The characteristic analysis of the solar energy photovoltaic power generation system

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Abstract. Solar energy is an inexhaustible, clean, renewable energy source. Photovoltaic cells are a key component in solar power generation, so thorough research on output characteristics is of far-reaching importance. In this paper, an illumination model and a photovoltaic power station output power model were established, and simulation analysis was conducted using Matlab and other software. The analysis evaluated the condition of solar energy resources in the Baicheng region in the western part of Jilin province, China. The characteristic curve of the power output from a photovoltaic power station was obtained by simulation calculation. It was shown that the monthly average output power of the photovoltaic power station is affected by seasonal changes; the output power is higher in summer and autumn, and lower in spring and winter.

Keywords: solar energy, photovoltaic cells, simulation analysis.

1. Introduction

Abundant, clean and environmentally friendly, solar power has become an important renewable resource for energy production all over the world. The degree to which this technology has been utilized, the available economic resources and the prospects for future development vary widely. Technological advances in solar power generation have the potential to impact a variety of stakeholders, such as power plants, power companies, equipment manufacturers and investors [1].

Solar photovoltaic power generation is widely recognized as an important renewable energy technology. The advantages of solar energy include inexhaustible reserves and clean production [2].In rural areas, islands and remote areas where transportation is inconvenient, solar energy is the ideal alternative energy source that is currently available. In addition, as a kind of distributed power system, photovoltaic power generation technology can improve and enhance the stability of the whole power system, especially given its potential to withstand natural disasters [3].

2. Modeling

2.1. The modeling and simulation of the external characteristics of photovoltaic cells

The photovoltaic array is a key component of a photovoltaic power generation system. Its current-voltage characteristic is the nonlinear function of sunshine intensity, environmental temperature and photovoltaic module parameters. Matlab software was selected to establish a simulation model of the photovoltaic array based on its physical mechanism [4]. In the design of a photovoltaic power generation system, the manufacturer of the photovoltaic panels usually provides the parameters of the photovoltaic array, including the open circuit voltage, short circuit current, peak voltage, peak current and maximum power. Applying these parameters to the corresponding mathematical model can directly yield the operation parameters of the photovoltaic array. The characteristic equation for the output of the photovoltaic battery component is:

$$I_L = I_{ph} - I_0 \left\{ \exp\left[\frac{q(U_{oc} + I_L R_S)}{36AkT} \right] - 1 \right\} \tag{1}$$

In equation (1), IL is the current flow through the load; Iph is the photoproduction current; Io is the reverse saturation current of the photovoltaic cell; Rs is the equivalent series resistance; q is the electron charge; Uoc is the open circuit voltage; A is the P-N junction ideal factor; K is the Boltzmann constant; T is the absolute temperature. The unknown variables in equation (1) are Iph, Io, and Rs., which were modeled using SIMULINK software.

Given the Isc, Uoc, Im and Um of the given model photovoltaic cells under standard conditions, we can obtain the current–voltage curve and power-voltage curve, which were used as the photovoltaic battery output characteristic. The current–voltage characteristic curve of the photovoltaic cells shows that a photovoltaic cell is a kind of nonlinear direct-current power supply, and it does not consistently provide the maximum power output. The power-voltage characteristic curve of photovoltaic cells is a single-peak curve with the maximum power point as its extreme value. To obtain the maximum benefit from the photovoltaic arrays, the system must be optimized to function near the maximum power point.

2.2. Acquisition of the solar radiation intensity sequence

The output power of a photovoltaic power station is related not only to the features of the photovoltaic battery, but also to the intensity of solar radiation that reaches the surface of the photovoltaic cells. The illumination model describes the intensity of solar radiation over a certain period of time. The intensity of naturally occurring solar radiation depends primarily on the geographical position of the photovoltaic power station. Using the latitude, longitude and altitude of the given location, the intensity of solar radiation in the region can be roughly determined.

$$R_T = f(\alpha, \beta, h) \tag{2}$$

In equation (2): R_T is the actual solar radiation intensity, kW/m2; α is the longitude of the photovoltaic power station site; β is the latitude; h is the altitude, m.

HOMER (Hybrid Optimization of Multiple Energy Resources) renewable energy microgrid software incorporates region-specific data such as the monthly average radiation and clear-sky index from the NREL (the United States government's National Renewable Energy Laboratory). Given the latitude, longitude and time zone of the photovoltaic power station, HOMER was used to calculate the solar radiation intensity sequence over one year (8,760 hours).

2.3. Photovoltaic power station output power modeling based on macroscopic analysis

By comparing local conditions with standard test conditions, especially considering the impact of the local solar radiation intensity and temperature on the photovoltaic battery power generation features, the following photovoltaic power station output power model can be derived:

$$P_{PV} = NR_T S_A \eta \tag{3}$$

$$\eta = \eta_{STC}\left[1+\alpha_P\left(T_C - T_{STC}\right)\right] = \frac{U_L I_L}{R_{STC} S_A}\left[1+\alpha_P\left(T_C - T_{STC}\right)\right] \tag{4}$$

In equation (3) and equation (4): PPV is photovoltaic power station output power, MW; N is the number of photovoltaic cells in the photovoltaic power station; SA is the area of a single photovoltaic cell, m2; RT is the actual intensity of solar radiation, kW/m2; η_{STC} is photovoltaic cell conversion efficiency under standard conditions; η is the actual conversion efficiency of a photovoltaic cell; α_P is the photovoltaic battery power temperature coefficient; TSTC is the temperature of the photovoltaic cells under standard test conditions, ℃; TC is the actual temperature of the photovoltaic cells, ℃; RSTC is solar radiation intensity under standard test conditions, kW/m2; IL is the current flowing through the load; UL is the voltage flowing through the load.

This model takes into account the influence of solar radiation intensity, temperature, photovoltaic conversion efficiency, the surface area of the photovoltaic array and other factors on the output power of a photovoltaic power station. The model can be used for macroscopic planning and quantitative analysis of the scale of photovoltaic power generation in the designated area.

3. The analysis of photovoltaic power station power output characteristics in west Jilin province

3.1. Distribution and feature analysis of solar energy resources in Jilin province

According to The Solar Energy Resources Evaluation Method, evaluating solar energy resources is the basis and theoretical foundation for the development and utilization of solar energy. HOMER simulation software evaluates the solar energy resources of a given area, providing information about the effects of seasonal changes on photovoltaic power generation.

The Baicheng area of Jilin province in China has rich solar energy resources. Based on its total annual radiation of 5,570 MJ/m^2, the Baicheng region is the most appropriate area in Jilin province to construct a large-scale photovoltaic power station. The annual temperature of Baicheng City is 276.5 ℃, the average annual sunshine hours is 2915.3 hours, and solar-thermal resources per capita is the highest in Jilin Province [5]. Analysis of solar energy resources in the Baicheng area shows that total monthly solar radiation varies throughout the year between 183.5 MJ/m2 and 710.5 MJ/m2; the minimum appears in December, while the maximum occurs in May. When evaluating the solar resources of a region, just as important as the total annual radiation is the stability of the solar resources, which can be assessed by measuring the sunshine hours per day. The monthly distribution change trend of the number of sunshine hours is approximately the same as the change trend of the total radiation in the region. Sunshine hours are relatively high in the month with the highest total radiation, and significant differences are seen between seasons. During each season, the distribution of sunshine hours is stable for months without sharp fluctuations. A radiation intensity distribution nephogram was obtained using HOMER software by entering the coordinates for the Baicheng region.

On the whole, the solar energy resources in the Baicheng area are relatively rich and stable. Favorable weather and other necessary resources exist to make the development of large-scale solar power generation feasible [6].

3.2. The analysis of the photovoltaic power station output characteristic in west Jilin province

Due to the high level of solar energy resources in the Baicheng region, the “Twelfth Five-Year Plan” for Jilin province includes plans to build a 100 MW photovoltaic power station in Zhenlai County in the Baicheng area. In order to model this proposed power plant, a basic photovoltaic power generation unit with 500 kW capacity will be assumed, using the parameters of GDM-235PE03 (polysilicon) photovoltaic cells. The cells are installed in series of 20 components. A basic power unit consists of 108 parallel series, which totals 2,160 components. Therefore, a photovoltaic power station with 100 MW rated capacity would need 432,000 solar panel components, which would cover an area of 705,672 m2. The annual output curve combined with the intensity of solar radiation and temperature data can be obtained by equation (3), as shown in Figure 1.

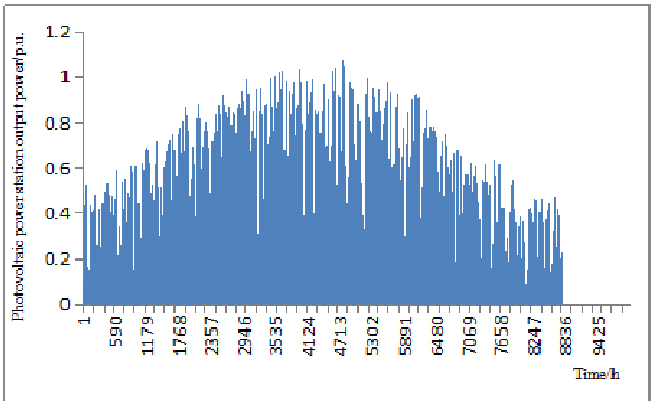

Figure 1. 100 MW photovoltaic power station annual output power.

The figure shows that the maximum output power is 1.086 p.u., occurring at 4,236 hours, and the number of equivalent full hours are 1,468. Photovoltaic power station annual output power distribution is almost the same as the local solar radiation intensity annual distribution. In order to reflect the fluctuation characteristics of the photovoltaic power station output power in more detail, the output power annual distribution curve was plotted separately for each month, taking a typical sunny day of each month.

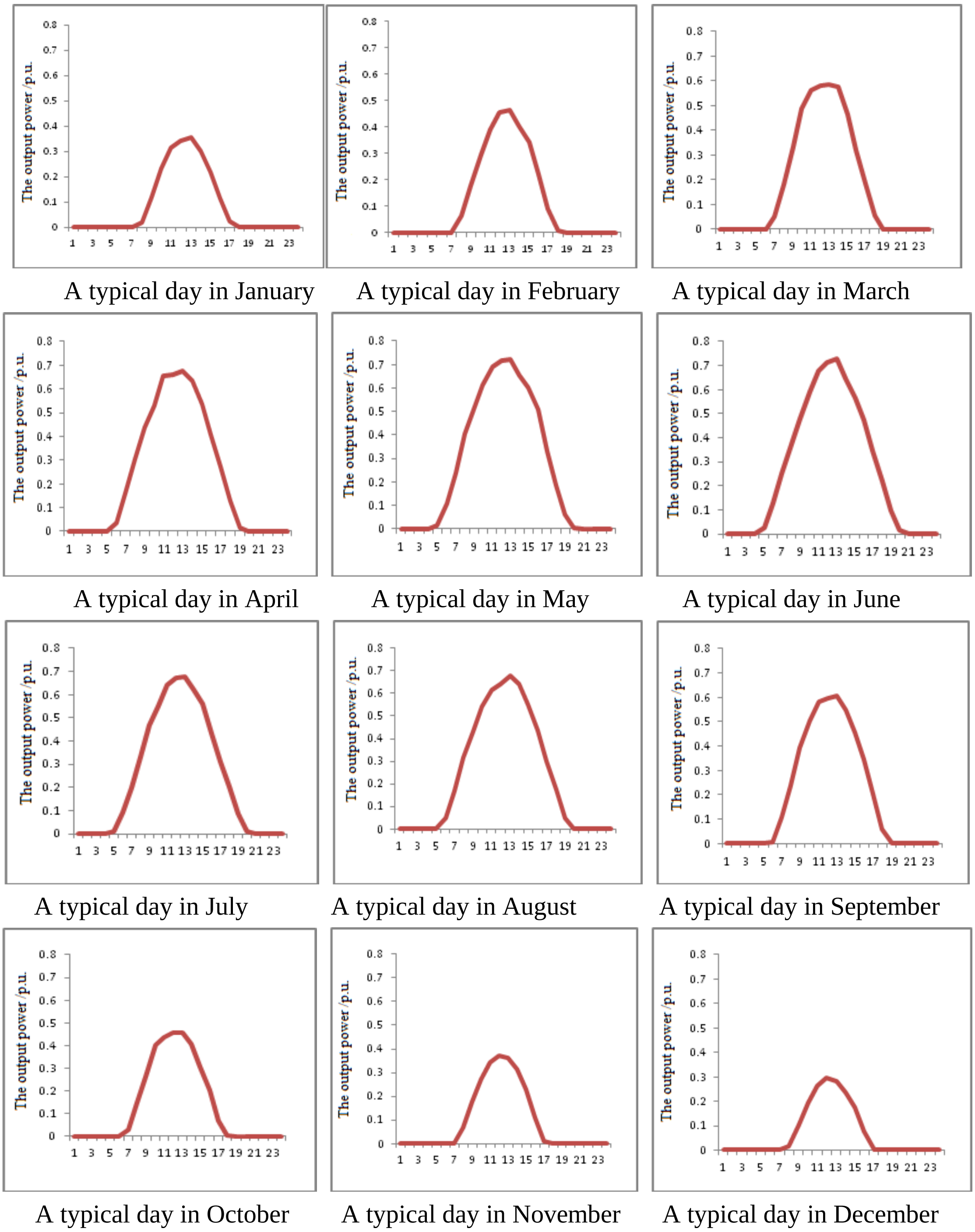

Figure 2. The month distribution of the output power of a 100 MW photovoltaic power station.

The Figure 2 shows that the monthly average output power of the photovoltaic power station is affected by seasonal changes, starting at a low value in January, increasing each month to reach its peak in May, and then decreasing each month, reaching its minimum value in December. The fact that output power is higher in summer and autumn and lower in spring and winter is consistent with the distribution of radiation intensity in the area. Photovoltaic power station output was limited to the hours of 5:00 to 20:00 every day. Daily maximum output power occurred during the period from 12:00 to 14:00; there is no output at night. The typical daily output was consistently less than 0.8 times the rated capacity of photovoltaic power plants. Most of the time, there is a large gap between the rated capacity and the actual output.

4. Conclusion

This paper analyzes the characteristics of photovoltaic battery power, establishes an illumination model, and builds a model for photovoltaic power station output power that accounts for the effects of solar radiation intensity and temperature change. Based on the condition of solar energy resources in the Baicheng region in the west of Jilin province, China, the photovoltaic power station power output characteristic curve was obtained using the established model. The results show that the monthly average output power of the photovoltaic power station is affected by seasonal changes; the output power is higher in summer and autumn and lower in spring and winter.

Acknowledgement

The authors would like to thank the Project by Clean Development Mechanism (CDM) of China (1113050) and the Science and Technology Project of Jilin Province Development and Reform Commission (2013-729).

References

[1] Xin P Y 2015 *Research on Solar Power Technology Economic Evaluation and Application Prospect* North China Electric Power University pp 1-5

[2] Wang Z H 2015 *Study on Optimizing Configuration of Integrated Power Transmission Capacity of the Clustering Photovoltaic-wind Joint Power Generation* Northeast Electric Power University pp 18-21

[3] Zhang H H 2013 Design for Photovoltaic Power Generation System Based on MATLAB *Control Engineering* **S1** 26-29

[4] Wu X J 2012 *The Simulation of Concentration Solar Cells in Matlab\Simulink* Wuhan University of Technology p 15

[5] Sun Z S 2012 *The Study of Grid-connected Photovoltaic Generation System Based on MATLAB Simulation* Nanchang Aviation University p 1

[6] Cheng L M 2012 The Present Development Situation, Problems and Countermeasures of Solar Industry in Jilin Province *The Regional Economic* **3** 3-4