants (PLTS). In recent years, solar power has increasingly become an alternative solution to meet energy needs, especially in areas that are difficult to reach by conventional electricity networks. Therefore, the utilization of solar power in the highlands of Pesanggrahan Gordo Mulyo is considered a strategic step to support energy security in the area, while making maximum use of available natural resources [1][2].

However, despite the huge potential of solar power in this area, there are significant challenges in terms of monitoring and maintenance of solar power plants. One of the main problems is the difficulty of monitoring the solar panels (PV) located in the highland area. Users or technicians have to physically visit the site to check the performance of the system, which is cumbersome and requires extra time and effort. In addition, the highland area also has limited access to communication signals, making the use of internet-based technology unreliable. This is exacerbated by geographical conditions full of tall trees and other obstacles that can interfere with direct access to the solar power plant site [3]-[5].

Faced with these critical issues, this research aims to develop an ESP32-based solar power monitoring system, which can then collect and manage data remotely without an internet connection [6][7]. The ESP32 is in the form of a main command unit that will read monitoring data from the solar power plant and transmit the

*Corresponding Author
Email: permanazufar08@gmail.com

results through an HT (Walkie Talkie) communication device automatically. That way, monitoring results such as voltage, current, and power outputted by the solar panel will be automatically instructed to be sent via HT radio communication, which can be received by anyone or technicians in other places that have easier access [8][9]. This system not only reduces the need for site visits to solar power plants, but also provides a reliable communication solution in areas without cellular signals or internet networks.

Some related research is the development and innovation of ESP 32 modulation [10]-[12], in addition to the development of monitoring using Solar Charger Controlling [13]-[15]. HT-related research is also gaining popularity, so the purpose of this research is a combination of them [16]-[18].

The main contribution of this research is the development of a monitoring system that is optimized for high-altitude conditions that are difficult to reach, such as in the Gordo Mulyo Reservation. The creation of a solar power plant equipped with an ESP32 and HT-based monitoring system is expected to facilitate the management of solar energy more efficiently and practically. In addition, the utilization of HT frequency as a remote communication tool also provides an innovative solution in areas that are limited by signal access. Modification of the previously manual monitoring form into an automatic one also has the potential to increase operational efficiency, reduce maintenance costs, and increase the reliability of the PLTS system as a whole.

2. METHOD

2.1 PV

Photovoltaic (PV) cells, commonly referred to as solar panels, are the core of the rooftop photovoltaic (PV) family that generates electricity with the help of solar energy [19]-[21]. In the process of the photovoltaic effect, each panel is composed of many photovoltaic cells, which are cells that make photons from sunlight change into electric current [22][23]. The aforementioned studies show that monocrystalline panels are more efficient than others, with efficiency estimated at 15-22% depending on the technology. A regular-sized solar panel with a power of 200 Wp (watt-peak) can generate an average range of 700-900 kWh per year in areas with high illumination levels such as the highlands of Pesanggrahan Gordo Mulyo [24][25]. One of the environmental factors that affect solar panel performance is temperature, installation angle, and tree shade. In this case, every degree above 25°C can reduce the efficiency of the solar panel by about 0.5%. Therefore, these design features should be carefully considered and the chosen installation location should be the hill that receives the most sunlight [26][27]. Table 1. Below describes the details of the pv solar panels used.

Table 1. Detailed specifications of solar panels

Parameters	Specification
Max Power (Pmax)	200 Wp
Optimum Operating Voltage (Vmp)	35,6 V
Optimum Operating Current (Imp)	5,62 A
Open-circuit Voltage (Voc)	42,6 V
Short-circuit Current (Isc)	5,95 A
Power Tolerance (P max)	0 - ± 3%
Module Dimension (mm)	1188 x 880 x 35
Weight	10,7 Kg
Max. Series Fuse Rating	20 A

2.2 SCC

Solar Charge Controller (SCC) functions as a regulator of power flow from solar panels to batteries, ensuring safe and efficient charging [13][28][29]. In this system, a PWM (Pulse Width Modulation) type SCC is used which works by adjusting the charging signal based on the battery capacity [14][30][31]. PWM SCCs are generally more affordable compared to MPPT (Maximum Power Point Tracking) SCCs, but with lower efficiency [32][33]. For example, in a solar PV system with 200 Wp solar panels, a PWM SCC can lose about 20-30% efficiency compared to MPPT, especially when solar radiation conditions are not ideal. SCC PWM regulates charging by rapidly disconnecting and connecting electric current, thus preventing the battery from overcharging [15][34]. For example, a 12V 100Ah battery has a nominal voltage of about 12.6V under full conditions. The SCC PWM will regulate charging so that the voltage does not exceed the maximum limit, typically 14.4V, to maintain battery life. In addition, the PWM keeps the charging efficient even if the sunlight intensity decreases. However, SCC PWM cannot optimally regulate the voltage from the solar panel at all times, so it is not as efficient as MPPT in utilizing the maximum power from the solar panel [28][35]-[37].

2.3 ESP32

ESP32 is a technological development that includes Wi-Fi and Bluetooth module places, so it has an excellent way of working with IoT systems. In the case of the ESP32, the dual-core 32-bit Xtensa LX6 processor is a version operating at MHz, with 520 KB of SRAM memory, and also a maximum of 16 MB of flash storage, so supervisory time coverage is a necessary task, such as real-time monitoring [10][11][38]. In addition, the power drawn by the ESP32 is also quite low, handling deep sleep mode in only about 10 µA, therefore, the ESP32 is also preferred in cases where the solar system must be energy efficient [39][40]. For this research, ESP32 is applied to consolidate the data extracted from sensors such as INA219 and then sent via HT- The unit used for this research is such a device. By using the GPIO connector, with a pin range of up to 34, the ESP32 can support more ports and sensors that the user desires. The ESP32, as a separate unit, also has built-in I2C, SPI, and UART communication protocols, which provide a way for the device to communicate with INA219 sensors and other devices [41][42]. In fact, the ESP32 can be programmed to perform several thousand tasks per second during operation, so it is no problem to commit to remote monitoring procedures in a short period of time with very fast reactions [12][43].

2.4 HT (Handy Talkie)

Handie Talkie (HT) is a two-way radio communication device that works on VHF (Very High Frequency) and UHF (Ultra High Frequency) frequencies [44][45]. HT can be the main solution for communication without network infrastructure in remote areas such as the Pesanggrahan Gordo Mulyo plateau where there is no cellular signal. The HT used in this study operates at UHF frequencies from 400 to 470 MHz, which is the main reason why it can penetrate trees and buildings up to 5-10 km away depending on geographical conditions [16][17]. One of the features of HT is that it can transmit voice data in real time without causing significant delay. In this system, the ESP32 transmits PV monitoring results such as voltage and current, which are converted into voice signals and relayed via HT to a receiver at a more convenient location. The UHF frequency used provides good resistance to interference and physical obstacles. The only thing that bothers UHF is that its range is quite limited than VHF frequencies, especially in mountainous areas [18][46]. Table 2. Is a detailed of the HT used.

Table 2. HT Specifications

Parameters	Specification
Frequency	136-174 MHz (VHF) / 400-520 MHz (UHF)
Channel Memory	128
Output Power	4/1 Watt (VHF/UHF)
Operating Mode	Simplex or Semi-duplex
Battery Type	Li-ion 1800 mAh
Standby Time	± 72 Hours

2.5 INA219

The INA219 sensor is a module for measuring current and voltage that uses shunt sensing technology. It has current measurements up to ±3.2 A with a resolution of 1 mA and voltage measurements up to 26 V with a resolution of 0.8 mV [47]-[49]. In solar PV systems, these sensors are required to monitor the performance of solar panels and batteries, as well as to obtain data on power consumption and electricity production [50][51]. For example, to monitor the current of solar panels and the current entering the battery simultaneously, we use the INA219. The data is processed by ESP32 to be displayed or sent via HT. The accuracy of this sensor is ±1% for current measurement and ±0.5% for voltage measurement, so it is expected to provide accurate and reliable values for real-time monitoring in this study [52][53]. By combining all these things, the designed solar power system can provide reliable monitoring solutions in remote areas, guaranteeing system performance and optimizing maintenance without internet access or cellular signal [54][55].

3. RESULTS AND DISCUSSION

The design of the tool starts with making a tool design scheme through Fritzing software to facilitate the assembly of hardware tools. Figure 1. is the tool design scheme.

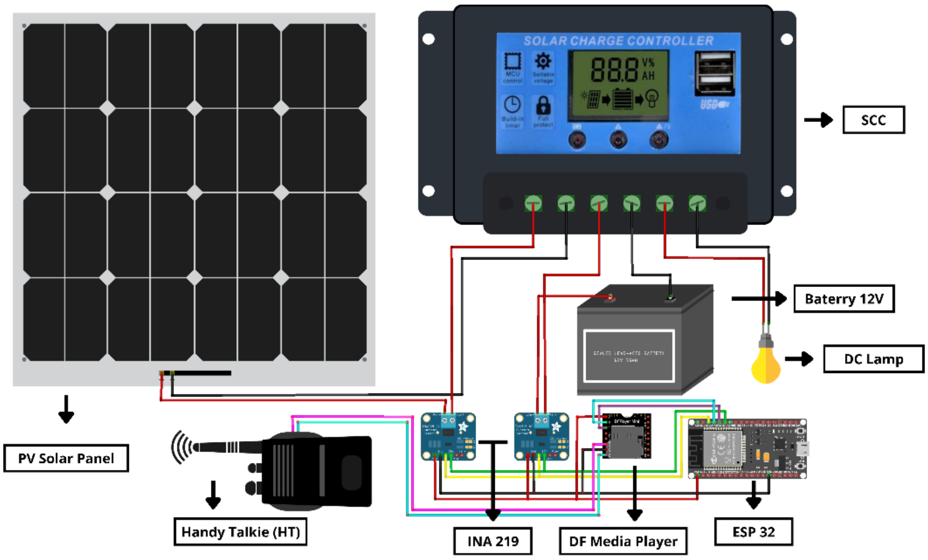

Figure 1. Tool Design Schematic

3.1 Tool Testing

Testing is carried out with 3 different categories, starting with testing the INA219 sensor to measure the results of the PV Solar panel. Then there is a calculation of the error rate (%) in each test. And the last is testing data transmission by HT.

3.1.1.1. PV Solar Panel Testing

The test results of PV solar panels on the 1st, 2nd, and 3rd days have been displayed in each of the 3,4,5 tables. On day 1, the highest value was obtained at 12.00 WIB, which was 35.9 Volts for voltage, 2A for current, and 81W for power. On the 2nd day there was an increase in the output of the PV Solar Panel, the highest state was still the same at 12.00 WIB with the highest voltage 37.1 V, the highest current was 2.1 A, and the highest power was 81W. There was a decrease in the work of PV solar panels in accordance with the surrounding conditions, PV again produced the highest value at 12.00 WIB with 36.6 V, 2.1 A, and 80 W. Each test data is shown in Figure 2 for voltage testing, Figure 2 for current testing, and Figure x for power testing.

Tabel 3. Day 1 Solar Panel PV Yield Testing

No.	Time (WIB)	PV Solar Panel		
		Voltage (V)	Current (A)	Power (W)
1	07.00	18,6	0,5	54
2	08.00	19,2	0,7	56
3	09.00	23,8	0,8	63
4	10.00	25,1	1,1	69
5	11.00	31,7	1,6	76
6	12.00	35,9	2	81
7	13.00	32,8	1,8	75
8	14.00	28,3	1,4	69
9	15.00	25,9	1	66
10	16.00	21,1	0,9	60

Tabel 4. Day 2 Solar Panel PV Yield Testing

No.	Time (WIB)	PV Solar Panel		
		Voltage (V)	Current (A)	Voltage (V)
1	07.00	18,8	0,7	56
2	08.00	21,3	0,9	62
3	09.00	26,9	1,2	67
4	10.00	28,4	1,5	70
5	11.00	32,6	1,8	78
6	12.00	37,1	2,1	81
7	13.00	36,9	2,1	79
8	14.00	34,3	1,7	66
9	15.00	30,5	1,5	64
10	16.00	23,1	1,2	58

Tabel 5. Day 3 Solar Panel PV Yield Testing

No.	Time (WIB)	PV Solar Panel		
		Voltage (V)	Current (A)	Voltage (V)
1	07.00	15,1	0,5	50
2	08.00	18,4	0,8	59
3	09.00	22,7	1	61
4	10.00	27,4	1,3	68
5	11.00	30,1	1,8	72
6	12.00	36,6	2,1	80
7	13.00	34,8	1,9	77
8	14.00	30,3	1,6	70
9	15.00	29,9	1,1	67
10	16.00	21,3	0,7	58

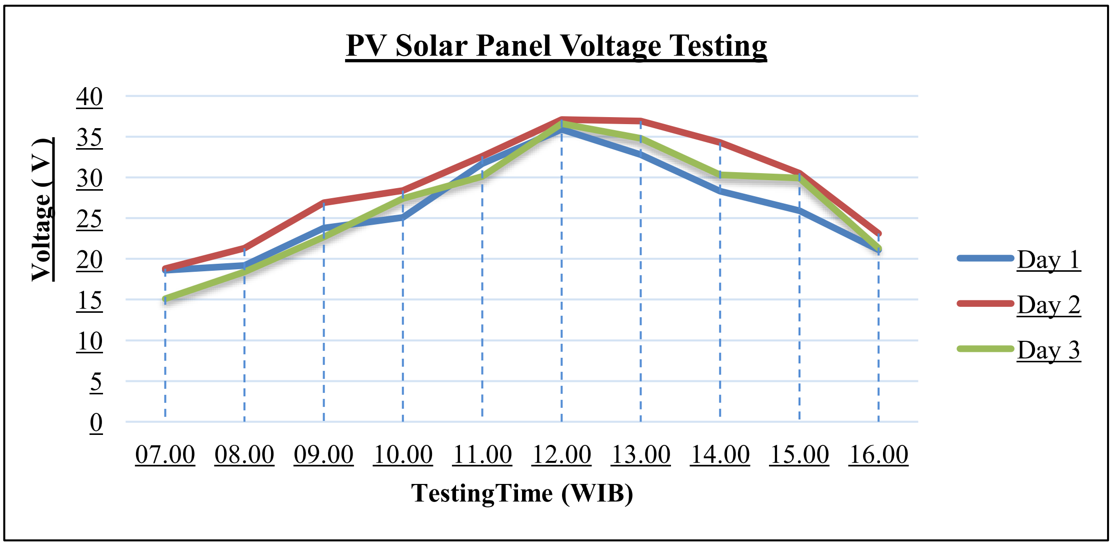

Figure 2. PV Solar Panel Voltage Testing

.

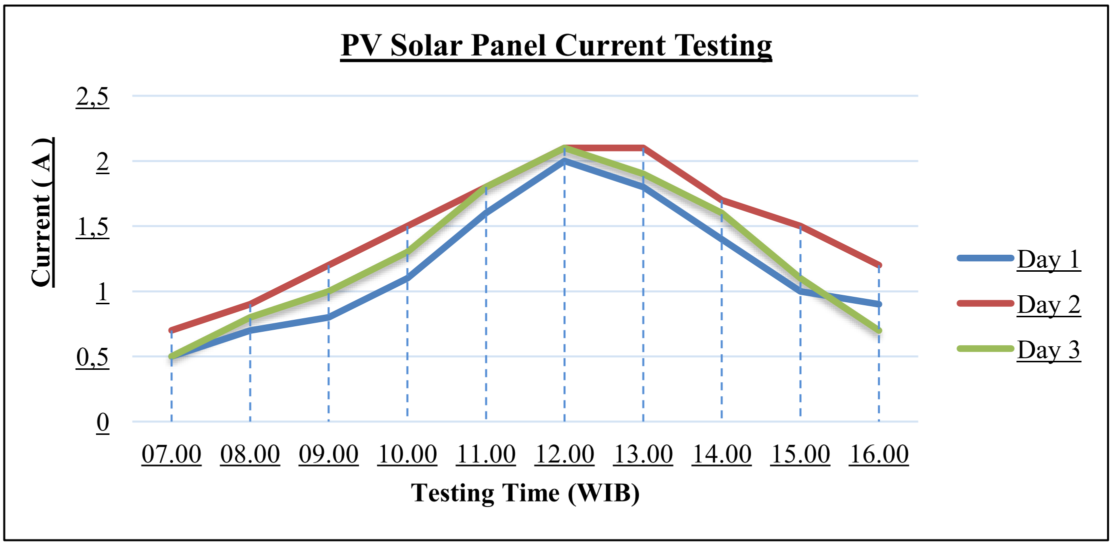

Figure 3. PV Solar Panel Current Testing

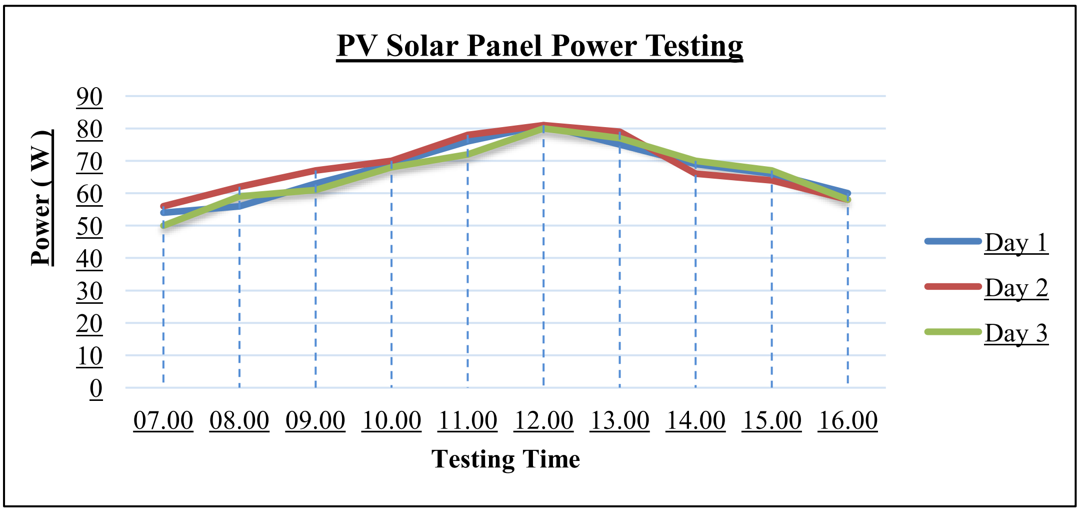

Figure 4. PV Solar Panel Power Testing

3.1.1.2. Error percentage testing between INA 219 sensor and multimeter measuring instrument

The error percentage in the table is calculated by comparing the difference between the measured voltage using the INA219 sensor and the multimeter, then expressing that difference as a percentage of the multimeter's reading. The formula to calculate the error percentage is:

$$Error(\%) = \left(\frac{Difference}{Multimeter\ Reading}\right) \times 100 \quad (1)$$

Tabel 6 Testing Percentage Error of Voltage Sensor Tool on PV Solar Panel

No.	Voltage (V)	Multimeter (V)	Difference	Error (%)
1	28,4	28,3	0,1	0,4
2	32,6	32,6	0	0
3	37,1	37,3	0,2	0,5
4	36,9	36,8	0,1	0,3
5	34,3	34,4	0,1	0,3
Average Error (%)				0,3 %

Tabel 7. Testing Percentage Error of Current Sensor Tool on PV Solar Panel

No.	Current (A)	Multimeter (A)	Difference	Error (%)
1	1,8	1,8	0	0
2	2,1	2,2	0,1	4,5
3	2,1	2,2	0,1	4,5
4	1,7	1,9	0	0
5	1,5	1,5	0	0
Average Error (%)				1,8%

Tabel 8. Testing Percentage Error of Power Sensor Tool on PV Solar Panel

No.	Power (W)	Multimeter (W)	Difference	Error (%)
1	70	71	1	1,4
2	78	79	1	1,2
3	81	83	2	2,4
4	79	78	1	1,3
5	66	66	0	0
Average Error (%)				1,26%

The next test is a comparison between the INA219 sensor and a multimeter measuring instrument to see the difference and percentage error of the sensor performance. Testing was carried out five times for each of the measured values that have been generated by PV solar panels. Voltage testing has an average error of 0.3%, current has an average error of 1.8%, and power gets an average error of 1.26%. Figure 5. displays a graph of testing error (%) on each INA219 sensor performance test.

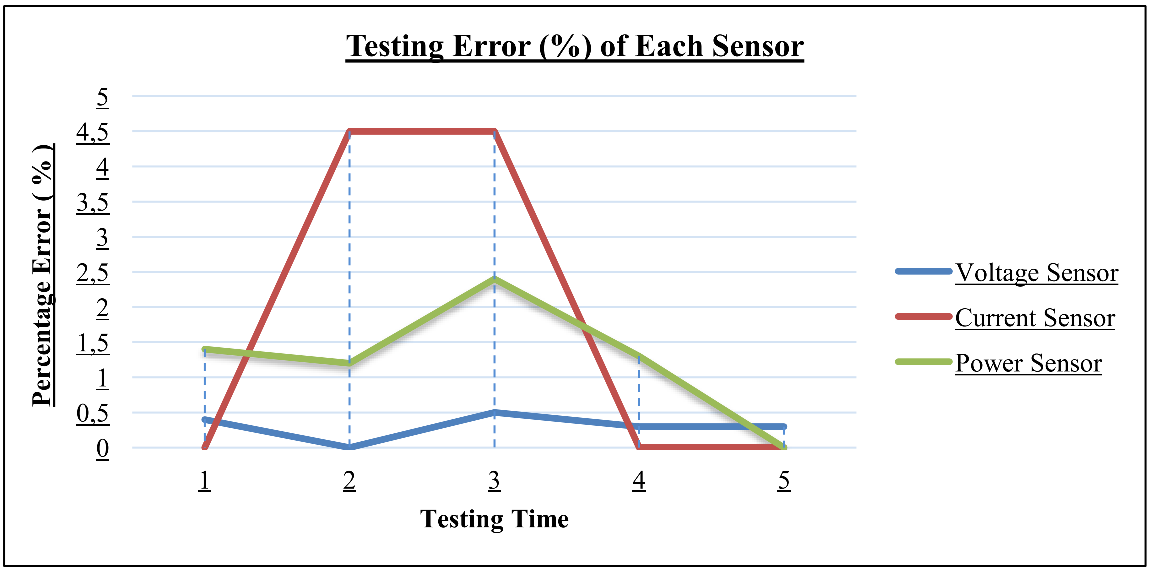

Figure 5. Testing Error (%) of Each Sensor

3.1.1.3. Testing the suitability of data transmission by HT

Table 9 displays the results of testing the contents of the data that has been managed by ESP32 to be transmitted in the form of voice by Handy Talkie (HT), then the data that has been transmitted is adjusted to the HT Reeciver or receiver. Each message is checked whether it is appropriate between data transceivers. Obtained during five tests, the performance of the tool is in perfect condition with all tests being successful.

Tabel 9. Data Transmission Conformance Testing

No.	Data Transmitted by HT Transmitter	Data Heard on HT Receiver	Succes Status
1	PV Voltage: 28 Volt PV Current: 1,8 Ampere PV Power: 70 Watt	PV Voltage: 28 Volt PV Current: 1,8 Ampere PV Power: 70 Watt	Connected
2	PV Voltage: 32 Volt PV Current: 2,1 Ampere PV Power: 78 Watt	PV Voltage: 32 Volt PV Current: 2,1 Ampere PV Power: 78 Watt	Connected
3	PV Voltage: 37 Volt PV Current: 2,1 Ampere PV Power: 81	PV Voltage: 37 Volt PV Current: 2,1 Ampere PV Power: 81	Connected
4	PV Voltage: 36 Volt PV Current: 1,7 Ampere PV Power: 79 Watt	PV Voltage: 36 Volt PV Current: 1,7 Ampere PV Power: 79 Watt	Connected
5	PV Voltage: 34 Volt PV Current: 1,5 Ampere PV Power: 66 Watt	PV Voltage: 34 Volt PV Current: 1,5 Ampere PV Power: 66 Watt	Connected

4. Conclusion

This research focuses on monitoring solar power plants through PV Solar panels that can be seen directly through data on the Solar Charge Controller (SCC), besides that there is an INA219 sensor that measures voltage, current, and power on PV. The sensor data is sent to the ESP32 to be managed, the data is again connected to the DF Media Player to be transmitted in the form of sound by Handy Talkie (HT). The development of HT is a good innovation in the world of monitoring with a transmission environment that is difficult to reach signals or exposed to many obstacles. The first test is monitoring the voltage, current, and power of the PV Solar Panel using the INA 219 Sensor for 3 consecutive days to see the difference. The highest voltage was 37.1 V, the highest current was 2.1 A, and the highest power was 81Watt. The second test is the comparison of the INA219 sensor with the Multimeter measuring instrument, the average error for each voltage, current, and power test is 0.3%, 1.8%, and 1.26%. In addition, there is data management by ESP32 which is then tested for data transmission into sound by HT, and obtained for 5 times testing data transmission has good suitability. From all tests, monitoring PV solar panels using INA219 sensors and data transceivers by HT is a good innovation, shown in the success and small error rate in each test.

REFERENCES

[1] M. J. Montes, R. Guedez, J. I. Linares, and M. A. Reyes-Belmonte, “Advances in solar thermal power plants based on pressurised central receivers and supercritical power cycles”, Energy Conversion and Management, vol. 293, 2023. doi: https://doi.org/10.1016/j.enconman.2023.117454.

[2] J. I. Linares, E. Arenas, M. J. Montes, A. Cantizano, J. R. Pérez-Domínguez, and J. Porras, “Direct coupling of pressurized gas receiver to a brayton supercritical CO2 power cycle in solar thermal power plants”, Case Studies in Thermal Engineering, vol. 61, 2024. doi: https://doi.org/10.1016/j.csite.2024.105021.

[3] X. Guo, “Research on desalination performance of novel free-interface evaporation synergism membrane distillation module: Suitable for solar drive scenarios”, Separation and Purification Technology, vol. 316, 2025. doi: https://doi.org/10.1016/j.seppur.2024.131350

[4] M. S. Taslimi, A. Khosravi, Y. K. Nugroho, and N. Rytter, “Optimization and analysis of methanol production from CO2 and solar-driven hydrogen production: A Danish case study”, International Journal of Hydrogen Energy, vol. 69, pp. 466–476, 2024. doi: https://doi.org/10.1016/j.ijhydene.2024.05.033.

[5] T. Lehtola,” Solar energy and wind power supply supported by battery storage and Vehicle to Grid operations”, Electric Power Systems Research, vol. 228, 2024. doi: https://doi.org/10.1016/j.epsr.2023.110035.

[6] Z. Balas, K. Tokarz, B. Zielinski, and T. Guzniczak, “Research on the behaviour of Bluetooth Low Energy protocol in the heart rate monitoring application”, Procedia Computer Science, pp. 63–69, 2023. doi: https://doi.org/10.1016/j.procs.2023.09.092.

[7] O. Mohammed, A. A. Rachida, D. Olivier, and M. Abdelaziz, “An open source and low-cost Smart Auditorium”, Procedia Computer Science, pp. 518–523, 2021. doi: https://doi.org/10.1016/j.procs.2021.07.076.

[8] A. Kamunen, P. Haddington, and I. Rautiainen, “It seems to be some kind of an accident: Perception and team decision-making in time critical situations”, Journal of Pragmatics, vol. 195, pp. 7–30, 2022. doi: https://doi.org/10.1016/j.pragma.2022.04.001.

[9] D. Ruslanjari, E. W. Safitri, F. A. Rahman, and C. Ramadhan, “ICT for public awareness culture on hydrometeorological disaster”, International Journal of Disaster Risk Reduction, vol. 92, 2023. doi: https://doi.org/10.1016/j.ijdrr.2023.103690.

[10] M. J. Espinosa-Gavira, A. Agüera-Pérez, J. C. Palomares-Salas, J. M. Sierra-Fernandez, P. Remigio-Carmona, and J. J. González de-La-Rosa, “Characterization and Performance Evaluation of ESP32 for Real-time Synchronized Sensor Networks”, pp. 261–268, 2024. doi: https://doi.org/10.1016/j.procs.2024.05.104.

[11] I. Anshori et al., “Design of smartphone-controlled low-cost potentiostat for cyclic voltammetry analysis based on ESP32 microcontroller”, Sensing and Biosensing Research, vol. 36, 2022. doi: https://doi.org/10.1016/j.sbsr.2022.100490.

[12] H. J. El-Khozondar et al., “A smart energy monitoring system using ESP32 microcontroller”, e-Prime - Advances in Electrical Engineering, Electronics and Energy, vol. 9, 2024. doi: https://doi.org/10.1016/j.prime.2024.100666.

[13] B.Patra, P. Nema, M.Z. Khan, O. Khan, “Optimization of solar energy using MPPT techniques and industry 4.0 modelling”, Sustainable Operations and Computers, vol.4, pp. 22-28, 2023. doi: https://doi.org/10.1016/j.susoc.2022.10.001

[14] M. Hasan, A. H. Sabry, and H. Serra Altinoluk, “Maximizing energy transfer of solar-battery charge controller using voltage balancing strategy”, Results in Engineering, vol. 23, 2024. doi: https://doi.org/10.1016/j.rineng.2024.102604.

[15] K. Anada Rao et al., “MPPT Charge Controller using Fuzzy Logic for Battery Integrated with Solar Photovoltaic System”, Journal of Advanced Research in Applied Sciences and Engineering Technology, vol. 42, no. 2, pp. 171-182, 2025. doi: https://doi.org/10.37934/ARASET.47.2.171182

[16] A. Sedunov, N. Sedunov, H. Salloum, A. Sutin,” Low-cost multichannel radio direction finding system based on software-defined radio”, IEEE International Symposium on Technologies for Homeland Security, 2022. doi: https://doi.org/10.1109/HST56032.2022.10025440

[17] N. Busaeri et al., “Design and Implementation of Real-Time Sensors for Three-Phase Induction Motor Performance Monitoring using Internet of Thing (IoT)”, Journal of Advanced Research in Applied Sciences and Engineering Technology, vol. 49, no. 2, pp. 162-175, 2025. doi: https://doi.org/10.37934/araset.49.2.162175

[18] A. Supardi, M. Y. Raya, and R. S. Anwar, “Development of a Low-Cost Portable Hydro and Wind Power as Emergency Power Source”, Journal of Physics, 2021. doi: https://doi.org/10.1088/1742-6596/1858/1/012049.

[19] M. M. Ismail, I. Dincer, Y. Bicer, and M. Z. Saghir, “Assessment of a Solar-Powered Trigeneration Plant Integrated with Thermal Energy Storage Using Phase Change Materials”, Process Safety and Environmental Protection, vol. 91, pp. 1339-1352, 2024. doi: https://doi.org/10.1016/j.psep.2024.09.012.

[20] A. Couto and A. Estanqueiro, “Wind power plants hybridised with solar power: A generation forecast perspective”, Journal of Cleaner Production, vol. 423, 2023. doi: https://doi.org/10.1016/j.jclepro.2023.138793.

[21] R. Villena-Ruiz, S. Martín-Martínez, A. Honrubia-Escribano, F. J. Ramírez, and E. Gómez-Lázaro, “Solar PV power plant revamping: Technical and economic analysis of different alternatives for a Spanish case”, Journal of Cleaner Production, vol. 446, 2024. doi: https://doi.org/10.1016/j.jclepro.2024.141439.

[22] I. Jamil et al., “Predictive evaluation of solar energy variables for a large-scale solar power plant based on triple deep learning forecast models”, Alexandria Engineering Journal, vol. 76, pp. 51–73, 2023. doi: https://doi.org/10.1016/j.aej.2023.06.023.

[23] D. Venkateswaran and Y. Cho, “Efficient solar power generation forecasting for greenhouses: A hybrid deep learning approach”, Alexandria Engineering Journal, vol. 91, pp. 222–236, 2024. doi: https://doi.org/10.1016/j.aej.2024.02.004.

[24] K. Nuortimo, J. Harkonen, and K. Breznik, “Global, regional, and local acceptance of solar power”, Renewable and Sustainable Energy Reviews, vol. 193, 2024. doi: https://doi.org/10.1016/j.rser.2024.114296.

[25] R. Thonig and J. Lilliestam, “Cross-technology legitimacy feedback: The politics of policy-led innovation for complementarity in concentrating solar power”, Environmental Innovation and Societal Transitions, vol. 52, 2024, doi: https://doi.org/10.1016/j.eist.2024.100884.

[26] M. Bin Yeamin et al., “Simulation and survey-based feasibility study of concentrated solar plant in northern and central Bangladesh”, Results in Engineering, vol. 23, 2024. doi: https://doi.org/10.1016/j.rineng.2024.102711.

[27] M.S. Saleem, N. Abas, “Optimal design of renewable driven polygeneration system: A novel approach integrating TRNSYS-GenOpt linkage”, Cleaner Engineering and Technology, vol. 24, 2025. doi: https://doi.org/10.1016/j.clet.2024.100856

[28] A.Z. Arshad, A.W.M. Zuhdi, A.D Azhar, C.F Chau, A. Ghazali, “Advancements in maximum power point tracking for solar charge controllers”, Renewable and Sustainable Energy Reviews, vol. 210, 2025. doi: https://doi.org/10.1016/j.rser.2024.115208.

[29] P. R. Pillewar, S. N. Patil, and M. G. Unde, “An implementation of solar PV array based multifunctional electrical vehicle charger”, Materials Today: Proceedings, vol. 68, pp. A12-A18, 2022, doi: https://doi.org/10.1016/j.matpr.2023.01.003.

[30] P. Singla et al., “Design and simulation of 4 kW solar power-based hybrid EV charging station”, Scientific Reports, vol. 14, no. 1, 2024. doi: https://doi.org/10.1038/s41598-024-56833-5

.

[31] G.N. Gusev, O.V. Zhdaneev, M.E. Gainullin, A.Yu Argatsev, D.N. Lapkin, "Solar PV system with maximum power tracking", International Journal of Hydrogen Energy, vol. 87, pp. 258-267, 2024. doi: https://doi.org/10.1016/j.ijhydene.2024.08.441

[32] M. S. Islam, H. Mohamad, and S. Z. Mohammad Noor, "Development of a New Controller for Solar Home System: PWM Charge Controller & DC to DC Converter (12V to 120V)", Journal of Electrical & Electronic Systems Research, vol. 20, no. APR2022, pp. 41–50, 2022. doi: https://doi.org/10.24191/jeesr.v20i1.006.

[33] J. Reegan, A. Ghana Saravanan, "Optimized PI Control for PV-Powered PMBLDC Motor with SEPIC-Zeta Converter", Journal of Electrical Engineering and Technology, vol. 19, no. 7, pp. 4215-4237, 2024. doi: https://doi.org/ 10.1007/s42835-024-01841-8.

[34] Kumuthawathe Ananda-Rao et al., "MPPT Charge Controller using Fuzzy Logic for Battery Integrated with Solar Photovoltaic System", Journal of Advanced Research in Applied Sciences and Engineering Technology, vol. 47, no. 2, pp. 171–182, 2024. doi: https://doi.org/10.37934/araset.47.2.171182.

[35] M. Nur-E-Alam et al., "Optimization of energy management in Malaysian microgrids using fuzzy logic-based EMS scheduling controller", Scientific Reports, vol. 15, no. 1, 2025. doi: https://doi.org/10.1038/s41598-024-82360-4.

[36] X. Yu et al., "Simulation and Optimization of a Hybrid Photovoltaic/Li-Ion Battery System", Batteries, vol. 10, no. 11, 2024. doi: https://doi.org/10.3390/batteries10110393

[37] W. Indrasari, G. Rama, and R. N. Setiadi, "Circuit Simulation of the DC-DC Converter with Variation of PWM Load in Solar Panel Electrical Energy Storage", Journal of Physics, 2022. doi: https://doi.org/10.1088/1742-6596/2377/1/012020.

[38] A. Zhaxalikov, A. Mombekov, and Z. Sotsial, "Surveillance Camera Using Wi-Fi Connection", Procedia Computer Science, pp. 721–726, 2024. doi: https://doi.org/10.1016/j.procs.2023.12.147.

[39] A. Abu Sneineh and A. A. A. Shabaneh, "Design of a smart hydroponics monitoring system using an ESP32 microcontroller and the Internet of Things", MethodsX, vol. 11, 2023. doi: https://doi.org/10.1016/j.mex.2023.102401.

[40] M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "Design and implementation of an open-Source IoT and blockchain-based peer-to-peer energy trading platform using ESP32-S2, Node-Red and, MQTT protocol", Energy Reports, vol. 7, pp. 5733–5746, 2021. doi: https://doi.org/10.1016/j.egyr.2021.08.190.

[41] M. R. Pretel, V. Vidal, D. Kienigiel, and C. Forcato, "A low-cost and open-hardware portable 3-electrode sleep monitoring device", HardwareX, vol. 19, 2024. doi: https://doi.org/10.1016/j.ohx.2024.e00553.

[42] N. Abekiri, A. Rachdy, M. Ajaamoum, B. Nassiri, L. Elmahni, And Y. Oubail, "Platform for hands-on remote labs based on the ESP32 and NOD-red", Scientific African, vol. 19, 2023. doi: https://doi.org/10.1016/j.sciaf.2022.e01502.

[43] T. Chen, X. Li, H. Li, and G. Zhu, "Deep learning-based fall detection using commodity Wi-Fi", Journal of Information and Intelligence, vol. 2, no. 4, pp. 355–364, 2024. doi: https://doi.org/10.1016/j.jiixd.2024.04.001.

[44] P. Baskar, P. Kumar, S. Chidambaram, Y.K Choukiker, A. Bhowmick, "Performance of a nonlinear energy harvesting CR-enabled D2D network with censoring and NOMA", Alexandria Engineering Journal, vol. 118, pp. 234-245, 2025. doi: https://doi.org/10.1016/j.aej.2025.01.006

[45] A. Es-saleh, M. bendaoued, S.Lakrit, S. Das, A.Faize, "Design aspects of MIMO antennas and its applications: A comprehensive review", Results in Engineering, vol. 25, 2025. doi: https://doi.org/10.1016/j.rineng.2024.103797

[46] G. U. Nugraha, A. A. Nur, P. A. Pranantya, R. F. Lubis, and H. Bakti, 'Analysis of groundwater potential zones using Dar-Zarrouk parameters in Pangkalpinang city, Indonesia', Environment Development and Sustainability, vol. 25, no. 2, pp. 1876–1898, 2023. doi: https://doi.org/10.1007/s10668-021-02103-7.

[47] J. Lambert, R. Monahan, and K. Casey, "Power consumption profiling of a lightweight development board: Sensing with the INA219 and Teensy 4.0 microcontroller", Electronics (Switzerland), vol. 10, no. 7, 2021. doi: https://doi.org/10.3390/electronics10070775.

[48] M.Z. Hussin, J. Jalani, M.H. Powdzi, S.M. Rejab, and M.K. Ishak, "Smart Robot Cleaner Using Internet of Things", Journal of Advanced Research in Applied Sciences and Engineering Technology, vol. 46, no. 1, pp. 175-186, 2025. doi: https://doi.org/10.37934/araset.46.1.175186.

[49] C. M. Nkinyam et al., "Design and implementation of a waterless solar panel cleaning system", Unconventional Resources, vol. 5, 2025. doi: https://doi.org/10.1016/j.uncres.2024.100131

[50] C.D. Le, C.P. Vo, D.L. Vu, T.H. Nguyen, K.K. Ahn, "Water electrification based triboelectric nanogenerator integrated harmonic oscillator for waste mechanical energy harvesting", Energy Conversion and Management, vol. 251, 2022. Doi: https://doi.org/10.1016/j.enconman.2021.115014

[51] B. Liu, X. Li, Z. Li, P. He, "Construction of power load control and management terminal operation system based on machine learning technology", Intelligent Decision Technologies, vol. 18, no. 4, pp. 2841-2854, 2024. doi: https://doi.org/0.3233/IDT-230239.

[52] A. Mariyaraj and S. P. Thankappan, "IoT-integrated smart energy management system with enhanced ANN controller for small-scale microgrid", Electrical Engineering, vol. 106, no. 6, pp. 7363-7397, 2024. Doi: https://doi.org/10.1007/s00202-024-02448-y.

[53] H. Maghfiroh, J. T. Affandy, F. Adriyanto, and M. Nizam, "Single Phase Inverter with Power Monitoring using Arduino", Journal of Physics, 2021. doi: https://doi.org/10.1088/1742-6596/1844/1/012016.

[54] Y. Zheng et al., "A Family of Hybrid Topologies for Efficient Constant-Current and Constant-Voltage Output of Magnetically Coupled Wireless Power Transfer Systems", World Electric Vehicle Journal, vol. 15, no. 12, 2024. doi: https://doi.org/10.3390/wevj15120578

[55] U.Narayanan, P. Prajith, R.T Mathew, R. Alexandar, V.Vikraman, “Real Time Distracted Driver Detection Using Xception Architecture And Raspberry Pi”, Inteligencia Artificial, vol. 28, no. 75, pp. 15-29, 2025. doi: https://doi.org/10.4114/intartif.vol28iss75pp15-29

BIOGRAPHIES OF AUTHORS

Zufar Permana Muqorrobin is a Active student of D4 Electrical Engineering study program, State University of Surabaya. research fields of PLTS monitoring tools, microcontrollers, renewable energy, data analysis, software engineering. He is also active in developing projects on campus. can be contacted via email : permanazufar08@gmail.com

Akhmad Nawawi is a student of D4 Electrical Engineering Study Program at Faculty of Vocational Studies, Surabaya State University, Indonesia. He pursues studies in the fields of power systems, microcontrollers and telecommunications. He is active in several academic activities and research projects in campus organizations. For further information or to communicate with Akhmad Nawawi, he can be contacted via email: akhmad.20005@mhs.unesa.ac.id.

Singgang Putra Setia is a student of D4 Electrical Engineering Study Program at Faculty of Vocational Studies, Surabaya State University, Indonesia. He pursues studies in the building construction, microcontrollers and telecommunications. He is active in several academic activities and research projects in campus organizations. For further information or to communicate with Singgang Putra Setia, he can be contacted via email: singgangputra.21042@mhs.unesa.ac.id.

Achmad Aris Ardani is a Active student in the D4 electrical engineering study program at Surabaya State University. he has research fields such as microcontrollers, internet of things and renewable energy. He is also active in developing projects on and off campus. He can be contacted via email: achmadaris.21043@mhs.unesa.ac.id

Reza Rahmadian received received his Bachelor of Applied Science from ElectronicEngineering Polytechnic Institute of Surabaya (PENS), Surabaya, Indonesia, in 2006, and his Master of Engineering Science from Curtin University, Australia, in 2013. He is currently alecturer at the Department of Electrical Engineering, Universitas Negeri Surabaya, Indonesia. His research interests include renewable energy. He can be contacted at email: rezarahmadian@unesa.ac.id