Operational State Analysis of Wind Turbines Based on SCADA Data

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Abstract. For the multi-parameters evaluation problem of wind turbine operational status, the principal component analysis (PCA) methodology is firstly used to reduce dimension, standardize and de-correlate to the SCADA data of wind turbine operation, and get the principal component of the wind turbine operational SCADA data. Secondly, computing the total score of the principal component, which is utilized for evaluating the wind turbine. Finally, the operational status of nine wind turbines in a same wind farm are compared and analyzed by using PCA method proposed in this paper. The results show that the PCA method is effective for evaluating wind turbines.

Introduction

With the transformation and adjustment of energy structure, wind power generation has been developed rapidly and has become one of the main power generation methods. Wind turbines are generally located in remote areas, operating conditions are relatively poor, combined with other factors, failures occur frequently, up to 10% of the operation and maintenance costs have become the biggest bottleneck in the development of wind power industry.

Therefore, the reliability and operation and maintenance index of wind turbine has become the key part to ensure the safe and stable operation of the power grid, and the research on wind turbine operation evaluation has become the consensus of professionals in the industry [1].

In the prior art, there are a lot of state evaluation methods about the key components of the wind turbine. However, due to the complexity of a wind turbine structure, it is difficult to reflect the operation state of the wind turbine accurately and comprehensively only by evaluating a key component of the wind turbine. Therefore, it is necessary to propose some methods which is suitable for evaluating the operation state of wind turbines, such as intelligent method based on support vector machine, matter-element evaluation method and fuzzy comprehensive evaluation method. The basic idea of those methods is to establish an evaluation model by analyzing the real-time data of the Supervisory Control and Data Acquisition, named SCADA, and to make a quantitative evaluation of the running state of the complex system with multi-factor and multi-level. It is suitable for the characteristics of wind turbine system, so it has been used to evaluate the state of the systems, including wind turbines, which are operating in the complicated environments and working conditions.[2, 3]. However, these methods are prone to misjudgment when the operational conditions of wind turbines are mutational.

In this paper, the principal component analysis (PCA) method is used to evaluate the operation status of wind turbines, and the operation states of different wind turbines are compared and analyzed.

Methodology

The Principal component analysis (PCA) can simplify the index dimension, compress the information, and make the analysis of the problem more intuitive and effective [4,5]. Therefore, the PCA method is used in this paper to sort the operational indices of wind turbines, and then using the extracted principal components as new evaluation indices. Finally, according to the total scores of different principal components to determine the performance of different wind turbines.

The concrete evaluation steps are as follows:

1) Gathering the original data of different wind turbines in the same wind farm at the same operating time, and then constructing an evaluation matrix, X , The expression is as follows:

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix} \quad (1)$$

In the above expression, $x_{ij}\ (i = 1, 2, \ldots, m;\ \ j = 1, 2, \ldots, n)$ represented as the value of the j-th variable of the i-th wind turbine.

2) Doing the same chemotactic processing on the evaluation matrix X , and getting the Isochemotactic matrix Y , The expression is as follows:

$$Y = \begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{pmatrix} \quad (2)$$

The method of chemotactic treatment is to deal with the positive index, x_{ij}, in the evaluation matrix, $x_{ij} = x_{ij}$;inversely, for the inverse index, x_{ij} , in the evaluation matrix, $x_{ij} = -x_{ij}$ [6].

3) Obtaining a standardized evaluation matrix Z by a Standardized transformation to the Isochemotactic matrix Y . The expression of Standardized transformation is as follows:

$$z_{ij} = \frac{y_{ij} - \bar{y}_j}{\sqrt{D_j}}\ ,(i = 1, 2, \ldots, m;\ \ j = 1, 2, \ldots, n) \quad (3)$$

In which, $\bar{y}_j = \frac{1}{m}\sum_{i=1}^{m} y_{ij}$, $D_j = \frac{1}{m-1}\sum_{i=1}^{m}\left(y_{ij} - \bar{y}_j\right)^2$, and the expression of evaluation standard matrix is as follows:

$$Z = \begin{pmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{pmatrix} \quad (4)$$

(4) Calculating the correlation coefficient matrix R by transforming the standard matrix Z . The expression is as follows:

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{pmatrix} \quad (5)$$

Where, $r_{kl}\ (k=1, 2, \ldots, n;\ l=1, 2, \ldots, n)$ is the correlation coefficient between parameters z_k and z_l, which represents the degree of correlation between these two parameters, and the expression is as follows:

$$r_{kl}=\frac{\operatorname{cov}(z_k, z_l)}{\sqrt{D(z_k)}\sqrt{D(z_l)}} \tag{6}$$

In the above expression, $\operatorname{cov}(z_k, z_l)$ denotes the covariance between the parameters z_k and z_l.

5) Solving the characteristic equation of the correlation coefficient matrix (denoted by R), the expression is as follows:

$$|R-\lambda I_n|=0 \tag{7}$$

By solving above equation, obtaining the characteristic values, denoted by $\lambda_i\ (i=1,2,\ldots, n)$ $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_n$.

6) Calculating the variance contribution rate, denoted by $\alpha_i\ (i=1,2,\ldots, n)$, and the cumulative variance contribution rate, denoted by $\beta_p (i=1,2,\cdots,n)$, according to the obtained eigenvalues. And then determining the number of principal components according to the conditional expression, $\beta_p \geq 0.9$.

The expression for calculating the contribution rate of variance, denoted by $\alpha_i\ (i=1,2,\ldots, n)$, is as follows:

$$\alpha_i=\frac{\lambda_i}{\sum_{i=1}^{n}\lambda_i} \tag{8}$$

The expression for calculating the cumulative contribution rate of variance, denoted by β_P, is as follows:

$$\beta_p=\frac{\sum_{i=1}^{p}\lambda_i}{\sum_{i=1}^{n}\lambda_i} \tag{9}$$

7) Obtaining the eigenvectors $b_i\ (i=1,2,\ldots, P)$ of the principal components by solving the equation as follows:

$$Rb_i=\lambda b_i \quad (i=1,2,\ldots, P) \tag{10}$$

And the matrix B_v, which consisted of these Eigenvectors, i.e., $b_i\ (i=1,2,\ldots, P)$, The expression is as follows:

$$B_v=[b_1, b_2, \ldots, b_P\ ] \tag{11}$$

8) Obtaining the score matrix of the principal components according the following expression:

$$B_s=ZB_v \tag{12}$$

9) Obtaining the total score vector according the following expression:

$$V_{Ts}(i) = \sum_{j=1}^{n} B_s(i, j) \quad , (i = 1,2,\ldots, n) \tag{13}$$

The total scores of principal components were sorted in order from large to small, and the final evaluation results were obtained.

Case Analysis

18 parameters of SCADA of nine 2.0MW wind turbines in a wind farm were selected respectively to evaluate the operation performance of different wind turbines at the same time.

The parameters are denoted by $Idx_{i,1}$, $Idx_{i,2}$,……, $Idx_{i,18}$, respectively. The subscript i indicates the number of wind turbines. The details of the parameters are shown in table 1.

Table 1. Operational parameters of the SCADA system of wind turbines

Parameter	Name	Parameter	Name
$Idx_{i,1}$	Nacelle Cabinet Temperature	$Idx_{i,10}$	Generator Speed
$Idx_{i,2}$	Tower Base Cabinet Temperature	$Idx_{i,11}$	Generator Winding Temperature U
$Idx_{i,3}$	Gearbox Input Shaft Temperature	$Idx_{i,12}$	Generator Winding Temperature V
$Idx_{i,4}$	Gearbox Output Shaft Temperature	$Idx_{i,13}$	Generator Winding Temperature W
$Idx_{i,5}$	Gearbox Inlet Oil Temperature	$Idx_{i,14}$	Generator Cooling Air Temperature
$Idx_{i,6}$	Gearbox Oil Sump Temperature	$Idx_{i,15}$	Generator Bearing Temperature A
$Idx_{i,7}$	Main Bearing Rotor Side Temperature	$Idx_{i,16}$	Generator Bearing Temperature B
$Idx_{i,8}$	Main Bearing Gearbox Side Temperature	$Idx_{i,17}$	Reactive Power
$Idx_{i,9}$	Electrical Torque	$Idx_{i,18}$	Active Power

The data of the 9 wind turbines running under normal operating conditions are selected. The sampling frequency of the parameters is 1 second, and each parameter is the average value of 10 minutes selected as the evaluation data.

According to the expressions from (1) to (9) in the second section, the eigenvalues, the variance contribution rates and cumulative variance contribution rates are firstly calculated, respectively. And the number of the principal components is obtained secondly according to the restrictive condition of $\beta_p \geq 0.9$. By calculating, the number is 3, i.e., there are 3 principal components, denoted by $PCA1, PCA2, PCA3$ respectively. The score matrix and the total score vector of the principal components are calculated and sorted by total scores from big to small, and the final evaluation results of the 9 wind turbines are obtained, as shown in the following table.

Table 2. Evaluation results of the wind turbines

$PCA1$	$PCA2$	$PCA3$	Total score	Result sequencing
4.23	-0.40	2.78	6.60	7
3.41	-1.04	-0.07	2.29	2
4.21	-0.72	-1.82	1.66	1
-1.40	2.63	0.03	1.26	6
-0.53	2.02	-0.54	0.95	5
1.61	-0.48	-0.98	0.15	3
-1.88	1.31	0.51	-0.05	4
-3.93	-1.48	-0.55	-5.96	9
-5.73	-1.83	0.65	-6.90	8

Summary

A PCA method is used in this paper to analyze and compare the operational state of different wind turbines in a wind farm. The effectiveness of the method is verified by a case. The method can be used to assess the operation status of wind turbines and to provide a basis for maintenance personnel to optimize operation mode and strengthen operation management of wind farms.

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