Research and application of power system operation risk assessment method considering new energy grid connection

Zhijun Mu¹, Liang Song¹, Zhenkai Li¹, Wanli Mu² and Hongbin Geng¹

¹ State Grid Dezhou Power Supply Company, Dezhou, Shandong Province, 253000, China
² State Grid Xiajin Power Supply Company, Xiajin, Shandong Province, 253200, China
*Corresponding author’s e-mail: sddldzkj@163.com

Abstract. The traditional distribution network operation risk assessment does not fully consider the intermittency and volatility of new energy sources, which has an adverse impact on the security management of the power grid. Therefore, combined with the probabilistic characteristics of new energy power generation, this paper establishes a distribution network operation risk assessment model and a comprehensive risk index system including new energy grid-connected, mainly including voltage over-limit, voltage collapse, line active power over-limit, system load loss, abandoning the wind and abandoning the light, exceeding the frequency limit, etc. On this basis, this paper formulates the weighting factors of each risk index, and comprehensively judges the weak points of the system. The example analysis shows that the risk assessment method proposed in this paper can quantitatively analyze the weak links after the new energy is connected to the distribution network. This verifies the effectiveness of the proposed method and provides a reference for the future development of new energy grid-connected security.

1. Introduction
In recent years, China's new energy has developed rapidly. Due to the randomness and volatility of new energy sources such as wind power and photovoltaics, new energy sources have added more uncertainties to the originally complex power system, which has made it more difficult to assess the operation risk of the power system. By carrying out the operational risk assessment of new energy integration into the power grid, the project management unit can effectively guarantee the reasonable construction site selection and scale selection of wind farms and photovoltaic power plants, and can also improve the operational safety of the grid-connected system.

The randomness of distributed power sources and loads to construct risk assessment models. In the field of wind power grid-connected system operation risk assessment research, literature[1] considers the impact of weather on wind farm output and real-time operating conditions, and includes wind power fluctuation risk in the risk indicator system, which more comprehensively reflects the operation of wind power to the power system. The risks posed. Literature[2] uses the algorithm of wind power prediction error to improve the traditional power system operation risk assessment model, and incorporates wind power probability, load probability, and real-time status probability of units and lines into the model. In the field of operational risk research of photovoltaic grid-connected systems, the main research focuses on reliability assessment. Reference[3] considers the impact of weather on photovoltaic output, and establishes a multi-state transition time series model of photovoltaic power
plants, which is evaluated from two perspectives: load loss and power shortage. Reference [4] fully considers the solar irradiance and the output power characteristics of photovoltaic cells to model the output of photovoltaic power plants, and calculates the two indicators of power failure time expectation and power failure frequency, and conducts research on the peak load capacity of the system.

At present, in the existing power system operation risk assessment research, there are few researches on the system operation risk assessment involving wind power and photovoltaic grid-connected at the same time. At the same time, the elements in the evaluation model and the risk indicator system standards are not uniform, so the method for determining the weight of each indicator has limitations. To this end, this paper proposes a risk assessment method for distribution network operation considering the characteristics of new energy power generation, and conducts calculation and analysis based on typical cases, and establishes risk assessment indicators.

2. Calculation model

The operation risk assessment of the distribution network is based on the reliability assessment using a probability assessment algorithm. The risk assessment carried out by project managers is to comprehensively measure the possibility and severity of the uncertain factors faced by the power system [5-6]. The mathematical expression of the risk index is shown below.

\[
\text{Risk}(X_t) = \sum_{i=1}^{n} P_r(E_i) \times \text{Sev}(E_i, X_t) \quad (1)
\]

In the above formula, \(X_t\) represents the current operating mode of the system, \(E_i\) represents the status of the m-th system, \(n\) is the total number of system statuses, \(P_r(E_i)\) is the probability of \(E_i\) status, \(\text{Sev}(E_i, X_t)\) represents the severity of current operating mode under the \(E_i\) status, \(\text{Risk}(X_t)\) represents the risk indicator.

In view of the grid structure after new energy is connected to the distribution network, the operational risk assessment model is mainly composed of wind power output probability, photovoltaic output probability, load probability, etc. The calculation formula of specific risk indicators is shown below.

\[
\text{Risk} = \sum_{i=1}^{n} P_{r-wd}(E_m)P_{r-pv}(E_m)P_{r-q}(E_m)P_{r-t}(E_m)S_v(E_m) \quad (2)
\]

In the above formula, \(P_{r-wd}(E_m)\) represents the operating state probability of wind turbines under the \(E_m\) status, \(P_{r-pv}(E_m)\) represents the operating state probability of photovoltaic cells under the \(E_m\) status, \(P_{r-g}(E_m)\) is the operating state probability of power generation under the \(E_m\) status, \(P_{r-t}(E_m)\) is the operating state probability of transmission line under the \(E_m\) status, \(S_v(E_m)\) indicates the severity of the system under the \(E_m\) status.

When the power system is in normal operation, the probability of the system instability caused by the branch flow is very small. When the system is in abnormal operation state, the branch power flow will increase. When its value reaches the maximum value of the line, it will cause the relay protection device on the line to act, so it needs to be controlled within the normal working range to reduce the probability of line tripping.

Existing research usually establishes the risk index system from three perspectives of voltage, power and load [6-8], and rarely considers the system frequency. When new energy is connected to the power system, abandoning wind and light will also bring risks to the system.

The risk assessment process is shown in Figure 1. The specific method is shown as follows.

1. First, the project manager collects the raw data required for the random power flow calculation of the power system, tests the data, and obtains the required variables. These data include not only the
parameters required for the operating state of the system during the conventional power flow calculation, but also the information content of each node of the network system. On the basis of these data, the project manager calculates the numerical characteristics of the corresponding statistical model, the output power and probability distribution data of wind power generation and solar power generation.

(2) Second, non-sequential Monte Carlo sampling is performed on the input raw data. The real-time operating states of different systems are obtained, and the real-time state probabilities of lines and generators under each state are calculated.

(3) Next, the project manager performs the power flow calculation on each branch to obtain the expected value of the voltage at each node of the corresponding system, and the expected value corresponding to the power flow of each branch of the system.

(4) Further, by calculating the voltage of each node and the branch power flow, and using the knowledge of probability statistics, the curve corresponding to the expression of the probability density and cumulative distribution function corresponding to the different node voltages in the network system and the branch power flow of the network system is obtained.

(5) Finally, according to the probability distribution, a series of behavior indicators that will appear during the operation of the node voltage and branch power flow power of the operating system are evaluated accordingly.

![Figure 1. The Operational risk assessment process](image)

The traditional risk index system does not take into account the abandonment of wind and light and the steady-state frequency over-limit index, and the comprehensive risk value is relatively low, which fails to comprehensively consider the source of system risk. Combined with the operation requirements of new energy access to the power system, this paper proposes a comprehensive risk index system, which is more suitable for the risk assessment of power system operation when new energy is connected to the grid.

3. Example analysis
In this paper, the IEEE-14 node system is selected to conduct operational risk assessment of the established model on the MATLAB platform. The reference power was set to 100 MVA. The wiring diagram of the IEEE-14 node system is shown in Figure 2 below. The generators are connected to nodes 1, 2, 5, and 6, the wind farm is connected to node 14, and the photovoltaic power station is connected to node 9. The outage rates of wind farms, photovoltaic cells, lines and generators are all set to 6%. The weights of each risk indicator are 0.18, 0.32, 0.12, 0.25, 0.06, and 0.31 in sequence. The calculation results of the risk indicators under this scheme are shown in Table 1.

![Image]

Figure 2. IEEE-14 node system connection

It can be seen from Table 1 that the steady-state frequency index of the system is at a low risk level, the system voltage collapse and system loss load are all at a medium risk level, and the rest of the indicators are at a high risk level. This is related to the weak grid structure of the system and the uncertainty that new energy access adds to the system.

| Risk Indicator                  | Risk value   | Evaluation level |
|---------------------------------|--------------|-----------------|
| New energy waste electricity    | 2.26×10⁻³    | High            |
| Frequency limit violation       | 1.38×10⁻⁵    | Low             |
| Voltage limit violation         | 6.17×10⁻⁴    | High            |
| Voltage collapse                | 5.02×10⁻⁵    | Middle          |
| Line active power exceeded limit| 4.72×10⁻⁵    | High            |
| System load loss                | 6.16×10⁻⁶    | Middle          |
| Comprehensive risk index        | 2.35×10⁻⁷    | Low             |

Through the above data analysis, the amount of abandoned wind and light is only related to the capacity of the system as a whole that can accept new energy. It has nothing to do with the location of
wind power and photovoltaic access. The steady-state frequency out-of-limit and voltage collapse indicators will fluctuate slightly under different access schemes. The change of wind power and photovoltaic connection position will change the active power output of some conventional generators, resulting in certain fluctuations in the steady-state frequency of the system. The voltage collapse mainly depends on the system ability to bear the load and is determined by the strength of the system itself, so the location of wind power and photovoltaic access has little impact on it.

When the wind and optical access locations are close to each other, the uncertainties of the two are easily superimposed on each other, which will increase the risk of system operation. In addition, the conventional unit access node has the function of maintaining voltage stability. When the new energy source is close to the conventional unit, its interference to the system can be weakened and the operation risk can be reduced. Different wind power and photovoltaic access locations will change the active power distribution on the line, which will affect the line active power out-of-limit indicator.

4. Conclusion
This paper establishes a power system operation risk assessment model that takes into account wind power and photovoltaic grid-connected. The model is used to calculate the risk indicators such as abandonment of wind and solar power, steady-state frequency exceeding the limit, and voltage collapse. The traditional risk index system does not take into account the abandonment of wind and light and the steady-state frequency over-limit index, and the comprehensive risk value is relatively low, which fails to comprehensively consider the source of system risk. The risk index system proposed in this paper is more comprehensive and more suitable for the risk assessment of power system operation of new energy grid-connected power system, which provides a reference for the risk assessment of power system operation including new energy grid-connected power system.

Acknowledgments
This work was supported by science and technology project of state grid shandong electric power company(Research and application of high-proportion new energy multi-level coordinated regulation and absorption capacity improvement technology-2020A-041).

References
[1] Xu Yuan., Wang Ke., et al. (2013) Reliability and risk assessment techniques for distribution networks with distributed generations. Proceedings of the CSU EPSA, 25:117-121.
[2] Zhou Quan., Liao Jingshu., et al. (2013) Fast assessment of power failure risk in distribution network containing distributed generation. Power System Technology, 38:882-887.
[3] Ping Jian., Chen Sijie., et al. (2017) Credit risk management in distributed energy resource transactions based on blockchain. Proceedings of the CSEE, 37:3682-3690.
[4] Zhao J., Li L., et al. (2020) Full-scale distribution system topology identification using markov random field. IEEE Transactions on Smart Grid, 11:4714-4726.
[5] Zhang Xinjie., Ge Shaoyun., et al. (2014) Comprehensive assessment system and method of smart distribution grid. Power System Technology, 38:40-46.
[6] Shang Haoyu., Liu Tianqi., et al. (2020) Operational risk assessment of power system considering wind power and photovoltaic grid connection. Modern Electric Power, 37:358-367.
[7] Liao Jianbo., Li Zhenkun., et al. (2017) Operation risk assessment of active distribution network based on probabilistic power flow. Modern Electric Power, 34:20-27.
[8] Ding Y., Wang P., et al. (2006) Reliability and price risk assessment of a restructured power system with hybrid market structure. IEEE Transactions on Power Systems, 21:108-116.
[9] Hou K., Jia H., et al. (2016) A continuous time Markov chain based sequential analytical approach for composite power system reliability assessment. IEEE Transactions on Power Systems, 31:738-748.