Design and benefit analysis of intelligent distributed photovoltaic microgrid system in plateau Alpine Region

Min Wu *, Zewei Pu, SANGYONGLAMU, Wenyang Wang, Chengpeng Liu
Tibet Autonomous Region Energy Research Demonstration Center, Lasa 850000, China

*Corresponding author e-mail: xizangnengyuan@163.com

Abstract. Intelligent distributed photovoltaic microgrid technology is conducive to the rational and large-scale development and utilization of solar energy resources, which is one of the important components of the future power system in Plateau and alpine regions. However, the efficiency of solar energy collection and utilization is greatly affected by the natural environment, and it is unstable, random and uncontrollable. Therefore, the reliability of power supply and the quality of power supply have become the breakthrough problems of intelligent distributed photovoltaic microgrid technology. In view of the stable operation of the intelligent distributed photovoltaic microgrid system in the plateau alpine region, this paper designs the photovoltaic module, energy storage management system and real-time monitoring system of the micro grid system, and analyzes its benefits.

Keywords: Smart microgrid system; Photovoltaic system; Design; Benefit analysis

1. Introduction

It is widely accepted that smart distributed microgrid technology will be one of the important development directions of power system in the future. For developed countries, due to the advanced technology and the early development of power system, they have basically completed the relevant research work on the theory of smart distributed microgrid technology, and implemented the relevant projects with relatively mature technology. In 2003, in order to study the basic theory of smart distributed microgrid system in operation, monitoring, protection and communication, the EU science and technology framework program carried out two smart distributed microgrid projects: Microgrids and More microgrids [1], and established demonstration projects in Greece, the Netherlands and other member states; At the same time, in 2003, in order to conduct more in-depth research on new energy power generation technology, energy management and system monitoring technology, Japan's new energy industry development agency established demonstration projects in Aichi County, Kyoto and Aomori respectively [2]; In 2005, the British government established an intelligent distributed microgrid system in its capital city for grid connection switching [3]; In 2006, DOE and Ge in the United States carried out research on the commercial use of smart distributed microgrid technology and the impact of distributed generation on municipal power grid through cooperative development [4]; In the same year, not only the U.S. Department of energy proposed to take the smart distributed microgrid system as one of the important components of the future power system, but also the national solar Institute of Germany
established a smart microgrid laboratory with a distribution capacity of 200 kVA [5]; In 2010, Japan carried out demonstration research on smart distributed microgrid system by establishing Intelligent Community Alliance [6]. The research work on smart distributed microgrid system in China is mainly reflected in the "863" and "973" plans. In 2008, Tianjin University carried out the research on the optimization of operation strategy for the smart distributed microgrid system using various new energy sources for power generation [7]; In the same year, Hefei University of technology built a laboratory platform to study the coupling and coordinated operation of intelligent distributed microgrid system in the aspects of energy management and intelligent monitoring [8].

This paper mainly studies the design and benefit analysis of intelligent distributed photovoltaic microgrid system in Plateau and alpine region (Lhasa). It mainly includes the design of solar photovoltaic power generation system, energy storage system design, monitoring system design and the prediction benefit of the whole micro grid system. The research content of this paper has practical significance for the development of smart distributed microgrid system in Tibet. As a participant of the project, the author participated in the design and implementation of the whole microgrid system.

2. System design

The project is located in the Tibet Autonomous Region Energy Research Demonstration Center. It is composed of one set of photovoltaic power generation unit. The total installed capacity of photovoltaic modules is 45.9kWp. It is respectively arranged on the roof of old and new dormitory buildings and garages. It is equipped with two DC combiner boxes, one 50kVA energy storage inverter, 240kWh battery pack and one AC grid connected cabinet connected to the low-voltage side bus of distribution transformer. In order to realize the photovoltaic module power generation directly connected to the grid in the case of power supply, in the absence of power supply, the micro grid is established through the energy storage inverter to provide power for specific office buildings. In the energy storage building photovoltaic system, the battery is used to continuously provide power to specific office buildings through dual-mode inverter under special conditions such as no electricity, no sunlight and so on.

2.1. Design of photovoltaic system

In this paper, the solar photovoltaic module installation area of the project mainly includes three parts, namely, the roof of the new and old dormitory building and the roof of the garage. The layout of photovoltaic modules is shown in Figure 1. The 255Wp polysilicon module is selected as the solar photovoltaic module. The module size is 1650 × 990 × 40 (mm), the open circuit voltage is 37.7V, the MPPT voltage is 30V, and the short circuit current is 9.01A. 18 modules are connected in series into one string. Three strings can be installed in the new dormitory building, four strings can be installed in the old dormitory building, and three strings can be installed in the garage. A total of 180 photovoltaic modules are installed, with a DC power of 45.9kW.

![Fig. 1 layout scheme of solar PV modules](image)

2.1.1. The structure of smart micro grid in the United States.

The layout of solar photovoltaic array should avoid the shading caused by the shadow formed by roof structures or other tall buildings.
Otherwise, in the shading part, instead of power output, it will consume power, form local heating, and produce "hot spot effect", which will damage the solar photovoltaic module in serious cases. The determination principle of shadow shading is as follows: the solar altitude angle on the winter solstice is the lowest in the middle of the year, and the space D of the square array should be greater than the maximum length of the shadow at 9:00 a.m. and 15:00 p.m. during the winter solstice, so as to ensure that no shadow shading occurs in this period of time, then the solar photovoltaic array will not be shaded when the solar radiation is within the best utilization range of one year. According to the geographical latitude, solar motion and altitude difference of the project site, the maximum shadow length D can be calculated by the following formula.

\[
D = \cos \beta \times H \div \tan(\arcsin \alpha)
\]  

(1)

\[
\sin \alpha = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega
\]  

(2)

\[
\sin \beta = \cos \delta \sin \omega \div \cos \alpha
\]  

(3)

Where: \( \phi \) is the local latitude (positive in the northern hemisphere and negative in the southern hemisphere), and the north latitude of the project site is 29.66°; \( \delta \) is the declination angle of the sun on the winter solstice, and the project location is -23.5°; \( \omega \) is the hour angle, the time angle of 9:00 a.m. and 3:00 p.m. is ±45°; \( \alpha \) is the height angle of the sun; \( \beta \) is the azimuth of the sun.

In this paper, the solar photovoltaic array on the roof of the project adopts the best vertical inclination arrangement of single row, that is, when \( \theta = 35^\circ \), \( D = 3.05 \text{m} \) is obtained, and the design value in this paper is 3.1m.

### 2.1.2. Calculation of series parallel connection number of photovoltaic modules.

In this project, the determination of series parallel connection number of solar photovoltaic modules needs to match with the selected grid connected inverter. The matching calculation value and formula are as follows:

a) Calculation parameters of solar photovoltaic modules

As 255Wp polycrystalline silicon solar photovoltaic modules are selected for this project, the technical parameters are shown in Table 1. In order to ensure the safe and reliable operation of the solar photovoltaic system, according to the meteorological data of the construction site, the photovoltaic system should be able to work normally at -20°C~70°C. As the parameters of solar photovoltaic modules will change under the limit temperature, the temperature coefficient should be as shown in Table 2.

**Tab. 1** Technical parameters of 255wp polysilicon solar photovoltaic module

| Project                        | Parameter                | Value          |
|--------------------------------|--------------------------|----------------|
| **Electrical properties**      | Maximum power (Pm)       | 255            |
|                                | Tolerance of output power (%) | 0~+5          |
|                                | Conversion efficiency of components (%) | 15.0          |
|                                | Optimum operating voltage (Vm) | 30            |
|                                | Optimum operating current (Im) | 8.34          |
|                                | Open circuit voltage (Voc)  | 37.7           |
|                                | Short circuit current (Isc) | 9.01           |
|                                | Maximum system voltage (V) | 1000           |
| **Temperature characteristic** | Rated operating temperature of battery (°C) | 46            |
|                                | Temperature coefficient of peak power (1/K) | -0.0045       |
|                                | Temperature coefficients of Voc (1/K) | -0.0032       |
|                                | Temperature coefficient of short circuit current (1/K) | 0.0005       |
| **Other**                      | Working temperature      | -40°C~85°C     |
|                                | Stored temperature       | -40°C~85°C     |
|                                | Maximum snow pressure    | 5400Pa         |
|                                | Maximum wind pressure    | 2400Pa         |
|                                | Size (L×W×T)             | 1650mm×990mm×40mm |
Tab. 2 Temperature coefficient of 255Wp polycrystalline silicon solar photovoltaic module

| Project                                      | Company | Data     |
|----------------------------------------------|---------|----------|
| Temperature coefficient of peak power       | I/K     | -0.0045  |
| Temperature coefficients of Voc             | I/K     | -0.0032  |
| Temperature coefficient of short circuit current | I/K | +0.0005  |

b) The calculation formula of series parallel combination of solar photovoltaic modules is as follows [9]:

\[
N \leq \frac{V_{dc\text{ max}}}{V_{oc} \times \left[ 1 + (t - 25) \times K_v \right]}
\]

\[
\frac{V_{mppt\text{ max}}}{V_{pm} \times \left[ 1 + (t - 25) \times K_v' \right]} \leq N \leq \frac{V_{mppt\text{ min}}}{V_{pm} \times \left[ 1 + (t - 25) \times K_v' \right]}
\]

Where: N is the serial number of solar photovoltaic modules (N takes integer); Kv is the open circuit voltage temperature coefficient of solar photovoltaic module; Kv’ is the working voltage temperature coefficient of solar photovoltaic module; t is the extreme low temperature of solar photovoltaic modules under working conditions, ℃; t’ is the extreme high temperature of solar photovoltaic modules under working conditions, ℃; Vdc max is the maximum allowable DC input voltage of the inverter, V; Vmppt max is the maximum value of inverter MPPT voltage, V; Vmppt min is the minimum value of inverter MPPT voltage, V; Voc is the open circuit voltage of the solar photovoltaic module, V; Vpm is the working voltage of the solar photovoltaic module, V.

Through the calculation of the above formula, we can get that: for the grid connected inverter and charging controller, when designing the number of solar photovoltaic series, we should also consider the problem of electrical insulation performance derating in Plateau and alpine region (the capacity reduction is about 10% for every 1000m elevation). Therefore, it is most appropriate for each branch to connect 18-20 solar photovoltaic modules in series, and 18 solar photovoltaic modules are selected in this paper.

2.2. Design of energy storage system

2.2.1. Energy storage inverter. In this paper, the energy storage inverter is a power electronic interface device connected with municipal power grid, solar photovoltaic modules and energy storage batteries. The AC / DC bidirectional conversion function of voltage and current can be realized through control. It consists of maximum power tracking module, main power part, signal detection part, control part, driving part, monitoring and display part and auxiliary power supply. In this paper, the required functions of the energy storage inverter are as follows:

a) It can realize switching operation mode between grid connected and off grid;

b) Battery charging function;

c) Battery charge and discharge protection function.

The charging and discharging modes of the energy storage system are as follows:

a) Charging: operate in P/Q source mode and charge with constant power following grid voltage;

b) Discharge: operate in V / F source mode, output a constant voltage and frequency, supply power according to the actual load demand of the user side.

In addition, the energy storage system should also have the following characteristics:

a) Comprehensive and multi-level battery protection strategy, fault isolation measures, high security;

b) Open Ethernet interface design can provide convenient communication interface;

c) The operation of lithium battery system is affected by temperature. The energy storage system has designed a set of battery system and battery management system with cold resistance performance, which can run efficiently in the plateau alpine region, ensure the load power supply and backup power.
demand, have the temperature compensation function, and flexibly respond to the temperature change in the plateau and alpine region;

d) In view of the situation of thin air, low temperature and frequent electrostatic phenomena in Plateau and alpine areas, a battery management system suitable for plateau and alpine regions is developed. The cold resistance is improved, and the effective anti-static function is provided. The battery management system can quickly detect the information of battery operation and respond to the fault information quickly.

2.2.2. Battery management system. In this paper, the battery management system (BMS) consists of: battery management unit BMU, battery string management system MBMS, battery stack management system BAMS and high voltage control box HVC. The BMS system has the functions of high precision analog signal detection and reporting, fault alarm, upload and storage, battery protection, parameter setting, active equalization, battery pack SOC calibration and information interaction with other equipment. In this design, the BMS system is designed for the situation that the air is thin, the temperature is low, and the static electricity phenomenon is frequent in the alpine region of Tibet Plateau. The battery management system is designed for the plateau alpine region. Fig.2 is the composition diagram of the battery cabinet.

![Composition diagram of battery cabinet](image)

2.3. Design of monitoring system
This paper adheres to the principles of scientific safety, green environmental protection, and intensive land use, so as to promote the environment-friendly development under the condition of minimizing the construction period of the project. The key technologies of the monitoring system are as follows:

a) Self learning SOC/SOH evaluation algorithm: both conventional SOC estimation and battery system capacity estimation have the problem of cumulative error, so it is difficult to realize the available capacity of battery system and the accuracy of SOC calibration. This design adopts the unique SOC patent technology of Shenzhen xinwanda. According to the real-time status of the system, it can learn independently and correct independently, which can effectively eliminate the accumulated error and improve the accuracy of SOC/SOH calibration;

b) Lossless equalization technology: in this paper, through real-time monitoring the operation status of each power saving cell, the high-efficiency equalization technology is adopted to ensure the consistency of each string of cells and prolong the service life of the whole system;

c) High precision information acquisition technology: the higher the accuracy of information acquisition, the higher the reliability, consistency and SOC accuracy of the cell. This paper selects Shenzhen xinwanda mature BMS system;

d) Battery consistency assurance technology: in this paper, all cells are required to pass the strict automatic sorting, equalization, thermal management and other aspects of technical testing to ensure the consistency of each cell during the system operation, so as to extend the service life of the system.

3. Benefits of the system

3.1. Forecast of power generation
In this paper, the total efficiency of the intelligent distributed photovoltaic microgrid system is determined to be about 80% by comprehensively considering the effects of solar photovoltaic module.

efficiency, low voltage confluence, energy storage inverter efficiency and AC efficiency. The power output attenuation range of solar photovoltaic power generation system is - 0.8% per year in 25 years operation cycle, until the end of 25 years. Therefore, it is estimated that after the completion of the project, the annual average power generation is about 73000 kWh, and the average annual equivalent installed utilization hours is about 1738h. Table 3 shows the forecast of annual power generation in 25 years.

| Time | Power generation (kWh) | Time | Power generation (kWh) |
|------|------------------------|------|------------------------|
| Year 1 | 79774.20576 | Year 14 | 72081.68572 |
| Year 2 | 78896.68383 | Year 15 | 71541.07305 |
| Year 3 | 78304.95867 | Year 16 | 71004.51501 |
| Year 4 | 77717.67148 | Year 17 | 70471.98114 |
| Year 5 | 77134.78895 | Year 18 | 69943.44129 |
| Year 6 | 76556.27803 | Year 19 | 69418.86548 |
| Year 7 | 75982.10594 | Year 20 | 68898.22398 |
| Year 8 | 75412.24015 | Year 21 | 68381.48731 |
| Year 9 | 74846.64835 | Year 22 | 67868.62615 |
| Year 10 | 74285.29848 | Year 23 | 67359.61145 |
| Year 11 | 73728.15875 | Year 24 | 66854.41437 |
| Year 12 | 73175.19756 | Year 25 | 66353.00626 |
| Year 13 | 72626.38357 | | |

3.2. Environmental benefit

Because fossil energy such as coal, oil and natural gas is non-renewable, and solar photovoltaic power generation uses solar light to generate electricity, and there is no noise, waste and waste gas in the process of power generation, it is a real renewable energy. In this paper, the power generated by the intelligent distributed microgrid system in the first 1 to 1.5 years can offset the energy consumed by photovoltaic equipment in the production process, which is really environmentally friendly and sustainable.

It is predicted that after the completion of the project, the power generation in the first year can reach 79774.2kWh, which can reduce the emission of carbon dioxide (CO2) by 79774.2Kg/year, which is equivalent to planting 4.36 trees. At the same time, it can also reduce sulfur dioxide (SO2) emission by 126.45Kg/year, smoke emission by 19.51Kg/year, and nitrogen oxide (NOx) emission by 126.45Kg/year. It has made due contributions to the protection of the ecological environment in Tibet.

4. Conclusion

Based on the actual project, this paper designs the solar photovoltaic power generation system, energy storage management system and real-time monitoring system of the intelligent distributed photovoltaic microgrid system in the plateau alpine region, and analyzes the benefits of the project after completion. In the design of photovoltaic system, according to the actual situation, the maximum shadow length is 3.1m, and the optimal number of PV modules in series is 18-20; In the design of energy storage and monitoring system, we should mainly consider the influence of thin air, large temperature difference, low temperature and frequent electrostatic phenomena on the equipment in Plateau and alpine areas. Through the design of this paper, after the completion of the project, the annual average power generation is about 73000 kWh, the average annual equivalent installed utilization hours is about 1738h, and the first year's power generation can reach 79774.2kWh, which greatly reduces the emission of pollution gas and smoke, and achieves the purpose of energy conservation and emission reduction.
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