Distributed Photovoltaic Monitoring Application - E-Learning Information Collection and Monitoring of Distributed Photovoltaic Power Plants

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Abstract. Real-time monitoring, control, and operation management of distributed photovoltaic power supply are essential means to ensure the safe operation of the power grid. It can grasp the operating status of the power station in real-time, obtain fault information, get the power quality, and take control and adjustment measures. Essential work for advanced applications such as power supply prediction, regional group control, and comprehensive evaluation. The primary purpose of this paper is to study the application of distributed photovoltaic monitoring and the related technologies of information collection (IC) and monitoring of distributed PPS (photovoltaic power stations/photovoltaic power plants). In this paper, through the real-time monitoring data analysis and efficiency measurement of PPS, we can quickly locate the abnormal efficiency of each link of PPS, provide strong support for operation and maintenance, and improve the intelligent management level of distributed PPS. A comprehensive analysis of the system efficiency can obtain essential factors that affect the system efficiency of PPS. Experiments show that the mismatch loss of the power station system components and the line loss from the elements to the power station combiner box are the main losses of the system efficiency in this section. The conversion efficiency of the photovoltaic inverter is more significant than 97.1%, and the overall system efficiency of the PPS is 92.60 %.

Keywords: Photovoltaic Power Station, Distributed Photovoltaic Power Plants, Information Collection, Operation Monitoring, E-Learning Information Collection.
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1 INTRODUCTION

Today's world is an information-based society, and the need to access all kinds of information anywhere has penetrated all areas of life. However, because the data is scattered in various incompatible structures, it is not easy to realize the sharing of information at any time, and it is challenging to analyze cross-application and cross-platform programs. For distributed photovoltaic monitoring systems, the same problem exists. Based on the importance of data and information to the photovoltaic monitoring system, constructing a photovoltaic power generation monitoring system on a unified platform to realize data collection and information sharing will play a significant role in the future development of the power grid [3],[7].

In a related study, Wakasa et al. proposed an improved Lipschitz optimization (LO) method and applied it to maximum power point tracking (MPPT) control of photovoltaic (PV) systems [12]. Standard LO can deterministically find the global maximum of a Lipschitz continuous function in a closed interval. The proposed method skips the evaluation of low objective function values (i.e., low power points) by using prior information about the output characteristics of the PV array. It is theoretically proved that the proposed method is guaranteed to converge to the global optimal solution. Ais et al. introduced a system based on connecting photovoltaic (PV) power generation to the grid [1]. Synchronization of the inverter and grid AC waveforms is accomplished using a phase-locked loop (PLL) circuit. An effective decoupling strategy based on the fuzzy logic controller (DFLC) aims to eliminate the interaction between the two current components. Simulation results of photovoltaic systems run using accurate irradiance data are presented to demonstrate the performance of the proposed decoupling and control strategy under different grid conditions.

This paper mainly studies the application of distributed photovoltaic monitoring and the related technologies of IC and monitoring of distributed PPS. The software system designed in this paper is a comprehensive information system integrating monitoring data collection and energy efficiency analysis, including real-time data collection of distributed PPS, power plant information management, OM, energy efficiency analysis, alarm notification, query statistics, and other functions. Through real-time monitoring data analysis and efficiency measurement of PPS, the system can quickly locate abnormal efficiency problems in each link of PPS, provide strong support for operation and maintenance, and improve the intelligent management level of distributed PPS. A comprehensive analysis of the efficiency of the power station system can identify important factors that affect the efficiency of the PPS system and provide an auxiliary decision-making basis for the future investment and construction of the distributed PPS.

2 DESIGN RESEARCH

2.1 Construction and Management of Distributed Photovoltaic Power Monitoring Center

Distributed photovoltaic power points are broad in multiple areas and small in a single capacity, so it is challenging to solve the information transmission and coordinated control technology under the multi-modal access of distributed photovoltaic power sources [11],5]. To realize the real-time monitoring of regional distributed power sources, it is necessary to solve the problems of the central station monitoring system, communication channel, and local IC (as shown in Figure 1).

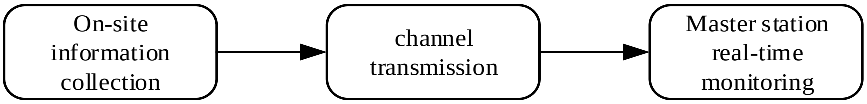

Figure 1: Flowchart of real-time OM.

Currently, the construction of the domestic monitoring center mainly has the following problems: First, the construction of the monitoring master station system is complex. There is no OM master station system specifically for distributed photovoltaics in China. For power station information, whether it is access scheduling automation, distribution network automation, or a new system, how to implement the security protection of the monitoring system, existing technical standards, and technical specifications None of them are covered, and there are no mature cases for reference; second, the construction of communication channels is complex. The construction of distributed photovoltaic power communication channels requires a comprehensive investment scale, construction period, construction funds, information security, and other factors. However, the power station needs more planning and a short construction period, and the traditional substation and power plant solutions cannot be applied to distributed PPS; three. On-site IC is complex. The conventional on-site IC scheme requires multiple sets of equipment, including IC, transmission, and access in the power station construction, which has high investment cost, long construction period, complex equipment, and difficult monitoring and management [8],[9].

2.2 Application Requirements of Distributed Photovoltaic Monitoring

1. Management and data storage requirements

It has the function of in-situ web publishing, which can display data and information.

It manages the information of 20,000 measuring points (about 500 measuring points for one grid-connected point), which can be stored in the log mode, and the storage capacity is not less than 16G.

2. Requirements for photovoltaic power sources

The working state of the inverter can be directly collected. Inverter open power control, allowing remote setting of the maximum active power allowable value of the inverter, reactive power setting value (installed capacity 20%~30%, capacitive to inductive), inverter shutdown control word, inverter Grid connection control word is allowed.

The photovoltaic power supply needs to provide voltage, current, power, power generation, power quality data (10kV), solar radiation intensity (10kV), temperature (10kV), and grid-connected switch location information. Provides a remote trip function for the grid-connected switch.

The remote measurement of PPS can come from inverters, integrated grid-connected interface devices, independent grid-connected port monitoring devices, watt-hour meters, PPS monitoring systems, etc. The principle is to refrain from repeatedly investing in hardware acquisition devices but must meet the requirements of the four telemetry points [2],[4].

3. Requirements for condition monitoring controller

The state monitoring controller is applied to multiple 0.4kV grid-connected points in the region to realize the function of the state access controller. The data measurement points of a single state monitoring controller are at least 20,000: collect telemetry and telemetry from multiple grid-connected points and collect various inverters. Remote measurement and remote signaling, collect electricity from multiple metering points, and issue instructions for grid-connected point control and inverter control and adjustment instructions.

4. Management and data storage requirements

The condition monitoring controller has the function of in-situ web publishing, which can display simple information.

The state monitoring controller can manage the information of 20,000 measuring points (about 500 measuring points for one grid-connected point), which can be stored in the log mode, and the storage capacity is at least 16G, realizing redundant data storage.

5. Remote control technology of local IC device

It should have the following functions:

1. Remote control. The master station issues control commands to the switch on and off at the grid-connected point and issues remote adjustment commands for the power generated by the inverter.

2. Power generation control. Control the power regulation (AGC/AVC) of each power station and the start/stop of power generation units according to the instructions of the power grid dispatching agency.

3. Control instruction encryption. The device is authenticated and encrypted.

2.3 OM

OM means that the system can monitor the operating status of each PPS and the equipment in the power station, which is divided into two parts: power production data monitoring of the power station and equipment OM in the station. The overall OM of the PPS, the group monitoring of the equipment in the power station, and the monitoring of a single device in the power station are three monitoring levels from the overall power station to the local power station [6],[10].

1. Monitoring of power station production data

The power station production data monitoring module mainly provides users with an overall map overview and real-time power generation data display functions.

2. Monitoring of equipment operation in the station

The operation monitoring (OM) of equipment in the station mainly refers to the dynamic monitoring of the overall operation status of various equipment in the station of a specific grid-connected PPS.

3. Overall equipment operation status

Monitoring all PPS equipment in various states, including operation, shutdown, failure, etc.

4. Monitoring of single equipment in the station

Monitor the running status and alarm information of equipment in a specific station.

2.4 Algorithm Research

1. Calculation of similarity

The influencing factors of photovoltaic power generation are composed of the following vectors:

$$Y = [Y_1, Y_2, Y_3] \tag{1}$$

In the formula, Y1 is the solar illuminance, Y2 is the ambient temperature, and Y3 is the ambient humidity.

Let Yp and YN (N=1, 2,) be the characteristic vectors of meteorological factors for forecasting the hourly hour and the historical hourly hour, respectively, so we have:

$$Y_p = \left[Y_{p(1)}, Y_{p(2)}, Y_{p(3)}\right]^T \quad (2)$$

$$Y_N = \left[Y_{N(1)}, Y_{N(2)}, Y_{N(3)}\right]^T \quad (3)$$

After the difference is normalized, the correlation coefficient between Yp and YN is

$$\varepsilon_N(i) = \frac{\min_N \min_i Z'_n(i) + \rho \max_N \max_i Z'_n(i)}{Z'_n(i) + \rho \max_N \max_i Z'_n(i)} \quad (4)$$

In the formula, ρ: resolution coefficient, and its value is generally 0.5.

3 EXPERIMENTAL STUDY

3.1 Monitoring the Running Status of the Master Station

Status monitoring works on geographic diagrams, electrical principal wiring diagrams, system diagrams, and lists. Operation status monitoring includes DG telemetry, tele signal status, power flow, and voltage of power grid operation. Communication and working status of central system equipment; alarm status.

1. Grid connection status monitoring

1. Grid connection status display. Display the switch status of the distributed power grid connection point by customer number, customer name, regional unit, power generation type, and voltage level, and display it in a list.

2. Grid-connected status statistics. The overall switching state of the grid-connected points of the distributed power generation in the selected area is counted, and the number of grid-connected and off-grid power sources in the designated area is displayed as a bar chart.

3. Display of grid-connected status changes. Please select a specific distributed power source in the table to understand its historical grid-connected state change and display it in a graphical form.

4. Dynamic display of abnormal status.

5. Abnormal reminder.

6. Exception handling.

7. Abnormal audit.

2. Electrical parameter monitoring

Monitor the electrical parameters of the grid-connected point and the public connection point of the distributed power supply and the power of the distributed power supply, display the monitoring results statistically, find the distributed power supply with abnormal parameters, and display the electrical parameters of each electrical parameter in different periods in the form of graphics. Changes and statistics of power increments.

1. Display the electrical parameters and power indication.

2. Changes in electrical parameters. In the table, you can view the voltage, current, active power, reactive power, and power factor changes of a single user at a specific metering point (common connection point or grid connection point) and display them in graphics.

3. Changes in power increments. In the table, you can view the changes in the power generation increment, on-grid power increment, and grid-consumption increment of a single user in different periods and display them in graphs.

4. Dynamic display of abnormal parameters.

5. Abnormal reminder.

6. Exception handling.

7. Abnormal audit.

3. Power quality monitoring

1. Count the voltage violations of distributed power generation by region and power generation type and display them as a list.

2. View the power quality information of each grid-connected and public connection point in the area and display the power quality changes in different periods.

3. Display the changes in power quality in different periods in tables, graphs, etc., including power supply voltage over-limit, harmonic over-limit, power factor over-limit, three-phase unbalance, and voltage flicker quantity.

4. Early warning display for areas with poor power quality.

4. Monitoring of environmental parameters

By monitoring the ecological parameters of the location, we can grasp the overall natural environment information.

1. Statistics on the wind direction, wind speed, light temperature, and humidity information of distributed power generation by region and power generation type, and display them as a list.

2. View the environmental parameter information of each distributed power source in the area and display the changes in ecological parameters in different periods.

3. Display the changes in environmental parameters of each distributed power source in the region at different times in tables, graphs, etc., including wind direction, wind speed, light, temperature, humidity, etc.

4. Early warning display for areas with harsh environments.

5. Security incident monitoring

From the dimensions of regional units, power generation types, voltage levels, etc., statistical methods are used to analyze the safety events that occur during the grid-connected operation of distributed power generation, to display the operation safety situation, and to provide data support for operation analysis.

1. Security event display. Statistically analyze the occurrence time and event type of distributed power security events by regional unit, power generation type, event occurrence time, and voltage level, and display them in a list.

2. Changes in security incidents. From time and area unit to latitude, the distribution of distributed power security events in the area is displayed as a graph.

3. Regional distribution of security incidents. The number of occurrences of safety events in different periods of the distributed power supply in the region is displayed in a graph.

4. Incident monitoring. Set the security event early warning benchmark value.

5. Abnormal reminder.

6. Exception handling.

7. Process the audit.

3.2 Monitoring Master Station Data Collection

1. Strategy for data collection

1. The channel with high reliability is preferred.

2. Monitor the channel and alarm immediately if any abnormality is found.

3. The uplink and downlink communication messages can be monitored in real-time through any CRT, including remote methods. They can be viewed by category, saved by category, or printed out as needed.

4. The complete data scan cycle can be manually set.

5. For the factory station with channel failure, the data on the CRT screen has noticeable differences to indicate its failure.

6. For each quantity, if it is not refreshed for a long time (adjustable time, in seconds), it will also be marked.

2. Data reception and processing

Parse and format data and information and prepare for database interface calls. Manual shielding and processing functions for jitter remote signaling were added.

3. Remote control module.

1. The module executes to meet the requirements of the emergency opening command issued by the central station, taking the grid-connected point as the object.

2. Meet the requirements of the module to execute the remote time synchronization command and the remote fixed value modification command issued by the master station.

3.3 The specific Steps of the Server Data Collection and Transmission Process are as follows:

1. After starting the program, initialize the parameter configuration and wait for access;

2. The acquisition node will automatically initiate a data transmission request and establish a corresponding TCP connection;

3. Check the protocol's binding; the same communication protocol is used between the collection node and the server, and the new connection must be bound to the communication protocol. Otherwise, it will be regarded as illegal, and it will be disconnected;

4. Before data analysis and data verification, the communication protocol is first bound; when the protocol is successfully attached, the work is handed over to the verification and analysis link and finally enters the loading entity data and data storage link;

5. After the data transmission is over, if no retransmission request is found, the connection is disconnected. If data is to be retransmitted, a retransmission command is sent to the data collection node to retransmit the data.

4 EXPERIMENT ANALYSIS

4.1 Error Analysis of Photovoltaic Power Generation

Model training takes meteorological and historical data of similar days as input and output, respectively. After the model training is completed, input the forecast weather information on the forecast day to get the hourly power generation on the forecast day. The percentage error between the predicted power generation data and the actual power generation data at each time point of the PPS is shown in Table 1. The results are as follows:

time	*actual power generation*	*forecast power generation*	*percent error*
5:00	*0*	*0*	*0.00%*
6:00	*558.96*	*481.2*	*-13.8%*
7:00	*1185.58*	*1143.7*	*-3.7%*
8:00	*3550.17*	*3325.6*	*-5.9%*
9:00	*4750.52*	*4867.2*	*2.5%*
10:00	*5595.27*	*5274.1*	*-5.4%*
11:00	*5765.18*	*5463.5*	*-5.1%*
12:00	*5979.36*	*5833.9*	*-2.3%*
13:00	*5815.41*	*5655.8*	*-2.4%*
14:00	*5586.66*	*5124.6*	*-8.4%*
15:00	*4165.56*	*4183.1*	*0.4%*
16:00	*3545.83*	*2985.6*	*-15.5%*
17:00	*1715.63*	*1461.2*	*-14.3%*
18:00	*358.96*	*278.3*	*-23.1%*

Table 1: The error percentage between PPS's actual and predicted power generation.

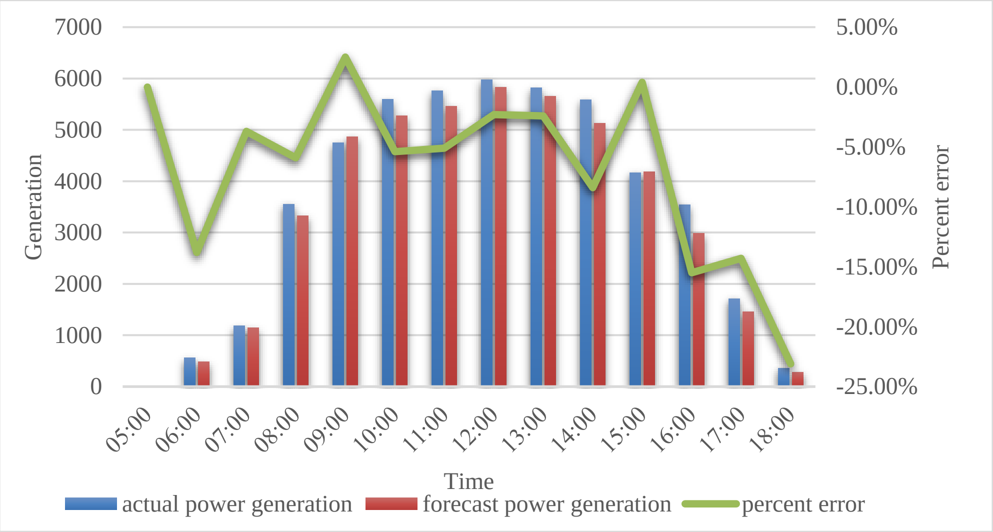

Figure 2: Comparative analysis of actual power generation and predicted power generation of PPS.

By comparing the curves, it can be found that in sunny weather, the photovoltaic power generation forecast has a good forecast effect, the error is small, and the trend is stable. It can be seen from the figure that the prediction error of photovoltaic power generation in the early morning and evening is relatively large. The reason is that the photovoltaic system is in the start-stop stage, and the panel and the ambient temperature do not match, so the optimal power generation effect cannot be achieved.

4.2 Verification Analysis

1. Efficiency of the first stage

The power station combiner box first collects the multi-circuit currents output by the photovoltaic module array in one place and then transmits it to the power station inverter. In this link, the power station photovoltaic modules' series loss and line loss are significant to the entire power generation system. Of.

The photovoltaic arrays and the corresponding combiner boxes numbered 1 to 4 in the power station are collected, and the calculation results are summarized in Table 2.

Numbering	*number 1*	*number 2*	*number 3*	*number 4*
string number	*45*	*45*	*45*	*45*
Average current/A	*6.85*	*6.84*	*6.79*	*6.81*
Average PV voltage/V	*586.17*	*590.86*	*589.27*	*586.17*
Single PV string power/W	*4016.99*	*4042.72*	*4003.03*	*3990.98*
Correction current/A	*6.99*	*6.98*	*6.93*	*6.95*
Correction voltage/V	*589.38*	*594.10*	*592.50*	*589.38*
Single string correction power delta correction/W	*4134.07*	*4160.56*	*4119.71*	*4107.31*
Single string correction power (P=UI)/W	*4121.74*	*4148.14*	*4107.42*	*4095.06*

Table 2: Combiner box data.

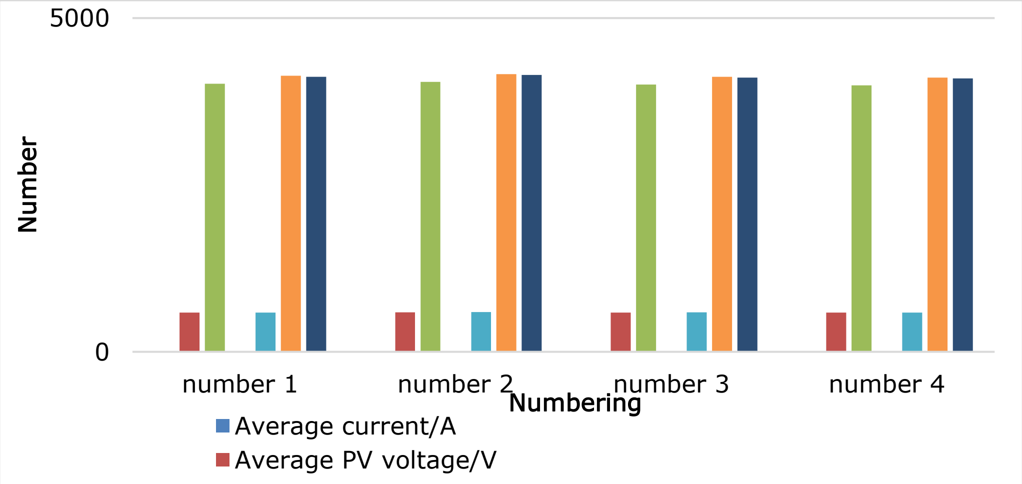

Figure 3: Combiner box data analysis.

Through comprehensive calculation by the combination of corrected voltage and corrected current, for a single photovoltaic string, the fixed power can be obtained as 4118.6W; through complete calculation with temperature and power coefficient correction, for a single photovoltaic string, its power can be obtained. It is 4130.14W; the error data value between them is 0.28%.

2. Second stage efficiency

The PPS inverter is a vital core equipment in the second stage of the grid-connected PPS system. The power data of the inverter of this PPS is obtained by collecting data as follows.

Numbering	*Active measured value (KW)*
1	*359.98*
2	*359.86*

Table 3: Inverter data.

The PPS combiner box's self-loss, the PPS inverter conversion loss, and the line loss from the PPS combiner box to the inverter are the main losses of the second stage of the power station system.

3. Loss analysis

Based on the data of the PPS system, combined with the data, the efficiency and loss of the PPS system can be calculated, see Table 4.

	First stage loss	*Second stage loss*	*Third stage loss*
Incoming side power of combiner box/kW	*741.3*	*719.8*	*700.3*
Outgoing side power of the module //kW	*752.4*	*741.3*	*719.8*
attenuation/%	*1.5*	*2.9*	*2.7*
efficiency/%	*98.5%*	*97.1%*	*97.3%*

Table 4: Loss statistics.

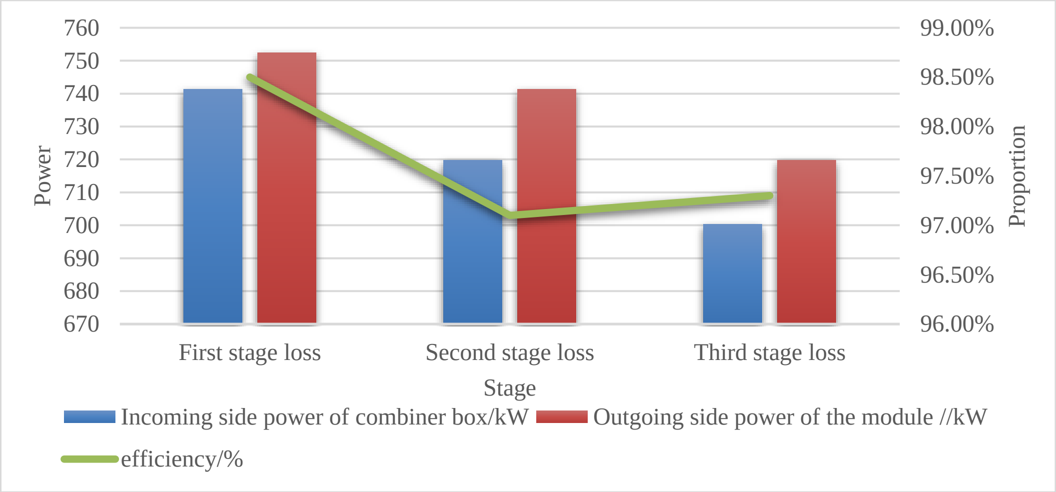

Figure 4: Loss efficiency analysis.

The above figure shows that the system efficiency loss of the first stage of the PPS system is about 1.48%, and the system efficiency is 98.5%. This section's main system efficiency losses are the mismatch loss of the power station system components and the line loss from the elements to the power station combiner box. Then, the efficiency of the second stage of the system is 97.1%. Each of the efficiencies must be greater than 97.1%, which also shows that the conversion efficiency of the photovoltaic inverter of the power station is more significant than 97.1%. The third stage loss of the power station system is 2.7%, and the efficiency is 96.8%. From this, it can be seen that the overall system efficiency of the PPS is 92.60%.

5 CONCLUSIONS

At present, with the current level of science and technology, there are roughly two ways in which humans can directly develop and utilize solar energy: one is to convert solar energy into heat energy, such as solar water heaters (generally, they can only be used locally in miniaturization, and it is not easy to scale up). It is not easy to transmit); the second is to convert solar energy into electricity. Electric energy has been widely used in all aspects of people's production and life. The demand for electric energy in modern human society is increasing. Research shows that the importance of electric energy has surpassed other energy sources and has become the most critical energy required by humans. Therefore, research, development, and utilization of solar photovoltaic power generation has become a prevalent direction in energy research. Solar photovoltaic power generation is essential in the global ecological environment and sustainable human development. Integrating e-learning modules ensures ongoing education, equipping users with knowledge about PV technology, maintenance best practices, safety measures, and energy efficiency tactics.

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