Research on Yaw Error Detection of Wind Turbine Based on Particle Swarm Optimization

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Abstract. Yaw system is an important part of the wind turbine, one of its main functions is to automatically face the wind when the wind turbine is in normal operation, to ensure that the engine room is facing the wind direction, so that the wind turbine can make efficient use of wind energy. However, the yaw system can not guarantee the accuracy at all times, which leads to the wind deviation. Too large deviation of wind energy not only reduces the efficiency of wind turbine using wind energy, but also leads to abnormal wear of equipment parts, which is not conducive to the normal operation of the unit. In this paper, a wind turbine deviation detection algorithm based on SCADA data is proposed. The detection algorithm mainly includes wind speed segmentation, data fitting, particle swarm optimization and other key technologies. After wind field verification, the algorithm proposed in this paper can effectively detect the wind deviation of wind turbines, and help to improve the efficiency of wind turbines.

1. Introduction

At present, the problems of environmental pollution and energy shortage in the world seriously restrict the social and economic development[1]. Therefore, the use of clean energy has been paid more and more attention by all countries, and in the current goal of carbon peak and carbon neutral, renewable energy will also occupy an increasingly important position[2]. In renewable energy, wind energy has achieved a substantial increase in installed capacity with its advantages of no pollution, less land occupation, small investment and flexible deployment.

Fig.1 Yaw error of wind turbine

Yaw system is an important part of the wind turbine, one of its main functions is to automatically face the wind when the wind turbine is in normal operation, to ensure that the engine room is facing the wind direction, so that the wind turbine can make efficient use of wind energy. However, due to the installation error of wind vane, electrical measurement, wake effect and other factors, wind
turbines are likely to have wind deviation[3]. The yaw deviation angle is defined as the angle between the engine room axis and the wind direction, expressed by $\alpha$, and we can get formula 1.

$$P = \frac{1}{2} \rho S C_p v^3 \cos \alpha$$

(1)

Where $P$ is the power of the wind turbine, $\rho$ is the air density, $S$ is the swept area of the wind turbine, $C_p$ is the wind energy utilization coefficient, and $v$ is the wind speed.

It can be seen that the power loss of wind turbine is proportional to the third power of cosine of wind deviation angle. When the wind deviation angle is 10 degrees, the power loss is 4.5 percent, and when the wind deviation angle is 15 degrees, the power loss has reached 9.9 percent. Therefore, in order to ensure the efficient operation of wind turbine, it is necessary to eliminate the wind deviation.

In view of the above problems, this paper proposes a wind deviation detection algorithm based on particle swarm optimization, gives the detailed steps of the algorithm, and carries out the actual verification in a wind farm. The results show that the algorithm proposed in this paper can effectively detect the wind deviation of wind turbines.

2. Theoretical basis

2.1. Particle swarm optimization

Particle swarm optimization (PSO) was first proposed by Eberhart and Kennedy in 1995[4]. Its basic concept comes from the study of birds' foraging behavior. Each particle can be regarded as a search individual in the n-dimensional search space, and the current position of the particle is a candidate solution of the corresponding optimization problem. The flight process of a particle is the search process of the individual. The flight speed of the particle can be dynamically adjusted according to the historical optimal position of the particle and the historical optimal position of the population. The particle has only two attributes: speed and position. The speed represents the speed of movement, and the position represents the direction of movement. The optimal solution searched by each particle is called individual extremum, and the optimal individual extremum in particle swarm optimization is the current global optimal solution. Iterate continuously to update the speed and position. Finally, the optimal solution satisfying the termination condition is obtained. The algorithm flow is as follows:

1) First of all, we set the maximum number of iterations, the number of independent variables of the objective function, the maximum speed of particles, and the position information for the whole search space. We initialize the speed and position randomly in the speed range and search space, set the particle swarm size to m, and each particle initializes a speed randomly.

2) The fitness function is defined, and the individual extremum is the optimal solution found for each particle. Finding a global value from these optimal solutions is called this global optimal solution. Compared with the historical global optimum, it can be updated.

3) Update speed and location.

4) When the number of iterations reaches the set value or the difference between algebraics meets the minimum limit, the calculation is stopped.

2.2. Data Fitting

According to Formula 1, when the wind speed $V$ is fixed, the smaller the wind deviation angle is, the larger the wind turbine power is. Especially, when the wind deviation is 0, the power is the largest. According to this property, the wind deviation can be detected by judging the relationship between the power of wind turbine and wind speed. Figure 2 shows the fitting diagram of wind deviation. When the wind deviation is 0, the wind turbine power is the maximum. When the wind turbine deviates from a certain angle, the whole curve deviates from the origin, and the maximum value of the curve will also decrease. The angle that the maximum value of the curve deviates from the origin is the required deviation angle to the wind.
Fig.2 The correspondence between yaw error and power

Suppose that the curve shown in Fig. 1 is a quadratic function, which is expressed by formula 2:

\[ y = a(x_i - x_0)^2 + b \]  

(2)

\[ T_s(l,t) = T_g(l,t) \]  

(3)

Where y is the ordinate value, \( x_i \) is the abscissa, a and B are constants, and \( x_0 \) is the center value of the curve, which is also the yaw deviation we require. Due to the advantages of particle swarm optimization in finding the optimal value, we choose to use it to solve \( x_0 \).

3. Algorithm process

The wind deviation detection algorithm proposed in this paper is based on the SCADA data of wind turbine operation. The specific calculation can be divided into the following five steps.

3.1. Data collection

Data is the basis for our calculations. In this step, we need to obtain a suitable amount of data for the next step. The SCADA system generally records data in seconds or minutes. If the selected time is too short, too little data will affect the accuracy of the wind deviation calculation. If the selected time is too long, it will lead to insufficient accuracy and poor timeliness of the results. In this paper, the data of one month is selected for calculation.

3.2. Data filtering

Due to shutdown, power limitation, abnormal sensor and other reasons, the data in SCADA system will contain abnormal data. The existence of abnormal data will interfere with the calculation of wind deviation, so it is necessary to eliminate the abnormal data. In this paper, with the help of the theoretical power curve of wind turbine provided by the manufacturer, the data are eliminated, and only 20% of the data points above and below the power curve are retained.

In addition, data screening also needs to eliminate the data points of full power operation of the wind turbine, because although the wind turbine is in normal operation, its power is always at the maximum due to the high wind speed, so the wind deviation angle can not be obtained by the above method. Therefore, this paper only selects the data of power climbing phase.
3.3. Data slicing
According to the above description, we calculate the wind deviation angle by comparing the power of wind turbines under the same wind speed. In fact, the number of data points meeting the same wind speed may be very small, so the usual practice is to divide the wind speed into small areas. The size of the interval should not only meet the same wind speed, but also meet the requirement that the number of data points in the interval can not be too small. The interval length selected in this paper is 0.5m/s.

3.4. Calculation with PSO
The wind deviation is calculated by using the data of each interval divided above. The calculation method is to calculate the optimal value of the coefficient in formula 2 through particle swarm optimization algorithm. In this way, the wind deviation angle of wind turbine in each wind speed range can be obtained.

3.5. Weighted average
The weighted average of the wind deviation value of each interval is carried out, and then the total wind power deviation of the wind turbine can be obtained[5].

4. Case study
A case study of 20 1500KW wind turbines in a wind farm was conducted, and the data of May 2020 was selected to calculate the wind deviation angle. The wind speed during the power climbing stage of the unit is 3.25-9.25m/s, and the size of the wind speed interval set here is 0.5m/s. The calculation results of the wind deviation of 30 units are shown in Table 1.
Table 1. Yaw error detection results of 20 turbines

| Number | Yaw error (°) |
|--------|---------------|
| N01    | 0.1           |
| N02    | 2.3           |
| N03    | -1.5          |
| N04    | -3.0          |
| N05    | 5.1           |
| N06    | 10.3          |
| N07    | 1.7           |
| N08    | -0.8          |
| N09    | -2.6          |
| N10    | -1.1          |
| N11    | 2.3           |
| N12    | 2.6           |
| N13    | 1.7           |
| N14    | 0.9           |
| N15    | 0.4           |
| N16    | -0.7          |
| N17    | 1.1           |
| N18    | 7.8           |
| N19    | 4.2           |
| N20    | -6.9          |

From the above calculation results, it can be seen that the wind deviation angle of unit 6 is greater than 10 °. The deviation is serious. After on-the-spot inspection, it is found that the unit does have the problem of inaccurate wind, and it has been adjusted.

After the adjustment, the wind speed power curve of unit 6 has been significantly improved, as shown in Figure 5.

Fig.5 Comparison of power generation before and after adjustment

Assuming that the availability of wind turbine 6 is 100%, the number of hours in a year is about 8760h. According to the Rayleigh distribution, the annual power generation of the unit before correction is 2662.9mwh, and the annual power generation after adjustment is 2944.7mwh, an increase of 10.6%.

5. Conclusion
In this paper, aiming at the problem of wind deviation of wind turbine, based on the data of wind turbine SCADA system, the parameters of fitting curve are calculated by particle swarm optimization algorithm, and the wind deviation angle is obtained. During the verification in a wind farm, it is found
that there are 10 faults in a unit. The above deviation, after on-site adjustment, the wind speed power curve of this unit has been significantly improved, and the power generation has also been greatly improved.

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