Impact analysis and risk assessment of supply and demand bilateral randomness on power system

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Abstract. With the high proportion of new energy access, the randomness of the supply side increases. The electrical power system system is transformed from a unilateral stochastic system on the demand side to a bilateral stochastic system on the supply and demand side. Firstly, this paper studies the potential risks of power system under the randomness of supply and demand sides; then, according to the principles of integrity, relevance, operability, quantitative and qualitative combination, the evaluation index system of bilateral randomness for the safety and stability risk of power system is constructed. Finally, a risk assessment model is constructed based on the static subjective weights of FAHP and similarity clustering analysis and the dynamic objective weights of the improved CRITIC weighting method.

1. Introduction
The power system is widely embedded and deeply affects the economic and social development. Any changes in its operational characteristics and its corresponding technological upgrades will affect many aspects of the country and society. The traditional supply-side thermal power generation has a high proportion and strong regulation ability. The output of the thermal power unit can respond faster with the change of the demand side power load.

The large-scale intermittent renewable energy grid connection makes the supply side controllability gradually decrease, the randomness gradually increases, and the basic operational characteristics of the power system change accordingly. From the demand side single-sided stochastic system to the supply and demand two-sided stochastic system [¹].

2. Analysis of the Influence of Bilateral Randomness on Power System Security and Stability.
Renewable energy power generation has strong random volatility. With the development of clean energy, the scale of renewable energy integration is expanding, and the proportion of renewable energy generation in the power supply side is constantly increasing, requiring a large number of conventional power sources to complement each other to stabilize the volatility [²]. There is no coordination between current renewable energy construction and grid planning. With the further deepening of the bilateral randomness characteristics, the mutual influence between the source networks will gradually become obvious. The specific performance is that the energy consumption of
renewable energy is insufficient, and a large number of abandoned water, abandoned wind and abandoned light appear, resulting in serious waste of resources and the controllability of the output of the electric side is poor, which increase the influence of the bilateral random volatility on the operation of the system [3].

3. Bilateral randomness to power system security and stability risk assessment index system

3.1. Index system construction

This section mainly constructs the risk assessment index system of power system security stability from the aspects of power supply complementation and source network coordination [4]. As shown in Table 1.

1) Power supply complementary risk R1
   a. Capacity validity R11: Describe the effective utilization of the capacity of the machine assembly machine, reflecting the abundance of the unit's power generation
   b. Power generation intensity R12: Describe the continuity of the unit's power generation, which is the ratio of the equivalent full power generation hours of the unit to the statistical time of 8760 hours.
   c. Operating safety R13: Describe the degree of safe operation of the unit, reflecting the degree of impact of unit outage and grid failure on unit reliability.
   d. Relative benefit coefficient and R14: Describe the superiority of the renewable energy unit relative to the thermal power unit.

2) Coordination risk between power and grid R2
   a. Peaking ability R21: Reflecting the indicators of renewable energy consumption, the stronger the peaking ability of the system, the larger the range of power fluctuations allowed by the system.
   b. Transmission capacity R22: Reflecting the indicators of renewable energy consumption capacity, the stronger the system's transmission capacity, the more energy that renewable energy delivers, and the greater the capacity of renewable energy.
   c. Grid-connected technology R23: Indicators reflecting the ability of renewable energy to absorb, the more mature the grid-connected technology, the less volatility caused by the integration of renewable energy, and the more renewable energy that can be absorbed.
   d. Power load matching degree R24: Reflecting the degree of matching between power supply and load, the higher the matching degree between power supply and load, the lower the frequency of abandoned power generation and power failure.
   e. System security R25: Indicators that reflect the operational level of the power system, including static and dynamic security. Static security mainly refers to the ability of the system to maintain the initial stable operating state due to line failure or load fluctuation.
   f. Power quality R26: Indicators that reflect the operating level of the power system, mainly related to voltage, voltage sag, voltage fluctuations and flicker, harmonics, and frequency.
   g. Abandon power loss R27: The indicator reflecting the degree of incompatibility between the power and the grid is the sum of the waste of resources caused by the abandonment of water wind or light.
   h. Loss of power failure R28: The indicator reflecting the degree of uncoordinated power and grid is the sum of direct and indirect losses caused by power failure.

4. Potential risk assessment model under the bilateral randomness of supply and demand

4.1. Static subjective weights based on FAHP and similarity clustering analysis

FAHP is run by the maker’s subjective judgment [5]. Subjective authority is a feature of the method. Therefore, this chapter establishes the index sorting vector matrix L of the expert group based on FAHP, applies the similarity clustering analysis to establish the authoritative factor matrix $\gamma$ of the expert group, and combines the two matrices to determine the static subjective weight of the potential risk assessment index system under the bilateral randomness of supply and demand.
The steps for calculating the authoritative factor matrix $\gamma$ are:

Step 1: Use $L$ to establish a similarity correlation matrix $S = [s_{pq}]_{mn}$

The following formula is used to specifically define the similarity of the row vectors $l_p$ and $l_q$, and the similarity is represented by the vector angle cosine $s_{pq}$ ($p \neq q; \ p,q=1,2,\ldots,n$).

$$s_{pq} = \frac{l_p^T l_q}{\|l_p\| \|l_q\|}$$  \hspace{1cm} (4-1)

Where $l_q^T$ is the transpose of vector $l_q$, and $\|l_p\|$ and $\|l_q\|$ are the norms of the corresponding vector.

Step 2: Expert Cluster Analysis

(a) Find the largest off-diagonal element $S_{ab}$ in matrix $S$, and put experts $e_a$ and $e_b$ into set $E$; (b) Let $S_{ab} = S_{ba} = 0$, determine the largest off-diagonal element $S_{ac}(S_{bc})$, and classify $e_c$ into set $E$; (c) Let $S_{ac} = S_{ca} = 0$ (Let $S_{bc} = S_{cb} = 0$), determine the off-diagonal element $S_{cd}$, and classify $e_d$ into set $E$; (d) And so on, until all experts are included in the set $E$; (e) Determine a threshold $T$. If $S_{lk} \leq T$, the experts $e_l, e_k$ are classified into one class, and if not, $e_l$ and $e_k$ are different categories.

Step 3: Authoritative factor $\alpha$ between expert categories

If the clustering is successful, $n$ experts total $r$ categories, where the expert $e_i$ belongs to the $h$-th ($1 \leq h \leq r$) class, and the class includes $\varphi_h$ experts, then the authoritative factor $\alpha_h$ of the class is:

$$\alpha_h = \frac{\sum_{i=1}^{\varphi_h} \|l_i - l_h^T\|}{\varphi_h}$$

$$N_i = \frac{\sum_{j=1}^{\varphi_h} \|l_j - l_h^T\|}{\varphi_h}$$

$$\alpha_h = \frac{\varphi_h^2}{N_h} / \sum_{i=1}^{\varphi_h} \left( \frac{\varphi_i^2}{N_i} \right)$$

Among them, $N_i$ is the comprehensive consistency difference value between the index sorting vectors established by experts $e_i$ and other experts; $N_h$ is the comprehensive consistency difference value between the category $h$ expert and other expert categories.

Step 4: Calculate the authority coefficient $\beta$ in the expert categories

The authoritative coefficient $\beta_i$ of the expert $e_i$ in the $h$-th category is:

$$\beta_i = \frac{1}{1 + cC_{Ri}} \frac{1}{\sum_{j=1}^{\varphi_h} \frac{1}{1 + cC_{Rj}}}$$

Where $c$ is the adjustment scale factor, let $c=10$; $C_{Ri}$ and $C_{Rj}$ are the consistency ratios of the fuzzy judgment matrices established by the experts $e_i$ and $e_j$ in the $h$-th category, respectively.

Step 5: Calculate $\gamma$

The authoritative factor of expert $e_i$ is:

$$\gamma_i = \alpha_i \beta_i$$

4.2. Dynamic objective weight based on improved CRITIC Empowerment Method

The model based on the CRITIC Empowerment Method to obtain objective empowerment is \cite{6}:

$$\sigma_i = \left[ \sum_{j=1}^{\varphi_h} (x_{i,j,k} - x_{i,ave}^k)^2 / u \right]^{1/2}$$

$$r_{ij} = \frac{\sum_{k=1}^{\varphi_h} (x_{i,j,k} - x_{i,ave}^k)(x_{i,k} - x_{i,ave}^k)}{\sum_{k=1}^{\varphi_h} (x_{i,j,k} - x_{i,ave}^k)^2 \sum_{k=1}^{\varphi_h} (x_{i,k} - x_{i,ave}^k)^2}$$

$$\omega_2(i) = \frac{\sigma_i \sum_{j=1}^{\varphi_h} (1 - r_{ij})}{\sqrt{\sum_{i=1}^{\varphi_h} \sigma_i \sum_{j=1}^{\varphi_h} (1 - r_{ij})}}$$
Where $\sigma_i$ is the standard deviation of the index $i$; $u$ is the number of decision schemes; $x_{i,k}$ and $x_{j,k}$ are the normalized parameter values of the indicators $i$ and $j$ in the $k$-th decision scheme, respectively; $r_{ij}$ is the correlation coefficient for indicators $i$ and $j$; $w_2(i)$ is the dynamic objective weight, and $v$ is the number of indicators. The parameters of indicators $i$ and $j$ are normalized.

Because CRITIC lacks the discreteness of the metrics, this chapter uses the formula of information entropy to consider the weights between the indicators to compare strength, conflict, and discreteness.

$$
\omega_2(i) = \frac{(\sigma_i + x_i) \sum_{j \neq i} (1 - r_{ij})}{\sum_{j \neq i} (\sigma_i + x_i) \sum_{j \neq i} (1 - r_{ij})}
$$

(4-6) Obtaining optimal variable weight

For the index $i$, the formula for calculating the optimal variable weight is as follows:

$$
\omega(i) = \frac{\omega_1(i) \omega_2(i)}{\sum_{i=1}^v \omega_1(i) \omega_2(i)}
$$

(4-7)

Where $w_1(i)$ and $w_2(i)$ are the static subjective weights and dynamic objective weights of indicator $i$, respectively; $t$ is the total number of indicators of the same category as indicator $i$.

5. Case analysis

The power system safety and stability risk assessment system proposed in the previous paper is used to obtain the safety and stability risk value of the power system.

Step 1: Calculate the risk value of each micro indicator

Calculate the risk value of each micro-indicator of the power system in the recent development stage according to the previous steps, as shown in Table 2.

| Macro risk | Micro indicator | Recent | Medium-term | Long-term |
|------------|-----------------|--------|-------------|-----------|
| Power supply complementary risk $R_1$ | Capacity validity $R_{11}$ | 12.047 | 13.681 | 10.354 |
| | Power generation intensity $R_{12}$ | 15.368 | 12.976 | 10.252 |
| | Operational safety $R_{13}$ | 16.324 | 15.024 | 10.687 |
| | Relative benefit coefficient $R_{14}$ | 11.578 | 12.649 | 10.208 |
| | Peaking ability $R_{21}$ | 9.427 | 8.514 | 7.138 |
| | Transmission capacity $R_{22}$ | 10.088 | 8.289 | 7.651 |
| | Grid-connected technology $R_{23}$ | 11.235 | 9.802 | 7.064 |
| Coordination risk between power and grid $R_2$ | Power load matching degree $R_{24}$ | 13.864 | 16.334 | 11.240 |
| | System security $R_{25}$ | 14.392 | 11.446 | 8.083 |
| | Power quality $R_{26}$ | 15.027 | 10.066 | 5.9863 |
| | Abandon power loss $R_{27}$ | 14.239 | 10.872 | 9.624 |
| | Loss of power failure $R_{28}$ | 11.947 | 10.368 | 6.248 |

Step 2: Calculate the optimal variable weight

According to the static subjective weight solving process, the calculated static subjective weights are:

$R_1 = [0.2867, 0.3302, 0.1846, 0.01985]$, $R_2 = [0.1045, 0.1372, 0.1672, 0.0967, 0.1824, 0.0726, 0.1285, 0.1106]$, $R = [0.4026, 0.5974]$.

Combined with the contents of Table 4-1, the dynamic objective weights of the micro-indicators are determined according to the improved CRITIC Empowerment Method:

$R'_1 = [0.2525, 0.4302, 0.1066, 0.2107]$. 


\[ R_2 = [0.1503, 0.1244, 0.0987, 0.1234, 0.1406, 0.1720, 0.1047, 0.0859]. \]
\[ R_1 = [0.2634, 0.5147, 0.0713, 0.1515], \quad R_2 = [0.1284, 0.1395, 0.1349, 0.0975, 0.2096, 0.1021, 0.1100, 0.0776] \] was calculated according to the optimal variable weight formula.

Step 3: Calculation of overall risk value

Based on the above calculation results, the weighted average method is used to obtain the safety value of the two-sided randomness to the power system security stability. As shown in Table 3.

Step 4: Risk rating

In the case study, the safety and stability risk value of the power system is 12.601. Compared with the risk feature vector, the risk level is close to the third level, and the risk is medium risk.

| Table 2. Power system security stability risk value |
|-------------------------------|------------------|------------------|
| assess target | Risk value | Risk description |
| R1 | 10.028 | medium |
| R2 | 14.336 | medium |
| R3 | 12.601 | medium |

The safety and stability risk level of the power system after the renewable energy is connected to the grid is general. Therefore, based on the risk assessment model established in this section, the safety and stability risk situation of the power system is consistent with the actual situation, and the validity of the model is verified.

6. Conclusion

This paper studies the impact of bilateral randomness on the safety and stability of power system, analyzes the risk of bilateral randomness on the safety and stability of power system, constructs a risk assessment index system, and establishes a risk assessment model.

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