Hindawi
International Journal of Photoenergy
Volume 2023, Article ID 6701631, 11 pages
https://doi.org/10.1155/2023/6701631

Research Article

Application of Photovoltaic Systems in Field Observation and Research Stations: Research on the Relationship between Power Generation Scale and Electricity Consumption to Improve Photovoltaic Application in Field Observation Stations

Jianan Yao ,[1,2,3] Junfeng Zhu ,[1,2] Binbin Wang,[4] Junkui Niu,[1,2] Wenbing Liu,[1,2] Long Chen,[4] and Yifan Song[1,2]

[1]*Yinshanbeilu Grassland Eco-Hydrology National Observation and Research Station, China Institute of Water Resources and Hydropower Research, Beijing 100038, China*
[2]*State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100044, China*
[3]*School of Science, Inner Mongolia University of Technology, Hohhot 010051, China*
[4]*Inner Mongolia Institute of Metrology Testing and Research, Hohhot 010010, China*

Correspondence should be addressed to Jianan Yao; yaojn@iwhr.com and Junfeng Zhu; zhujf@iwhr.com

Received 27 October 2022; Revised 22 March 2023; Accepted 29 March 2023; Published 17 April 2023

Academic Editor: Daniel T. Cotfas

Most field scientific observation and research stations are located at the end of power grids which are usually not extended to such areas. Consequently, the power supply of equipment in field observation stations cannot be guaranteed. Meanwhile, regions with poor ecosystem stability are relatively sensitive to environmental changes and thus prone to degradation and succession due to external interference. In this paper, the photovoltaic (PV) power generation system of a grassland ecohydrological field scientific observation and research station was taken as the research object. Two kinds of distributed PV power generation systems were simulated and analyzed by use of PVsyst software. The total power of laboratory equipment, PV power generation efficiency, and system cost of the field observation station were calculated and analyzed. The design scheme and scale of PV power generation systems suitable for field observation stations were determined. Finally, a PV power generation test system was set up, and PV power generation data were sorted out. The feasibility of the design scheme of PV power generation systems was verified by analyzing the relationship between the simulated and actual power generation of systems and that between the daily energy use proportions of field observation stations. Besides, the environmental benefits of PV systems were analyzed, and their amount of energy saving and emission reduction was calculated. This study can solve the issue of the low power supply guarantee rate of field observation stations, provide a design basis and beneficial reference for the construction of environment-friendly field laboratory stations, and realize green energy saving and the sustainable use of energy while protecting the ecosystem from being destroyed.

1. Introduction

The population and the demand of the world for energy are increasing and accelerating, while the sources of fossil fuels are rapidly declining [1]. In recent years, the emission of greenhouse gases has seen a rapid increase due to the burning of fossil fuels, which leads to global warming and a series of extreme weather. This will bring many consequences to the ecosystem of the earth and human life [2]. Photovoltaic (PV) power generation technology is mature, with good basic conditions. From the perspective of cost, PV power generation is relatively cheaper and able to reduce the environmental pollution caused by the massive use of traditional energy such as thermal power generation. Compared with

Table 1: Solar PV applications.

Location	Investment cost/USD/kWh	System size/kwp	Electrical load contents	Analytical methods
Gusau, Nigeria	0.40	164.00	300 households' electrical loads	Mathematical modeling
Famagusta, Cyprus	0.23	7.46	A residential household's electric loads	Mathematical modeling
University of Port Harcourt	0.60	12.00	Computers, printers, and scanners	Mathematical modeling
Rajshahi, Bangladesh	0.72	3.90	50 households	Spreadsheet modeling
Siyambalanduwa, Sri Lanka	0.30	30.00	A village of 150 household	HOMER

wind power generation, PV power generation has the advantages of high stability, strong environmental adaptability, convenient overhauling, maintenance, etc. [3]. Field scientific observation stations are often located in remote areas, where the construction of power grids is relatively weak. Power grids have yet not been extended to these areas because of economic considerations. The construction of distributed power generation systems in field scientific observation stations can solve the power supply problem of equipment in field observation stations and prevent the data loss caused by the insufficient power supply of equipment. Meanwhile, regions with poor ecosystem stability are relatively sensitive to environmental changes and thus prone to degradation and succession due to external interference. As a result, the use of distributed power generation systems can also protect the ecosystem from being destroyed.

Over the past few years, different model selection methods and a simulation software have been widely used in the design and analysis of PV power generation systems. Ahmad et al. used OMER software to discuss the optimization and implementation of institution-based sustainable microgrids from the cost analysis, carbon emission, energy availability, and other aspects of the campus network [4]. Abideen et al. [5] study proposed two algorithms from a new improved iterative approach and a new repeated particle swarm optimization (RPSO) approach and calculated the optimal hosting capacity based on six annual load and distributed energy resource generation scenarios. In recent years, different sizing methods and a simulation software have been widely used for the design and analysis of photovoltaic power systems. Amrollahi and Bathaee completed the mathematical modeling of microgrid components within the framework of the mixed integer linear programming method. In addition, programs were optimized using HOMER and GAMS software [6]. Crossland et al. studied the development of models of optimum size based on the iterative method and predicted the optimal configuration based on the minimum cost [7]. Das et al. studied the performance of a 2.02 KWp stand-alone solar PV system and analyzed the efficiency of different power generation modes using PVSYST V5.74 software [8]. Mandelli et al. proposed an approach to solve the scale of electric energy in independent rural areas in Uganda by considering the levelized cost of energy supplied and lost [9]. The parameters identified included PV module, battery, inverter cost, operation, and maintenance costs [10]. Kaabeche and Ibtiouen performed a technoeconomic analysis and used RETScreen software to compare an off-grid hybrid PV-diesel battery with a PV battery in a household in Urumqi, China [11]. Lang et al. reviewed the role of size optimization in achieving the lowest system cost. They summarized the significance of reliability-based models for evaluating the performance of hybrid renewable energy systems [12]. Ismail et al. made a technoeconomic analysis of a hybrid independent PV-battery-diesel generator in a peripheral residential building in Malaysia to achieve the lowest cost while meeting the demand of the building for power load [13]. Li et al. used the hybrid optimization model for electric renewable (HOMIE) for economic analysis and took energy demand, climate conditions, and technoeconomic data as the main parameters for comparative analysis [14]. Mandelli et al. used RETScreen software for technoeconomic analysis in Coatzacoalcos, Mexico [9]. Perea-Moreno et al. adopted HOMER software to analyze the technoeconomic feasibility of off-grid PVs [15]. Siddaiah and Saini used Matlab and HOMER modeling software to perform social and technical analysis of PV performance and economic comparison between PV and diesel systems [16] Different approaches deployed in different parts of the world are summarized in Table 1.

Located at the end of power grids, field stations are equipped with low-standard infrastructure and incomplete supporting facilities, which leads to difficulty in ensuring the power supply guarantee rate. PV power generation was used to power laboratory equipment to prevent the loss of laboratory data caused by the unstable power supply. The PV power generation system of a grassland ecohydrological field scientific observation and a research station was taken as the research object for the design and research of PV power generation systems. Two kinds of distributed PV power generation systems were simulated and analyzed by PVsyst software. The total power of laboratory equipment, PV power generation efficiency, and system cost of the field observation station were calculated and analyzed. The design scheme and scale of PV power generation systems suitable for field observation stations were determined. The test platform of PV power generation systems was built, and PV power generation data were sorted out and analyzed. The relationship between the simulated power generation and

Figure 1: Location map.

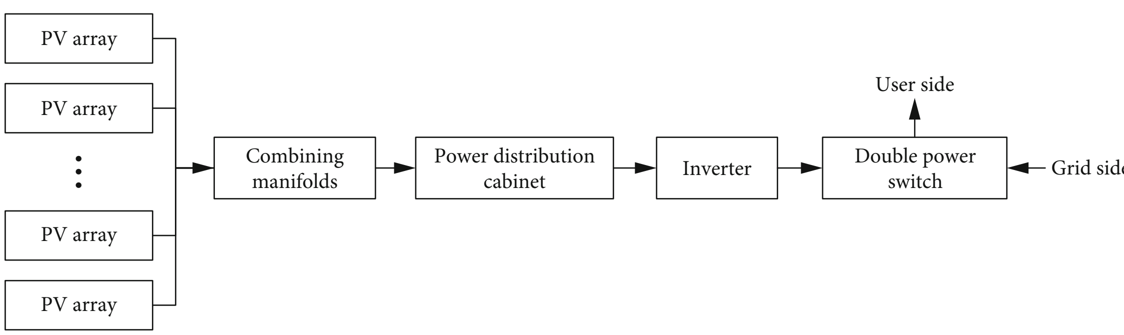

Figure 2: Schematic diagram of the PV power generation system.

the actual power generation of systems and that between the daily energy use proportions of field observation stations were obtained, which thus verified the feasibility of the design scheme of PV power generation systems. Besides, the environmental benefits of PV systems were analyzed, and their amount of energy saving and emission reduction was calculated. The study of this paper can solve the issue of the low power supply guarantee rate of field observation stations, provide a design basis and beneficial reference for the construction of environment-friendly field laboratory stations, and realize green energy saving and the sustainable use of energy while protecting the ecosystem from being destroyed.

2. Research Background

Situated in Xilamuren Town, Damao Banner, Baotou city, Inner Mongolia, China, Yinshanbeilu Grassland Eco-hydrology National Observation and Research Station is among the first batch of field scientific observation and research stations of the Ministry of Water Resources of China. Its coordinate is N111.210244°E41.350775°. The construction scope of the distributed PV power generation system in the field observation station is shown in Figure 1. The system covers an area of 6,473 m^2.

3. Research Proposal

3.1. Overall Plan. Assessing the load of electric equipment is of vital importance to simulate PV power generation systems. Compared with HOMER software, the PVsyst software has a higher degree of intelligent optimization. Simulation can take into account load growth. Therefore, PVsyst software with more comprehensive load models was used for simulation in this paper. First, the load demand of a national field observation station was analyzed to estimate and predict its average annual load. Second, the PV power generation system was simulated and analyzed according to the operation and load size of laboratory equipment in the field station and in combination with the scale of

Table 2: Summary table of a load of laboratory equipment.

Equipment name	Rated power/W	Working time/h	Quantity/set	Electricity consumption/kW·h
Air oven	3.340	2	1	2.68
Weighing type lysimeter	0.600	6	2	7.20
Flow instrument	0.010	12	8	0.96
Water gauge	0.050	12	4	2.40
Water erosion meter	0.060	12	4	2.88
Sediment sampler	0.005	12	4	0.24
Moisture content detector	0.030	12	2	0.72
Soil conductivity meter	0.500	6	1	3.00
Unsaturated water conductivity meter	0.200	12	2	4.80
Soil and fertilizer nutrient tester	0.005	6	2	0.06
Ecological environment observation station	0.300	24	1	7.20
Large aperture scintilometer	0.015	12	2	0.36

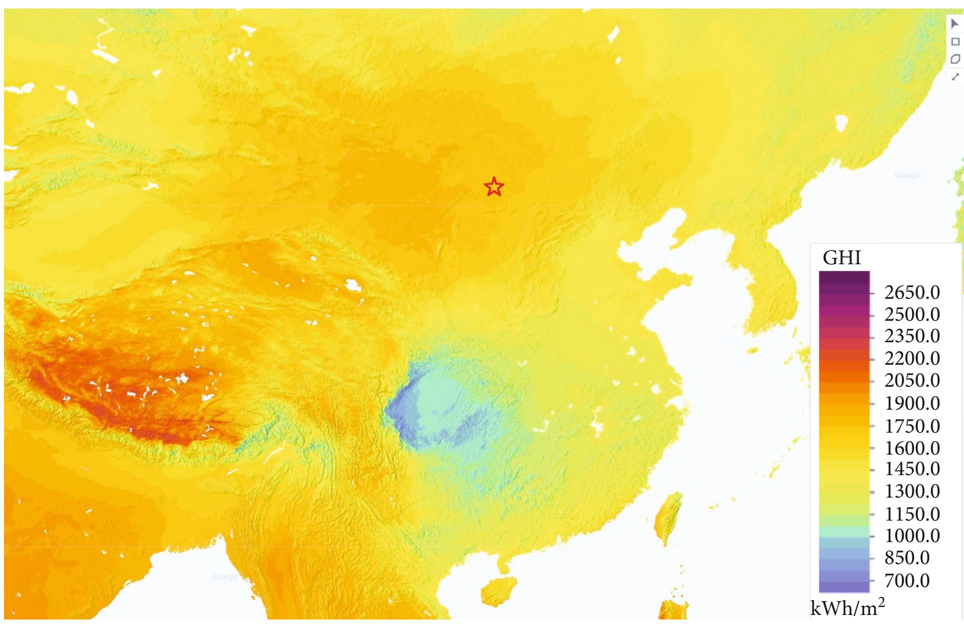

Figure 3: Global horizontal irradiance.

the PV power generation calculation system. The design and configuration of the PV system were completed. The system schematic diagram is shown in Figure 2.

3.2. Load Analysis of the Laboratory Station. The daily load data of the field observation station were analyzed, as shown in Table 2. The laboratory equipment and annual daily load of the field observation station were simulated and analyzed first. It was obtained that daily, monthly, and annual electricity consumption was 32.5, 975 and around 1,170 kWh, respectively.

3.3. Analysis and Calculation of Optical Resources. The SOLAR GIS map of the location of the field station is shown in Figure 3. The parameters of optical resources in the field station are shown in Table 3.

Table 3: Table for the parameters of optical resources.

No.	Parameters	Numerical value
1	Global horizontal irradiance/GHI	1685.2 kWh·m^2
2	Direct normal irradiance/DNI	1921.2 kWh·m^2
3	Diffuse horizontal irradiance/DIF	648.8 kWh·m^2
4	Diffuse-to-global ratio/D2G	0.385
5	Optimal global tilted irradiance/GTI opta	2110.5 kWh·m^2
6	Optimal tilted angle/OPTA	42°

The location coordinate of the field observation station was imported into Meteonorm. The corresponding monthly data of optical resources are shown in Table 4.

The formula for calculating photovoltaic power generation is as follows:

Table 4: Related meteorological data of Damaoqi, Baotou city.

Month	Global horizontal irradiance/kWh·m^2	Diffuse horizontal irradiance/kWh·m^2	Environmental temperature/°C
January	88.10	19.28	-9.13
February	104.20	30.11	-5.09
March	141.50	47. 00	2.06
April	173.50	71.70	9. 50
May	201.90	78.72	16.10
June	191.60	92.87	20.37
July	185.40	85. 64	23.15
August	172.60	71.16	20.87
September	146.50	56. 50	14.89
October	121.30	39.16	8.22
November	83.70	28. 06	-0. 48
December	74.90	20.35	-7.49
The whole year	1685.20	648.80	7.82

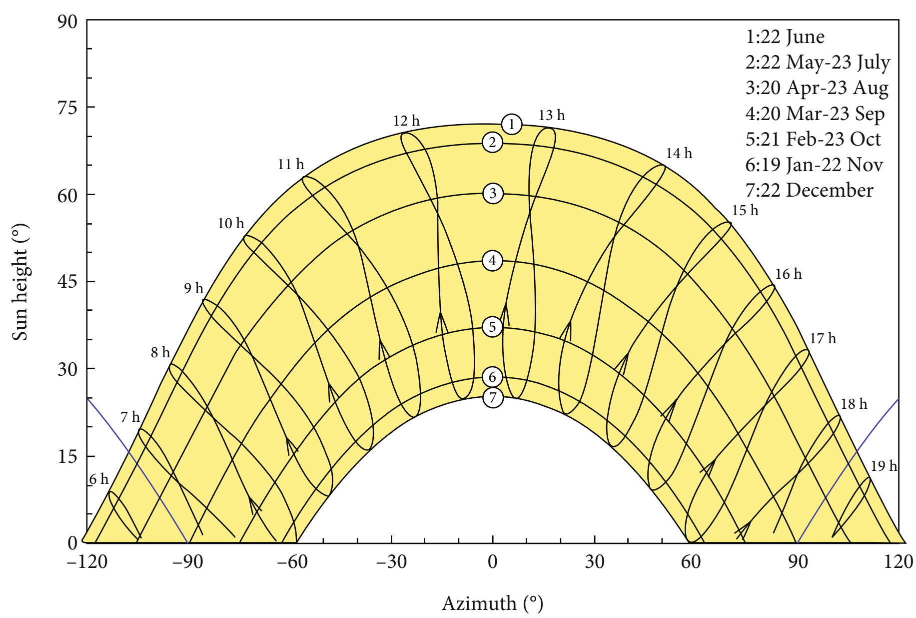

Figure 4: Trajectory map of solar altitude by month.

$$E_P = H_A \times A\eta_i \times K = H_A \times \frac{P_{AZ}}{E_S} \times K, \quad (1)$$

where H_A represents global horizontal irradiance (kW·h/m^2); A stands for the installation area of components (m^2); η_i denotes the conversion efficiency of components (%); K refers to comprehensive efficiency coefficient.

The trajectory map of solar altitude in different months is shown in Figure 4. The total power of laboratory equipment, PV power generation efficiency, and system cost of the field station were calculated and analyzed. In addition, the formula for the calculation of power generation was combined to finally determine the scale of the distributed PV power generation system as 8 kWp.

3.4. PV Module Design. In this paper, the solar cell module with the best comprehensive indicators was selected through comparative analysis and by combining it with the natural environment and construction and transportation conditions around the field laboratory station [17]. As an important component of the power system of solar power plants, the PV module is a device used to convert solar energy into electricity. The PV modules of the solar system have a variety of types. The types, efficiency, advantages, and disadvantages of commonly used solar cells are shown in Table 5.

The electrical performance, life, and other important indicators of the two solar modules showed little difference. In crystalline silicon PV cells, the conversion efficiency of monocrystalline silicon was higher than that of polycrystalline silicon. The single-chip photoelectric conversion efficiency of

Table 5: Summary table for the classification of solar cells (IEC60904-3: 2008, ASTM G-173-03 global).

Category	Cell type	Actual efficiency	Advantages	Disadvantages
Crystalline silicon cell	Monocrystalline silicon	15%~21%	High efficiency and maturity	High cost
	Polycrystalline silicon	14%~20%	High efficiency and maturity	High cost
Thin film cell	Noncrystalline silicon	8%~11%	Good weak light effect	Low efficiency
	Cadmium telluride	12%~14%	Good weak light effect	Environmental protection
	Copper indium diselenide	9%~11%	Good weak light effect	High cost
Concentrator cell	High-concentration light gathering	20%~27%	High efficiency	High cost

Table 6: Technical parameters of PV modules.

No.	Parameter	Numerical value
1	Size (mm)	$1215 \times 545 \times 30$
2	Test conditions	STC
3	Peak power (Wp)	100
4	Peak voltage (V)	36.40
5	Peak current (I)	2.75
6	Open-circuit voltage (V)	44.80
7	Short-circuit current (I)	3.06
8	Component efficiency (%)	17.74
9	Weight (kg)	9.50
10	Open-circuit voltage temperature coefficient	-0.30%

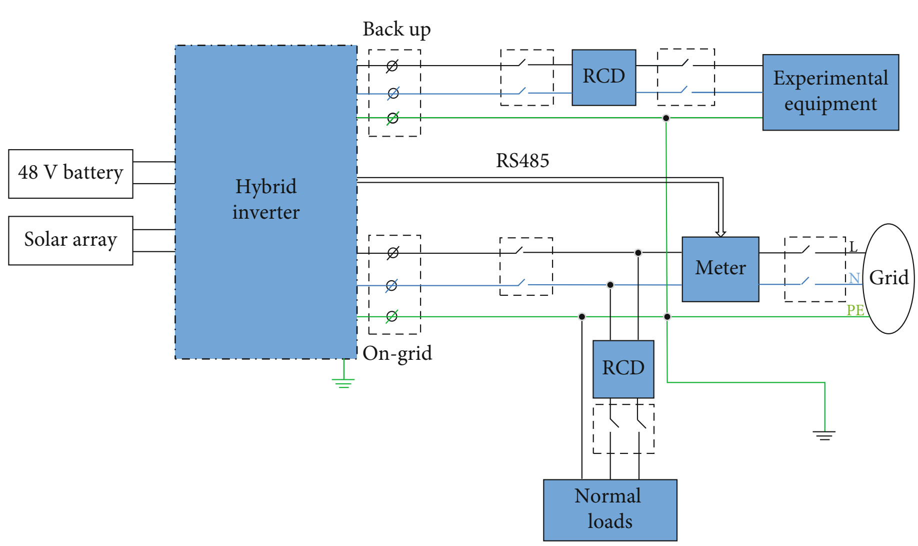

Figure 5: Wiring diagram of the electrical system.

monocrystalline silicon cells was about 18%, while that of polycrystalline silicon cells was about 17%. As shown in Table 4, the photoelectric conversion efficiency of monocrystalline silicon was about 1% higher than that of polycrystalline silicon in terms of crystalline silicon PV cells [18]. In recent years, passivated emitter and rear cells have been able to improve the absorption efficiency of long-wave light, which thus increases the conversion efficiency of batteries. The improved conversion efficiency is about 0.5% (polycrystalline silicon) and 1% (monocrystalline silicon).

To ensure the stability and power generation efficiency of the system, monocrystal silicon PV cells with a capacity of 100 Wp were selected after comparative analysis. Their parameters are shown in Table 6.

3.5. Electrical System Design. In this paper, a 100 Wp monocrystalline silicon PV module and a 5 kWp inverter were selected for the design. The construction capacity is 5 kW (alternating current side), and the installed capacity at the direct current (DC) side is 8 KWp. Each 4 KWp PV power

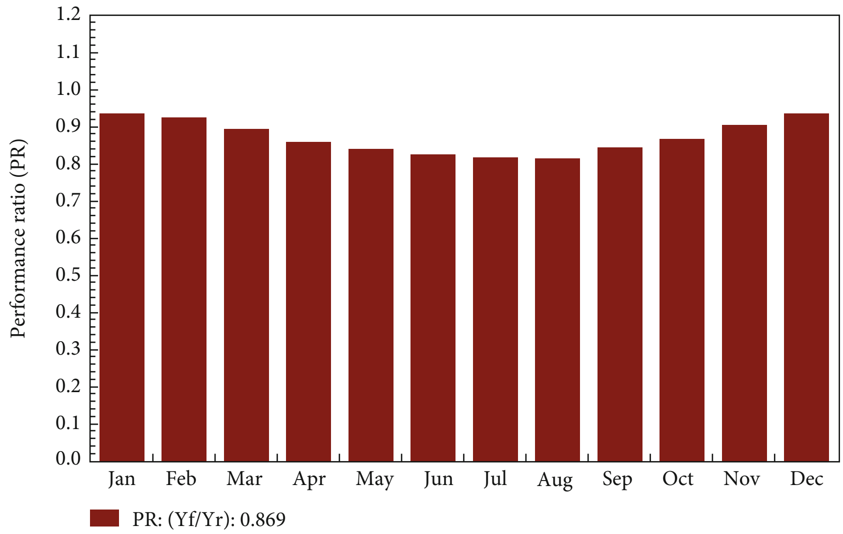

Figure 6: Self-generated electricity for self-use and surplus electricity for grid-connection system.

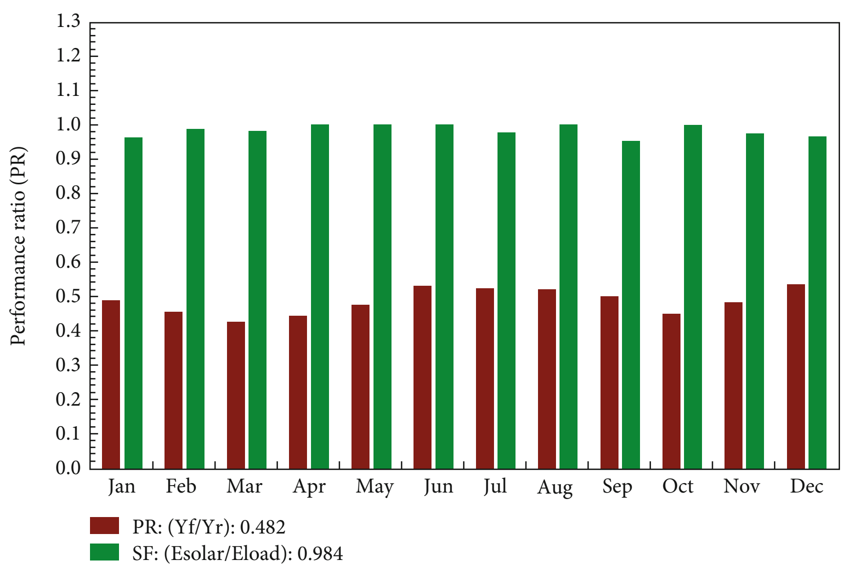

Figure 7: Off-grid PV power generation system.

generation unit was installed with 40 100 Wp PV modules. Every 10 photovoltaic modules in series formed a circuit branch, and a total of eight circuit branches were formed. A 5 KW inverter was used in the one PV zone. PV modules were connected to the 5 kW inverter (two maximum power point tracking (MPPT) channels) after passing through a DC confluence box (eight in and two out). On the premise of guaranteeing DC side capacity, the scheme maximized the use of the capacity space of the inverter. In this study, a 5 kW energy storage inverter was chosen to configure battery capacity according to the situation of one-day independent operation without PV input. The system selected and used two lithium batteries with a rated voltage of 51.2 V and a rated capacity of 5.4 kWh to form a battery pack. The battery pack has a rated voltage of 51.2 V and a rated capacity of 10.8 kWh. The wiring diagram of the electrical system is shown in Figure 5.

4. System Simulation and Experiment

PVsyst is the most commonly used software for designing and estimating the performance parameters of solar PV power stations. The software can import different optical resources and experimental test data to evaluate the performance parameters of PV power generation systems in off-grid and grid-connected systems. Through system simulation, the overall system performance of PV power stations can be evaluated. PVsyst was used to simulate the annual power generation and system scheme of the PV power generation system of Inner Mongolia Yinshanbeilu Grassland Eco-hydrology National Observation and Research Station.

4.1. System Simulation Analysis. Two kinds of photovoltaic power generation systems were simulated and analyzed by use of PVsyst. The annual power generation was 14,228 kWh,

Figure 8: Photovoltaic panel site array view.

Figure 9: Inverter and control cabinet diagram.

and the simulation result of the annual self-use electricity in the mode of self-generated electricity for self-use and surplus electricity for grid-connection was 7,811 kWh. This satisfied the electric load of laboratory equipment in the field station in one year. The annual on-grid electricity of the power generation system using this mode was 6,417 kWh. The performance ratio (PR) of the system was the overall efficiency of the PV system [19].

$$\mathrm{PR} = \frac{Y_f}{Y_r}, \tag{2}$$

where Y_f represents the daily available energy of the system, kWh/kW; Y_r stands for incident energy, kWh/kW. Through simulation and calculation, the monthly PR value of the PV power generation system adopting the mode of self-generated electricity for self-use and surplus electricity for grid connection is shown in Figure 6.

Some laboratory equipment required 24 h data monitoring. Thus, the PV power generation system adopting the off-grid system mode needed to be equipped with a battery pack. After an analysis of the reliability and economical efficiency of a load of laboratory equipment, it was confirmed that the system configured with 10.8 kWh batteries can meet the electrical load of laboratory equipment at night. The histogram of PR values of the off-grid PV power generation system is shown in Figure 7. The energy produced by PV panels during the day was not fully utilized, which thus led to the PR value of 0.574.

To ensure the operational reliability of laboratory equipment at night, batteries were configured to avoid the stoppage of laboratory equipment due to power failure, reduce investment costs, and facilitate future maintenance. Under the premise of not changing battery capacity, the frequency band of the acquisition time of electrical equipment was optimized, and the sampling time of some high-power laboratory equipment was changed to use when the light was sufficient. In this way, the energy loss of the power system was reduced, and the use efficiency of energy was optimized, which hence improved the PR value [20].

Comprehensive consideration was given to the overall efficiency of the PV system and the actual requirements of laboratory equipment in the field station. At last, the PV power generation system adopting the mode of self-generated electricity for self-use and surplus electricity for grid-connection was selected and used for system building.

4.2. Test System Building. The array diagram of PV modules after system building is shown in Figure 8. PV modules were connected to the inverter in the blue container in the form of buried cables through the confluence box. The inverter and battery pack (as shown in Figure 9) were then connected to the power distribution cabinet of the field laboratory station. Finally, the PPV power generation test system was built.

The real-time monitoring system of the web terminal was established to monitor the electricity consumption of the national field station. The monitoring interface is shown in Figure 10.

4.3. Comparative Analysis of Test and Simulation Data. The monitoring data of PV power generation in one year was compared with the data simulated by PVsyst. As shown in Figure 11, the one-year simulated power generation was compared with the actual power generation of the system.

Figure 10: Monitoring platform of test data.

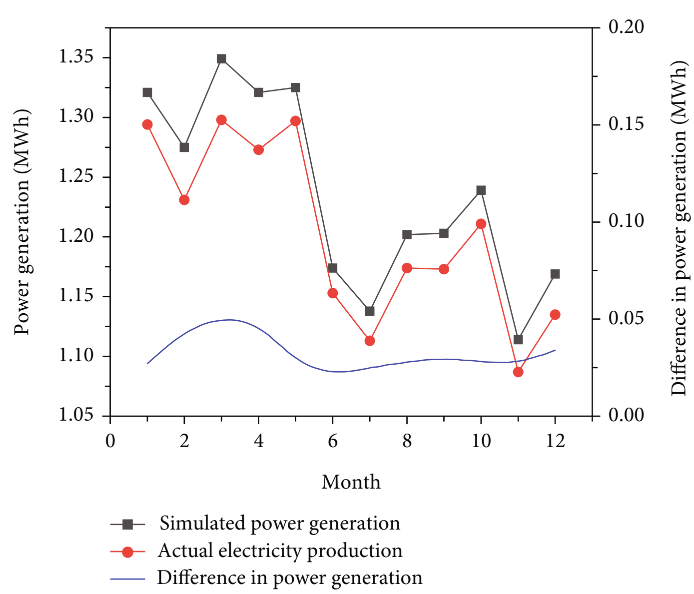

Figure 11: Comparison diagram of annual power generation.

The coordinate on the right was the difference between simulated and actual power generation. The maximum difference of power generation was no more than 0.05 MWh, which was within the controllable range. This proves that the simulation of the power generation system has certain reliability. Figure 12 shows detailed information on annual electricity consumption. It can be seen that the power generation of the system can satisfy the basic electricity consumption of laboratory equipment in the field station. A part of the electricity was supplied from the power grid, but the power supply from the power grid accounted for 2.71% of annual electricity consumption, which was in line with expectations. Therefore, the system can meet the daily use needs of the field station.

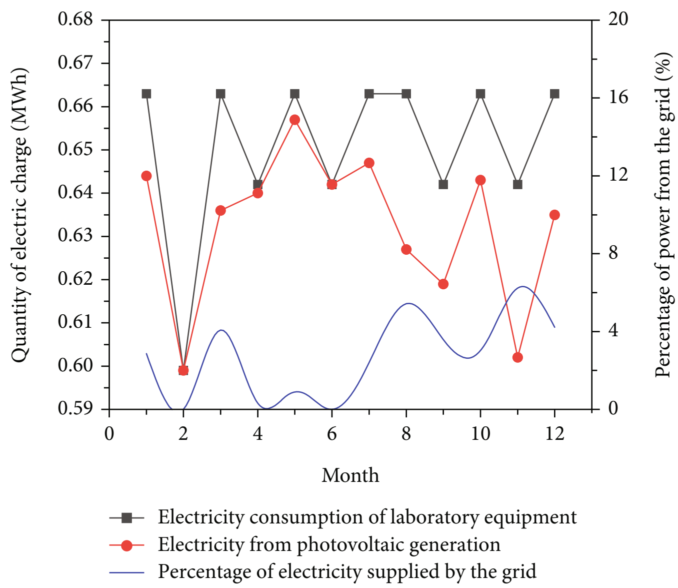

FIGURE 12: Detailed diagram of annual electricity consumption.

TABLE 7: Table for the amount of energy saving and emission reduction.

Energy conservation and emission reduction item	The annual amount of energy saving and emission reduction	Amount of energy saving and emission reduction during operation (20 years)
Carbon dioxide (CO_2)/t	14.396	287.914
Carbon dust/t	3.927	78.548
Sulfur dioxide (SO_2)/t	0.433	8.663
Nitric oxide/t	0.217	4.332

4.4. Environmental Benefit Analysis. Thermal power generation will produce a lot of dust particles, sulfur dioxide, and nitrogen oxide, which seriously pollute the environment. In China, coal-based power generation takes up more than 70% of the total power generation. Solar PV power generation systems are characterized by zero emission and pollution [21, 22].

According to the average energy consumption of power generation in China, each kilowatt-hour saved contributes to the reduction of various pollution indicators. As a result, information on the energy conservation and emission reduction of the power generation project was obtained [23]. The 8 kW PV power generation system of the field observation station generated 14.439 MWh of electricity annually. The corresponding emission reduction is shown in Table 7.

5. Conclusion

In this paper, a set of distributed PV power generation systems was designed. The load of laboratory equipment in a national field station was analyzed. The annual power generation, power loss, and PR values of the PV power generation system adopting the mode of self-generated electricity for self-use and surplus electricity for grid connection and the off-grid PV power generation system were simulated and analyzed by PVsyst software. The system scheme was determined, and the distributed PV power generation test system was built. The monitoring and simulation results of one-year PV power generation data were compared and analyzed to obtain the difference between simulated and actual power generation. The maximum difference in power generation was no more than 0.05 MWh. Power supply from the power grid accounted for 2.71% of annual electricity consumption. The system met expectations and satisfied the daily use needs of laboratory equipment in the field station on the premise of ensuring economical efficiency. In the meantime, the system generated 14.439 MWh of electricity throughout the year. It can reduce the emissions of about 287.914 t of CO_2, 78.548 t of carbon dust, 8.663 t of SO_2 and 4.332 t of nitrogen oxides after 20 years of operation.

The design method of this paper provides valuable experience for constructing the power supply system of field scientific observation stations. Using distributed generation technology to supply power to field scientific observation stations cannot only solve the problem of low power supply guarantee rate caused by field observation stations located at the end of power grids but also protect the fragile ecosystem from being destroyed. It is concluded that the off-grid PV power generation system is effective and suitable for supporting the power consumption of power supply equipment. The scheme was determined through analysis. The off-grid PV power system is feasible technically and economically.

The effective use of solar PV power generation can reduce carbon emissions and achieve the purpose of energy conservation and environmental protection while building zero-carbon field observation stations. In addition, it can promote the development and expansion of solar power generation technology and provide a good design basis and reference significance for the application of PV power generation technology in field laboratory stations in the future.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Central Funds to guide local science and technology development of China (nos. 2021ZY0030 and 2022ZY0027), the Inner Mongolia Autonomous Region Science and Technology Plan Project (no. 2021GG0051), the China Academy of Water Sciences Section Basic Scientific Research Business Fund Special Project (no. MK2021J03).

References

[1] P. Shrivastava, T. K. Soon, S. Mekhilef, and F. Ahmad, "Economic and environmental analysis of a solar-powered EV charging system in India—a case study," in *Innovations in Electrical and Electronic Engineering*, S. Mekhilef, M. Favorskaya, R. K. Pandey, and R. N. Shaw, Eds., vol. 756 of Lecture Notes in Electrical Engineering, pp. 301–315, Springer Singapore, Singapore, 2021.

[2] Q. Q. Miao, S. C. Yan, and Z. X. Ping, "Photovoltaic technology under carbon neutrality," *Chemical Progress*, vol. 41, no. 3, pp. 1125–1131, 2022.

[3] H. Yigeng, A. Xiaotong, R. Ma, and G. Luo, "Multi-mode energy control and management for stand-alone wind-photovoltaic hybrid power system," *Journal of Northwestern Polytechnical University*, vol. 31, no. 3, pp. 470–475, 2013.

[4] F. Ahmad, M. S. Alam, and I. S. Alsaidan, "Campus microgrid: a case study," in *2020 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, pp. 1–6, Chicago, IL, USA, 2020.

[5] M. Z. U. Abideen, O. Ellabban, F. Ahmad, and L. al-Fagih, "An enhanced approach for solar PV hosting capacity analysis in distribution networks," *IEEE Access*, vol. 10, pp. 120563–120577, 2022.

[6] M. H. Amrollahi and S. M. T. Bathaee, "Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response," *Applied Energy*, vol. 202, pp. 66–77, 2017.

[7] A. F. Crossland, O. H. Anuta, and N. S. Wade, "A socio-technical approach to increasing the battery lifetime of off-grid photovoltaic systems applied to a case study in Rwanda," *Renewable Energy*, vol. 83, pp. 30–40, 2015.

[8] B. K. Das, N. Hoque, S. Mandal, T. K. Pal, and M. A. Raihan, "A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh," *Energy*, vol. 134, pp. 775–788, 2017.

[9] S. Mandelli, C. Brivio, E. Colombo, and M. Merlo, "A sizing methodology based on levelized cost of supplied and lost energy for off-grid rural electrification systems," *Renewable Energy*, vol. 89, pp. 475–488, 2016.

[10] M. S. Ismail, M. Moghavvemi, and T. Mahlia, "Techno-economic analysis of an optimized photovoltaic and diesel generator hybrid power system for remote houses in a tropical climate," *Energy Conversion and Management*, vol. 69, pp. 163–173, 2013.

[11] A. Kaabeche and R. Ibtiouen, "Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system," *Solar Energy*, vol. 103, pp. 171–182, 2014.

[12] T. Lang, D. Ammann, and B. Girod, "Profitability in absence of subsidies: a techno-economic analysis of rooftop photovoltaic self-consumption in residential and commercial buildings," *Renewable Energy*, vol. 87, pp. 77–87, 2016.

[13] C. Li and W. Yu, "Techno-economic comparative analysis of off-grid hybrid photovoltaic/diesel/battery and photovoltaic/battery power systems for a household in Urumqi, China," *Journal of Cleaner Production*, vol. 124, pp. 258–265, 2016.

[14] C. Li, D. Zhou, W. Yu et al., "Performance of off-grid residential solar photovoltaic power systems using five solar tracking modes in Kunming, China," *International Journal of Hydrogen Energy*, vol. 42, no. 10, pp. 6502–6510, 2017.

[15] A.-J. Perea-Moreno, Q. Hernandez-Escobedo, J. Garrido, and J. Verdugo-Diaz, "Stand-alone photovoltaic system assessment in warmer urban areas in Mexico," *Energies*, vol. 11, no. 2, p. 284, 2018.

[16] R. Siddaiah and R. Saini, "A review on planning, configurations, modeling and optimization techniques of hybrid renewable energy systems for off grid applications," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 376–396, 2016.

[17] Z. Guanglei, "Design of off-grid photovoltaic power generation and utility complementary automatic switching system," *Science and Technology Innovation Herald*, vol. 15, no. 35, pp. 62-63, 2018.

[18] H. Zhu, *Study on the comprehensive benefits of HD's Henan Ruyang 50MW photovoltaic power generation project*, Nanjing University of Aeronautics and Astronautics, 2018.

[19] H. Wei, *Feasibility Study of Photovoltaic Power Plant Investment Project in Aba*, Chongqing University, Sichuan, 2015.

[20] S. Dofeng, L. Zhenpeng, Z. Siqing, W. Shuyu, and Z. Zhiyan, "Design and research of residential photovoltaic power generation system based on PVsyst," *Power Technology*, vol. 45, no. 4, pp. 499–502, 2021.

[21] N. Gaoyuan, W. Yixiao, G. Xiaowei, C. Wang, M. Zhao, and M. Zhu, "Study of efficiency analysis and optimization for distributed grid_connected photovoltaic power generation systems based on PVsyst," *Renewable Energy*, vol. 2, p. 7, 2016.

[22] L. Xiaowei, L. Zhaogang, T. Wensong, and C. Zhang, "Study on the economic and social benefits of 3kW distributed photovoltaic power generation system," *Green Technology*, vol. 4, pp. 253–255, 2015.

[23] Z. Cai, X. Bo, X. Huaqing et al., "The role of new energy in carbon neutral," *Petroleum Exploration and Development*, vol. 48, no. 2, pp. 411–420, 2021.