The construction of power grid operation index system considering the risk of maintenance

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Abstract. In recent years, large-scale blackout occurred at home and abroad caused widespread concern about the operation of the grid in the world, and the maintenance risk is an important indicator of grid safety. The barrier operation of the circuit breaker exists in the process of overhaul of the power grid. The operation of the different barrier is of great significance to the change of the power flow, thus affecting the safe operation of the system. Most of the grid operating status evaluation index system did not consider the risk of maintenance, to this end, this paper from the security, economy, quality and cleanliness of the four angles, build the power grid operation index system considering the risk of maintenance.

1. Introduction
In the power grid operation index system, the literature [1] proposed a comprehensive index system, which can be a comprehensive analysis and evaluation of the smart grid, but the indicators of the statistical cycle is long, suitable for power grid planning program analysis and evaluation. In the literature [2], the corresponding index system is put forward from the point of view of safety, power quality, low carbon and cleanliness, and the operation of one side of the power grid can be analyzed accurately and deeply.

There are three methods of risk assessment of grid operation: deterministic analysis method, probability analysis method and risk assessment method. Literature [3] uses single or multiple indexes to analyze the operation risk of power grid. These studies provide a way for risk assessment to be applied in the power grid, making it possible for grid operation risk assessment to be applied in practice.

This paper constructs the power grid operation index system considering the risk of maintenance including safety, economy, quality and cleanliness.

2. Key Indicator System
The evaluation system of power grid operation is tree structure, among which the index is divided into two categories according to nature.

1) Qualitative indexes. It has the function of determining the direction and scope of evaluation, there is no fixed formula and data source.
2) Quantitative index. It has the function of decomposition and deep analysis, and has fixed calculation methods and data sources.

2.1. Qualitative index frame
The selection of qualitative index follows three principles: systematic, independence and scientific. Qualitative indexes framework as shown in figure 1, the security can be divided into static and dynamic two aspects. Considering the actual situation of dispatching operation.

2.2. Quantitative Index
Quantitative index is the basis of the whole index system, which is the decomposition and quantification of the superior directional index, and has four characteristics: testability, clarity, consistency and timeliness.

3. The Power Grid Operation Index System Considering the Risk of Maintenance

3.1. Safety index set
Safety accident (S₁₁): Statistics of the power limit of the bar, The number of trip failures, the non-scheduled stop service of direct generator unit and other major accidents such as power grid solution and other accidents.

Secondary protection (S₁₂): to calculate the name or number of power equipment that cannot normally work under the current secondary protection device.

Meteorological early warning (S₁₃): according to the weather forecast is estimated in the grid may be struck by lightning, high temperature, freezing, rainfall and a tropical storm, under the influence of the generator (group), transformer and bus, name and number of statistics.

Main variable maintenance (S₂₁) and important line maintenance (S₂₂): the number of transformers and important lines that are being overhauled for the maintenance of 220/330/500/1000kv.

Unit/lower rotating standby capacity (S₂₃): the units are calculated according to the statistics of the two planned periods in the same day and 10 min respectively.

\[ S_{2,3} = \{S'_{2,3}, S''_{2,3}\} \times 100\% \] (1)
In the formula: rotation reserve rate on the unit $S'_{2,3} = (P - P)/\bar{P}$, under the rotation standby $S''_{2,3} = (P - P)/P_\bar{P}$ and P, respectively, for the unit in the period of active power on the lower limit and the current active output.

Unit up / down regulation reserve capacity ($S_{2,4}$): the units were the same day and 10min 2 planned time by the following statistics.

$$S_{2,4} = \left\{S'_{2,4}, S''_{2,4}\right\} \times 100\%$$  \hspace{1cm} (2)

In the formula: adjust the reserve rate on the unit $S'_{2,4} = (P - P)/\bar{P}$, down regulation reserve rate $S''_{2,4} = (P - P)/P_\bar{P}$ and P, respectively, for the crew in the period of active adjustment on the lower limit.

Total Internet/bottom rotation reserve ($S_{2,5}$): In the same day, 10 min and 30 min, three plan time periods are calculated according to the statistics.

$$S_{2,5} = \left\{S'_{2,5}, S''_{2,5}\right\} \times 100\%$$  \hspace{1cm} (3)

In the formula: rotate spare capacity all over the net $S'_{2,5} = \sum_{i\in\Omega_1}(\bar{P}_i - P_i)t$, under the rotation reserves $S''_{2,5} = \sum_{i\in\Omega_1}(\bar{P}_i - P_i)$, respectively, for the unit i in the period of active power on the lower limit and the current active output, $\Omega_1$ for the whole network reconciliation crew collection.

Full network / down regulation ($S_{2,6}$): Respectively, the day, 10 min and 30 min within 3 planned time periods are calculated according to the statistics.

$$S_{2,6} = \left\{S'_{2,6}, S''_{2,6}\right\} \times 100\%$$  \hspace{1cm} (4)

In the formula: total online adjustments $S'_{2,6} = \sum_{i\in\Omega_1}(\bar{P}_i - P_i)$, the amount of reserve that can be adjusted $S''_{2,6} = \sum_{i\in\Omega_1}(\bar{P}_i - P_i)$, respectively, for the unit i in the period of active adjustment on the lower limit.

The component over / reload margin ($S_{31,1}$) is as follows.

$$S_{31,1} = \frac{IN - I}{IN} \times 100\%$$  \hspace{1cm} (5)

In the formula: IN is the component thermal stability limit; I is the component in the current operating mode of the tidal solution, the unit is A or MVA.

Busbar voltage margin margin ($S_{31,2}$) is as follows.

$$S_{31,2} = \left(1 - \frac{U - U_{\text{min}}}{U_{\text{max}} - U_{\text{min}}}\right) \times 100\%$$  \hspace{1cm} (6)

In the formula: $\bar{U}$, $U$, and $U_{\text{min}}$ respectively, for the evaluation of the bus voltage, the lower limit and the current to calculate the voltage.

Cross section trend margin margin ($S_{31,3}$): according to the results of the current flow, the statistical margin is less than 20% of the transmission section.

Component Overload / Overload Margin ($S_{32,1}$), Voltage margin margin ($S_{32,2}$): the N-1 scan results are substituted into (5) (6). Statistical minimum and early warning of the calculated value, take the weighted average.

Number of power loss components ($S_{32,3}$): after n-1 scan, the number of lost lines caused by all kinds of failures was calculated and the maximum value was taken.

Bus short circuit current ($S_{32,4}$): according to the expected failure set, the current limit and the maximum value of the current of each bus are calculated.

Circuit breaker short circuit current ($S_{32,5}$): calculate the maximum current limit of the circuit breaker when the fault of all bus lines is short.
The calculation of transient stability margin (S_{412_1}), transient frequency stability margin (S_{421_1}) and transient voltage stability margin (S_{431_1}) is shown in [4]. Small disturbance stability margin (S_{411_1}) is the current failure of the online analysis system to determine the displacement point and calculate all critical eigenvalues of the point through the IRAM method.

Static stability reserve coefficient (S_{411_2}) is to specify the contact line or contact section, press the calculation.

Large perturbation stability margin (S_{412_2}) is Prony analysis of the active power curve of each key contact line specified after the expected failure, the minimum value of its damping margin.

3.2. Economic index set
Device light load rate (E_{1_1}) is the actual load rate is less than 30% of the equipment (such as units, transformers, etc.) and the ratio of the total number of equipment. High voltage transmission network loss rate (E_{1_2}) is calculated according to the calculation.

\[
E_{1_2} = \frac{\sum_{i \in \Omega} W_i - W_e}{\sum_{i \in \Omega} W_i} \times 100\%
\]  
(7)

In the formula: \(W_i\) is the total generating capacity of unit i in the statistical cycle; The total amount of power to be sold by \(W_e\) for high voltage (220 kV and above); \(\Omega\) said linked to high voltage power grid unit set.

Monthly generation plan deviation rate (E_{1_3}) is the ratio between the difference between the monthly actual power generation and the planned quantity and the planned quantity.

Unit purchase cost (E_{1_4}) is the ratio of the total cost of the power company’s purchase of electricity from the power plant to the total purchase quantity.

Feed-in tariff (E_{1_5}) is the electricity and power provided in the contract for electricity purchase, and the metering price of the power generation enterprises connected to the main grid.

Power generation average coal consumption (E_{1_6}) is calculated according to the calculation.

\[
E_{1_6} = \frac{\sum_{i \in \Omega} (P_i \lambda_i)}{\sum_{i \in \Omega} P_i}
\]  
(8)

In the formula: \(P_i\) is the current active force of the unit i; \(\lambda_i\) for its coal consumption (fuel needs to be converted to standard coal); \(\Omega\) as fuel collection unit.

Power supply average coal consumption (E_{1_7}) is calculated by the following formula.

\[
E_{1_7} = \frac{\sum_{i \in \Omega} (P_i \lambda_i)}{\sum_{i \in \Omega} P_i}
\]  
(9)

In the formula: \(\lambda_i\) for the power supply of unit i; The units of E_{1_6} and E_{1_7} are all g/kW.

3.3. Quality Index Set
System frequency (Q_{1_1}) statistics of total network system frequency and 50 Hz frequency deviation, accurate to 0.01 Hz. Grid maximum/low frequency (Q_{1_2}) is peak and valley value of power grid liability frequency in the statistical cycle.

CPS1, CPS2 (Q_{1_3}): in the real-time scheduling operation, the power grid will exchange the power of the contact line and the level of frequency control in the region.

Responsibility frequency overrun time (Q_{1_4}) is statistical frequency cycle responsibility more than \(50 + \Delta f\) (\(\Delta f\) can be set as 0.2) length of Hz.

Responsibility frequency pass rate (Q_{1_5}) is the sum of the total time of the responsibility frequency and the ratio of the statistical period.

One frequency conversion rate (Q_{1_6}) is in the statistical cycle, the time of one frequency shift is the proportion of the total operating time of the unit.

A frequency modulation power (Q_{1_7}) is a set frequency deviation value epsilon (0.033 Hz), from the grid frequency exceeds 50 plus or minus epsilon when restoring to 50 Hz plus or minus epsilon stop when Hz, the difference between the actual power output and starting the actual power output of integral, integral time up to 2 min.
AGC command adjustment performance (Q1_8) : the average response speed and average adjustment accuracy of the operating units on AGC instructions.

AGC adjusting speed (Q1_9) : the rate of response to unit load, including the rise and fall of two direction.

Voltage pass rate of main network (Q2_1) : the length of the main network voltage (upper/lower limit) is the ratio of the statistical cycle.

Comprehensive voltage pass rate (Q2_2) : the weighted average of the power supply voltage of all kinds (A/B/C/D) is calculated.

\[ \Omega_{2-2} = a \cdot U_{a} + b \cdot \frac{U_{b} + U_{c} + U_{d}}{3} \]  

(10)

In the formula: \( a, b \) is the assessment coefficient; \( U_{A}, U_{B}, U_{C}, U_{D} \) represent 4 types of voltage pass rate, and the calculation method is referred to Q2_1. Class A: substation 10 kV bus; Class B: 35 kV and above special line customers; Class C: 10 kV customers; Class D: 38/220 V low-voltage customer.

Central point voltage pass rate (Q2_3) : the ratio of the central point voltage points in the control area to the total number of monitoring points.

Voltage disqualified factory station (Q2_4) : for the factory station with all the voltage limits of the current power grid, the number of voltage disqualification points is calculated.

The voltage fluctuation rate (Q2_5) is calculated according to the calculation.

\[ \xi_{2-5} = \frac{(U_{max} - U_{min})}{U_{e}} \]  

(11)

In the formula: \( U_{max} \) and \( U_{min} \) respectively represent the maximum and minimum value of the voltage of the bus in 24 h; To assess the voltage level of the bus.

3.4. Cleanliness Index Set

The renewable energy generation grid rate (C1_1) is calculated by the following formula.

\[ C_{1-1} = \frac{\sum_{i \in \Omega_{e}} (P_{i} T_{i})}{\sum_{i \in \Omega_{e}} W_{i}} \times 100\% \]  

(12)

In the formula, \( P_{i} \) is the active force of the unit \( i \); The length of the parallel network of \( T_{i} \) for the unit \( i \); The total power generated by \( W_{i} \) for the unit \( i \) in the statistical cycle; \( \Omega_{e} \) for the entire network of renewable energy collection unit.

The renewable energy generation ratio (C1_2) is calculated by the following formula.

\[ C_{1-2} = \frac{\sum_{i \in \Omega_{e}} (P_{i} T_{i})}{W_{T}} \]  

(13)

The \( W_{T} \) in the formula is the total net generating capacity in the statistical cycle.

The water utilization rate (C1_3) of the direct water power plant is calculated as follows.

\[ C_{1-3} = \frac{(\sum_{i \in \Omega_{e}} W_{i} - W^T)}{W^T} \times 100\% \]  

(14)

In the formula: \( W^T \) for the assessment of electricity; \( \Omega_{e} \) for the entire network water power plant set straight. The concentration of smoke concentration (C2_1), the concentration of sulfur dioxide (C2_2) and the concentration of nitrogen oxides (C2_3) is the concentration of the base oxygen content.

\[ C_{2-1/2/3} = \frac{\sum_{i \in \Omega_{e}} O_{2}}{21 - O_{2}^{e}} \]  

(15)

In the formula: \( C' \) indicates the measured concentration of the pollutant, and the unit is mg/m³; \( O_{2}^{e} \) and \( O_{2} \) are measured and baseline oxygen content respectively, and the unit is %.

4. Conclusions

According to the actual demand of grid dispatching work, this paper constructs the index system of grid operation taking into account the risk of Maintenance. The index system includes four aspects: safety, economy, high quality and cleanliness. It has good practicability. Among them, the qualitative indexes can fully cover all aspects of the operation of the power grid, quantitative indexes with
detailed ability to decompose their respective directions, the indexes can reflect the real operation of the grid state.

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