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Supervisory control and data acquisition system for solar panel based on Internet of things (IoT)

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ABSTRACT

Supervisory control and data acquisition (SCADA) system on IoT-based solar power plant using HMI, PC, and Smartphone interfaces. HMI uses KTP 700 Comfrot, Siemens S7-1200 PLC connected to the internet via Ngrok, using Siemens TIA Portal V17. The purpose of monitoring the realtime state of the PLTS such as the condition of batteries, solar panels, inverters and loads used and maintaining from troubleshooting. This research designs hardware and software devices to develop a SCADA system. including PLC, HMI, PC, battery, SCC, inverter, solar panel and sensor devices and other actuators are arranged in such a way. software design is carried out in TIA Portal to program PLC and HMI, Node Red as an implementation of the internet of things. in the research it can be concluded that the application of ngrok on the localhost system is very easy, because it does not require a homebase to connect with an external network. and the output of solar panels is not always monitored by the temperature and solar radiation of the SCADA system on solar power plants based on the internet of things. the implementation of the internet of things uses Node Red and Ngrok software as a link between localhost and external networks. So the internet of things in this test can be controlled and monitored remotely with a cacatan must always be connected to the internet. Monitoring, control and data access systems work well.

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1. INTRODUCTION

Indonesia is located on the equator so it has abundant solar energy sources, with an average national solar radiation intensity of around 4.8 kWh/m2 per day [1]. Indonesia as a tropical country has great potential in utilizing solar energy as a resource that can play an important role in the development of large-scale solar power plants (PLTS). The electrical energy produced by solar cells is greatly influenced by differences in environmental conditions where the solar cells are placed [2]-[3]. Solar systems must be maintained regularly. Therefore, monitoring the energy production of your solar panels will increase the overall efficiency of the system. Recent events in the energy sector show that the solar energy market is one of the fastest growing renewable energy markets in the world. Solar energy is converted into electricity and heat. Sunlight is collected directly through photovoltaic cells or indirectly through concentrated solar energy [4]-[8].

Photovoltaic (PV) systems generate electricity from sunlight. This system consists of batteries, inverters, solar modules or panels, chargers, and inverters [9]. Where SCC (Solar Charge Controller) is a module that controls the battery charging process and prevents overcharging and overdischarging to extend battery life [10]. Cut off the current on the battery to prevent the battery from being too often in a gassing condition that causes evaporation of battery fluid and corrosion on the battery grid [11]. Some of the most common types of solar cells sold on the market are monocrystalline and polycrystalline [12]. Monocrystalline solar panels are the most efficient in producing power but decrease when in cloudy conditions, polycrystalline solar panels are lower in efficiency than monocrystalline but can produce better power than monocrystalline in cloudy or cloudy weather [13]-[15].

One device that facilitates monitoring is HMI (Human Machine Interface), HMI is a computer-based interface software that allows visual interaction between humans and machines or equipment that is controlled [16]. HMI is a system that is integrated with PLC that can facilitate communication between humans and machines using a screen display [17]. PLC is a device that can control the process or operation of a machine by viewing input signals and controlling output as needed. The program's logic instructions are stored in memory. Monitoring the use of electrical energy is an effort to maintain the availability of energy and make energy more efficient. This is implemented through supporting systems such as monitoring, device control, and data processing. The Supervisory Control and Data Acquisition (SCADA) system includes a monitoring and control system that collects and analyzes data in real time under various operating conditions and can be accessed via the Internet [18]-[21].

The implementation of the SCADA system with IoT requires a remote application that allows users to access data/devices via the internet. In addition, the interface currently needed in the world of technology is an interface based on IoT (Internet of things) [20]. SCADA (Supervisory Control and Data Acquisition) is a system in an energy management system that is used to control and monitor physically distributed devices and collect data in real time. Usually, SCADA is used to control industrial processes [22]. In this study, the application of the internet of things aims to connect the Siemens S7-1200 PLC to the internet through Node-Red software. Node-RED is a browser-based tool for creating Internet of things (IoT) applications where its visual programming environment makes it easy for users to create applications as flows. To connect node-red and PLC S7-1200 to an external network, additional software is required, one of which is Ngrok. Ngrok functions as a bridge between the localhost node red to a wider network [23].

The SCADA system on IoT-based solar power plants is designed using a combination of several functions from hardware and software. In this study, the Siemens S7-1200 PLC is the main controller, the SCC is the battery charging controller, the inverter is the DC voltage converter to AC voltage [12], and the battery is the component that stores the output power from the solar panel. PLC programming uses TIA Portal V17 and is connected to Node-Red as the HMI Dashboard on the internet of things system. System testing is carried out by monitoring the solar power generation system at different time intervals in order to collect data and analyze whether the system is running well or not.

2. METHOD

This research was conducted by creating a monitoring, control, and data collection system. Monitoring, controlling, and collecting data from solar power plants controlled from several interfaces such as PCs and Smartphones. This system uses the Internet of Thing (IoT) concept which is a communication link between hardware and software through a special node red web server. PLC functions as a data processing center, where data will be sent to the HMI and IoT which are used as control and monitoring of stand-alone PLTS. The monitored PLTS parameters include voltage, current, power, radiation, solar panel temperature. Voltage and current and State of Charge (SOC) of the battery. SCC with MPPT system can work in cloudy conditions [24]-[27]. Inverter output voltage and current. Data for each parameter is obtained from the sensor. ACS712 is a high-precision sensor as an AC or DC current sensor. There are 3 voltage sensors used in the system, namely the ZMPT10B1B sensor, Voltage Transducer, and Voltage Transmitter. Pyranometer PYR20 sensor to obtain the amount of solar radiation [28]. K-type thermocouple temperature sensors work with different metal densities converting temperature differences into voltage changes[29]-[34].

The control of the PLTS includes ON or OFF and protection against overcurrent which will automatically turn off the contactor. To turn ON or OFF the solar panel, battery and AC load using a contactor that can be operated on the HMI screen and PC server. Figure 1 shows a block diagram of the SCADA system parts for the solar power plant based on the internet of things applied in this study. Figure 1 uses HMI TP700 Comfort, PLC S7 1200 DC/DC/Relay, solar panels, inverters, batteries, voltage sensors, current sensors, AC loads, and contactors to run the IoT-based PLTS SCADA system. The PLC functions as a data processing center and sends data to the HMI and IoT, which are used to control and monitor separate PLTS. Voltage, current, solar panel power, voltage, and current, as well as battery voltage, current, and State of Charge (SOC), inverter output voltage, and current are all PLTS parameters monitored by sensors. PLTS control includes ON or OFF and overcurrent protection. To turn ON or OFF solar panels, batteries and AC loads using contactors that can be operated on the HMI screen and PC server. Overcurrent protection also uses contactors, where the contactor will disconnect the current from the solar panel if the amount of current produced exceeds the set current sensor value.

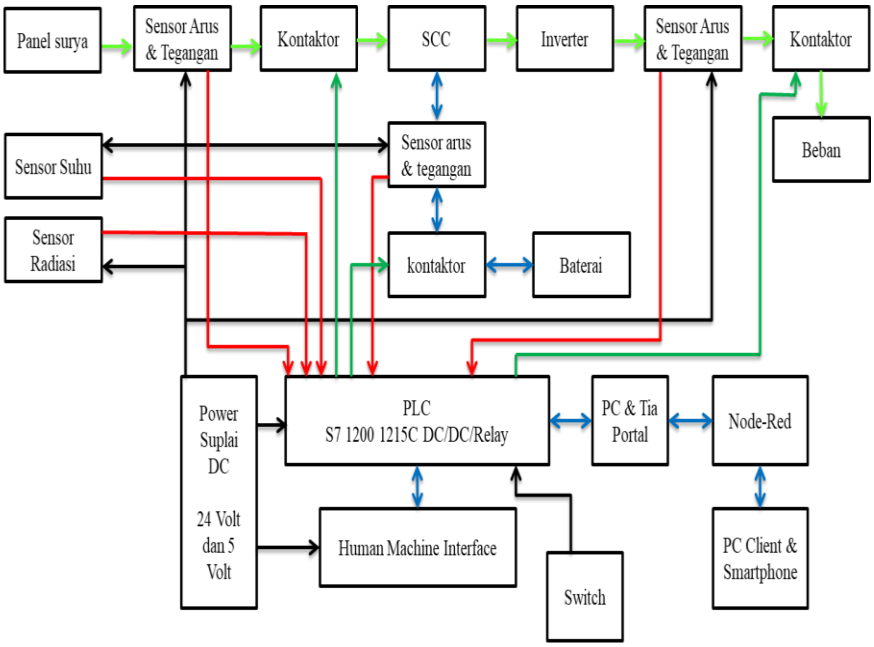


Figure 1. Diagram block of proposed SCADA system for solar panel

Figure 2 shows the PLC digital input in the form of a main switch that activates the control system. For analog input on the analog module in the form of voltage and current signals from the sensor. Where the DC voltage sensor DVV 100, Thermocouple sensor, and Pyranometer sensor PYR20 will produce an analog signal in the form of a current with a range of 4-20 mA. For the ZMPT101B voltage sensor and ACS712 current sensor will produce an analog signal in the form of a voltage with a range of 0-5 Volts. All of these analog signals are input to the PLC analog input module that is capable of voltage and current signals. Figure 2 is equipped with a 24 VDC power supply for HMI and PLC and 5 VDC for parameter measuring components such as sensors.

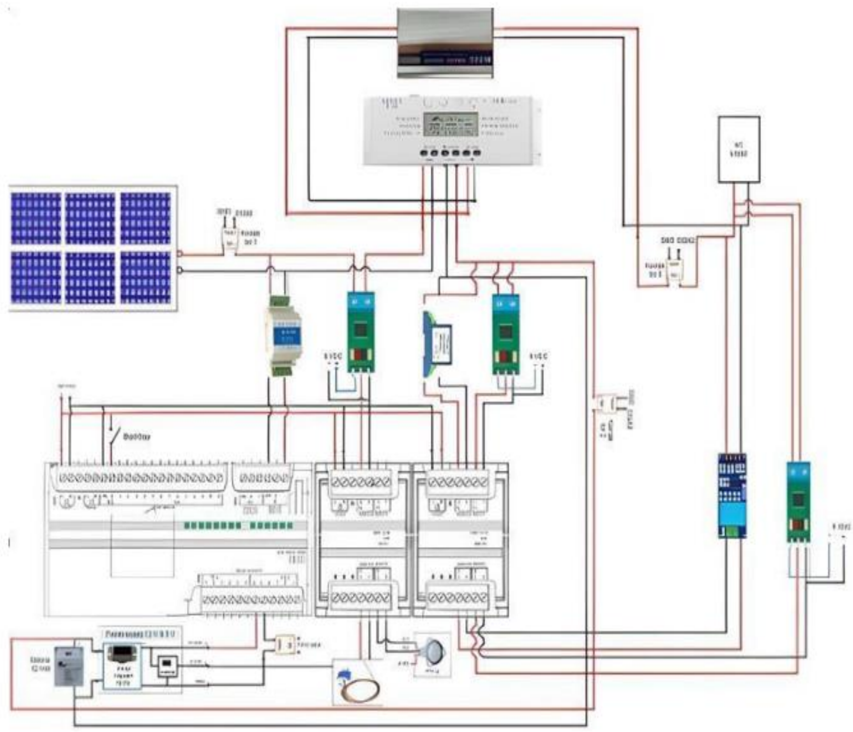


Figure 2. Circuit schematic of proposed SCADA system for solar panel

The working principle of this tool is to monitor, control and collect data from solar power plants controlled from several interfaces such as HMI, PC, and Smartphone. This system uses the Internet of Thing (IoT) concept which is a communication link between hardware and software through a special node red web server. PLC functions as a data processing center, where data will be sent to the HMI and IoT which are used as control and monitoring of stand-alone PLTS. The monitored PLTS parameters include voltage, current, power, temperature, solar panel radiation, voltage and current and State of Charge (SOC) battery, inverter output voltage and current. Data for each parameter is obtained from the sensor. PLTS control includes ON or OFF and protection against overcurrent. To turn ON or OFF solar panels, batteries and AC loads using contactors that can be operated on the HMI screen and PC server. The following is the work of the IoT-based solar power plant SCADA system proposed in this study can be seen in Figure 3 below.

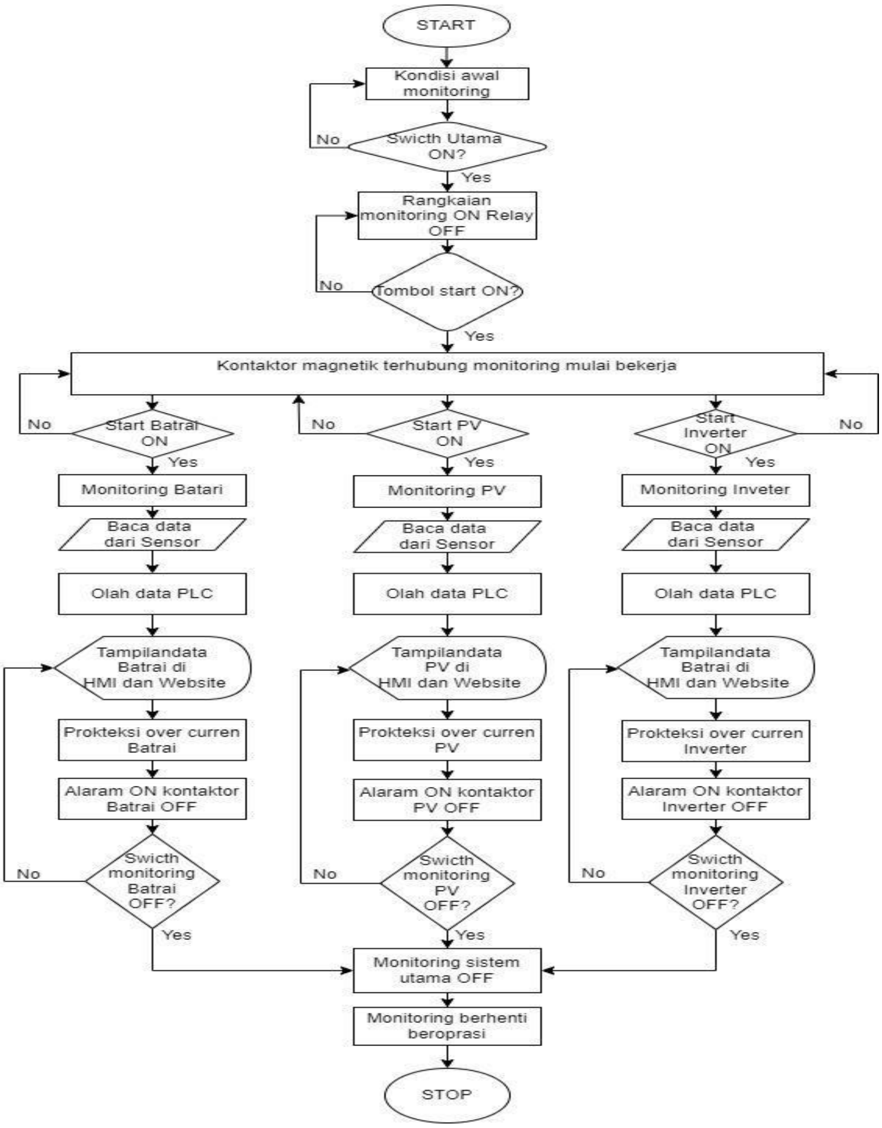


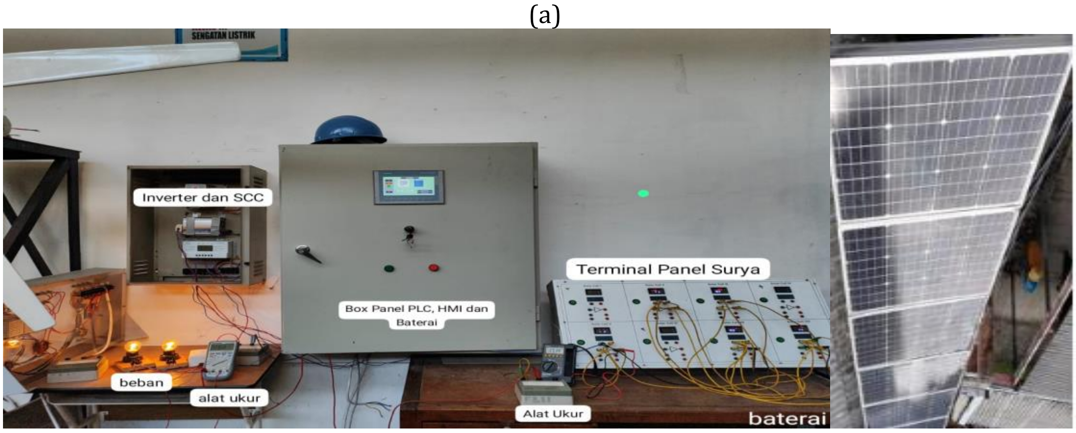
Figure 3. Flowchart of SCADA system for solar panel

Figure 3 shows that this monitoring system will be active when the switch is turned on and the start button on the HMI screen is pressed. After the monitoring system is activated, the battery, inverter, and PV will start operating. At the same time, the monitoring screen will display information about the status of the battery, inverter, and PV. Each component, namely the battery, inverter, and PV, has parameters to be measured and the data will be sent to the PLC for further processing. The PLC will take data from the connected sensors to obtain information about the system condition. This information will be stored and then displayed on the HMI screen and website. Overcurrent protection will be activated, and when the alarm is active, the contactor will be turned off. This results in the monitoring system stopping operation.

3. RESULTS AND DISCUSSION

The SCADA system on the solar power plant based on the internet of things (IoT) was carried out in the electrical engineering energy conversion laboratory of Padang State University. The test was carried out with five units of Polycrystalline 50 WP solar panels. Which are connected in parallel. Equipped with a Solar Charge Controller with a Maximum Power Point Tracking (MPPT) system with a capacity of 30 Ampere. The mechanical design of the hardware circuit in the form of PLC, HMI, power supply, sensors, and batteries is placed in one panel box measuring 0.8 x 0.6 x 0.3 m and the solar charge controller and inverter are arranged in a different panel box measuring 0.3 x 0.4 x 0.2 m, and using a load output of 2 incandescent lamps. For the PC server and PC client are positioned on the laboratory table. The 50 WP polycrystalline solar panel is installed on the roof of the laboratory building. In the study, the PLC and HMI are connected with a profinet LAN cable and programmed with TIA Portal V17. In this test, the data will be displayed on several interfaces such as HMI, PC server, PC client, and Smartphone as in Figure 4

(a)



(b)

Figure 4. Hardware circuit layout (a) monitoring PC server, PC client and smartphone (b) Hardware installation

The TIA portal application is used to design the PLTS control interface. It includes the title, main system indicators, battery control section, inverter, and solar panel (PV). The main system shows whether it is active or not. System activation can be done via the main switch in front of the main panel. There are ON and OFF buttons on the battery, inverter, and photovoltaic sections to activate the battery, inverter, and photovoltaic circuits. To enter the parameter monitor page, select the battery, inverter, and PV buttons. To activate the battery, inverter, and PV circuits, press the ON button on the ON button shown. When the green indicator appears, the battery, inverter, and PV circuits are in the ON condition. Three PLC output terminals are used in the form of contactors. Contactor one is to activate the solar panel circuit, contactor two activates the battery circuit, and contactor three activates the AC load circuit as an automatic off switch when troubleshooting occurs such as overcurrent set on the TIA Portal, as shown in Figure 5.

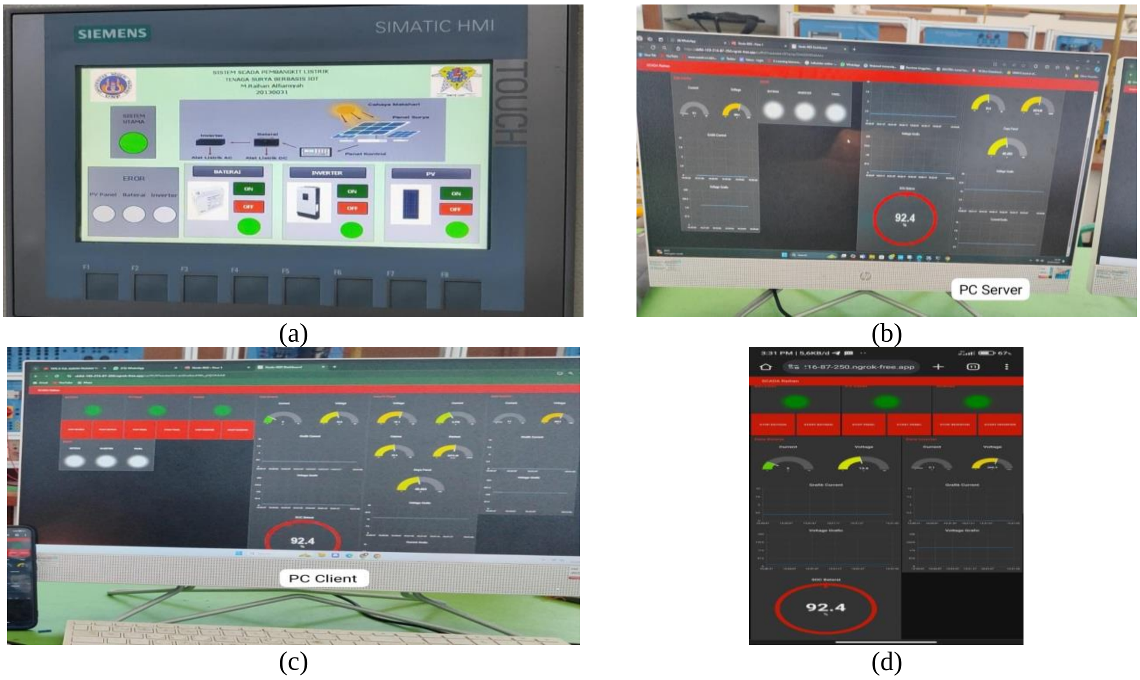


Figure 5. Display of PLTS monitoring and control, (a) HMI display, (b) PC server monitoring, (c) PC client monitoring, (d) Smartphone monitoring

Figure 6 shows the screen used to monitor the battery. When tested, the battery voltage is around 13.7 Volts with an incoming current of 2.6 Ampere. The SOC of the battery is also ± 99%, as shown in Figure 6. In this situation, current flows into the battery from the solar charger. When the battery is in a charging state, This indicates that the solar panel supplies the load and the battery. This can happen because the power required by the solar panel is lower than the power it produces. In addition, the battery is not fully charged..

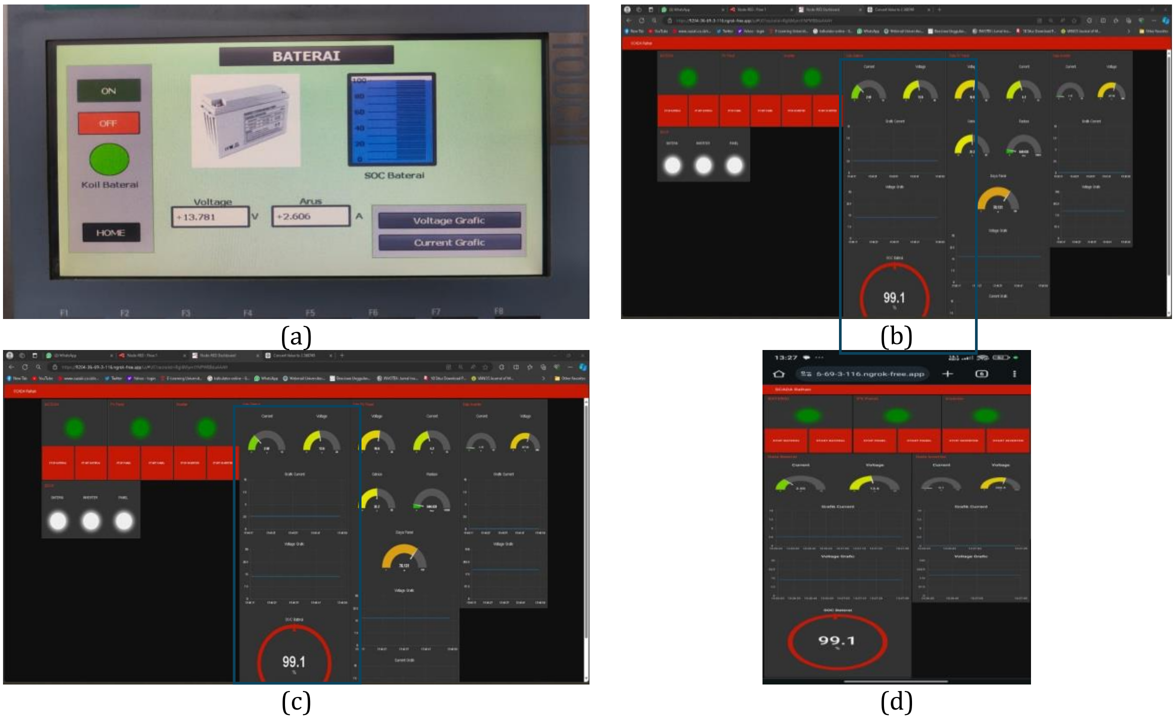


Figure 6. Battery Testing, (a) Battery HMI display, (b) PC server monitoring, (c) PC client monitoring, (d) Smartphone monitoring

Data logging is one of the important parts of the Supervisory Control and Data Acquisition system. In this system, data logging is implemented on the TIA Portal by creating the addresses of the parameters to be recorded and converted into CSV files that will be stored on the PC server. Data storage from data logging can be seen in Table 2.

Table 2. Log data

No	Time	Solar panel			SCC (Battery)			Inverter		
		V	A	W	V	A	W	V	A	W
1	11.30	13.7	3.95	54.4	13.94	3.26	45.4	207	0.16	33.1
2	11.40	14.3	3.79	53.1	13.89	3.10	43.05	205	0.16	32.8
3	11.50	15.2	3.42	51.9	13,90	3.32	46.1	205	0.16	32.8
4	12.00	15.8	3,41	53.7	13.73	3.46	47.5	206	0.16	32.9
5	12.10	15.7	3.45	54.1	13.80	3.28	45.2	206	0.16	32.9
6	12.20	15.2	3.57	54.2	13,66	3.16	42.9	205	0.16	32.8
7	12.30	15.8	2.94	46.5	13,41	3.20	42.8	206	0.16	32.9
8	12.40	16.4	3.32	54.4	13,7	3.01	41.5	206	0.16	32.9
9	12.50	16.4	3.29	53.9	13.8	3.12	43.05	206	0.16	32.9

The data obtained in table 2. On the solar panel, the lowest voltage of the solar panel is 13.7 Volts and the highest voltage is 16.4 Volts, with an average voltage produced by the solar panel of 15.38 Volts. The amount of current produced by the solar panel ranges from 2.94 A to 3.95 A. The data in table 2 shows the highest SCC output voltage for battery charging is 13.94 Volts, the lowest is 13.41 Volts and the SCC output current ranges from 3.01A to 3.46 Ampere with an average current used to charge the battery capacity is 3.21 Ampere. The highest inverter voltage output data is 207 Volts while the lowest voltage is 205 V. The inverter output current is also stable at 0.16 Ampere. can be seen in figure 10 Voltage graph from Solar Panel, Inverter, and battery and figure 7 Current graph from Solar Panel, Inverter, and battery.

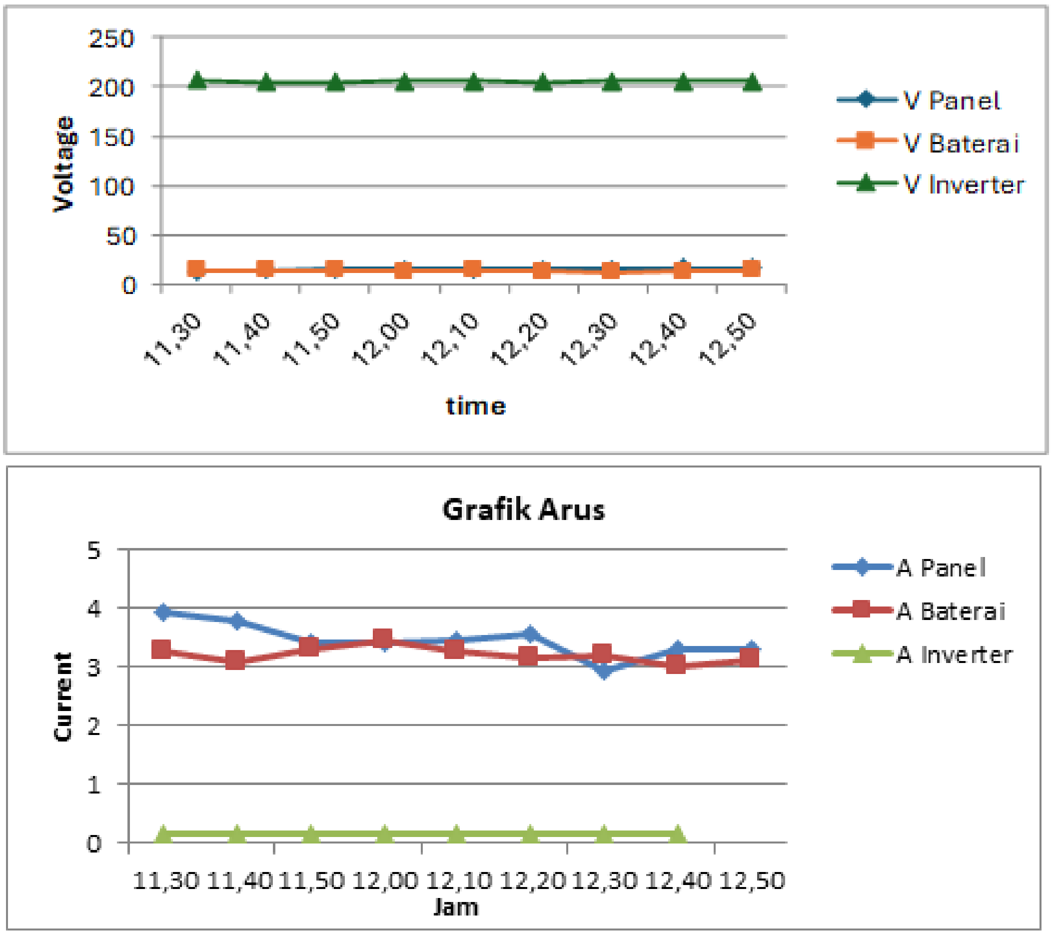


Figure 7. Current and voltage graph

Based on 7, the measurement of the output voltage and current from the solar panel, SCC (battery), and inverter, it was found that the power generated by the solar panel ranged from 46.5 W to 54.4 W, with an average of 54.5 W generated by the solar panel. The power obtained from the output of the solar charger controller for the battery ranged from 41.5 W to 47.5 Watts with an average power generated by the battery of 44.1 Watts. And the power generated by the inverter ranged from 32.8 W to 33.1 Watts with an average power generated by the inverter of 32.88 Watts. The effect of light intensity and temperature on the current, voltage and output power of the solar changer controller which is for battery charging and the effect. The effect of sunlight intensity and temperature on the current, voltage and output power of the solar panel. Data on light intensity, temperature and output of the MPPT Solar charger controller are presented in Table 3. The surface temperature of the solar panel was also tested against the current, voltage and output power of the solar panel. The PYR20 pyranometer sensor is used to collect data on sunlight intensity, and the k-type thermocouple is used to collect data on solar panel temperature. Table 3 also describes the calculation of how long the battery is charged.

Table 3. Effect of sunlight intensity, temperature and battery charging time

No	Irradiation (W/m^2)	Temperature (^{0}c)	Battery charging (h)	*Solar panel*			*Battery*		
				V	A	W	V	A	*W*
1	606	34	3.68	13.7	3.95	54.4	13.94	3.26	45.4
2	640	35	3.87	14.3	3.79	53.1	13.89	3.10	43.05
3	655	34	3.61	15.2	3.42	51.9	13,90	3.32	46.1
4	663	35	3.46	15.8	3,41	53.7	13.73	3.46	47.5
5	660	35	3.65	15.7	3.45	54.1	13.80	3.28	45.2
6	631	34	3.79	15.2	3.57	54.2	13,66	3.16	42.9
7	627	34	3.75	15.8	2.94	46.5	13,41	3.20	42.8
8	620	34	3.98	16.4	3.32	54.4	13,7	3.01	41.5
9	612	34	3.84	16.4	3.29	53.9	13.8	3.12	43.05

Based on Table 3, it can be concluded that the output of solar panels and SCC can be affected by the intensity of light and temperature entering the solar panel, although it does not have a significant impact. It can be seen in the 4th test showing the highest sunlight intensity value in the test of 663 W/m2 and a temperature of 35 0c which produces a solar panel voltage of 15.8V, while the 9th test shows the sunlight intensity value of 612 W/m2 which is the second lowest intensity in the test and the surface temperature of the solar panel is 340c which produces a solar panel output voltage of 16.4 Volts. In the first test, which is the lowest light intensity in the test of 606 W/m2, and a temperature of 340c produces a voltage of 13.7. It can be concluded that the level of solar radiation intensity does not always affect the output of solar panels. This is in line with what was studied by saying that sunlight intensity is not always the main reason for the increase or decrease in the output voltage of solar panels. Figure 8 shows a comparison of solar panel power with battery power.

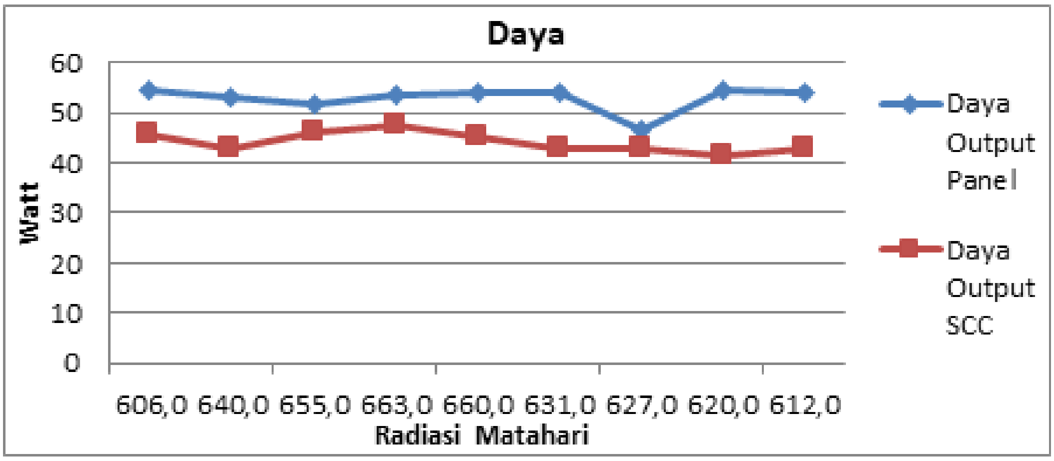


Figure 8. Graph of solar panel output power and SCC output power.

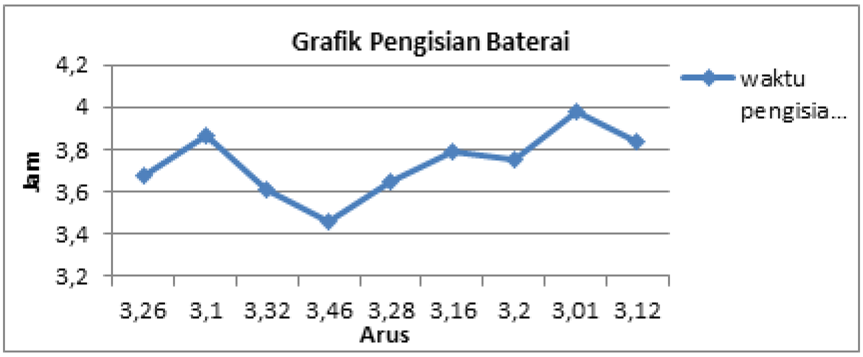


Figure 9. Battery charging time

Figure 9 shows the battery capacity charging time using a 30 Ampere MPPT solar charger controller with a battery capacity of 12Ah. The battery capacity charging time of 12 Ah with an average battery charging time of 3 hours 43 minutes, this can be obtained after collecting data from several tests.

4. CONCLUSION

This study develops a SCADA system on a solar power plant based on the internet of things. Where the implementation of the internet of things uses Node Red and Ngrok software as a liaison between the Node Red localhost and the external network. So the internet of things in this test can be controlled and monitored remotely with the note that it must always be connected to the internet, because when the system interface dies or restarts, Ngrok must be re-run to access it remotely. And this is a weakness of the Ngrok software. The monitoring, control and data access systems work well, HMI and IoT have successfully monitored, controlled and collected from the PLTS. In the development of this system, the Siemens S7-1200 PLC is used as the main controller, with 5 units of 50 WP polycrystalline solar panels. Equipped with SCC MPPT, 500 Watt 1-phase inverter and one 12 V 12 Ah battery. For the output of the power that has been produced using an AC load in the form of 2 incandescent lamps. In data logging, data is stored in Integer format, where the results of sensor readings are rounded to non-decimal numbers.

REFERENCES

[1] F. Azizah and M. Yuhendri, “Solar Panel Monitoring and Control System Using Human Machine Interface,” *Andalasian International Journal of Applied Science, Engineering and Technology*, vol. 2, no. 03, pp. 149–158, 2022, doi: 10.25077/aijaset.v2i03.64.

[2] A. Khadra and R. Rammal, "SCADA System for Solar Backup Power System Automation," *2022 International Conference on Smart Systems and Power Management (IC2SPM)*, Beirut, Lebanon, 2022, pp. 75-79, doi: 10.1109/IC2SPM56638.2022.9988760.

[3] L. O. Aghenta and M. T. Iqbal, "Development of an IoT Based Open Source SCADA System for PV System Monitoring," *2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*, Edmonton, AB, Canada, 2019, pp. 1-4, doi: 10.1109/CCECE.2019.8861827

[4] H. Singh and N. Kumar, "PLC and SCADA based electricity supply switching with integration of Solar Cells," *2022 IEEE Delhi Section Conference (DELCON)*, New Delhi, India, 2022, pp. 1-6, doi: 10.1109/DELCON54057.2022.9753014.

[5] H. Masrepol and M. Yuhendri, “Implementasi MPPT Panel Surya Berbasis Algoritma Perturbasi & Observasi (PO) Menggunakan Arduino,” *JTEIN: Jurnal Teknik Elektro Indonesia*, vol. 2, no. 2, pp. 162–167, 2021, doi: 10.24036/jtein.v2i2.155.

[6] V. Voicu, D. Petreus, E. Cebuc and R. Etz, "Industrial IoT (IIOT) Architecture for Remote Solar Plant Monitoring," *2022 21st RoEduNet Conference: Networking in Education and Research (RoEduNet)*, Sovata, Romania, 2022, pp. 1-4, doi: 10.1109/RoEduNet57163.2022.9921045.

[7] M. Kermani, S. Abbasi, E. Shirdare and L. Martirano, "Real-Time PLC-Based Control for Microgrid Operations Using SCADA System," *2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, Madrid, Spain, 2023, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope57605.2023.10194668.

[8] E. Mustafa, M. Yuhendri, J. Sardi, and D. T. Yanto, “Kendali dan Monitoring Pembangkit Listrik Tenaga Surya Stand Alone Berbasis Human Machine Interface,” *JTEIN: Jurnal Teknik Elektro Indonesia*, vol. 4, no. 1, pp. 179–189, 2023.

[9] I. C. Hoarcă, "Energy management for a photovoltaic power plant based on SCADA system," *2021 13th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, Pitesti, Romania, 2021, pp. 1-9, doi: 10.1109/ECAI52376.2021.9515136.

[10] A. Dong, Y. Zhao, X. Liu, L. Shang, Q. Liu and D. Kang, "Fault Diagnosis and Classification in Photovoltaic Systems Using SCADA Data," *2017 International Conference on Sensing, Diagnostics, Prognostics, and Control (SDPC)*, Shanghai, China, 2017, pp. 117-122, doi: 10.1109/SDPC.2017.31.

[11] S. Samara and E. Natsheh, "Intelligent Real-Time Photovoltaic Panel Monitoring System Using Artificial Neural Networks," *IEEE Access*, vol. 7, pp. 50287-50299, 2019, doi: 10.1109/ACCESS.2019.2911250.

[12] F. J. Sánchez-Pacheco, P. J. Sotorrío-Ruiz, J. R. Heredia-Larrubia, F. Pérez-Hidalgo and M. S. de Cardona, "PLC-Based PV Plants Smart Monitoring System: Field Measurements and Uncertainty Estimation," *IEEE Transactions on Instrumentation and*

Measurement, vol. 63, no. 9, pp. 2215-2222, Sept. 2014, doi: 10.1109/TIM.2014.2308972.
[13] M. Yuhendri and G. S. Putra, “Implementasi Sistem Kendali MPPT Panel Surya Berbasis Algoritma Incremental Conductance,” *JTEIN: Jurnal Teknik Elektro Indonesia*, vol. 1, no. 2, pp. 218–223, 2020, doi: 10.24036/jtein.v1i2.72.
[14] A. Nirmal, A. K. K. Kyaw, W. Jianxiong, K. Dev, X. Sun and H. V. Demir, "Light Trapping in Inverted Organic Photovoltaics With Nanoimprinted ZnO Photonic Crystals," *IEEE Journal of Photovoltaics*, vol. 7, no. 2, pp. 545-549, March 2017, doi: 10.1109/JPHOTOV.2017.2650560.
[15] M. Ma, Z. Zhang, P. Yun, Z. Xie, H. Wang and W. Ma, "Photovoltaic Module Current Mismatch Fault Diagnosis Based on I-V Data," *IEEE Journal of Photovoltaics*, vol. 11, no. 3, pp. 779-788, May 2021, doi: 10.1109/JPHOTOV.2021.3059425.
[16] F. Hanifah and M. Yuhendri, “Kontrol dan Monitoring Kecepatan Motor Induksi Berbasis Internet of Things,” *JTEIN: Jurnal Teknik Elektro Indonesia*, vol. 4, no. 2, pp. 519–528, 2023.
[17] E. Lázár, R. Etz, D. Petreuş, T. Pătărău and I. Ciocan, "SCADA development for an islanded microgrid," *2015 IEEE 21st International Symposium for Design and Technology in Electronic Packaging (SIITME)*, Brasov, Romania, 2015, pp. 147-150, doi: 10.1109/SIITME.2015.7342314.
[18] I. Ahmed and F. Ahmed, "Priority Based Hybrid Renewable Energy Monitoring and Management System with SCADA Autonomous Operation Based on Demand Response," *2022 12th International Conference on Electrical and Computer Engineering (ICECE)*, Dhaka, Bangladesh, 2022, pp. 409-412, doi: 10.1109/ICECE57408.
[19] M. H. Ridwan, M. Yuhendri, and J. Sardi, “Sistem Kendali Dan Monitoring Pompa Air Otomatis Berbasis Human Machine Interface,” *JTEIN: Jurnal Teknik Elektro Indonesia*, vol. 4, no. 2, pp. 592–600, 2023
[20] C. A. Osaretin, M. Zamanlou, M. T. Iqbal and S. Butt, "Open Source IoT-Based SCADA System for Remote Oil Facilities Using Node-RED and Arduino Microcontrollers," *2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, Vancouver, BC, Canada, 2020, pp. 0571-0575, doi: 10.1109/IEMCON51383.2020 .9284826. .
[21] C. Ndukwe, M. T. Iqbal and J. Khan, "Development of a Low-cost LoRa based SCADA system for Monitoring and Supervisory Control of Small Renewable Energy Generation Systems," *2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, Vancouver, BC, Canada, 2020, pp. 0479-0484, doi: 10.1109/IEMCON51383.2020.9284933.
[22] M. Alfa Z Fikri *et al.*, “Sistem SCADA pada miniatur Smart Home Bertenaga Surya,” *J. FORTECH*, vol. 3, no. 2, pp. 93–100, 2023, doi: 10.56795/fortech.v3i2.106.
[23] R. Parlika, H. Khariono, H. Ananta Kusuma, M. Risalul Abrori, and M. Ainur Rofik, “Implementasi Akses Mysql dan Web Server Lokal Melalui Jaringan Internet Menggunakan Ngrok,” *JIKO (Jurnal Inform. dan Komputer)*, vol. 3, no. 3, pp. 131–136, 2020, doi: 10.33387/jiko.v3i3.1799.
[24] A. Lindo and M. Yuhendri, “Sistem Kendali Daya Maksimum Panel Surya Berbasis Fuzzy Logic Controller,” *JTEIN J. Tek. Elektro Indones.*, vol. 3, no. 1, pp. 102–110, 2022, doi: 10.24036/jtein.v3i1.207.
[25] M. Suyanto, S. Priyambodo, P. E.P, and A. Purnama Aji, “Optimalisasi Pengisian Accu Pada Sistem Pembangkit Listrik Tenaga Surya (PLTS) Dengan Solar Charge Controller (MPPT),” *J. Teknol.*, vol. 15, no. 1, pp. 22–29, 2022, doi: 10.34151/jurtek.v15i1.3929.
[26] M. Etezadinejad, B. Asaei, S. Farhangi and A. Anvari-Moghaddam, "An Improved and Fast MPPT Algorithm for PV Systems Under Partially Shaded Conditions," *IEEE Transactions on Sustainable Energy*, vol. 13, no. 2, pp. 732-742, April 2022, doi: 10.1109/TSTE.2021.3130827.
[27] S. Xu, R. Shao, B. Cao and L. Chang, "Single-phase grid-connected PV system with golden section search-based MPPT algorithm," *Chinese Journal of Electrical Engineering*, vol. 7, no. 4, pp. 25-36, Dec. 2021, doi: 10.23919/CJEE.2021.000035.
[28] R. Mayangsari and M. Yuhendri, “Sistem Kontrol dan Monitoring Pembangkit Listrik Tenaga Surya Berbasis Human Machine Interface dan Internet of Thing,” *JTEIN J. Tek. Elektro Indones.*, vol. 4, no. 2, pp. 738-749–738 – 749, 2023.
[29] R. Dubey *et al.*, "Measurement of temperature coefficient of photovoltaic modules in field and comparison with laboratory measurements," *2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC)*, New Orleans, LA, USA, 2015, pp. 1-5, doi: 10.1109/PVSC.2015.7355852.
[30] Y. Hishikawa *et al.*, "Voltage-Dependent Temperature Coefficient of the I–V Curves of Crystalline Silicon Photovoltaic Modules," *IEEE Journal of Photovoltaics*, vol. 8, no. 1, pp. 48-53, Jan. 2018, doi: 10.1109/JPHOTOV.2017.2766529.
[31] S. Priyadarshi, S. Bhaduri and N. Shiradkar, "IoT Based, Inexpensive System for Large Scale, Wireless, Remote Temperature Monitoring of Photovoltaic Modules," *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, Waikoloa, HI, USA, 2018, pp. 0749-0752, doi: 10.1109/PVSC.2018.8547354.
[32] M. Libra, T. Petrík, V. Poulek, I. I. Tyukhov and P. Kouřím, "Changes in the Efficiency of Photovoltaic Energy Conversion in Temperature Range With Extreme Limits," *IEEE Journal of Photovoltaics*, vol. 11, no. 6, pp. 1479-1484, Nov. 2021, doi: 10.1109/JPHOTOV.2021.3108484.
[33] F. Rahmaniah, W. Zhang and S. E. R. Tay, "State Space Transient Model for Photovoltaic Module Temperature Estimation," *2020 47th IEEE Photovoltaic Specialists Conference (PVSC)*, Calgary, AB, Canada, 2020, pp. 2505-2508, doi: 10.1109/PVSC45281.2020.9300581.
[34] Z. Zhen, X. Taoyun, S. Yanping, L. Wang, P. Jia and J. Yu, "A Method to Test Operating Cell Temperature for BIPV Modules," *IEEE Journal of Photovoltaics*, vol. 6, no. 1, pp. 272-277, Jan. 2016, doi: 10.1109/JPHOTOV.2015.2501719.