Reliability Analysis of Real Time Operation State of Power System Based on K-Nearest Neighbor

Tie Li[1](✉), Jun-ci Tang[1], Jian-ming Yu[2], Dai Cui[1], and Di Jiang[1]

[1] State Grid Liaoning Electric Power Supply Co., Ltd., Shenyang 110000, China
litie9982543@163.com
[2] Beijing Kedong Power Control System Co., Ltd., Beijing 100031, China

Abstract. In order to better guarantee the real-time operation state of power system, a k-nearest neighbor based reliability method for real-time operation state of power system is proposed. The k-nearest neighbor technology is used to collect the information of the real-time operation state of the power system, and the evaluation algorithm of the system operation state is optimized according to the collection results. According to the calculation results, the reliability of the real-time operation state of the power system is analyzed, so as to better guarantee the security and stability of the power system operation.

Keywords: k nearest neighbor · Power system · Operation reliability

1 Introduction

People's daily life and work can not be separated from electricity, in daily life, production need the support of electricity, otherwise it is difficult to carry out normal life and work. Power belongs to energy, and to maintain the balance of power demand, the most important task is to carry out reasonable power dispatching. Using k nearest neighbor technology, we can master and evaluate the faults that people have during the power consumption period, and then carry out the power distribution pertinently, which will bring valuable reference for the establishment of a sound power operation management system. Information management of distribution network is very important, and the composition of the system is also extremely complex. Distribution network should not only be responsible for the operation and management of power enterprises, but also supervise the operation of the power grid, so as to ensure the operation effect of the distribution network [1, 2]. The state model is more practical and simple than the traditional model. It can fully demonstrate the Markov nature of state space transfer of power system. That is, with the support of sufficient sample number, the transfer probability matrix of system state is counted out, and then the current system state and matrix are used, Thus, the change of the probability of system state is analyzed and obtained, which is convenient for power system planning, operation and maintenance. With the advent of big data era, big data has been widely used in power system, and plays a great role in ensuring reliable and stable operation of distribution network.

S. Wang et al. (Eds.): IoTCare 2021, LNICST 414, pp. 344–360, 2022.
https://doi.org/10.1007/978-3-030-94185-7_23

Therefore, the relevant staff should analyze the reliability of distribution network operation based on big data technology.

Relevant scholars have made some progress in this field. According to the method of reference [2], an optimization method of data manipulation in power system estimation loop is proposed. The operation state of power system is captured by phase capacity measurement, and the bad data parameters of power system fault are simulated by model compensation method to realize the optimization of data manipulation in power system operation capture. This method can reduce the data noise, But the reliability analysis of power grid data operation state is not accurate. According to the actual demand of multi-source interconnected power system, a four area multi-source interconnected power system including fire, water, gas and renewable energy is established. PID controller based on gray wolf optimization algorithm is used for load frequency control, This method can realize the optimization of load frequency control, but the security of power system operation is poor.

To solve the above problems, this paper proposes a k-nearest neighbor based real-time operation state reliability analysis method of power system, which can effectively improve the security and stability of power system operation.

2 Reliability Analysis of Real Time Operation State of Power System

2.1 Real Time Operation State Information Collection of Power System

At present, in the process of power system operation reliability evaluation, the electric power department of our country often carries on the related operation according to different types of reliability criteria, and divides different states. Based on this, in order to further promote the effective development of power system operation reliability evaluation, it is necessary to effectively collect the real-time operation state information of power system [3]. Generally, in the actual operation process, operators often divide the operation status of power system into two kinds: normal state and risk state. With the further deepening of related research, the normal state of power system is further divided into healthy state and critical state. Overall, the detailed performance of power system operation state division plays a strong guiding role in security control. Based on this, in the process of related problems analysis, the power system operation state is divided into three kinds: normal state, accident state and risk state [4]. The so-called "normal state" means that there is no component failure in the process of power system operation, and it meets the relevant requirements of "N − 1". The collection and constraint processing of component failure information in the process of power system operation will have a certain impact on the security and stability of the system. Based on this, the state space of power system operation three state model is set to $\mathrm{E} = \{1, 2, 3\}$. Based on this, the collection system of power system operation state characteristics is optimized as follows (Fig. 1):

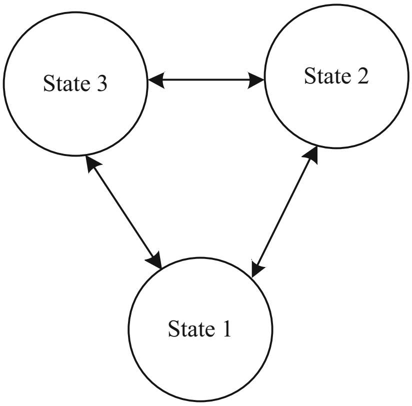

Fig. 1. Collection system of power system operation state characteristics

Combined with the method of principal component analysis and the reliability data generated in the process of historical operation, the characteristics of various data are selected to reasonably evaluate the indicators of distribution operation stability [5]. Determine the influencing factors, and then regard it as an important part of the artificial neural network, use important standards as the output content, and create a perfect prediction model on the premise of training. The real-time data is transmitted in the model, and then the prediction is made to obtain the standard value of operation reliability in the following specific time period. In addition, the state transition probability matrix is as follows:

$$P = \begin{bmatrix} 1 - p_{12} - p_{13} & p_{12} & p_{13} \\ p_{21} & 1 - p_{21} - p_{23} & p_{23} \\ p_{31} & p_{32} & 1 - p_{31} - p_{32} \end{bmatrix} \tag{1}$$

The power system state transfer algorithm is further obtained as follows:

$$\pi(i) = \begin{bmatrix} \pi_1(i) \\ \pi_2(i) \\ \pi_3(i) \end{bmatrix}^{\mathrm{T}} = \begin{bmatrix} P[X(t_{\mathrm{i}}) = e_1] \\ P[X(t_{\mathrm{i}}) = e_2] \\ P[X(t_{\mathrm{i}}) = e_3] \end{bmatrix}^{\mathrm{T}} \tag{2}$$

In general, row vector $X(t_{\mathrm{i}})$ refers to the state distribution of power system at time t_{i}. Assuming that the initial state of the power system is $\pi(i)$, we can know that based on the definition of power system state transition probability matrix P, through e After Δt, the state of the power system changes to:

$$\pi(m) = \pi(m-1)\Delta \mathrm{t} P = \pi(0)P^{\mathrm{m}}\sigma_X \tag{3}$$

Through the understanding and mastering of the current power system state transfer probability matrix π, the operators can realize the understanding and mastery of the steady-state value of the power system state distribution after every 4t time interval in the future based on the above knowledge and mastery in the actual operation processing process [6]. When the number of time intervals n → ∞, the operation state of the power system will be kept in a certain stable value area, and this value is called the probability of stable state of power system, or the probability of long-term state. The expression of the probability of stable state of power system is as follows:

$$\pi(\infty) = \lim_{n \to \infty} \pi(m) = \lim_{n \to \infty} \pi(0)P^{\mathrm{n}} \tag{4}$$

The core connotation of stationary state probability is that the probability of power system in state i will be close to that in state $\pi_{\mathrm{i}}(\infty)$ after a long period of operation. Based on the above formula, the stationary state probability of the system can be further derived:

$$\sum_{i=1}^{n} \pi_{\mathrm{i}}(\infty) = 1 \tag{5}$$

The availability of power system can be further defined as the probability that the power system is in an acceptable state at ti:

$$\begin{aligned} A(i) &= \sum_{i=1}^{n} \pi_{\mathrm{i}}(\infty) \sum_{j \in W} \pi_{\mathrm{j}}(i) \\ &= \pi_1(i) + \pi_2(i) \\ &= 1 - \pi_3(i). \end{aligned} \tag{6}$$

Since the traditional planning reliability evaluation reflects the long-term reliability level of the system, the average value of the long-term statistical data is used for the failure probability and failure rate of components, as shown by the dotted line in the Fig. 2.

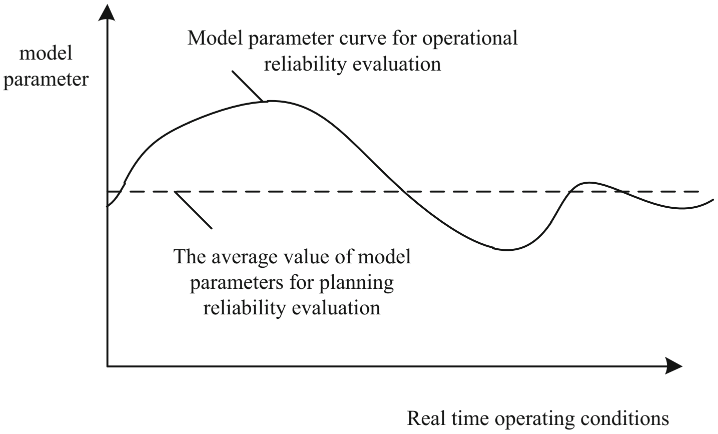

Fig. 2. Characteristic parameter curve of reliability model

In recent years, the power grid accident records show that this kind of fault often occurs, causing the theory seriously divorced from practice. The reason is that there is a problem in the reliability modeling of components, and the outage probability of components should change with the change of system operation conditions [7]. In the actual statistical work of line reliability data, the outage probability of lines is not classified according to the size of power flow, so the relationship between outage probability and power flow cannot be obtained. In this paper, according to the following assumptions, the curve F(L) of line outage probability changing with power flow is fitted, as shown in Fig. 3:

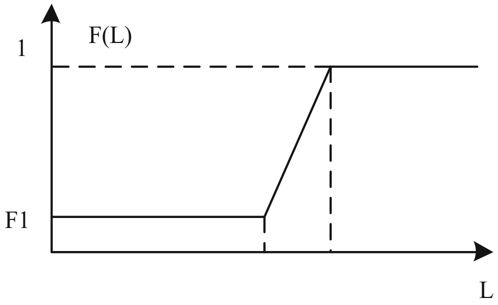

Fig. 3. Curve of power system operation changing with power flow

When the line power flow is within the normal range, the influence of power flow on line outage probability is very small. The line outage probability F(L) is taken as the statistical value F of line outage probability, as follows:

$$F(L) = A(i) - \overline{F}_1 \quad \left(L_{\min^{\text{normal}}} \le L \le L_{\max^{\text{normal}}}\right) \tag{7}$$

where $L_{\min^{\text{normal}}}$ is the lower limit of the normal value of line power flow and $L_{\max^{\text{normal}}}$ is the upper limit of the normal value of line power flow. When the line power flow is between the normal value and the limit value, the probability of line fusing or protection device action increases with the increase of line power flow, and the line outage probability is fitted by straight line, as shown in the formula:

$$F(L) = \frac{1 - \overline{F}_1}{L_{\max} - L_{\max^{\text{normal}}}} \times F(L) + \frac{\overline{F}_1 \times L_{\max} - L_{\max^{\text{normal}}}}{L_{\max} - L_{\max^{\text{normal}}}} \sigma_X \tag{8}$$

When the generator frequency is within the normal range, the frequency has little effect on the generator outage probability. The generator outage probability F(FG) is taken as the statistical value $\overline{F}_{\text{g}}$ of the generator outage probability, as shown in the following formula.

$$
\begin{gathered}
F(F_{\mathrm{G}}) = F(L)/\overline{F}_{\mathrm{g}} - 1 \\
\left(F_{\mathrm{G,min}}^{\mathrm{nomal}} \le F_{\mathrm{G}} \le F_{\mathrm{G,max}}^{\mathrm{nomal}}\right)
\end{gathered} \tag{9}
$$

where FG is the normal value of generator frequency; $F_{\mathrm{G,min}}^{\mathrm{nomal}}$ is the lower limit of normal value of generator frequency; $F_{\mathrm{G,max}}^{\mathrm{nomal}}$ is the upper limit of normal value of generator frequency. When the generator frequency exceeds the limit value, the generator protection device acts, and the generator outage probability is 1, as shown in the following formula

$$
\begin{cases}
F(F_{\mathrm{G}}) = 1 & \left(F_{\mathrm{G}} \ge F_{\mathrm{G,max}}\right) \\
F(F_{\mathrm{G}}) = 1 & \left(F_{\mathrm{G}} \le F_{\mathrm{G,min}}\right)
\end{cases} \tag{10}
$$

where $\mathrm{F}_{\mathrm{G,max}}$ is the upper limit of generator frequency; $\mathrm{F}_{\mathrm{G,min}}$ is the lower limit of generator frequency [8]. When the generator frequency is between the normal value and the limit value, the action probability of the generator protection device increases with the frequency approaching the limit value.

$$
F(F_{\mathrm{G}}) = \frac{1 - \overline{F}_{\mathrm{g}}}{F_{\mathrm{G,max}} - F_{\mathrm{G,max}}^{\mathrm{normal}}} \times F_{\mathrm{G}} + \frac{\overline{F}_{\mathrm{g}} \times F_{\mathrm{G,max}} - F_{\mathrm{G,max}}^{\mathrm{normal}}}{F_{\mathrm{G,max}} - F_{\mathrm{G,max}}^{\mathrm{nomal}}} \tag{11}
$$

$$
\Delta F(F_{\mathrm{G}}) = \frac{\overline{F}_{\mathrm{g}} - 1}{F_{\mathrm{G,min}}^{\mathrm{nomal}} - F_{\mathrm{G,min}}} + \frac{F_{\mathrm{G,min}}^{\mathrm{sommal}} - \overline{F}_{\mathrm{g}} \times F_{\mathrm{G,min}}}{F_{\mathrm{G,min}}^{\mathrm{nomal}} - F_{\mathrm{G,min}}} \tag{12}
$$

Considering the influence of real-time operation conditions on reliability model, it is not difficult to understand the frequent occurrence of chain failures in real-time systems. According to the definition of time-varying reliability model of power system, after the initial failure, the operating conditions of the system change. Some elements are running near the limit value. At this time, the outage probability of these components is not statistical average but close to 1, and new faults are likely to occur. So the probability of chain failure is the product of single outage probability based on real-time operation conditions, which is much greater than the product of single fault probability based on statistical average defined by traditional reliability evaluation method.

2.2 Power System Operation State Evaluation Algorithm

The key of power grid operation reliability evaluation is to solve the problem of reliability model of components under operation conditions, especially in fault state and special operation mode. As an important component of power grid, the reliability level of generator set is closely related to the system reliability [9]. In the actual operation of power grid, the main factors that affect the operation of generating units include start-up time, start-up failure probability, load increase rate and outage delay.

At the same time, the operation modes of units are different when they are put into operation at different locations, such as base load or peak shaving operation, and under different standby modes, such as cold standby, hot standby and rotary standby. Therefore, it is necessary to further study the generator unit model suitable for operation planning reliability evaluation [10]. It takes a certain time for each unit from receiving the order to put into operation to full output state, which is called start-up time, acceleration time or start-up lead time. According to the type of unit and the state, the time can be divided into several minutes to more than ten hours. The start-up delay characteristic will delay the rapid recovery of the accident, prolong the fault duration and increase the system risk. Based on this, the startup delay of typical units in power system is investigated and recorded, as shown in the table below (Table 1).

Table 1. Startup delay of typical units in power system

Unit type	Time delay T_S (min)	
	Hot state	Cold state
Gas turbine	$3\sim5$	$10\sim15$
Condensing thermal power unit	$30\sim60$	$120\sim180$
Hydropower and pumped storage power stations	$0.5\sim2$	$1\sim3$
Variable pressure operation thermal power unit	$60\sim80$	360
Extraction type thermal power unit	$30\sim60$	$90\sim180$

Based on the information in the above table, two state or three state models are further used to describe the reliability of the above units. The specific model is shown in the figure below (Fig. 4):

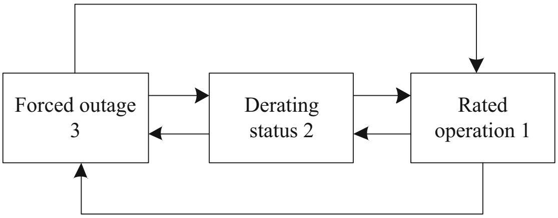

Fig. 4. Simulation diagram of three state unit in power system

For intermittent operating units, all states of the generator can be divided into: the set of forced shutdown states when the system is needed, the set of forced shutdown states when the system is not needed, and the set of running states. According to the definition of CFOR, the general calculation can be obtained formula:

$$\mathrm{CFOR} = \frac{\sum\limits_{i \in I} p_i}{\sum\limits_{i \in l} p_i + \sum\limits_{i \in M} p_i} \tag{13}$$

The probabilistic reasoning of system reliability is based on the k-nearest neighbor technology, which is used to calculate the probability interval of each state of the node random variable under the condition of known correlation and evidence. The reasoning method includes precise reasoning algorithm and approximate reasoning algorithm. The precise reasoning algorithm of reliability. The joint probability mass function algorithm formed by traversing the vertices of the reliability set is:

$$\overline{P}\left(x_q \middle| \mathbf{x}_e\right) = \Delta F(F_{\mathrm{G}}) \max_{j=1,\ldots} \frac{\sum_{X_{N1}} \prod_{i=1}^{N} P_j(x_i|\pi_i)}{\sum_{X_{M2}} \prod_{i=1}^{N} P_j(x_i|\pi_i)} \tag{14}$$

Based on this further calculation, before the imprecise condition estimation of the power system outage probability, the mathematical expression of the equipment outage probability is clarified, and the relationship between the outage rate and the outage probability is clarified. Reliability refers to the probability that the equipment will operate normally within time t, that is, the probability that the equipment will not be out of service within time t. Suppose the continuous random variable T (T > 0) represents the time from continuous normal operation of the equipment to before shutdown, then the reliability function can be expressed as:

$$R(t) = P - \overline{P}\left(x_q \middle| \mathbf{x}_e\right)(T \geq t) \tag{15}$$

The fault distribution function F(t) describes the probability of a power equipment outage event before the arrival of the equipment at time t. It can be seen that its relationship with the reliability function is:

$$\mathrm{F(t)} = 1 - \mathrm{R(t)} \tag{16}$$

Outage rate is a commonly used reliability index. Its statistical description is the ratio of equipment outages per unit time. It is defined by the following formula, and its probability is described as:

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{\mathrm{F(t)}\Delta t \cdot R(t)} = \frac{dF(t)}{\mathrm{F(t)}dt \cdot (1 - F(t))} \tag{17}$$

When the transmission line is under heavy load operation, as its carrying capacity increases and reaches the set value, it will trigger the relay protection action and cause it to stop. Therefore, the probability of line outage under this condition will also increase. Therefore, the operating conditions that significantly affect the reliability of the transmission line and the operating status of the transmission line are used as the node evidence variables of reliability, and the reliability estimation model of the power system operating state reliability estimation is constructed, as shown in the Fig. 5.

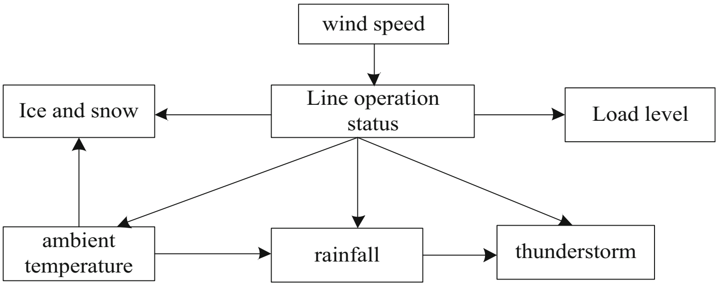

Fig. 5. Reliability estimation reliability of power system operating state

In the figure, in order to realize the inaccurate condition estimation of the outage probability of a transmission line under a given operating condition, it is necessary to know the prior probability of the equipment operating state and the probability correlation between the line operating state and the operating condition. The prior probability of line outage can be replaced by the long-term statistical outage probability of the line. For the probabilistic correlation between the line operating state and its operating conditions, the condition $K(E_a|H_z), a \in \{1,2,5\}, z \in \{1,2\}$, $K\left(E_3|H_z, E_{1,b1}\right)$ corresponding to each evidence node is used to analyze the reliability of the power system based on a deterministic method, that is, for certain expected system operation modes or events, through power flow calculation or stability Performance analysis, to clearly obtain these system operation modes or the consequences of the system after the occurrence of the event, in order to determine the reliability of the power system. The decision-making goal based on the deterministic criterion is generally that the power system will not fail under these expected methods. By introducing the K nearest neighbor theory, we not only analyze the results of each scene, but also consider the possibility of each scene, and take the characteristics of the K nearest neighbor theory to characterize the reliability of the system. When the number of scenes is large enough, You can get the probability method of power system reliability analysis and risk assessment as shown in the formula. The simulation method to calculate the reliability of the power system can be uniformly expressed in the form shown in the formula.

$$E[f] = \sum_{x \in X} f(x) \cdot \frac{n_x}{\lambda(t)n} = \frac{1}{\lambda(t)n} \sum_{x=1}^{n} f(x) \tag{18}$$

Under normal circumstances, “year” is the main unit of reliability analysis, which conducts a comprehensive analysis of the average reliability of various operating states of the system. The main indicators include two indicators: system and load. The system indicators mainly include indicators such as the time and frequency of the system’s continuous power outages, lines, etc., while the load indicators include the duration of power outages and the average failure probability of the load point. Evaluating the reliability can effectively improve the planning and design system. Therefore, the operation reliability of the distribution network must show the load loss and load margin, and use this as the basic condition to show the reliability of the entire system. The operational reliability index mechanism accommodates many index variables. At the same time, it is difficult to model or calculate. In addition, there is a lot of complex information in each index, and analysis one by one will shoulder a huge workload.. Among them, the principal component analysis should adopt the multivariate statistical analysis method, which can make the modeling easier, and can also extract valuable information from it, and reduce the variable dimension as much as possible. Principal component analysis generally uses variance, sum of squares of deviations, etc. to perform calculations on various indicators, clean up repeated indicators, and extract indicators that have little relevance and include a lot of original information. Afterwards, the components and ranges that will interfere with the system's operational reliability are selected in a targeted manner, so as to gradually reduce the evaluation range. Standardized evaluation indicators. Under normal circumstances, various operational feasibility indicators have obvious differences, and they are distributed in different places, and they must be processed according to the indicator parameters. Therefore, it is necessary to use distribution big data to obtain various index distribution functions, carry out normal distribution according to various index variables, and then use this as a standard to transform into normal distribution variables. Regarding matrix creation and eigenvalue calculations, the values of other variables are established.

2.3 Realization of Reliability Analysis of Power System Operation State

Security can also be called dynamic reliability, which refers to the ability of the power system to withstand the disturbance after scene switching, such as whether the power system can return to its original operating state or transition to a state after a sudden short circuit or loss of system components. The new stable operating state, the ability to provide users with electrical energy uninterrupted. The basic evaluation index for the reliability of the power system's operating state is: uninterrupted supply of qualified power to all users. The essence of power system reliability and risk research is to pre-consider the probabilities and consequences of various operating modes, and make comprehensive decisions to give full play to the potential of each device in the system, so as to meet the load requirements of all users with quality and quantity. Based on this, the main frame structure of power system engineering reliability is shown in the following Fig. 6:

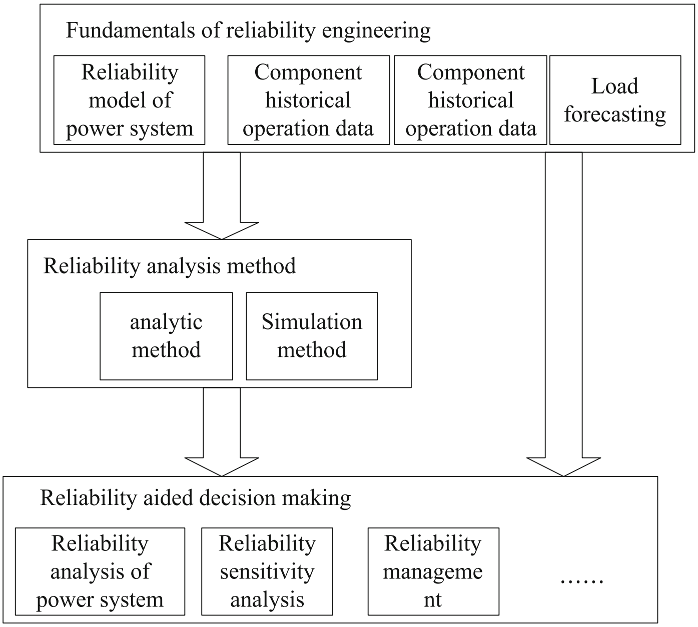

Fig. 6. Power system engineering reliability model

The main task of the reliability model of power system engineering is to accumulate historical operating data of components and component reliability test data, and analyze component reliability models and parameters. Based on the power system reliability model and expected load changes, analyze or simulate the phenomenon that the power system cannot complete the specified function within the specified time, and calculate its occurrence probability and consequences to obtain quantitative evaluation indicators and standards. On the basis of coordinating reliability and system input, comprehensive evaluation and auxiliary decision-making of power system operation and control are carried out. Find out the key links that restrict the reliability of the power system, and propose specific measures to improve and increase the reliability level, and organize or assist relevant departments to implement them. Power system reliability analysis refers to the probability analysis and evaluation of the power system's ability to continuously and uninterruptedly supply power that meets the voltage quality requirements of the regulations to each load point within a specified time and under specified conditions by using reliability indicators, and find out the impact the key link of system reliability. Reliability analysis and risk assessment of the power system in the operating environment are based on the effective information in the operating environment, including deterministic and predictive information, to establish component reliability models, and to consider the recent possible operating status and random failures of the power system, analyze and predict The adequacy and safety of short-term operation of the power system. The focus of power system reliability analysis and evaluation is different, and the selected reliability indicators are not the same, but they can all be expressed as the expected value of a certain measurement function, as shown in the formula.

$$\Delta E[f] = E[f] / \sum_{x \in X} f(x)p(x) \tag{19}$$

The sufficiency evaluation of wiring reliability is mainly based on the ability of wiring to distribute load demand. Traditional adequacy indicators include the following four categories: expected value, probability, frequency and duration. Based on the non-sequential simulation method, the following indicators are selected to measure the reliability level of plant and station wiring:

$$EENS = \frac{\sum_{k=1}^{n} (P_{bk} \cdot t_k)}{\Delta E[f] - n} \tag{20}$$

Since the sufficiency analysis only involves the steady-state calculation of the power system, the analysis models and calculation methods are relatively mature, and the requirements for calculation time are not high, so the existing research and

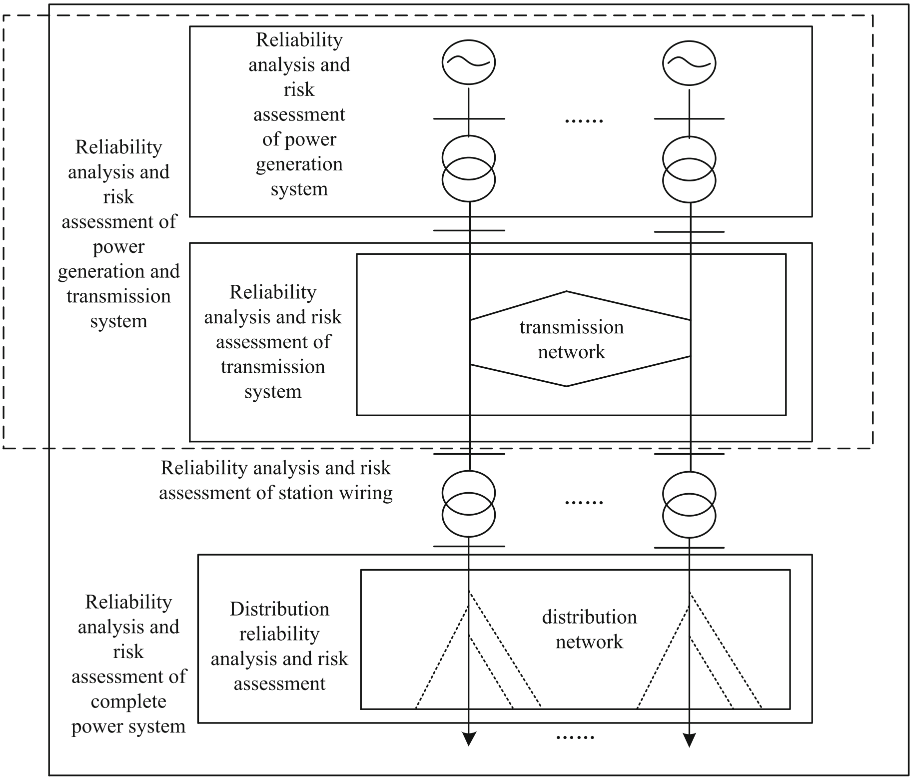

Fig. 7. Hierarchical levels of power system reliability analysis

application of power system reliability analysis and risk assessment are mainly concentrated on This aspect. With the increase in the number of components in the power system to be analyzed, the number of system scenarios X has also expanded dramatically. Due to the limitations of calculation tools and calculation methods, it is still difficult to calculate and analyze the reliability and risk of the entire power system in a unified manner.. According to different functions, structures, voltage levels, etc., the power system can be divided into different subsystems such as power generation, transmission, and distribution in the project. The wiring form, operation mode, equipment redundancy, failure loss, etc. of each subsystem are different, and the strategies used in the calculation of their sufficiency are also different. Therefore, the reliability of these subsystems is usually analyzed separately and based on this combination produces different levels of power system reliability analysis, as shown in the Fig. 7.

As a key hub in the power grid, the reliability of the substation plays a vital role in the reliability of the entire power grid. Except for transformers, the electrical distances of other components in the plant and station wiring are relatively short and the cross-section selection is relatively large. They are all regarded as non-impedance components in the power system analysis process, and only need to be connected to judge to generate equivalent nodes. No need to directly participate in the power flow calculation. In addition to the limited number of internal components in the plant and the large wiring redundancy, the reliability of the plant's wiring is generally independently studied to obtain an equivalent bus model with corresponding probability characteristics. When performing system reliability analysis, this model is generally used directly, instead of unfolding the plant and station wiring. Rely on the parallel relationship to mine the main influencing factors. At present, there are many factors that affect the reliability of the distribution network. Therefore, it is difficult to establish an accurate prediction model, and the speed accuracy will also be affected. If you want to improve this situation, you can use the association rule mining method to extract the influencing factors from the heterogeneous multi-source data of the distribution network, and bring a certain reference basis for the establishment of the prediction model, reduce the input dimension as much as possible, and further Improve the prediction speed, thereby improving the reliability of the power system.

3 Analysis of Results

In order to verify the necessity and effectiveness of the power system real-time operating state reliability method based on K nearest neighbors, a comparison experiment was carried out with double busbars with bypass and 3/2 wiring as examples. For the sake of comparison, there are two incoming lines and four outgoing lines for the two types of wiring. The power upper limit of the incoming line is 250 kW, and the power demand of the outgoing line is 100 kW. To ensure the true and effective experimental results, the specific experimental equipment and parameters are unified Settings, as shown in the following table (Table 2):

Table 2. Experimental equipment and parameters

Component type	Average repair time Yi/(H/time)	Unreliability q_i/(times/(set))
High voltage circuit breaker	160	0.06
High voltage disconnector	56	0.00149
High voltage bus	20	0.015

Further regulate the operating conditions of the power system, as shown in the table (Table 3).

Table 3. Power system operating conditions

state	Generator fault description	Generator voltage/pu	Load voltage/pu	System frequency/Hz	Line transmission capacity/MW	Reserve capacity MW
1	0 fault	1.010	1.019	50.00	168.5	415.7
2	1 fault	1.006	1.007	49.73	168.4	125.7
3	2 fault	1.001	0.9879	49.15	168.4	15.7
4	2 faults + 1 unit output reduction 10 MW	1.000	0.9873	48.64	168.4	5.7
5	2 faults + 1 unit reduced output 30 MW	0.9997	0.9857	47.57	168.4	0.0
6	2-fold fault + 1 set of reduction output 40 MW	0.9994	0.9848	47.02	168.4	0.0
7	2-fold fault + 1 set of reduction output 50 MW	0.9989	0.9839	46.44	168.4	0.0

Based on the above environment, the reliability index of the power system in the fault state is further detected, as follows (Figs. 8 and 9):

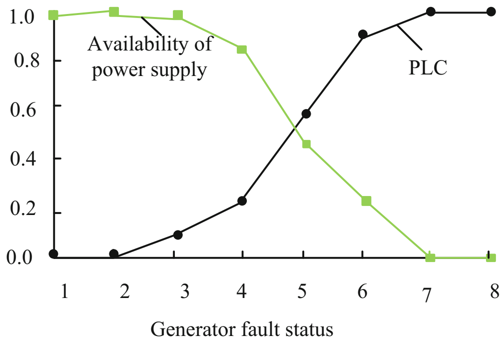

Fig. 8. The reliability index of the method in this paper under the failure state

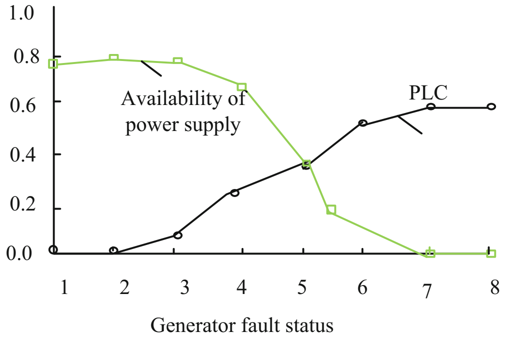

Fig. 9. Reliability index under the failure state of the traditional method

According to the evaluation results, the following conclusions can be drawn: the reliability level of the traditional system under the operating state is much lower than the reliability level under the operating state of this article, and the traditional reliability evaluation cannot express the reliability of the system under the generator failure state. Level. Based on this, further statistics are made on the outage probability during the operation of the power system and the reliability index under the power system line fault state, as shown in the table (Tables 4 and 5).

Table 4. Probability of component outage in power system fault state

State	Generator outage probability	Line outage probability	Load outage probability
1	1.668×10^{-2}	1.000	0
2	1.668×10^{-2}	8.092×10^{-1}	0
3	1.668×10^{-2}	1.811×10^{-4}	0
4	1.668×10^{-2}	1.811×10^{-4}	0
5	–	–	–

Table 5. Reliability index under power system line fault state

State	PLC	SI/(system minute/year)	EEMS/(MWh/a)	Availability of power supply
1	1.0000	5.256×10^5	8.410×10^6	0.0000
2	1.0000	5.256×10^5	8.410×10^6	0.0000
3	0.8819	4.075×10^5	6.517×10^6	0.2247
4	0.0011	7.714×10	1.234×10^3	0.9998
5	0.0002	1.596×10	2.554×10^2	0.9999

According to the evaluation results, the following conclusions can be drawn: the reliability level of the system in the fault state is much lower than the reliability level in the normal operation state, and the traditional reliability evaluation cannot express the reliability level of the system in the line fault state. In order to further test the effectiveness of the method proposed in this article, the simulation system generates a total of 50,000 h of samples, and each sample contains the operating condition information and equipment operating status information during the period. Compare the standard reliability values during the operation of the power system for comparative testing to determine the authenticity of the state reliability test results. The specific test results are shown in the following Fig. 10:

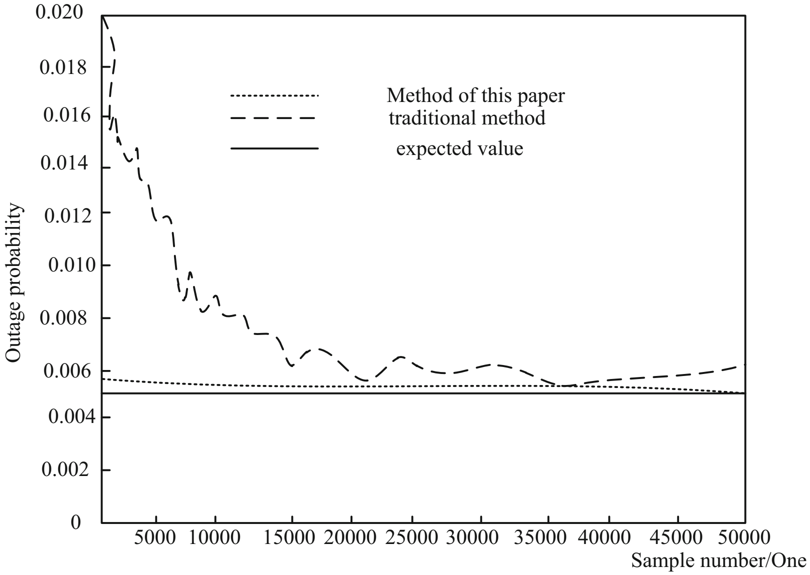

Fig. 10. Comparison test results

It can be seen from the figure that the method proposed in this paper has advantages over traditional methods, and is basically consistent with the expected operating state reliability curve. It can be seen from the figure that the estimation result obtained by the method in this paper is always significantly close to the true value of the line outage probability, and as the number of samples increases, the outage probability interval obtained by the method in this paper gradually shrinks and converges to the true line outage probability. Probability reflects the reasonableness of the estimation results of this paper.

4 Concluding Remarks

The development of science and technology makes the power system more and more perfect. In the context of big data, big data technology has been widely used, which has allowed the power industry to develop further. At present, because many factors will affect the reliability of the operation of the distribution network, relevant workers must analyze the relevant influencing factors in an all-round way when evaluating the reliability of the operation, and formulate a complete control plan to ensure the distribution the net can get sustainable development. Based on this, an optimization study on the reliability analysis method of power system real-time operation state based on K nearest neighbors is carried out, so as to better guarantee the power system operation quality. In addition, it is necessary to use the big data of the distribution network correctly to extract valuable data from a large amount of information, so as to improve the reliability of the operation of the distribution network.

Acknowledgement. This paper is supported by the “Research and demonstration application of key technologies of intelligent control robot assistant (SGTYHT/19-JS-215)”, the project of headquarters management science and technology of State Grid Corporation of China.

References

1. Liao, M., Chakrabortty, A.: Optimization algorithms for catching data manipulators in power system estimation loops. IEEE Trans. Control Syst. Technol. **27**(3), 1203–1218 (2019)
2. Kumar, R., Sharma, V.K.: Whale optimization controller for load frequency control of a two-area multi-source deregulated power system. Int. J. Fuzzy Syst. **22**(1), 122–137 (2020)
3. Chaubey, P., Lather, J.S., Yelisetti, S., et al.: Robust power system stabilizer based on static output feedback approach to enhance power system stability. Energy Procedia **158**(2), 2960–2965 (2019)
4. Seck, G.S., Krakowski, V., Assoumou, E., et al.: Embedding power system’s reliability within a long-term energy system optimization model: linking high renewable energy integration and future grid stability for France by 2050. Appl. Energy **257**(11), 114037–114039 (2020)
5. Jimada-Ojuolape, B., Teh, J.: Impact of the integration of information and communication technology on power system reliability: a review. IEEE Access **8**(10), 24600–24615 (2020)
6. Peyghami, S., Davari, P., Blaabjerg, F.: System-level reliability-oriented power sharing strategy for DC power systems. IEEE Trans. Ind. Appl. **55**, 4865–4875 (2019)
7. da Costa, L., Thomé, F.S., Garcia, J.D., et al.: Reliability-constrained power system expansion planning: a stochastic risk-averse optimization approach. IEEE Trans. Power Syst. **39**, 97–106 (2020)
8. Zhao, Y., Xie, W., Jiang, J., et al.: Replacement of Marx generator by tesla transformer for pulsed power system reliability improvement. IEEE Trans. Plasma Sci. **47**(1), 574–580 (2019)
9. Abunima, H., Teh, J., Jabir, H.J.: A new solar radiation model for a power system reliability study. IEEE Access **7**, 64758–64766 (2019)
10. Altamimi, A., Jayaweera, D.: Reliability of power systems with climate change impacts on hierarchical levels of PV systems. Electr. Power Syst. Res. **190**, 116–123 (2021)