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IoT-Based Monitoring of a Dual-Axis Solar Tracking System

Abstract. This paper describes the comprehensive design, execution, and observation of a dual-axis solar tracking system. Solar tracking systems are essential for optimizing incident solar radiation and increasing the efficiency of photovoltaic (PV) systems. The purpose is to develop a dual-axis solar tracker real-time monitoring and data acquisition system. Data collected from sensors is sent to a web page for system supervision, real-time data display, and remote control. A SCADA system using OPC technology and a specific software is used for system monitoring.

*Streszczenie.. W artykule opisano kompleksowy projekt, wykonanie i obserwację dwuosiowego systemu śledzenia Słońca. Systemy śledzenia energii słonecznej są niezbędne do optymalizacji padającego promieniowania słonecznego i zwiększenia wydajności systemów fotowoltaicznych (PV). Celem jest opracowanie dwuosiowego trackera słonecznego, systemu monitorowania i gromadzenia danych w czasie rzeczywistym. Dane zebrane z czujników są przesyłane na stronę internetową w celu nadzoru systemu, wyświetlania danych w czasie rzeczywistym i zdalnego sterowania. Do monitorowania systemu wykorzystywany jest system SCADA wykorzystujący technologię OPC oraz specjalistyczne oprogramowanie. (**Monitorowanie oparte na IoT dwuosiowego systemu śledzenia energii słonecznej**)*

Keywords: Solar tracker, Monitoring, SCADA, GSM, OPC server.
Słowa kluczowe: Śledzenie słońca, Monitoring, SCADA, GSM, OPC serwer.

Introduction

Interest in solar power technologies is rising as a result of the growing need for sustainable energy sources. Particularly, photovoltaic systems have emerged as a major source of renewable energy. Effective solar tracking mechanisms are necessary to optimize the energy output of these systems. The design and monitoring of a dual-axis solar tracking system are the main topics of this paper, which addresses the need for greater accuracy and flexibility in response to shifting environmental conditions.

Research organizations worldwide are focusing on improving PV conversion equipment using computer technology for security and system surveillance. GSM is the most widely used standard for mobile communication, with billions of subscribers. A data acquisition system based on GSM technology, connected to a PLC, and applied to a solar tracker, will boost power generation using clean and renewable energy sources. This system will function as a SCADA system, monitoring the proper functioning of a system or activity. SCADA is used in industries like energy, electricity, telecommunications, and oil and gas refining. Developing a SCADA system, integrating the tracking system with a PLC, and connecting it to a website we designed are the goals of this project. The purpose of this webpage is to compile tracking system data so that the system's performance can be evaluated in real time. With additional improvements achieved by integrating IoT functionalities, the use of GSM technology is intended to implement a telemetry device for remote monitoring and control of the system.

The creation and evaluation of a dual-axis solar tracking system are the main goals of this research project. The focus is on developing a system that places accuracy and dependability in the alignment of solar panels first. The solar panel placements will be able to be changed in real time thanks to the implementation of sophisticated control algorithms. Furthermore, a thorough monitoring system will be developed to methodically assess the tracking system's performance in various environmental settings. The goal of the research is to provide a comprehensive analysis with an emphasis on important parameters including energy yield, tracking accuracy, and overall system reliability. By tackling these goals, the study hopes to provide insightful information about how to optimize dual-axis solar tracking technology for increased efficacy and efficiency.

Literature Survey

In [1], an Arduino-based dual-axis solar tracker with an Internet of Things monitoring system, utilizing light-dependent resistors, servo motors, and a WIFI ESP8266 chip to enhance solar panel efficiency.

In [2], a microcontroller, four light-based resistors (LDRs), and three stepper motors are used in an Arduino prototype-based automated sun tracking system to track the sun. Firmware programming and hardware are used in the operation of the system. The software controls the panel's tilt angle and horizontal rotation, enabling it to track the direction and vertical movement of the Sun.

The article [3] details the design and implementation of a heliostat control system that utilizes an integrated fuzzy logic controller on a low-cost microcontroller for orientation control, and is based on a SCADA system with a standalone remote terminal unit. An overview of active sun tracking systems for PV modules is given in the paper [4].

The paper [5] proposes designing an automatic tracking control algorithm using Zelio Soft 5.4.0 and a supervision algorithm using SCADA software on Vijeo Citect and Android platforms with Tesla SCADA 2, using PLC Zelio for Supervisory Control and Data Acquisition of a biaxial photovoltaic tracker.

The paper [6] describes the creation of an affordable online wireless monitoring system for two linear Fresnel reflector (LFR) solar facilities spread across two nations. Fault Detection in PV Tracking Systems Using an Image Processing Algorithm Based on PCA is a study published in [7].

The article [8] suggests utilizing a fuzzy controller to manage the directional wheel conveyor's location in order to track the set point angle. The wheel slip output was calculated using a programmable logic controller (PLC) and a camera image sensor to change the object's transfer direction.

Methodology

A solar tracker is the ideal tool for tracking the sun's direction from east to west during the day. Solar trackers are often divided into two types: single-axis trackers and dual-axis trackers. The sun moves from east to west on a defined solar path every day along a specific line of longitude. However, the sun passes across degrees north and south throughout the seasonal revision. The primary

function of all tracking systems is to offer one or two degrees of free movement. This movement is used to maintain the system in the right position for irradiation.

There are several alternatives available to meet the functional requirements. Different solar power systems require various solutions with varied precision; therefore, defining a general guideline for what sort of tracking system works best is challenging. The elevation angle takes into account the height at which the sun may be seen in the sky.

The dual-axis solar tracking system's mechanical design includes choosing the right actuators, gears, and supports. The mechanical parts that were selected and how they were arranged to guarantee accurate movement along the azimuth and elevation axes are described in depth in this section.

The structure consists of a U-shaped surface holder and a second servo motor for rotating the tracker. The surface will hold solar cells and four LDR sensors. The ESP32SIM800L microcontroller is the main component, converting analog measurements from LDR sensors into digitals. The top servo motor rotates the tracker, while the bottom motor moves it left to right. The LDR sensors detect sunlight and send signals to the ESP32SIM800L via Bluetooth or Wi-Fi to monitor the system.

The servo motors spin in the direction of the sun. A converter adjusts the DC voltage to achieve the maximum output of the system. The tracking panel's operation relies on the program loaded in the ESP32 microcontroller. The tracker's voltage and current were used to measure the voltage and current sensors. The AM2301 sensor was also utilized to keep the weather conditions updated.
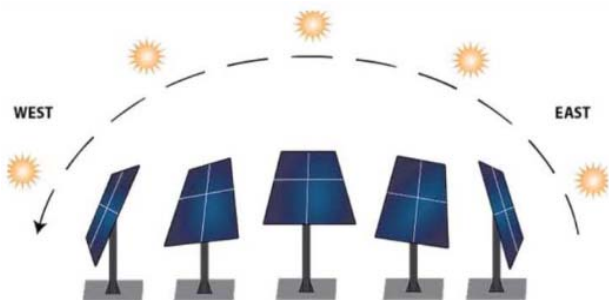

Figure.1. Solar tracking system model.

Materials and methods

The data acquisition system plays an important role in any monitoring system and is used to collect data from different sensors of a solar panel system. Then this data is digitized for storage and data sends data to control center for processing and presentation. In this paper, we will go through the project execution techniques as well as the prototype creation procedure, and finally, we will be including a block diagram of its internal processes and a schematic representation of the whole design.

Solar tracker prototype making:

Our solar tracking system rotates the solar cells to collect as much solar energy as possible while tracking the sun's position on two axes: vertical and horizontal. As a result, rotational solar trackers are preferable to fixed ones due to better system outcomes and higher power generation; these trackers exhibit the connections between the Esp32sim800l board and the system's sensors. Here are the main components of the prototype.

The hardware equipments are:
- Polycrystalline solar cell.
- ESP32SIM800L (GSM module integrated).
- Current Sensor ACS712.
- Voltage Sensor Module (B25).
- AM2301 sensor.
- LDR.
- MG90S Servo.
- Display.
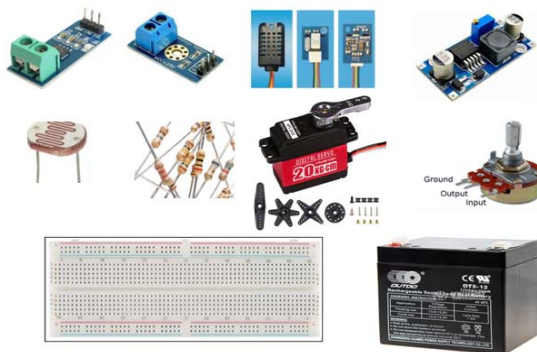- Potentiometer.
- Resistor.
- Converter.
- Breadboard.

Figure.2. The hardware equipments for Solar tracking system.

Web or IoT based systems

It is the fourth generation of SCADA systems, which encompasses distributed cognitive computing, CPS, IoT, and cloud computing. IoT differs in terms of interoperability, scalability, and big data analytics capability. A fourth generation SCADA system, such as Industry 4.0, includes distributed cognitive computing, CPS, IoT, and cloud computing. The Internet of Things (IoT) is a network of devices that focuses on the transfer, control, and analysis of huge insights of data.
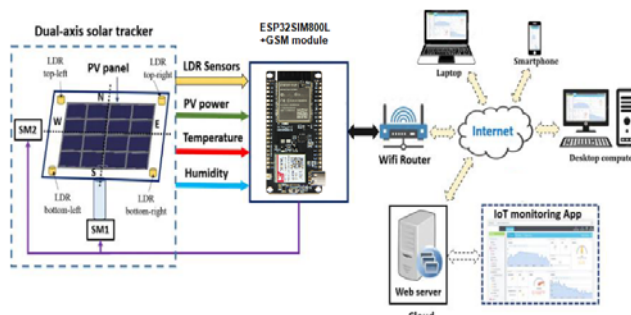

Figure.3. Monitoring of Solar tracking system principle.

OPC server

OPC (Open Platform Communications) is named as an open process control protocol. It is an interoperability standard for the reliable and secure exchange of data in industrial automation and other industries. Today, OPC has gained great importance in the field of industrial automation. It has become the service of choice in a process control environment.

OPC server can perform functions such as saving data to a database or providing a link to the PLC and SCADA system. This proposed method can realize advanced data processing and control in the industrial field, to improve the quality of the control.

ESP32SIM800L

The ESP32 is a versatile microcontroller that integrates Wi-Fi and Bluetooth connectivity. It is widely used in IoT (Internet of Things) projects due to its capabilities, low power consumption, and support for various communication protocols.

Figure.4. ESP32SIM800L.

ESP32 can be programmed using the Arduino IDE, making it accessible for a broad range of developers. The SIM800L is a GSM/GPRS module designed for mobile communication. It allows devices to communicate over the GSM network, enabling functions such as sending SMS, making calls, and connecting to the internet in areas with GSM coverage.

The module includes features like a built-in TCP/IP stack, making it suitable for IoT applications where cellular connectivity is required. The combination of ESP32 and SIM800L refers to a hardware setup utilizing the ESP32 microcontroller and the SIM800L module for GSM (Global System for Mobile Communications) communication.

Software equipments

Arduino IDE software

IDE is an official Arduino.cc program that is used to edit, compile, and upload the code to the Arduino device. All Arduino modules are mostly compatible with this software, which is available to install and compile the code easily.

Figure.5. Arduino IDE software.

Let us explain the code step by step:

Rotary system :

This software manages a dual-axis solar tracking system powered by an esp32 microcontroller, LDR, and servo motors. It includes the Servo library for controlling servo motors. Vertical and horizontal servo objects are created, with "ServohLimitHigh" and "ServovLimitLow" determining their limits. LDR pins are assigned variables. The setup function connects servo objects to their proper pins when the Arduino board is switched on or reset. The loop function runs after the setup function, controlling the solar tracker.

Current servo positions are read, LDR sensor analog data is received, and average readings are created. The solar tracker adjusts servo positions based on light intensity observations. If the average top reading is less than the average bottom reading, the vertical servo moves higher, rotating the solar panel. If the average bottom reading is less than the average top reading, the vertical servo decreases, and the solar panel moves downward. If the average left reading is larger than the average right reading, the horizontal servo moves one revolution to the left. The servo's speed is modified by a 50-millisecond delay before the loop repeats, ensuring the solar panel is rotated to face the direction with maximum light intensity, increasing solar energy absorption.

Voltage measurement

The code measures DC voltage using an analog input pin on an esp32 microcontroller. It starts with the Setup() function, changes the volt pin mode to INPUT, and sends a message to the serial monitor. The loop() function reads the analog value from the volt pin, calculates the input voltage, and prints it to the serial monitor. This ensures the solar panel faces the maximum light intensity, increasing solar energy absorption.

Current measurement

This code uses an ACS712 current sensor and an analog input pin on the ESP32 board to calculate current values. The loop function converts the analog input value to a voltage range of 0 to 3.3 V, determining current based on the sensor's sensitivity. The data is displayed on a serial monitor, with a 1000 millisecond pause before the next loop cycle.

Temperature measuring

The DHT sensor initialization code includes library, pin and sensor initialization, setup, and loop functions. It initiates serial communication at 9600 baud rate and receives temperature and humidity information from the sensor. The loop adds a 2-second delay for real-time monitoring of environmental conditions.

Data acquisition system

Web page

This code consists of two sections: an HTML page with styles, tables, and JavaScript code for creating charts using the "Highcharts" library. The HTML structure includes a table with sensor measurements, and the JavaScript code generates charts for temperature, humidity, power, voltage, and current. The 'toggleDataLogging' method handles data logging, and the 'logData' function collects sensor values from the database. The 'downloadData' method creates a CSV file containing the recorded data. The charts are updated regularly using the 'setInterval' function. The second part includes an ESP32-based web server that connects to the web page and executes actions based on user inputs.

The setup function initiates serial communication, assigns pin modes to fan, LED, and other pins, sets up LED PWM feature, activates DHT sensor, and launches server. The 'loop' function reads sensor data, handles web page actions, updates fan speed, and handles button pushes. The code also sends the main web page and XML data, containing sensor readings and other information.
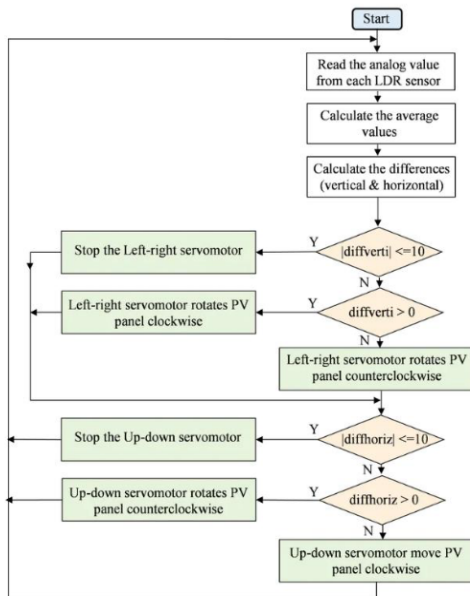The flowchart of operation is shown Below:

Figure .6.The operation flowchart.

To summarize, the code configures an ESP32-based web server to deliver a web page and manage user interactions. It receives sensor data, regulates fan speed, switches LEDs and output pins, and sends XML data to a web page for display and processing. Results are displayed in the following figures:

	DATE	TEMPERATURE	HUMIDITY		PUISSANCE	VOLTAGE	CURRENT
1							
2	2023-06-17T21:-	27.9	28.7		21.18	12.4	1.6
3	2023-06-17T21:-	27.9	28.7		24.82	12.5	1.9
4	2023-06-17T21:-	27.9	28.7	23.01		12.5	1.8
5	2023-06-17T21:-	27.8	28.7		21.96	12.5	1.7
6	2023-06-17T21:-	27.8	28.7		22.18	12.5	1.7
7	2023-06-17T21:-	27.7	28.6		24.45	12.5	1.9
8	2023-06-17T21:-	27.7	28.6		21.97	12.5	1.7
9	2023-06-17T21:!	27.6	28.6		21.84	12.5	1.7
10	2023-06-17T21:!	27.6	28.6		26.31	12.5	2.1
11	2023-06-17T21:!	27.5	28.6		21.66	12.5	1.7
12	2023-06-17T21:!	27.5	28.5		22.18	12.5	1.7
13	2023-06-17T21:!	27.5	28.5		21.96	12.5	1.7
14	2023-06-17T21:!	27.5	28.6	22.3		12.5	1.7
15	2023-06-17T21:!	27.4	28.5		22.52	12.5	1.7
16	2023-06-17T21:!	28.4	88.9		43.44	12.8	3.3

Figure .7. Web page data log

Figure . 8. Results graphic view

SCADA system :

TIA PORTAL software:
SIMATIC STEP 7 is a comprehensive engineering tool for configuring and programming SIMATIC controllers, including PLC and PC-based models. It offers transparency, intelligent navigation, and simple workflows, making it suitable for designing SIMATIC S7-1200 and SIMATIC HMI Basic Panels, regardless of user experience.

Figure. 9. TIA PORTAL V13.

SIMATIC STEP 7 is a widely used industrial automation programming software that configures SIMATIC S7-1200, S7-1500, S7-300/400, and WinAC controller families. It has two variants: Basic S7-1200 Configuration and STEP 7 Professional for S7-1200, S7-1500, and S7-300/400 configuring, and WinAC TIA Portal 13 SP1 version Basic for network configuration. The software combines two separate applications, reducing configuration time and offering benefits like direct online diagnostics and easy technology object creation.

Principal screen (Home page)
The principal screen, also known as the home page, is the main interface of the SCADA system, offering a comprehensive overview of the system, key information, alerts, and notifications. It allows users to configure and alter the settings of their connected devices or components, print reports, logs, and other essential SCADA system information, and view trends over time. The report section allows users to build detailed reports based on collected data, providing insights, statistics, and summaries of the system's performance.

The log-on area provides a safe identification mechanism for accessing the system, typically requiring a user name and password or additional credentials. The exit area allows users to safely exit the system, ensuring proper management of unsaved data or configurations. The shutdown department is responsible for shutting down the system, often used for maintenance or switching off the entire system.

Figure.10. Principal screen (Home page).

Measurements screen
The measures screen is a part of the SCADA system that displays real-time measurements and data from connected devices or sensors. It provides an overview of the system's current state and includes sensor readings, alarms and alerts, status indications, and graphical representations. Sensor readings include temperature, pressure, flow rate, voltage, and other system-specific characteristics.

Alarms and alerts highlight abnormal or critical situations, aiding in quick response. Status indications show the system's health or performance, including devices in standby mode or experiencing troubleshooting. Graphical representations help track trends, compare results, and identify errors.
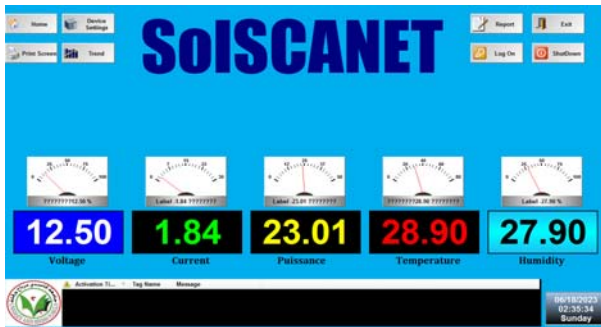

Figure.11. Measures screen.

The design process for a SCADA system using TIA Portal involves identifying the system's requirements, selecting the appropriate SCADA software, and connecting it to the PLC using OPC as a configurable communication protocol. The main screen of the SCADA system is constructed using the chosen software, with essential parts like Home, Device Setting, Print, Trend, Report, Log On, Exit, and Shutdown. Sensor readings, warnings, system measurements, and graphical representations are included for easy access to real-time data.

Data acquisition is configured using the SCADA software, with variables to be monitored, data types, and polling rates. Device parameter configuration options are added, and reports are created under the Print section. Finally, the system is tested by connecting it to the PLC.

Results and Discussion

A photovoltaic cell is used to collect solar energy in our established dual-axis solar tracking system. The tracker watches the sun and changes its position as needed before sending the data to a specially created web page. This system will be linked to a PLC using GSM technology. In this paper, we provided a summary description of our project, a broad overview of solar energy, solar tracking PV systems, and GSM technology, and a focus on the hardware and software.

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REFERENCES
[1]. Said, M. N. A. M., Siti Amely Jumaat, and Clarence Rimong Anak Jawa. "Dual axis solar tracker with IoT monitoring system using arduino." Int. J. Power Electron. Drive Syst 11.1 (2020): 451-458.
[2]. Mohanapriya, V., et al. "Implementation of dual axis solar tracking system." IOP Conference Series: Materials Science and Engineering. Vol. 1084. No. 1. IOP Publishing, 2021.
[3]. Salgado-Plasencia, Eugenio, et al. "SCADA-based heliostat control system with a fuzzy logic controller for the heliostat orientation." Applied Sciences 9.15 (2019): 2966.
[4]. Mpodi, Emmanuel Karabo, et al. "Review of solar tracking devices for photovoltaic systems." design of a dual axis solar tracker concept for photovoltaic applications: 72.
[5]. Raimondi, Francesco Maria, and Andrea Guercio. "Implementation of a supervisory control and data acquisition for a biaxial photovoltaic tracker by means of a low cost PLC Zelio." 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe. IEEE, 2023.
[6]. Patil, Suprita M., M. Vijayalashmi, and Rakesh Tapaskar. "IoT based solar energy monitoring system." 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS). IEEE, 2017.
[7]. Howimanporn, Suppachai, Sasithorn Chookaew, and Chaiyaporn Silawatchananai. "Real-Time evaluation position control of directional wheel conveyor using fuzzy embedded PLC and SCADA." International Journal of Mechanical Engineering and Robotics Research 10.6 (2021): 328-336.
[8]. Achbi M.S., and Kechida S. "Methodology for monitoring and diagnosing faults of hybrid dynamic systems: a case study on a desalination plant." Diagnostyka 21.1 (2020): 27-33.
[9]. Mhamdi, Lotfi, et al. "Diagnosis of hybrid systems through bond graph, observers and timed automata." Diagnostyka 21.3 (2020): 113-125.
[10] Mateoiu, Ana-Maria, et al. "Supervisory Monitoring and Control Solution on Android Mobile Devices for the Water Industry 4.0." Sustainability 15.22 (2023): 16022.
[11] Achbi, M. S. Surveillance et commande tolérante aux défauts appliquées à une classe des systèmes dynamiques hybrides (Doctoral dissertation). (2022).
[12] DUYMAZLAR, Okan, and Dilşad ENGİN. "Design, application and analysis of an OPC-based SCADA system." Politeknik Dergisi (2023): 1-1.
[13] Abdallah, E. L., Mohammed OUASSAID, and Youssef ZIDANI. "Development of a Real-time Framework between MATLAB and PLC through OPC-UA: A case study of a microgrid energy management system." (2022).
[14] Bagal, K., Kadu, C., Parvat, B., and Vikhe, P., "Plc based real time process control using scada and matlab," in 2018 fourth international conference on computing communication control and automation (ICCUBEA). IEEE, 2018, pp. 1–5
[15] Rouabah, B., Toubakh, H., Djemai, M., Ben-Brahim, L., & Kafi, M. R. (2022). New Active Fault tolerant control of multicellular converter. 7th International Conference on Environment Friendly Energies and Applications (pp. 1-6)
[16] Rouabah, B., Toubakh, H., Djemai, M., Benbrahim, L., & Ghandour, R. (2023). Fault diagnosis based machine learning and Fault tolerant control of multicellular converter used in photovoltaic water pumping system. IEEE Access
[17] Vardar, E., Giraz, A. H., Orenbas¸, H., and S¸ahin, S., "Opc server based and¨ real time motor speed control with plc communication system," in 2018 26th Signal Processing and Communications Applications Conference. IEEE, 2018, pp.1–4.
[18] Yoo, Yoon-Sik, SH Shah Newaz, and Il-Woo Lee. "Developing a Real-time OPC UA based Aggregated Monitoring System for Small-scale Distributed Energy Resources among Microgrids." 2021 International Conference on Information and Communication Technology Convergence (ICTC). IEEE, 2021
[19] Achbi, M. S., Kechida, S., Mhamdi, L., & Dhouibi, H. (2021). A neural-fuzzy approach for fault diagnosis of hybrid dynamical systems: demonstration on three-tank system. acta mechanica et automatica, 15(1), 1-8.
[20] Laayati, Oussama, et al. "Smart Energy Management System: Design of a Smart Grid Test Bench for Educational Purposes." Energies 15.7 (2022): 2702.
[21] Chen, Huaizhong, Riliang Xu, and Ziqing Xie. "Design of Anti-islanding Intelligent Monitoring System for Photovoltaic Microgrid Based on IoT." International conference on Advances in Materials and Manufacturing. Singapore: Springer Nature Singapore, 2022.
[22] Prihantoro, Junanto, et al. "Implementation SCADA Web Client For Monitoring Geothermal Power Plant 3 MW Kamojang-Indonesia." 2022 2nd International Conference on Electronic and Electrical Engineering and Intelligent System (ICE3IS). IEEE, 2022.
[23] Kim, Min-Soo, et al. "A Novel Strategy for Monitoring a PV Junction Box Based on LoRa in a 3 kW Residential PV System." Electronics 11.5 (2022): 709