Comprehensive Evaluation of the Transient Reactive Power Support Capability of New Energy Stations Based on TOPSIS

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Abstract. In order to effectively evaluate the reactive power support capability of new energy stations, an evaluation system is established with the high voltage ride through (HVRT) capability, low voltage ride through (LVRT) capability and reactive power support capability selected as the evaluation index. And then, a comprehensive evaluation method to effectively evaluate the transient reactive support capability of new energy stations is proposed in this paper. The weight of a single index was determined by the coefficient of variation method and then the comprehensive evaluation index was determined based on TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution). Finally, the rationality and effectiveness of the proposed evaluation method are verified by the measured data of a wind farm.

1. Introduction

In the context of dual-carbon, the maximum development and utilization of new energy stations, has become an important mission. However, with the continuous access of new energy, the reactive power support capability of new energy stations is becoming more prominent. Severe LVRT and HVRT will lead to wind power and photovoltaic (PV) off-grid. In this case, it is of great significance to exert the reactive power support capability of reactive power compensation equipment in wind farm and PV field to support voltage. Therefore, establishing a feasible evaluation method of reactive power support capability is of great guiding significance to reduce the problem.

At present, the method of the evaluation of new energy stations performance has also achieved certain results. In [1,2], a method used as evaluation of new energy grid-connected system by hierarchical analysis and entropy power is proposed. In [3], an evaluation method combining the improved hierarchical analysis, the index weight determination and approximating the ideal solution sorting is presented. A comprehensive decision method based on entropy weight and grey association analysis is proposed in [4]. A combinatorial empowerment ideal solution considering the probability distribution is proposed in [5]. Two subjective weighting methods, analytic hierarchy process (AHP) and optimal order graph method, and two objective weighting methods, entropy weight method and variation coefficient method, are used in [6]. In [7,8], the coefficient variability and a sorting method approximate using TOPSIS is combined. In [9], a method with entropy weights is used. Authors in [10] has presented an evaluation method for the severity of system side voltage reduction. Combining the
ITIC curve, SEMI curve and sensitive equipment tolerance curve, the influence of voltage drop on the equipment is evaluated in [11].

Considering that the above methods have unreasonable distribution of evaluation functions, this paper presents a way for evaluation using a combination of coefficient of variation and TOPSIS. The HVRT and LVRT capability and the reactive power support capability of the wind farm, the PV field and the reactive power compensation equipment are all evaluated systematically. Finally, the rationality and effectiveness of the proposed evaluation method are verified by the measured data of a wind farm.

2. Evaluation Indicators of Reactive Power Support Capability of New Energy Stations

2.1. Evaluation Index of Transient Reactive Support Capability of Reactive Power Compensation Equipment

2.1.1. Dynamic Response Index of Reactive Power Compensation Equipment. When the abnormal connection network voltage reaches the time required to trigger the set value, until the actual output value of the reactive power compensation device reaches 90% of the difference between the control target value and the initial value, namely the dynamic response time of the reactive compensation.

Record the dynamic response time of reactive power compensation equipment, and take the ratio of the measured value to the specified value as the dynamic response index of the reactive power compensation equipment:

\[ S_{DRT} = \frac{t}{t_0} \]  \tag{1}

Where \( t \) indicates the measured value of dynamic response time of reactive power compensation equipment; \( t_0 \) is the standard value of the dynamic response time of reactive reactive compensation equipment.

2.1.2. Power Factor Adjustment Index. Reactive power compensation equipment (SVG, SVC) operates in the constant power factor control mode, determines the power factor adjustment ability, and should meet the power factor fluctuation range is not more than 3%. Measure the ratio of power factor to the specified value of reactive power compensation equipment as a measure of its power factor adjustment ability:

\[ S_{\cos \phi} = \frac{\cos \phi}{\cos \phi_0} \]  \tag{2}

Where \( \cos \phi \) indicates the measured power factor of reactive compensation equipment; \( \cos \phi_0 \) is the specified value.

2.2. Reactive Power Support Capability Index of Wind Farm

2.2.1. LVRT Capability. The LVRT capability of wind farm is specified in GB / T19963-2021, requirements of the wind farm are shown in figure 1.

![Figure 1. LVRT of the wind farm.](image-url)
Combined with LVRT characteristics of wind farm, $S_{LVRT_e}$ is defined as the LVRT capability of wind farm.

$$S_{LVTR} = \begin{cases} \frac{U}{U_0} \times \frac{t}{0.625}, & 0 \leq t \leq 0.625 \\ \frac{U}{U_0} \times \frac{t}{1.9643U + 0.23213}, & 0.625 < t \leq 2 \end{cases}$$  \hspace{1cm} (3)

Where $U$ is the measured voltage unitary of the wind farm and network; $U_0$ is the ideal experimental voltage unitary of the wind farm and network; $t$ is the time (s).

2.2.2. HVRT Capability. The HVRT capability of the wind farm is that when the power system accident is caused by the disturbance and the network voltage increases, the wind farm can ensure the continuous operation of the off-grid during a certain voltage increase range and time interval.

HVRT requirements of the wind farm are shown in figure 2.

![Figure 2. HVRT of the wind farm.](image)

The same definition method of HVRT index of wind farm. $S_{HVRT_e}$ is defined as the evaluation index of HVRT of wind farm.

$$S_{HVT} = \begin{cases} \frac{U_e}{U} \times \frac{t}{0.5}, & 0 \leq t < 0.5 \\ \frac{U_e}{U} \times \frac{t-0.5}{0.5}, & 0.5 \leq t < 1 \\ \frac{U_e}{U} \times \frac{t-1}{9}, & 1 \leq t < 10 \end{cases}$$  \hspace{1cm} (4)

2.2.3. Dynamic Reactive Power Support Capability. The rising time of dynamic reactive current is an important index to evaluate the reactive power support capability of wind farms. The rise time of dynamic reactive current is the time required for the connection point voltage to rise or decrease to reach the trigger set point, until the change of the actual output value of dynamic reactive current in the wind farm reaches 90% of the difference between the control target value and the initial value.

When the LVRT occurs in the wind farm, the dynamic reactive current rise time is not more than 60ms; when the HVRT occurs, the dynamic reactive current rise time is not more than 40ms. $S_s$ was defined as the dynamic reactive power support capability evaluation index of wind farms.

$$S_s = \frac{t_{Lr0}}{t_{Lr}} \times \frac{t_{Hr0}}{t_{Hr}}$$  \hspace{1cm} (5)

Where $t_{Lr0}$ is the maximum operating time of low voltage dynamic reactive current; $t_{Lr}$ the actual value of low voltage dynamic reactive current rise time of the wind farm; $t_{Hr0}$ the maximum operating time of low voltage dynamic reactive current; $t_{Hr}$ the actual value of low voltage dynamic reactive current rise time of the wind farm.
2.3. Index of Reactive Power Support Capability of PV field

2.3.1. LVRT Evaluation. LVRT capability is an important factor to consider whether the PV field can stabilize the grid. The LVRT requirements of the PV field are shown in Figure 3.

![Figure 3. LVRT capability requirements of the PV field.](image)

Because the LVRT capability of the PV field is also only related to the junction network voltage and the LVRT time. \( S_{LVRT}^{PV} \) is defined as the evaluation index of LVRT of PV field.

\[
S_{LVRT}^{PV} = \begin{cases} 
\frac{U}{U_0} \times \frac{t}{0.15}, & 0 \leq t \leq 0.15 \\
\frac{U}{U_0} \times \frac{0.15}{0.625}, & 0.15 \leq t \leq 0.625 \\
\frac{U}{U_0} \times \frac{0.625}{1.964U+0.232}, & 0.625 \leq t \leq 2
\end{cases}
\]  

(6)

2.3.2. Dynamic Reactive Power Response Time Evaluation. The response time of the dynamic reactive current of the PV field shall not be no more than 30 ms. To evaluate the dynamic reactive response ability, it is now defined as \( S'_{IU} \).

\[
S'_{IU} = \frac{t'_{r0}}{t'_{r}}
\]  

(7)

Where \( t'_{r} \) is the actual dynamic reactive response time; \( t'_{r0} \) is the maximum dynamic reactive response time.

3. Comprehensive Evaluation of Reactive Power Support Capability of New Energy Stations

3.1. Variability Coefficient Method

The weight of the evaluation index was determined by the variation coefficient method. Variation coefficient method is an objective authorization method, which directly uses the information contained in indexes to calculate the weight of indexes.

3.1.1. Constitute the Initial Matrix \( X \). Assuming that there are \( m \) groups of evaluation samples and \( N \) evaluation indexes, the initial index matrix:

\[
X = \begin{bmatrix}
x_{i1} & \cdots & x_{in} \\
\vdots & \ddots & \vdots \\
x_{m1} & \cdots & x_{mn}
\end{bmatrix}
\]  

(8)

Where \( x_{ij} \) are the values representing the evaluation index of group \( i \) evaluation sample.

// Calculate the average and standard deviation of the evaluation index

After obtaining the original index data matrix, the average and standard deviation of each evaluation index were calculated and the formula is Equation (9).
Where \( \bar{x}_j \) is the average of \( j \)th index, and \( s_j \) is the standard deviation.

2) Calculate the weights of each indicator

The coefficient of variation of each index is processed in units to obtain the weight of each index.

\[
\omega_j = \frac{s_j}{\sqrt{\sum_{i=1}^{n}(x_{ij}-\bar{x}_j)^2}}
\]

Where \( \omega_j \) is the weight of the evaluation index of item \( j \).

3.2. Comprehensive Evaluation of Reactive Power Support Capability of New Energy Stations

3.2.1. Principles of TOPSIS. TOPSIS is an effective multi-index evaluation method. The importance of each index is different to the reactive power support capability of new energy field stations. The weight of each index is obtained by the coefficient of variation method. TOPSIS weights the Euclidean distance between the calculated evaluation target and the positive and negative ideal solutions. \( C^+ \) represents a positive ideal solution; \( C^- \) represents a negative ideal solution.

3.2.2. Basic steps of TOPSIS. The evaluation methods of transient reactive support capability of new energy stations are as follows:

\( a) \) Constitute normative decision matrix

\[ B = (b_{ij})_{m \times n} \]

\[ b_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n}x_{ij}}, i = 1,2,\ldots,n \]

\( b) \) Constitute weighted gauge array

We average the weight vector using the coefficient of variability and entropy method \( W = [w_1, w_2, \ldots, w_n]^T \)

\[ c_{ij} = w_j * b_{ij}, i = 1,2,\ldots,n \]

Weighted gauge array \( C = (c_{ij})_{m \times n} \)

\( c) \) Determine both the positive \( C^+ \) and the negative ideal solutions \( C^- \)

The positive ideal solution \( C^+ \) and negative ideal solution \( C^- \) are selected from the normalized data. Let the positive ideal solution of the \( j \)-th attribute be \( C^+_j \) and the negative ideal set be \( C^-_j \).

\[ C^+_j = \max c_{ij}, i = 1,2,\ldots,m, j \in N^+ \]

\[ C^-_j = \min c_{ij}, i = 1,2,\ldots,m, j \in N^- \]

Where \( N^+ \) indicates a positive indicator set; \( N^- \) represents the negative indicator set.

\( d) \) The weighted Euco-type distance was calculated

\[ d^+_i = \sqrt{\sum_{j=1}^{n}w_j^2(c_{ij} - c^+_j)^2}, i = 1,2,\ldots,m \]

\[ d^-_i = \sqrt{\sum_{j=1}^{n}w_j^2(c_{ij} - c^-_j)^2}, i = 1,2,\ldots,m \]

\( e) \) The comprehensive evaluation index of the evaluation object is calculated
The evaluation objects are ranked in order according to the size of the comprehensive evaluation index $f_i$, and $f_i$ the larger, the better the evaluation objects.

3.2.3. **Quantitative Classification of Indicators.** In this paper, the reactive power supporting capacity index of new energy stations is defined as super large index, that is, the larger the value is, the stronger the reactive power supporting capacity is. Each index is quantified according to Table 1. According to the evaluation results, it is divided into five levels: great, good, secondary, qualified and unqualified, among which $S$ is the evaluation ability value corresponding to the measured value.

**Table 1.** Index evaluation and classification.

| Grade       | Evaluation | Great          | Good           | Secondary      | Qualified      | Unqualified   |
|-------------|------------|----------------|----------------|----------------|----------------|--------------|
| $S \geq 2$  | $1.33 \leq S < 2$ | $1.14 \leq S < 1.33$ | $1.33 \leq S < 1$ | $S < 1$        |

The boundary value of each evaluation level and the measured data are taken for comprehensive evaluation, and arranged according to the order from large to small of the comprehensive evaluation index $f_i$, that is, the rank is arranged from excellent to unqualified, to determine the measured data evaluation level.

4. **Example Analysis**

In this paper, the test data of a wind farm in Shanxi are selected for analysis. The planned installed capability of the wind farm is 150MW, the first-stage construction capability is 60MW, and the current construction capability is 50MW. The newly-built 3-circuit collector line is connected to 35kV bus of booster station, and a set of dynamic reactive power compensation device with 25Mvar capability is installed. Curve 1 in figure 4 is the response characteristic curve of SVG.

![SVG response characteristic curve.](image)

The measured data of a wind farm in Shanxi are analyzed and the original matrix $X$ is formed. Each column of $X$ represents an index, which is: wind farm dynamic reactive power device response capability, power factor regulation capability, HVRT capability, LVRT capability and dynamic reactive power support capability. The first line of $X$ is the measured data, and the other four lines are the lower bound value of the index evaluation grade in turn.

$$X = \begin{pmatrix}
1.1099 & 5.3571 & 1.0135 & 1.0731 & 6.5753 \\
2.0000 & 2.0000 & 2.0000 & 2.0000 & 2.0000 \\
1.3300 & 1.3300 & 1.3300 & 1.3300 & 1.3300 \\
1.1400 & 1.1400 & 1.1400 & 1.1400 & 1.1400 \\
1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000
\end{pmatrix}$$
Calculate the original matrix $X$ to get the evaluation results, grades and weights of each index, as shown in Table 2.

| Indicator | $S_{\text{DRT}}$ | $S_{\text{cos}}$ | $S_{\text{LVRT}}$ | $S_{\text{HVRT}}$ | $S_s$ |
|-----------|----------------|----------------|---------------|----------------|-------|
| Evaluation order | 1.1099 | 5.3571 | 1.0135 | 1.0731 | 6.5753 |
| weight | 0.11034 | 0.3057 | 0.1161 | 0.1124 | 0.3554 |

The measured data and the lower bound value of the index evaluation grade are comprehensively evaluated, and the comprehensive evaluation grade is obtained. The comprehensive evaluation index $f_i = 0.8924$ of the wind farm is obtained, and then the comprehensive evaluation grade of the wind farm is determined. As shown in Table 3.

| Order | Outstanding | Good | Secondary | Qualified | Unqualified |
|-------|-------------|------|-----------|-----------|-------------|
| Evaluating | $<f<1$ | $0.0788 < f$ | $0.0753 < f$ | $0.0817 < f$ | $0 <= f$ |
| $<f<1$ | $0.1593$ | $\leq 0.1593$ | $\leq 0.0788$ | $\leq 0.0753$ | $\leq 0.0817$ |

5. Conclusion
In this paper, the response time of reactive power equipment, power factor adjustment index, HVRT and LVRT capability and reactive power support capability are determined as the evaluation indicators of transient reactive power support, and they enhance the credibility of the evaluation results through the combination of various standards.

Assign a single index using the coefficient of variation method. This method can objectively find the weight of each index, allocate each index according to the change degree of current value and target value of each evaluation index, and improve the practicability of evaluation.

According to TOPSIS, the transient reactive support capability of the new energy stations can be comprehensively evaluated and graded, and the feasibility, accuracy and superiority of this proposed method are proved through the example of the wind farm.

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