NTU Journal for Renewable Energy (2023) Vol. 5 (1): 103-111
DOI: https://doi.org/10.56286/ntujre.v5i1

IRAQI Academic Scientific Journals

EISSN: 2788-9920
NTU Journal for Renewable Energy
Available online at:
https://journals.ntu.edu.iq/index.php/NTU-JRE

Web Server Based Data Monitoring System of PV Panels Using S7-1200 PLC

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Article Information's

Received: 23 – 08 - 2023
Accepted: 30 – 09 - 2023
Published: 05 – 10 - 2023

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Key words:
Web Server, S7-1200 PLC, Monitoring System, TIA Portal, and PV Panel.

ABSTRACT

This This paper presents the design and implementation of a solar panel data monitoring system using a Web Server as a real-time operating system. The system is built via the Siemens S7-1200 Programmable Logic Controller (PLC) and programmed using TIA (Totally Integrated Automation) Portal V17 software. This approach enables real-time data collection and visualization of essential parameters such as voltage, current, power output, temperature, irradiance, and environmental conditions. The S7-1200 PLC serves as the central control unit, interfacing with the PV panels and gathering data. The acquired data is then transmitted to a web server, which hosts a user-friendly interface accessible through web browsers. Users can remotely monitor the performance of PV panels, track historical data trends, and receive alerts in case of anomalies. This web server-based system offers a convenient and efficient solution for effective PV panel management, enabling users to optimize energy production, detect issues promptly, and make informed decisions for maintenance and operational improvements.

1. INTRODUTION

The solar PV industry is rapidly growing due to the huge demand for electrical energy [1]. In Solar Photovoltaic Plants, the traditional method of managing plenty of solar panels is very challenging and inefficient. Since each panel set needs a digital power meter, which is very expensive to use for collecting the data from the panel, to cope with this problem, a standalone monitoring system of solar panels has been proposed.

The integration of advanced technologies has revolutionized the way we monitor and manage various processes, and the realm of PV energy is no exception. With the integration of a Siemens S7-1200 PLC and a web server, this work aims to bridge the gap between conventional PV panel monitoring systems and modern information technology. By combining these elements, the system offers a streamlined approach to data acquisition, visualization, and remote access, thereby enhancing the efficiency and effectiveness of PV panel management [2].

The primary objective of this work is to design and develop a comprehensive data monitoring system that not only captures vital performance parameters of the PV panel, such as voltage, current, power output, and temperature, but also provides real-time access to this data through a user-friendly web interface. This enables stakeholders, including system operators, maintenance personnel, and even end-users, to remotely monitor and analyze the performance of the PV panel system. The utilization of a web server ensures seamless access to data from diverse locations, thereby removing geographical constraints and enhancing the system's practicality.

Several studies have used Arduino and Raspberry Pi technology for monitoring PV system performance [3-7]. Although these solutions are low-cost, open-source, and extensible, they should not be considered a replacement for PLC technology. The PLCs are designed for industrial applications; they have the required approvals and environmental specifications; and they are robust, scalable, and extensible [8-10].

In the manuscript, the use of Siemens S7-1200 PLC for PV panel monitoring is highlighted as a preferable choice over Arduino and Raspberry Pi. This preference is based on a detailed comparison considering cost, scalability, and extensibility:

Cost Concern: Arduino is the most budget-friendly option.

Industrial Robustness: For small to medium-sized industrial applications emphasizing robustness and reliability, Siemens S7-1200 PLC is preferred.

Intermediate Option: Raspberry Pi offers a balance between cost and computational power but may not match PLCs in industrial-grade reliability.

The choice of technology depends on specific PV panel monitoring system requirements. The manuscript underscores Siemens S7-1200 PLC's advantages in industrial settings, focusing on reliability, robustness, and scalability as critical factors. So, PLC technology can be considered a better choice for monitoring the PV system. Furthermore, the incorporation of the Siemens S7-1200 PLC enhances the accuracy and reliability of data acquisition and processing. The PLC serves as the core control unit, enabling efficient communication between the PV panel and the web server. This interconnectivity ensures that real-time data is captured, transmitted, and displayed accurately, allowing for timely decision-making and proactive maintenance. Therefore, this work tries to use a Siemens S7-1200 PLC to monitor a solar panel system, as it is able to receive data from various sensors that measure various parameters such as solar panel terminal voltage, load current, temperature, irradiance intensity, etc.

1.1 Significance of the Paper

This paper is significant in PV panel monitoring for the following reasons:

- Integration of Modern Technology: It bridges traditional monitoring methods with modern information technology by combining a Siemens S7-1200 PLC and a web server, showcasing how industrial automation enhances PV panel management.
- Real-Time Data Collection and Visualization: The system collects real-time data on vital parameters, such as voltage, current, power output, temperature, irradiance, and environmental conditions, enabling a deeper understanding of PV panel performance and immediate decision-making.
- User-Friendly Web Interface: Through a web-based interface, it enables remote monitoring and analysis by system operators, maintenance personnel, and end-users, eliminating geographical constraints and enhancing practicality.
- Improved Accuracy and Reliability: Utilizing the Siemens S7-1200 PLC, designed for industrial applications, ensures precise and reliable data

acquisition and processing, serving as the core control unit for accurate real-time data capture and transmission.

- Enhanced Efficiency: The system's efficient data capture and transmission support timely decision-making and proactive maintenance, vital for optimizing energy production and reducing downtime, ultimately boosting the efficiency of PV panel systems.

1.2 Limitations and Challenges

The "Web Server Based Data Monitoring System of PV Panels Using S7-1200 PLC" offers significant advancements in PV panel monitoring. However, it's essential to consider the encountered limitations and challenges for a balanced perspective:

- Technical Expertise: Implementing and programming PLCs, like the S7-1200, demands specialized technical knowledge, potentially limiting accessibility for users unfamiliar with PLC programming.
- Sensor Calibration: The system's accuracy depends on precise sensor calibration, which can be time-consuming and require periodic maintenance for ongoing accuracy.
- Data Transmission Reliability: Real-time monitoring relies on data transmission from the PLC to the web server. Network issues or server downtime could impact system reliability.
- Security Concerns: Web-based systems are vulnerable to cybersecurity threats, necessitating robust security measures to prevent unauthorized access and data breaches.
- Scalability: While designed for scalability, expanding the system with more PV panels and sensors may involve complex hardware and software adjustments.
- Environmental Conditions: Extreme environmental conditions, like temperature extremes and exposure to dust, can challenge the system's robustness, requiring durable sensor and hardware solutions.
- Compatibility: Thorough testing is required to ensure compatibility with various web browsers, operating systems, and devices for seamless user access.
- Maintenance: Regular system maintenance, including software updates, sensor calibration, and hardware inspections, is crucial to sustain reliability and accuracy.

These limitations and challenges provide a comprehensive understanding of the system's strengths and potential areas for improvement.

2. PROPOSED WEB SERVER MONITORING SYSTEM

The proposed circuit diagram of the PV panel monitoring system is depicted in Fig. 1. The web server system gathers data from the solar panels, encompassing parameters like voltage (V), current (I), and temperature (T), and presents this information in a user-friendly manner. This facilitates operators in overseeing the solar panel performance and recognizing potential issues or deviations. Additionally, the data amassed by the web server system can be utilized for analysis and optimization of the solar panel setup. This includes identifying areas for enhancement and forecasting future energy output. Four measurement sensors are used to collect the data from the PV panel (A 100-watt polycrystalline solar panel type) and its environment and transmit it to the PLC unit (S7–1200).

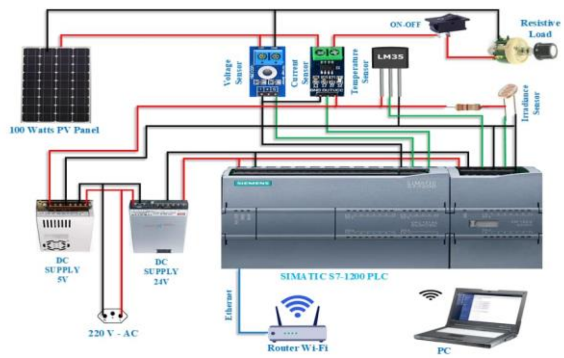

Fig 1: Circuit diagram of the proposed web server PV monitoring system

2.1 Voltage Sensor

A voltage divider was used with the PLC as a PV voltage sensor. It operates between 0 and 25 volts. According to eq. (1), its output voltage can be defined.

$$V_{out} = V_{in} * \frac{R_2}{R_1+R_2} \qquad (1)$$

where Vin is the input voltage, R1 equal to 30K ohm, and R2 equal to 7.5K ohm.

2.2 Current Sensor

The "ACS712 Current Sensor" was chosen for the load current measurement because of its excellent accuracy and simplicity. It is capable of detecting both AC and DC current. The operational principle of this device is based on the "Hall Effect". Then, as shown in [11], the PLC calibrates the hall voltage to the actual load current(I).

$$I = \frac{sensor\ value - 2.5}{scale\ factor} \qquad (2)$$

The scale factor value is dependent on the category of ACS-712 current sensor with regard to its current load capability; for the "ACS-712 ELCT-10A" used in this work, it equals 100 mV per amp.

2.3 Temperature Sensor

The low power, low cost, and high precision "LM35 temperature sensor" was created and manufactured by Texas Instruments. With a scale factor of 10.0 mV/°C, it outputs a voltage that is linearly proportional to the change in temperature.

2.4 LDR-Irradiance Sensor

For a typical LDR, the resistance RLDR and light intensity (in Lux) have the following relationships [12]:

$$R_{LDR} = \frac{500}{Lux} \qquad (3)$$

Using the voltage divider rule, if the LDR is connected to 5 volts through a 3.3 K ohm resistor, the LDR's output voltage (V out) is

$$V_{out} = \frac{5R_{LDR}}{R_{LDR} + 3.3} \qquad (4)$$

Substituting RLDR from eq. (3) into eq. (4) to attain the light intensity.

$$Lux = \frac{\frac{2500}{V} - 500}{3.3} \qquad (5)$$

Lux to W/m2 cannot be directly converted; instead, there is a rough conversion for sunlight as shown in eq. (6).

$$1\text{Lux} = 0.0079\ \text{W/m}^2 \qquad (6)$$

3. SOFTWARE IMPLEMENTATION

Software called TIA Portal V17 is used to program Siemens SIMATIC S7-1200 PLCs [12]. All sensor measurement values were read by the PLC. With it, analogue input pins are used as the connection. First, the minimum and maximum voltage sensor signal (%IW64) values were chosen from 0 to 27648 and the value was given in "NORM_X" for the measurement of the terminal voltage of the PV panel. Using "SCALE_X" function blocks, it was then scaled to the actual voltage value (0–25) in volts. The voltage sensor's error rate was discovered to be 5% during calibration.

To guarantee the precision and reliability of the voltage sensor calibration within the PLC, a meticulous calibration process was conducted, wherein the sensor's readings were aligned with those acquired from a high-precision voltmeter. Subsequently, a rigorous analysis affirmed a complete congruence of 100% between the two sets of readings, conclusively establishing the sensor's proficiency in accurately discerning the voltage output of the solar panel.

Figure 2 (a) illustrates the alignment of the PLC readings with those obtained from the voltmeter, thereby corroborating the calibration process.

Figure 2 (a). The correlation between the PLC readings and the voltage sensor's measurements taken with a voltmeter

The "NORM_X" block function was used to normalize the min. and max. of the load current sensor signal (IW66%) from the (0-27468) value in order to measure the load current. Then, using the "SCALE_X" block to specify the min. and max. values, it scaled with a range of 0–10 amps. The necessary calibration equation for this sensor, eq. (2), was implemented using a "CALCULATE" block function.

In order to ascertain and affirm the precision of the calibration process for the current sensor integrated into the PLC, a meticulous procedure was conducted. This procedure involved aligning the sensor's readings with those acquired from a high-precision voltmeter, and the results unequivocally demonstrated a complete alignment of 100%. This, in turn, substantiated the sensor's capability to accurately measure the current output of the solar panel. Figure 2(b). visually represents the alignment between the PLC's readings and the readings obtained from the voltmeter, thereby illustrating the calibration process for the current sensor.

Figure 2(b). The synchronization of PLC readings with the voltmeter measurements for the current sensor.

As illustrated in Fig. 2 (c), the PV terminal voltage value was multiplied by the load current value using the multiplication function block "MUL" to determine the consumption power (in Watt) from the PV panel.

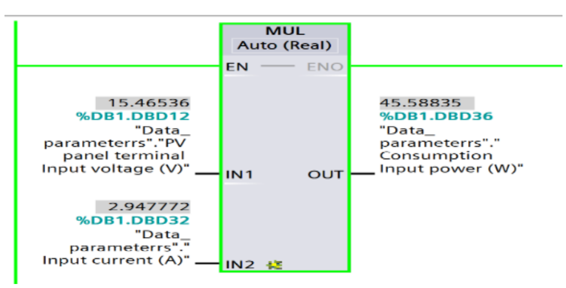

Figure 2 (c). Consumption power calculation network

The "NORM_X" block function is used to equalize the parameters of the LM35 temperature sensor signal (%IW100) and scale the normalized data with a range of 0-100 °C.

The "NORM_X" function block was then used to normalize the minimum and maximum values of the light sensor signal (%IW102) with a value between 0 and 27468 in order to determine the irradiance. According to equations (5) and (6), a function block called "CALCULATE" was used to determine the irradiance value in "W/m^2" units

4. CONFIGURATION WEB SERVER SYSTEM

The web server enables remote access via internet or intranet, facilitating real-time system monitoring and diagnostics. This approach is particularly valuable for overseeing extensive PV panel monitoring systems spanning vast geographic regions. Integration of a web server and S7-1200 PLCs permits rapid issue identification and resolution, optimizing performance and minimizing downtime, ensuring efficient PV panel system operation across long distances.

For CPU web access via PG/PC. The PROFINET interface is used to connect the client (PG/PC) to the CPU. Open a web browser and type the CPU IP address in the "Address" field using the format http://ww.xx.yy.zz (for instance, http://192.168.16.141). Opens the CPU start page. You can then get more information from the home.

Designed through TIA Portal V17, the web server interface configures communication settings with the S7-1200 PLC and for each sensor. Sensor identification and appropriate data type assignment (e.g., voltage, current, power, temperature, radiation) is established. Screen editor in TIA portal generates display screens, incorporating graphical elements like metrics, charts, and tables to showcase sensor data. Alerts and events are programmed for sensors, triggering warnings upon surpassing predefined thresholds.

The web server interface integrates trend charts for visualizing historical sensor data. S7-1200 PLC retrieves sensor data, transmitting it via configured communication protocol. Predefined thresholds establish alerts for parameter breaches, notifying operators.

Within the web server interface, trend charts illustrate curve values (voltage, current, power, temperature, radiation) over time. Interface enables PLC start/stop control, integrating buttons/graphical elements to initiate commands. PLC responds accordingly to received signals.

5. RESULTS AND DISCUSSION

In Figure 3, the fundamental web server interface is showcased, along with the procedure to access it through the input of the designated user credentials established earlier. Figure 4 depicts the visualization of data on a computer screen, highlighting the graphical representation of the monitored information. Figure 5 exhibits the remote display of data on a mobile phone screen. This enables remote monitoring of solar panel data from any location outside the operational site.

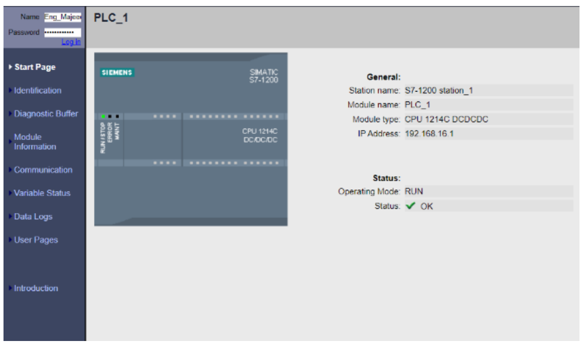

Figure 3: the fundamental web server interface

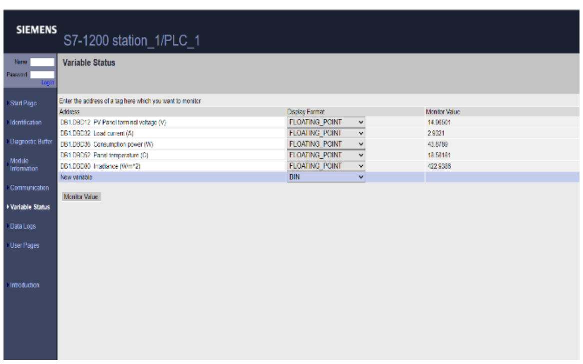

Figure 4. Data of the proposed PV monitoring system is displayed on a PC screen via a web server

The web server system stores and saves data in various formats, including Excel files. By doing so, the system can track and analyze historical data for future reference, troubleshooting, and optimization purposes. Saving data in Excel files can also help operators and engineers easily analyze and visualize trends and patterns in the system's performance over time. Additionally, Excel files can be easily shared and exported to other software applications for further analysis or reporting purposes. Fig 7. displays the link and barcode pertaining to the data acquired from the photovoltaic system within the proposed framework on 10/5/2023, formatted as an Excel file.

Figure 5. Data of the proposed PV monitoring system is displayed on a mobile device via a web server

https://drive.google.com/file/d/1TJ9TqZYM3m1-5oie40QrTrQKe8rgs7Q4/view?usp=sharing

Fig. 7: PV monitoring data in Excel file format (scan the QR- Code)

It appears from the collected data in the Excel file that the data is updated every one minute, and this time can be reduced to increase the resolution of the results.

The choice of a one-minute update interval in the PV panel monitoring system reflects a balance between real-time monitoring needs and practical considerations. It serves several key purposes:

- Real-Time Monitoring: The system aims to provide real-time data on critical PV panel parameters (e.g., voltage, current, power output). A one-minute update interval enables frequent updates for close monitoring and prompt anomaly detection.

- Responsiveness: With one-minute updates, the system can promptly respond to environmental or performance changes, facilitating timely corrective actions.
- Practicality: Frequent updates generate substantial data volumes, impacting management and processing. A one-minute interval strikes a practical balance.
- Network Bandwidth: Transmitting data to the web server requires bandwidth. One-minute updates ensure timely information without overwhelming the network.
- Historical Data Trends: High-resolution historical data supports trend analysis, aiding in the identification of performance variations over shorter time spans.
- User Experience: Frequent updates enhance the web interface experience, enabling users to observe parameter changes rapidly.
- Energy Efficiency: A one-minute interval balances real-time data needs with energy efficiency, crucial for systems relying on renewable energy sources or batteries.
- Threshold Alerts: Frequent updates facilitate effective threshold alerts for parameters exceeding predefined limits, enhancing system safety and reliability.

Utilizing the data compiled within the Excel spreadsheet, the MATLAB software was integrated with the Excel software to facilitate subsequent analytical procedures. Employing the MATLAB software, an assessment was conducted on the data encompassing a complete diurnal cycle. This evaluation encompassed the plotting of distinctive curves corresponding to the terminal voltage, current, power output, temperature, and solar radiation magnitude associated with individual solar cells. Within Figure 8, the voltage, current, and power output of curves are depicted, whereas Figure 9 illustrates the temperature and solar radiation intensity trends.

Through meticulous acquisition and subsequent scrutiny of the amassed dataset, the operational aptitude and dependability of the system have been conclusively validated. This validation extends to the system's proficiency in real-time monitoring, data collection, analysis, and comprehensive oversight of solar cell behavior and production processes.

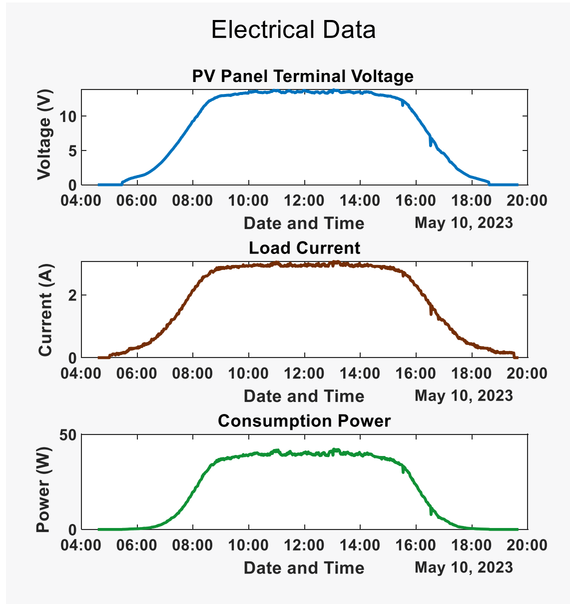

Fig 8: Curves depicting voltage, current, and power

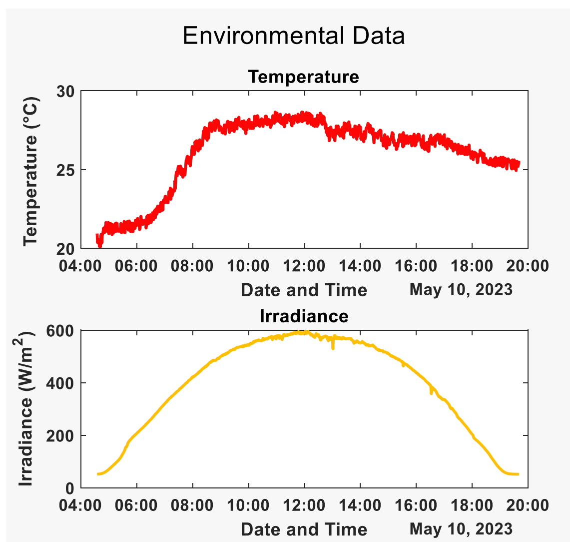

Fig 9: Curves depicting temperature and irradiance

The proposed work can easily be scaled to monitor a larger number of PV panels. Here are some key considerations regarding the scalability of the system:

- Data Collection and Sensors: The system's architecture supports multiple sensors for parameters like voltage, current, temperature, and irradiance. Additional sensors can be seamlessly integrated to monitor more PV panels.

- PLC Expandability: Siemens S7-1200 PLCs offer scalability through expansion modules and higher-end models. This flexibility allows the connection and monitoring of a larger number of PV panels without system overload.
- Communication and Networking: The system utilizes a web server for remote monitoring, accommodating multiple users simultaneously. As the number of PV panels increases, the system efficiently transmits data and provides remote access without compromise.
- Software Customization: TIA Portal software enables easy program and interface customization. The system can be tailored for larger PV arrays by adding visualization components and scaling the web interface to display data from additional panels.
- Data Storage and Analysis: The system stores data in various formats, including Excel files. Organized storage allows historical data retention for all panels, facilitating long-term trend analysis and performance optimization.
- Alert Mechanisms: Customizable alerts for parameter breaches can be configured for individual PV panels. This adaptability ensures prompt detection and resolution of issues as more panels are added.
- MATLAB Integration: Integration with MATLAB allows in-depth data analysis. As the number of monitored panels increases, MATLAB analysis can be adapted to handle larger data volumes, enabling comprehensive assessments of the entire PV panel array.
- Remote Access and Accessibility: The web server-based architecture supports remote access from any location. This scalability feature is particularly valuable for monitoring PV panels across diverse geographic areas or when adding new installations in different regions.

6. CONCLUSIONS

- In conclusion, the development and implementation of the "Web Server Based Data Monitoring System of PV Panel Using S7-1200 PLC" present a significant advancement in the realm of photovoltaic technology and data management. Through the integration of a web server interface and the utilization of the Siemens S7-1200 PLC, this system offers enhanced capabilities for real-time monitoring, data visualization, and remote access to critical parameters of PV panel systems.

- The successful execution of this work underscores the potential of modern technology to revolutionize the way PV panel performance is monitored and managed. The user-friendly web interface provides stakeholders with actionable insights into the system's behavior, enabling prompt responses to anomalies and proactive maintenance strategies. The integration of alert mechanisms ensures timely notifications of potential issues, minimizing downtime and optimizing performance.

- The inclusion of historical data storage and visualization features empowers users to analyze trends, make informed decisions, and fine-tune the PV panel system for optimal efficiency. The ability to remotely access and manage the system from any location is a key asset, promoting flexibility and accessibility for system operators and maintenance personnel.

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