A Prediction Model of Photo-thermal Power Generation Based on G (1,1) Optimization

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Abstract. In this paper, the photo-thermal power generation model is obtained by studying the operation process of solar radiation, light and thermal power generation equipment. By solving the gray model parameters by particle swarm optimization, a prediction model of light and heat generation based on G (1,1) optimization is proposed. In the case of example analysis, the amount of electricity generated by the solar radiation in the past few years was based on the photo-thermal power generation model, and the light and thermal power generation prediction model is used to obtain the photo-thermal power generation in the next few years. Photo-thermal power generation will provide data support for the planning of photo-thermal power generation, and it will also verify the reasonableness of the prediction model.

1 Introduction

Light and thermal power generation, combined with heat storage system or thermal power generation, can achieve continuous and stable power generation with adjustable, easy to grid, and less environmental impact throughout the life cycle. No reactive power compensation and high power quality are needed for light and heat. The rapid development of light and heat generation, especially the United States and Spain, which are rich in solar energy, are among the best in the world, both technically and commercially. Abundant domestic solar thermal resources and national policy support provide a good environment for the development of photo-thermal power generation technology. The application of photo-thermal technology in China is of great significance to China's industrial restructuring, the deteriorating environment improving, energy security and even national defense safety.

In recent years, many scholars at home and abroad have studied the optical and thermal power generation technology. The mathematical model of the light and thermal energy storage power station had been established in literature [1,2], but it was mainly used to analyze the economic value of the light and thermal energy storage power station in the given price curve, without considering the factors such as climbing, reserve and other factors, and no effective prediction of the optical and thermal power generation. CHEN Xuejuan^[3](2014) analyzed and forecasted the influence of photo-voltaic module shadow on photo-voltaic power generation, and proposed a method of distinguishing soft and hard shadows of photo-voltaic modules based on gray prediction. DU Ershun^[4](2016) produced a summary

and prospect of the grid connected photo-voltaic thermal energy storage. There was no specific model establishment or data grid connection analysis. In short, there are few studies on the prediction of the power generation of the thermal energy storage power station.

In this paper, through the study of the operation process of solar radiation and light and heat generation equipment, the optical and thermal power generation model is obtained. The gray model parameters are solved by particle swarm optimization (PSO), and a prediction model based on G(1,1) optimization is proposed. Through the example analysis, according to the solar radiation amount of the past few years according to the photo-thermal power generation model, the power generation amount is obtained, and then the light and heat generation prediction model is used to obtain the light and thermal power generation in the next few years. The results will provide data support for the planning of photo-thermal power generation.

2 photo-thermal power generation model

If the collectors are arranged horizontally, the incident angle is calculated according to the incident angle of the north and South tracking sun rays.^[5]

$$\theta = \sqrt{1 - \cos^2 s} * \sin^2 w \quad (1)$$

Conversely, the incident angle of sunlight is calculated according to the sun and the sun.

$$\theta = \sqrt{\cos^2 st + \cos^2 s * \sin^2 w} \quad (2)$$

In the formula, st is zenith angle; s is the solar declination angle; Omega is the solar horns.

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The parabola trough solar collector is used to realize the solar radiation of low energy flow by the parabolic reflector. Then, the solar radiation can be projected onto the collector and the heat energy conversion is realized through the collector tube. When the collector receives the solar radiation, the collector itself is affected by its own quality and structure, and it will cause some optical loss, which leads to the decrease of the efficiency of the self gathering heat of the solar thermal power generation system. The thermal efficiency of the whole solar thermal system can be divided into two types: optical efficiency and geometric efficiency.

The optical efficiency depends on the properties of the material itself, including the dust free soil in the mirror, the finish of the mirror, the permeation rate of the glass tube and the absorption rate of the heat pipe coating, which can be characterized as follows:

$$E_{opt} = z * x * c * v_1 * v_2 * k \quad (3)$$

In this formula, z is the coating absorption of the collector tube; x is the reflectivity of the collector mirror; c is the optical intercepting factor of the collector; v_1 is the penetration rate of the spotlight surface; v_2 is the cleanliness of the glass protection surface of the collector tube; k is the reflection mirror cleanliness.

The factors affecting the geometric efficiency of the collector include the value of the incident angle cosine, the degree of occlusion between the lines of the collector heat collector, the loss of the final part of each column of the concentrating collector and the correction of the incidence angle. Due to the increase of the incidence angle, the glass reflector will generate additional reflection and absorption, resulting in loss, and then the incident angle correction coefficient. The correction coefficient of incident angle is usually based on the empirical data given by the data used by some kind of collector.

The correction factor of the S collector can be calculated as follows:

$$S_{iam} = 1 + 8.84 * 10^{-4} \frac{\theta}{\cos \theta} - 5.37 * 10^{-5} \frac{\theta}{\cos \theta} \quad (4)$$

The calculation method of interline occlusion factor is as follows:

$$S_s = \frac{L_{sp}}{B_c} \times \frac{\cos \theta_z}{\cos \theta} \quad (5)$$

In this formula, the L_{sp} is the row spacing of the collector and B_c is the opening width of the trough condenser. The end part optical loss occurs at the end of the heat collector unit. When the sun is inclined to the collector plane, the end of the heat pipe can not absorb the reflection of the sun radiation, which leads to the end loss. The calculation of end loss is as follows:

$$S_e = 1 - \frac{f \tan \theta}{L_{sca}} \quad (6)$$

In the formula, f is parabolic trough focal length; L_{sca} is trough type condenser length.

Therefore, the geometric efficiency of the available collector is:

$$E_{geo} = S_{iam} * S_s * S_e * \cos \theta \quad (7)$$

The total efficiency of the concentrating heat collection system is the product of optical efficiency and geometric efficiency:

$$E_{sc} = E_{opt} * E_{geo} \quad (8)$$

The solar radiation energy absorbed by the spotlight collector is:

$$Q_r = I * A * E_{sc} \quad (9)$$

In the formula, I is irradiated directly by the sun, and A is the concentrating area of the collector.

The heat loss of the collector field includes two parts: the heat loss of the collector tube and the heat loss of the heat transmission pipeline.

The heat loss of the unit collector tube is:

$$Q_{HCE} = [a_0(T_0 - T_i) + \frac{a_1(T_0^2 - T_i^2)}{2} + \frac{a_2(T_0 - T_i^2)}{2} + I * [b_0(T_0 - T_i) + \frac{b_1(T_0^3 - T_i^3)}{3}]] / [(T_0 - T_i) * B_c] \quad (10)$$

In the formula, parameters, A_3 , and B are obtained from the experience values of the collector performance test.

Heat loss of a unit heat transfer pipe:

$$Q_{pip} = 0.01 \Delta T - 1.683 * 10^{-4} \Delta T^2 + 6.78 * 10^{-7} \Delta T^3$$

$$\Delta T = \frac{T_0 + T_i}{2} - T_{ab} \quad (11)$$

In this formula, the exit temperature of the solar photo-thermal collector field is the inlet temperature of the collector field, and the ambient temperature.

The heat absorption of the unit collector tube is

$$Q_{co} = Q_r - Q_{pip} - Q_{HCE} \quad (12)$$

The value of the thermal power is output to the thermal cycle system, which is converted into steam heat, and eventually into the steam turbine to realize the conversion of heat and mechanical energy, thus driving the generator to generate electricity. If the steam production and the efficiency of the turbogenerator are E_{te} , the generating power is:

$$P_{el} = Q_{co} * E_{te} \quad (13)$$

3 The gray prediction model of photo-thermal power generation

The amount of photo-thermal power generation in the past year is

$$x^{(0)} = (x^{(0)}(2), x^{(0)}(3), \dots, x^{(0)}(n)) \quad (14)$$

When the superscript represents the number of accumulative sums, the first order accumulation sequence is

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \dots, x^{(1)}(n)) \quad (15)$$

Among them:

$$x^{(1)}(k) = \sum_{i=1}^k x^{(0)}(i) = x^{(1)}(k-1) + x^{(0)}(k)$$

$$k = 1, 2, \dots, n \quad (16)$$

$Z^{(1)}$ is a sequence of near neighbor mean generation of $X^{(1)}$

$$Z^{(1)} = (Z^{(1)}(2), Z^{(1)}(3), \dots, Z^{(1)}(n)) \quad (17)$$

Among them:

$$z^{(1)}(k) = \frac{1}{2} [x^{(1)}(k) + x^{(1)}(k-1)], k = 2, 3, \dots, n$$

Differential equations are established for accumulative sequence:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (18)$$

The corresponding sequence of the $GM(1,1)$ model $x^{(0)}(k) + az^{(1)}(k) = b$ establishment time is

$$\hat{x}^{(0)}(k+1) = \left(x^{(1)} - \frac{b}{a} \right) e^{-ak} + \frac{b}{a}, k = 1, 2, \dots, n \quad (19)$$

Among them, a is called development coefficient and B is ash consumption.

Reduction reduction value^[6] is

$$\begin{aligned} \hat{x}^{(0)}(k+1) &= \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \\ &= (1 - e^a) \left(x^{(0)}(1) - \frac{b}{a} \right) e^{-ak}, k = 1, 2, \dots, n \end{aligned} \quad (20)$$

Estimation of parameters a , b value by the Particle swarm optimization.

Objective function: the minimum mean relative error

$$f(a, b) = \min_{a, b} \left[\frac{1}{n} \sum_{i=1}^n \frac{|\hat{x}^{(0)}(i) - x^{(0)}(i)|}{|x^{(0)}(i)|} \% \right] \quad (21)$$

Constraint conditions: the least squares estimation parameter method is used to get the A and B estimation values in the traditional model $GM(1,1)$, and the floating value of the estimated value of a and b is taken as the constraint condition.

The Particle swarm optimization is as follow:

4. Example analysis

This paper selects the solar radiation intensity value provided by SAM software. The parameters are showed in Tab1 and Fig1.

Figure1. Irradiance DNI from weather in one day

Table 1. Coefficients for Receiver Heat Loss: Vacuum Annulus.

Parameter	Value
a_0	-9.463e0
a_1	3.030e-1
a_2	-1.387e-3
a_3	6.930e-6
b_0	7.650e-2
b_1	1.129e-7

(1) Fig2 shows the generation of photo-thermal power generation using 2 section photo-thermal power generation model.

Figure2. Thermal power generation in one day

(2) Average annual power in former year is [768.9002976, 778.3690476, 783.796371, 773.6075269, 778.3602151, 776.7277778]. Using the data and the prediction model of photo-thermal power generation in the 3 section, we get the photo-thermal power generation (Fig3) in the next few years.

Figure3. Forecast average one day power of year

5. Summary

In the context of the global energy crisis and environmental pollution, all countries and regions are actively transforming patterns of energy production and consumption to clean energy, and renewable energy has received unprecedented attention and rapid development. At present, there are few researches on photo-thermal power generation in China, and the research and application of photo-thermal power generation technology is in its infancy.

With the increasing proportion of renewable energy in the power system, more investment goes into the photo-thermal power station. Based on the characteristics of solar radiation and its optical and thermal power generation technology, this paper optimizes the gray G (1,1) model using particle swarm optimization (PSO) algorithm. On this basis, a prediction model of light and heat generation is proposed. It is hoped that the prediction model proposed in this paper can provide a reference for the input and planning of photo-thermal power generation in China.

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