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# Synthetic fault factor features under Weibull stochastic interference

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ABSTRACT

Wind power is a rich, widespread and renewable energy, it is also one of the vitally important alternative energies. Wind power belongs to the renewable energy without pollution, and the power generation by wind can reduce harmful gas released from conventional power generation process with mineral fuel, and then decrease the development of greenhouse effect and acid rain. The wind power has been greatly developed in the global scope with maturing wind power techniques, and will maintain persistent growing. The development and utilization of renewable energy resources is the future development direction. In this paper, taking full account of the fluctuation and unpredictability of wind power, one will put forward two types of fault factor features extraction schemes, fault feature I: Factor coefficients and fault feature II: Factor scores, on the basis of these two schemes, one can realize accurate and reliable fault identification. The research in this paper has direct and practical significance for promoting the large-scale exploitation and utilization of wind energy. And the proposed fault factor features extraction schemes will contribute to the future construction of smart grid.



## Introduction

The continuous increase in consumption of world energy sources makes the energy crisis situation in the global scope become clear. It has been major measure of energy development strategy all over the world that the alleviation of energy crisis, the development of renewable energy and the realization of energies' sustainable development [1–5]. As an important renewable energy, wind power is also one of the oldest energies on the earth. Wind power has many characteristics, such as the huge reserves in the global scope, renewable, wide distribution, and no pollution, which have made wind power generation become an important direction of renewable energy development in the world.

The wind power generation has many characteristics which are different from conventional energy generation. Early wind farm scale is small, most of wind turbines adopt small-capacity asynchronous generator sets. The wind farm is directly connected to distribution network, which can satisfy the demand of regional power supply [6–9]. And the influences, wind farm brings to power grid, mainly include local harmonic pollution, voltage fluctuation, flicker and other power quality problems, it will not make a significant impact on the safe and stable operation of large power system. With the progress of technologies, the depth of incentive policy about renewable energy, and the pressure of worldwide environmental protection, wind power generation gradually goes to the scale and industrialization [10–14]. At present, the proportion of wind power generation in power grid is increasing, massive high-capacity wind farms are directly connected to high-voltage power transmission network. The wind power grid integration has impact on the security, stability and dispatch of power grid, and it will likely become a serious obstacle to the development of wind power capacity and scale.

In the research of complex electric power system, we have achieved abundant results [15–18]. In this paper, taking full account of the fluctuation and unpredictability of wind power, we will deeply investigate the synthetic fault factor features under Weibull stochastic interference. The paper is organized as follows. In section 'Fault factor features extraction theory', the fault factor features extraction theory is explained in details, especially the synthetic fault factor features extraction process under Weibull stochastic interference is presented. In section 'Synthetic fault factor features research under Weibull stochastic interference', according to the fault factor features extraction theory, we will put forward two schemes for factor features research: the first scheme is fault feature I: factor coefficients, and the second scheme is fault feature II: factor scores. Based on these, the system failure

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can be effectively identified. Finally the paper is concluded in section 'Conclusions'.

## Fault factor features extraction theory

Suppose the original index vector is $X = (x_1, x_2, \ldots, x_p)'$, one can calculate principal component vectors by principal component analysis [19,20],

$$\begin{pmatrix} z_1 \\ \vdots \\ z_p \end{pmatrix} = \begin{pmatrix} l_{11} & l_{12} & \cdots & l_{1p} \\ \vdots & \vdots & \vdots & \vdots \\ l_{p1} & l_{p2} & \cdots & l_{pp} \end{pmatrix}' \begin{pmatrix} x_1 \\ \vdots \\ x_p \end{pmatrix} \tag{1}$$

or it can be expressed as $Z = L'X$, wherein $L'L = LL' = I_p$.

In fact, each original index can also be expressed by the linear combination of these principal components $z_1, z_2, \cdots, z_p$:

$$X = LZ \tag{2}$$

namely,

$$\begin{pmatrix} x_1 \\ \vdots \\ x_p \end{pmatrix} = \begin{pmatrix} l_{11} & l_{12} & \cdots & l_{1p} \\ \vdots & \vdots & \vdots & \vdots \\ l_{p1} & l_{p2} & \cdots & l_{pp} \end{pmatrix} \begin{pmatrix} z_1 \\ \vdots \\ z_p \end{pmatrix} \tag{3}$$

If considering the dimension reduction function of principal components, one can only extract the first $k$ principal components ($k < p$). Then $X$ can be decomposed into:

$$\begin{pmatrix} x_1 \\ \vdots \\ x_p \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ \vdots & \vdots & \vdots & \vdots \\ a_{p1} & a_{p2} & \cdots & a_{pk} \end{pmatrix} \begin{pmatrix} z_1 \\ \vdots \\ z_k \end{pmatrix} + \begin{pmatrix} s_1 \\ \vdots \\ s_p \end{pmatrix} \tag{4}$$

Here, $z_1, z_2, \cdots, z_k$ are common factors.

If there are random vector $F = (f_1, f_2, \ldots, f_q)'(q \leqslant p)$ and $S = (s_1, s_2, \ldots, s_p)'$, which make

$$\begin{pmatrix} x_1 \\ \vdots \\ x_p \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1q} \\ \vdots & \vdots & \vdots & \vdots \\ a_{p1} & a_{p2} & \cdots & a_{pq} \end{pmatrix} \begin{pmatrix} f_1 \\ \vdots \\ f_q \end{pmatrix} + \begin{pmatrix} s_1 \\ \vdots \\ s_p \end{pmatrix} \tag{5}$$

or it can be expressed as $X = AF + S$, and satisfy

- $D(F) = I_q$, $F$ is a standardization random vector. And the components of $F$ are uncorrelated.
- $D(S) = \begin{pmatrix} \sigma_1^2 & & 0 \\ & \ddots & \\ 0 & & \sigma_p^2 \end{pmatrix}$, $S$ is a centralized random vector;
- $s_1, s_2, \cdots, s_p$ and $f_1, f_2, \cdots, f_q$ are uncorrelated.

In this case, random vector $X$ has orthogonal factor structure. $f_1$, $f_2, \cdots, f_q$ are common factors, $s_1, s_2, \cdots, s_p$ are specific factors, and $A = (a_{jk})_{p \times q}$ is factor loading matrix, $a_{jk}$ is just the loading of the *j-th* index on the *k-th* common factor.

In orthogonal factor modal, for

$$D(X) = AA' + D(S) \tag{6}$$

so

$$AA' = D(X) - D(S) \tag{7}$$

In particular, if $X$ is a standardization random vector, $D(X) = R$ (correlation matrix), then

$$AA' = R(X) - D(S) \tag{8}$$

If $R(X)$, $D(S)$ are known, then $R(X) - D(S) = R^*$, and $R^*$ can be carried out spectral decomposition,

$$R^* = \sum_{j=1}^{q} \lambda_j l_j l_j' \tag{9}$$

The sequential characteristic values of $R^*$ can be solved, and $\lambda_1 \geqslant \lambda_2 \geqslant \cdots \geqslant \lambda_q > 0$, their corresponding normalized characteristic vectors are,

$$l_1, l_2, \cdots, l_q \tag{10}$$

So one can get,

$$A = \left(\sqrt{\lambda_1} l_1, \sqrt{\lambda_2} l_2, \cdots, \sqrt{\lambda_q} l_q\right) = \begin{pmatrix} \sqrt{\lambda_1} l_{11}, & \sqrt{\lambda_2} l_{12}, & \cdots, & \sqrt{\lambda_q} l_{1q} \\ \sqrt{\lambda_1} l_{21}, & \sqrt{\lambda_2} l_{22}, & \cdots, & \sqrt{\lambda_q} l_{2q} \\ \vdots & \vdots & \vdots & \vdots \\ \sqrt{\lambda_1} l_{p1}, & \sqrt{\lambda_2} l_{p2}, & \cdots, & \sqrt{\lambda_q} l_{pq} \end{pmatrix} \tag{11}$$

Actually,

$$AA' = \left(\sqrt{\lambda_1} l_1, \sqrt{\lambda_2} l_2, \cdots, \sqrt{\lambda_q} l_q\right) \begin{pmatrix} \sqrt{\lambda_1} l_1' \\ \sqrt{\lambda_1} l_2' \\ \vdots \\ \sqrt{\lambda_1} l_q' \end{pmatrix} = \sum_{j=1}^{q} \lambda_j l_j l_j' = R^* \tag{12}$$

and

$$A'A = \begin{pmatrix} \sqrt{\lambda_1} l_1' \\ \sqrt{\lambda_1} l_2' \\ \vdots \\ \sqrt{\lambda_1} l_q' \end{pmatrix} \left(\sqrt{\lambda_1} l_1, \sqrt{\lambda_2} l_2, \cdots, \sqrt{\lambda_q} l_q\right) = \begin{pmatrix} \lambda_1 & & 0 \\ & \ddots & \\ 0 & & \lambda_q \end{pmatrix} \tag{13}$$

That is, the variance contribution $g_1, g_2, \cdots, g_q$ of $f_1, f_2, \cdots, f_q$ are $\lambda_1, \lambda_2, \ldots, \lambda_q$ respectively.

When random vector $X$ has orthogonal factor structure, if $X$ can be carried out orthogonal factorization as below,

$$X = AF + S \tag{14}$$

Then for any $q$-order orthogonal matrix $T$, one has

$$X = ATT'F + S \tag{15}$$

If let

$$F^* = T'F, \quad A^* = AT \tag{16}$$

then

$$D(F^*) = T'D(F)T = T'T = I_q \tag{17}$$

$$\mathrm{cov}(F^*, S) = E(F^* S') = T'F(F^* S') \tag{18}$$

and

$$A^* A^{*\prime} = ATT'A' = AA' \tag{19}$$

$$A^{*\prime} A^* = T'A'AT = T' \begin{pmatrix} \lambda_1 & & 0 \\ & \ddots & \\ 0 & & \lambda_p \end{pmatrix} T = \begin{pmatrix} \lambda_1 & & 0 \\ & \ddots & \\ 0 & & \lambda_p \end{pmatrix} \tag{20}$$

So, $X$ can also be expressed as

$$X = A^* F^* + S \tag{21}$$

wherein, $A^*$, $F^*$ can be obtained by the orthogonal transformations of $A$, $F$ respectively.

In the research of this paper, combining the Weibull stochastic interference of wind power integration, we have put forward a synthetic fault factor features extraction flowchart, see Fig. 1.