Design of 10kW Off-grid HCPV Power Generation System

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Abstract

Tibet region were chosen for the power plant site in this paper. And the composition of HCPV power generation system was designed, including the selection of the HCPV modules, the determination of the operating mode of the photovoltaic array, choice of accumulator battery and choice of off-grid inverter， etc. The results show that the annual power generation of the power station is 0.0153 million kW， and has the good economic benefits and environmental benefits.

Keywords

HCPV,off-grid,inverter, benefit.

1. Introduction

With the increasing demand of energy, solar photovoltaic power generation is becoming more and more important to Chinese solar scientists [1-3].Among them, the concentrated photovoltaic(CPV) system has the characteristics of high efficiency, high efficiency and low cost of land use,compared with conventional plate solar cell components [4-7].Recently, it has become the focus of research,many research projects have been carried out at home and abroad,and Many demonstration projects have been completed [8-10].

The western region is relatively large and has a small population, and many areas cannot get electricity through transmission lines.Tibet is the province with the smallest power coverage, because of the high altitude, clean atmosphere, dry air and the low latitude, so the total radiation of the sun is large, between 6000 and 8000MJ/m^2, is the solar energy development and utilization area [11].

Therefore, this paper focuses on the study and design of 10kW off-grid HCPV power generation system in Tibet,and analyzes its economic and environmental benefits, presents that it is of great significance to construction of concentrated power station in Tibet area.

2. Design of HCPV power generation system

The HCPV power generation system is mainly composed of the HCPV modules, sun tracking system, alternating current inverter, solar controller,accumulator battery. The ac-dc inverter is its main component,and the core components are PV modules and controllers. Its principle is to use solar cells convert the sun's light energy into electrical energy, through the control of the controller, on the one hand, to provide the electric circuit and the load directly, on the other hand, the excess electricity is stored in the storage battery.By night, or when the power generated by the solar cell is insufficient, the storage battery supplies the stored electrical energy to the converting circuit and the load.

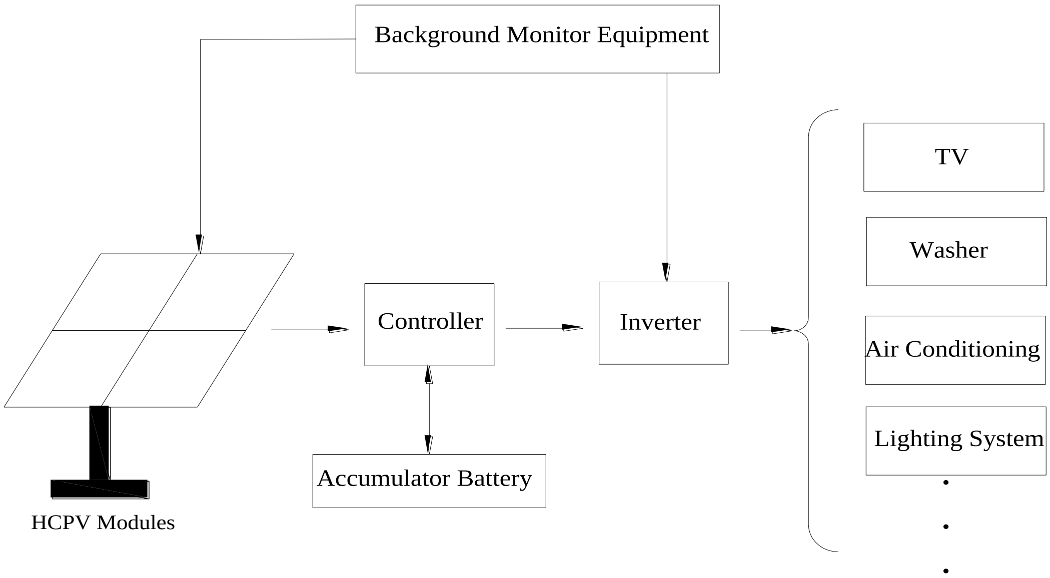

Fig.1 Schematic diagram of off-grid photovoltaic power generation system

2.1 Choice of the accumulator battery

The accumulator battery is the heart of the solar power system,is the shortest service life in the system and needs to be updated after a certain time. Therefore, the life expectancy is an important parameter to choice. In the present independent photovoltaic power generation system, batteries are used as storage devices. It is important to ensure that the load can continue to work for several days without illumination when designing the capacity of the battery.

Assume the average power consumption of the electrical equipment is 10kW.The lead-acid battery is usually used for solar off-grid system. When calculating the battery capacity, it is necessary to consider the power dc and ac load capacity of solar cell array and the efficiency of inverter, we use the following formula for calculation:

$$C = \frac{D \times F \times P_0}{L \times U \times K_a}$$

Where C is the battery capacity(kWh);D is the longest time in the absence of light(d);F is the correction factor of battery discharge efficiency(usually take 1.05);P_o is the average load capacity(kW);L is the battery maintenance rate(usually take 0.8);U is the discharge depth of the battery(usually take 0.5);K_a is the loss rate of ac circuits such as inverters (usually take 0.7).

So the capacity of the required accumulator is calculated according to the following calculation:

$$C=10\times3\times1.05/（0.7\times0.5\times0.8）=112.5\text{kWh}.$$

China's DC standard voltage levels are 12V, 24V, 48V, 110V etc[12]. We chose 24V. The 2 batteries(12V 200Ah) are strung together and divided into 12 groups in parallel. A total of 24 batteries are needed. So the total capacity of the battery is 4800Ah, that is 4800Ah×24V＝115.2 kWh. We selected a company's 6-GFM-200 type lead-acid batteries.The battery has the characteristics of long service life, good seismic performance and high utilization ratio of active material.

2.2 Design of the operation mode of the HCPV array

PV array operation will greatly affect the amount of solar radiation received by the system,thus the power generation capacity of the system is affected. The common PV modules include fixed support, horizontal single axis tracking support, tilt single track support and dual-axis tracking support. In this design, HCPV array must adopt the dual-axis automatic tracking system, which has high tracking accuracy[13].At present, the domestic manufacturers of concentrated dual axis automatic tracking system are very few，We selected a company's self-developed T series dual axis automatic tracking system.This system has the characteristics of high tracking accuracy ($\pm 0.5^{o}$), rotation angle range, its low power consumption, strong wind resistance etc. Its technical parameters are shown in Table 1.

Table.1 Main technical parameters of T series dual axis tracking system

Item	Parameter
Rated DC power	Customizable
Tracking mode	Dual axis automatic tracking
Azimuth tracking range	-135^{o}～135^{o}
Height angle tracking range	0^{o}～80^{o}
Tracking accuracy	$\pm 0.5^{o}$
Maximum operating wind speed	90km/h
Maximum wind resistance	144km/h
Tracking mechanism	Light control/ Time control

2.3 Choice of the HCPV modules

In various large-scale photovoltaic power station projects,monocrystalline silicon and polycrystalline silicon solar cells are widely used. Domestic research on CPV technology is relatively late,and manufacturers of CPV modules are fewer. The CPV module is the core component of solar power system,and its efficiency of photoelectric conversion and the advantages and disadvantages of each parameter index directly affect the electricity generating performance of the whole photovoltaic power system. We selected a relatively mature SKS-M10-33 type CPV module, its technical parameters are shown in Table 2.

The power of the CPV array can be calculated by the following calculation formula:

$$P = W_1 \times F / (T_m \times \eta_2 \times \eta_3 \times L \times K_a)$$

Where W_1 is the consumption power of the load (W);F is correction factor of battery discharge efficiency（usually take 1.05）;T_m is peak sunshine hours, its value is basically the same as the irradiation intensity,5.6h is calculated here; η_2 is a correction factor caused by dust obscuration or aging(usually take 0.9~0.95);η_3 is correction factor for square array loss,maximum power point deviation and controller efficiency(usually take 0.9~0.95);L is maintenance rate of the battery(usually take 0.8); K_a is the loss rate of ac circuits such as inverters (usually take 0.7).

So the power of the CPV array is calculated according to the following calculation:

$$P=10\times1.05/(5.6\times0.95\times0.95\times0.8\times0.8)=3.25\text{kW}$$

Considering that the system can refill the battery in a short amount of time after a continuous rainy day, it is reasonable to consider amplifying the cubic capacit. In this design, dual axis automatic tracking is adopted, and the efficiency of solar radiation receiving solar radiation can be increased by about 39.7% compared with the fixed installation method. Therefore, a set of T series dual axis tracking system is selected to install the SKS-M10-33 type HCPV modules (total 16 pieces) , and the total power is 16 ×218 = 3.488 kW. Since the rated voltage of the system is 24V, the PV array output voltage cannot be too large.According to the limitation of the voltage, the 18 modules are directly connected to the controller.

2.4 Choice of the controller

PV controller is the core part of solar power generation system, there are five types: parallel PV controller, series PV controller, pulse width modulation type PV controller, smart PV controller and maximum power tracking PV controller. Its role is to avoid overcharge and overdischarge.There should also be safety of lightning protection; battery polarity reverse protection; reverse discharge protection at night; full dimensional stereo protectionthe of open circuit, short circuit, overcurrent, overpressure and overpower of the output terminal and ensure the long-term stability of the whole system. We selected a company's QYK series PV controller. The controller has characteristics of high conversion efficiency, low dissipation and good transient response.

Table.2 Main technical parameters of SKS-M10-3 type HCPV modules

Item	Parameter
Peak power	218WpDC
Photoelectric conversion efficiency	26.2%
Voltage of the maximum power output	22.1V
Current of the maximum power output	9.9A
Open circuit voltage	26.5V
Short circuit current,	10.3A
Concentrated ratio	1100X
Battery count	9
Battery type	Three junction III-V solar cell
Heat dissipation technology	Passive aluminum heat dissipation
Size	1.081m×1.081m×5.23m

2.5 Choice of the inverter

The inverter is a device that converts a battery's direct current to 220/380V, 50 Hz alternating current, According to the use of inverters in photovoltaic power generation systems, they can be divided into two types: stand-alone power supply and grid connected. In this design,we pay attention to the following aspects: (a)adequate rated output capacity and load capacity; (b)the higher voltage stability; (c)high efficiency;(d)good overcurrent protection and short circuit protection function. Thus, we selected a company's Sunny Island 2224 type grid inverter, the inverter has the advantages of simple installation, completely from the network management, remote configuration and monitoring, intelligent battery management, high conversion efficiency (93.6%) etc.

3. Calculation and benefit analys of the annual energy output

3.1 Calculation of the annual energy output

There are many factors affecting the annual energy output calculation of the CPV off grid generation system.These factors is not only with the photovoltaic power plant area of light conditions, geographical location, climatic conditions, air quality, but also related to electric power, electricity load and power supply time, also related to the need to ensure the supply of rainy days,and the other is concentrating photovoltaic component orientation, tilt, surface cleanliness, temperature etc.Various factors analysis of concentrating photovoltaic off-grid power generation system are shown in Table3.

Table.3 Various factors analysis table of concentrating photovoltaic off-grid power generation system

Coefficient Code	Coefficient Name	Loss Rate
η_1	Surface cleanliness loss of photovoltaic modules	About 3%
η_2	Temperature increase loss	0.4%/℃
η_3	Square combination loss	About 3%
η_4	Maximum power point deviation loss	About 4%
η_5	Inverter loss	About 6%
η_6	Wire loss	About 3%
η_7	Battery overcharge protection loss	About 3%
η_8	Charge controller loss	About 8%
η_9	Battery efficiency	80～90%
Total η	Whole system	58～66%

In this design, the combined influence factor of the whole generation system is 62%.

In Tibet, the total solar radiation of the whole year is 6000～8000MJ/m^2, we take 7000MJ/m^2, and the common unit of converting it into solar energy is 1944.39kW• h/m^2. According to the standard radiation (AM1.5,1 000W/m^2) conversion, equivalent to the annual standard sunshine time is 1944.39 hours.Therefore, the annual generating capacity of 10kW off-grid HCPV power generation system is 19443.9kW• h (1944.39 ×10000/1000), the actual annual generation capacity is 1.21WkW• h,specific power generation depends on actual solar radiation.

The system employs dual axis automatic tracking system.Compared with fixed installation, the efficiency of the concentrated photovoltaic module receiving solar radiation can increase by about 39.7%. That said, photovoltaic power generation has increased by about 39.7%[14].Therefore,the annual generating capacity of 10kW off-grid HCPV power generation system is 1.69WkW• h(1.21 + 1.21×39.7%).Consider that the solar cell attenuation rate of the CPV modules is 0.8%,the cumulative total power generation in 25 years is 38.22WkW• h,the average annual capacity is 1.53 WkW• h.

3.2 Benefit analysis

3.2.1 Economic performance

At present, the electricity of the residents of Tibet is 0.4993 yuan/KW[15].Thus, the electricity bill would save 0.76 million yuan per year. The cumulative total power generation in 20 years is 38.22WkW• h,which will save 19.08 million yuan. After 25 years, the system is still capable of generating electricity and has good economic benefits.

3.2.2 Environmental benefit

The 10kW off-grid HCPV power generation system generates a total capacity of 1.53 WkW• h per year. It can save 5.508t standard coal and reduce 16.67t carbon dioxide, 0.099t sulfur dioxide, 0.043t nitrogen oxides and 0.024t dust. Thus, the system has obvious benefits of energy saving and emission reduction. The benefit of energy saving and emission reduction for 25 years is shown in Fig.2.

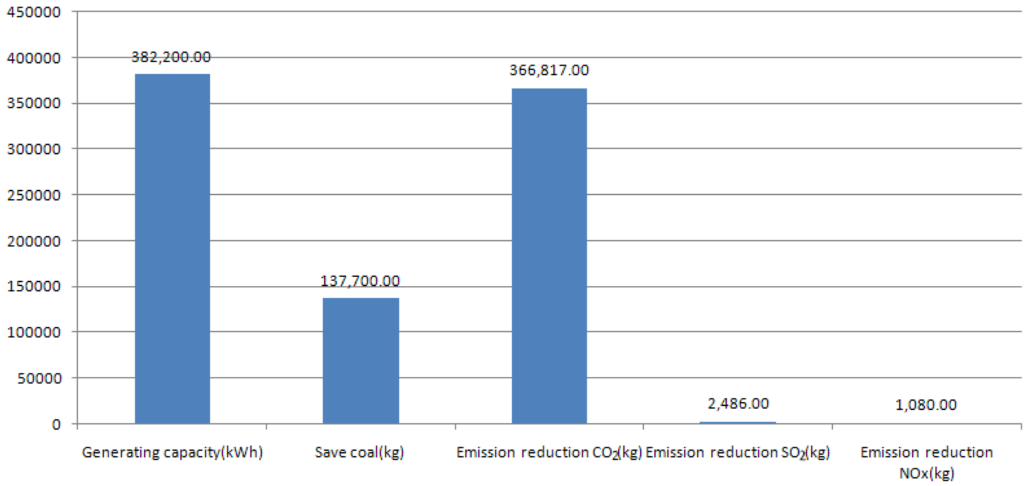

Fig.2 Energy conservation and emissions reduction benefits analysis to system for 25 years

4. Conclusion

This paper focuses on the study and design of 10kW off-grid HCPV power generation system in Tibet. In the design, we have adopted 16 sets of concentrating photovoltaic modules, 1 sets of dual axis automatic tracking systems,24 lead-acid batteries(12V 200Ah), 1 PV controllers, and 1 off-grid inverters. At the same time, we calculate the annual generating capacity of the system is 1.53 WkW. h.

The power in most areas of Tibet is seriously insufficient, but its solar energy resources is very rich. The construction of CPV power station in Tibet has good economic benefits and energy saving and emission reduction benefits and it will play a leading role in the development of CPV technology in Tibet area.

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