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Generating Capacity Analysis of Solar Thermal and PV Power Plants in Jiayuguan of Gansu Province

[1,2]Yong-Sheng Hu, [1]Rong-Rong Zhai, [1]Yong-Ping Yang and [2]Qin Yan
[1]School of Energy Power and Mechanical Engineering, North China Electric Power University, 102206, Beijing, China
[2]China Datang Corporation Renewable Power Co., Limited, 100053, Beijing, China

Abstract: In the study, three different solar power generating systems (including solar thermal and PV) are analyzed, according to same climate data in Jiayuguan, Gansu province. Solar parabolic trough and tower thermal power systems are selected as typical thermal system. Parabolic trough system and polycrystalline silicon cell are maturity and popularized in the world and tower system is developed to commercial stage in recent year. Then calculated and analyzed the generating capacity and economic characters of three power systems. The results can be used to support technology choice, operation and design optimization.

Key words: Generating capacity, parabolic trough, solar tower, PV

INTRODUCTION

Jiayuguan is located in the northwest of Gansu Province, central of Hexi Corridor, east of Jiuquan City. The altitude of the city is between 1412 and 2722 m and the average is 1600 m. Urban and industrial enterprises are located in Midwest where is almost desert.

With a temperate continental desert climate, the average annual temperature in Jiayuguan is between 6.7 and -7.7°C. It has 3077.9 h sunshine in a year. The annual frost-free period is approximate 134 days (Jiayuguan, 2013). According to local meteorological data and NREL data, the estimated annual direct normal radiation is 1970 kWh m^{-2}, the total level radiation is 1699 kWh m^{-2}. These are selected as typical data in the following analysis. Jiayuguan has 2935 km^2 where more than half is the Gobi Desert. Owing to the advantage of land and solar energy resources, a large number of power generation companies go to Jiayuguan to develop solar thermal and PV power plants in recent years. This article will research the generating capacity characters of solar thermal and PV power plants in this area.

TECHNICAL INTRODUCTION

The concept of solar thermal power technology was proposed firstly in the 19th century and it has been focused on since the 1980s. Gradually, some power plants have been put into commercial operation. This promotes the development and commercialization process of solar thermal power technology. In current situation, only solar trough and tower power systems and technologies reached commercial operation conditions. Both of them have the advantage of high focused magnification and temperature.

Introduction of solar parabolic trough power plant: Solar parabolic trough power plant uses parabolic trough mirrors to focus solar energy, the focused radiant energy is used to heat HTF (Heat transfer fluid) to generate steam inlet turbine. Solar parabolic trough power system consists of many trough concentrating collectors connected in series or parallel (Su *et al*., 2009). According to HTF types, there are two types of solar trough system, water and oil. Water is heated to steam directly in the collector before entering steam turbine. For oil type, the energy absorbed by oil will heat water in a heat exchanger. Now oil type has been large-scale applied.

According to data from Protermosolar Association, Spain has become the world's largest solar thermal power producer for its installed capacity had reached 432MW over the 422MW of US at the end of 2010 (Behar *et al*., 2013). Now Spain has 11 solar thermal power plants in operation while more than 20 projects are in the construction phase (Avila-Marin *et al*., 2013), including the famous plant Andasol 1 (50 MW), PS10 (11 MW), PS20 (20 MW) and so on.

Introduction of solar tower power plant: Solar tower system uses heliostats to track the sun and focus sunlight

Corresponding Author: Rong-rong Zhai, School of Energy Power and Mechanical Engineering, North China Electric Power University, 102206, Beijing, China

to the center receiver tower, different from solar parabolic trough power system. Tower System is a typical high-temperature solar thermal utilization methods, the system's maximum collector temperature can reach 1000°C or more. Compared to parabolic trough system, solar tower system is more prone to produce high-parameter steam for its collector temperature is higher, so the thermal efficiency will increase.

Since, the investment of tower system is larger and the capacity is limited, currently all solar tower power plants in the word are demonstration power plant. CASE-1 in Spain, EURELICS in European Union and SSPS-CRS of the International Energy Agency (IEA) have carried out experimental work for a long time. The U.S. Solar One is a successful tower solar thermal power system with capacity of 10MW and the average annual collector efficiency of heliostat field is 58.1% (Xiong *et al*., 2009). China's first 50MW demonstration tower thermal power plant is located in Qinghai Delingha which is invested by Zhejiang Supcon Corporation. It has completed test partially and operates steady.

Introduction of solar PV power plant: In 1839, French physicist AE Becquerel accidentally discovered that the two metal immersed in the solution can produce additional volta potential on light and called the phenomenon photovoltaic effect. 1873 British scientists Wifough B.Smith discovered the light-sensitive selenium material and figured out the conductivity of selenium increase proportionally with the light flux. The photoelectric conversion efficiency of semiconductor PN junction is the highest, these devices is called "photovoltaic" usually (Dong, 2007).

Nowadays, the conversion efficiency of photovoltaic cell increased gradually for technology continues to be exceeded. For market perspective, Europe is still the major market in PV industry (Wang, 2010). At end of 2012, the global cumulative PV capacity had reached 102 million kWs. Europe accounted for 70%, Germany 31% and Italy 16%, together of them account for nearly half of the world, followed by China (8%), the United States (7%) and Japan (7%). Annual production capacity in China is more than 2/3 of the word and installed capacity is also increasing every year. By the end of 2012, the national total installed capacity is 7,000,000 kW.

GENERATING CAPACITY ANALYSIS

In order to compare the superiority-inferiority of solar thermal and PV power plants in the same area, the installed capacity of 3 typical plants are set by 50 MW. Since, PV power plants generally no electricity storage systems, it is assumed that solar trough and tower plants are also not equipped with energy storage.

Solar parabolic trough power plant: Solar energy resources, as well as the efficiency of solar collectors, heat exchangers and power generation sector are considered in the program. The European conventional equipment basic parameters are set as the calculation standard. Major equipment models include:

- **Heat transfer fluid oil model:** VP (1-2) LS-3 of LUZ is selected as the collector which has been applied in many projects, (3) The receiver tube: Siemens UVAC 2010, (4) The capacity is 50MW, self-consumption rate is 12.3% (Europe generally uses 10%, due to the cold weather of Jiayuguan, 12.3% may be suit), the condenser is direct air cooling and (5) The efficiency of steam turbine is 35.6%; 6) In order to compare with the photovoltaic system, the storage systems don't be configured

Other parameters use the conventional data. Annual generation capacity of the solar parabolic trough power plant in this mode is 90, 298 and 400 kWh, equivalent annualized utilization hours of 1805.97 h, shown in Fig. 1. We can see from the figure, the heat received by the solar collector field in one year is 375783 MWh, the total generation capacity is 100302 MWh without auxiliary power.

In Fig. 1, solar power generation efficiency (defined as the ratio of solar power generation capacity and solar energy rceived by collector field) is 9.84%, net power efficiency (defined as the ratio of net generation capacity after deducting auxiliary power consumption and solar energy received by collector field) is 8.86% of solar parabolic trough power system without heat storage.

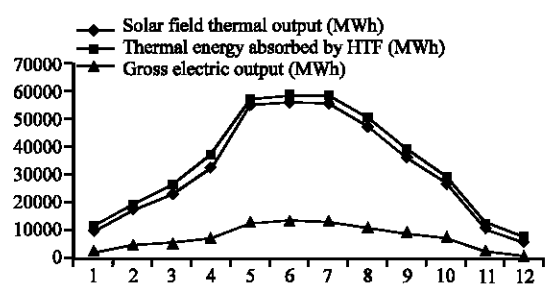

Fig. 1: 50MW solar parabolic trough system

Solar tower power plant: Solar tower power plant is also air-cooled without energy storage, in order to facilitate comparison with the solar trough and PV. Solar tower power plant is mainly constituted with concentrated layout of heliostat array, the receiver on the central tower and tracking systems. The main parameters of the system are as follows in Table 1.

Other parameters (such as heat efficiency, generator efficiency, etc.) refer to internationally accepted parameters range. After calculation we can know the annual net generating capacity is 836, 706 and 600 kWh (Annualized equivalent utilization hours 1673.41 h) under the conditions above. Monthly received heat and power generation of the solar tower power plant are shown in Fig. 2. It can be seen from the figure, that heat absorbed by the solar tower in one year is 263124 MWh, the total generation capacity is 97356 MWh without auxiliary power.The power generation efficiency of the 50 MW solar tower thermal power system is 7.04% and the net power efficiency is 6.05%.

Tower system is a typical high temperature solar thermal utilization method. The system's maximum collector temperature can reach above 1000 centigrade under the high-powered focus mode. The collector temperature of the solar tower power plant is higher than trough system, so the former can easier produce high-parameter steam. The overall efficiency is lower because of no storage. But in actual, the efficiency of solar tower system with thermal storage is still higher than trough system with thermal storage and the thermal storage time can be longer, because the heat storage temperature of the tower system is much higher than the trough. The maximum heat storage time of solar tower thermal power in Spain is 24 h, so it can basically achieve full-year uninterrupted operation and the system efficiency is higher.

Table 1: Main parameters of 50MW solar tower power plant

Name	Values	Name	Values
Capacity	50 MW	Total heliostat area	346752 m^2
Self consumption rate	13%	Tower height	161 m
Single heliostat area	144 m^2	HTF temperature	574/290°C
Number of heliostats	2408	Heat transfer fluid type	Molten salt
Total heliostat area	346752 m^2	Type of cooling	Air-cooled

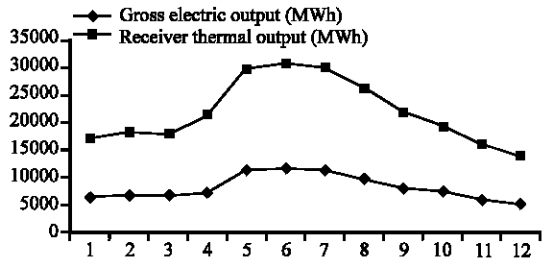

Fig. 2: 50 MW solar tower plant

PV power plants: The majority of PV projects are installed at a fixed angle. Some individual PV projects use an automatic tracking system or adjustable bracket which increase generating capacity by 20-30%. However, the sharp increase cost of stent system (1-2.5 times or more) as well as a substantial increase operation and maintenance cost. So, in the study we always uses a fixed angle installation. This installation method for generating capacity increase is evident especially at high latitudes.

By comparing different obliquity radiation data, it can conclude that when the installation angle is 37°, the total amount of radiation of the slope can reach its maximum. So we use the fixed 37° and consider that the cell attenuation is 20% in the operation period of 25 years or 0.8% of attenuation:

$$Q = P.Ht.\eta/Gs \quad (1)$$

Q is the annual energy production (kWh); P is the cell array capacity (kW) under standard conditions; Ht is the annual amount of radiation (kWh/m^2a) on the array surface; ç is the system efficiency (Including the efficiency of the PV array, inverter conversion efficiency and communication and network efficiency, the values is generally between 78-82% and take 80% in this system); Gs is pyranometer (kW/m^2) under standard conditions.

Power load of PV power plant is 81200MWh by calculation, monthly generation capacity is shown in Fig. 3, equivalent annualized utilization hours of 1,624 while in 25 years, the average is 1,480.

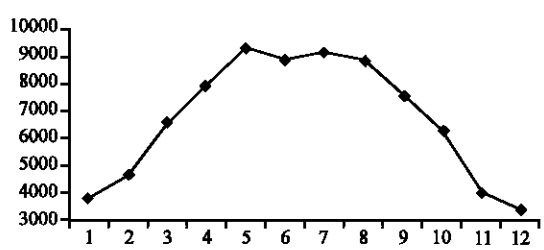

Fig. 3: Generating capacity of 50MW PV power plants

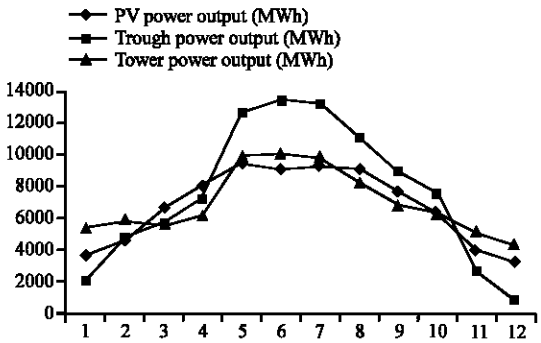

Fig. 4: Three typical 50MW solar power system generating capacity characters

Power capacity comparison of three typical systems: Power capacity comparison of three typical systems under the same weather conditions shows in following Fig. 4.

In order to facilitate comparative analysis, none of the three systems set up additional energy storage system. As can be seen from Figure 4, the maximum annual capacity is solar parabolic trough, followed by the tower, PV is the minimum. What's more, the solar tower power capacity was significantly higher than the other two systems in January to March and November to December period when the solar radiation is minor. However, in May to August, the solar trough power system has the highest capacity, followed by the tower, PV is the lowest.

ECONOMIC ANALYSIS

The solar parabolic trough power plant without energy storage is based on Datang Erdos 50 MW solar trough power plant investment data. This plant is the first demonstration project in China. When it doesn't install heat storage and equipment is mainly produced in China. The total investment is about 800, 000 and 000 Yuan. The interest rate is 6.55% of the current bank rate. This plant operational life is 25 years (excluding 3 years construction period). Consideration of depreciation, maintenance, management, staff wages and other costs, when the electricity price is 1.35 Yuan kWh^{-1}, project total investment internal rate of return reached 8.77 and 20% capital internal rate of return is 10% according to the economic calculation.

In China, no solar tower is in commercial at present. Qinghai 50 MW solar tower plant which is invested and developed by Zhejiang Supcon Company has completed the first 10MW test. The total investment of solar tower and solar trough are similar referring to the current status of domestic industry. The total investment of solar tower plant is about 750, 000 and 000 Yuan. This plant operational period is 25 years. When electricity price reached 1.46 Yuan kWh^{-1}, it can reach 10% internal rate of return of capital with the same measuring conditions of solar plant above.

Polycrystalline silicon PV industry has a mature development in China. It is more than 80% global PV cells are made in China. The price of polysilicon cell is about 4.5 Yuan W^{-1} with the shape decline price of amorphous silicon from 2011 to the present. And the price of Grid-connected PV inverter has dropped to 0.6 Yuan W^{-1}. The total investment of PV power plant is 10 Yuan W^{-1} for the benchmark considering the above costs, project development process in the construction period interest, grid system costs, land costs, the cost of supervision, inspection fees. So, the total investment of 50 MW project is 500, 000 and 000 Yuan. With the attenuation characteristics of the PV (25 years of 20% attenuation, annual attenuation of 0.8%) and the electricity price 1.0 Yuan kWh^{-1}, the whole investment project internal rate of return is 11.5% and the capital internal rate of return is 18.0%. So the project economic indicator is better and it has enterprise development value.

CONCLUSION

Utilization of solar energy has been vigorously concerned in recent years, especially China is become the largest PV component supplier in the world. The solar thermal power plant also gets attention gradually with the foreign industry mature. Some projects are started to develop in recent years.

In this study, three kinds of typical non-storage solar power system have been analyzed. Then the system generation capacity is calculated in same location and the same weather conditions.

The conclusions show that losses in design phase and the self-consumption can influence system character. What's more, the self-consumption power load use purchased electricity as much as possible to replace more higher prices generating capacity can both have a greater impact to generating capacity of the plant, especially for solar thermal power.

Meanwhile, China has no commercial solar thermal electricity. So, the government departments should to develop fit solar thermal electricity price as soon as possible according to solar thermal industry development. According to the analysis, when the electricity price of solar parabolic trough plant without energy storage system is higher than 1.35 and 1.46 Yuan kWh^{-1} of solar tower power plant can reach company investment conditions. The PV investment benefit is significantly

higher than that of solar thermal as the PV cost has dropped substantially. So, the government departments should enact reasonable electricity price integrated solar thermal and PV industry balanced development. This will promote the orderly development of solar industry in China.

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