State assessment of protective devices based on data of information processing system

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Abstract: At present, the evaluation of relay status maintenance depends on a large amount of manpower. However, the data sources of relay protection devices and fault recorder information system (as known as the information processing system) have reached the basic requirements of online prediction of status evaluation of protection devices. Taking the exported information as the data source, according to the configuration file information, the state-space information that can be monitored by the protection device can be automatically extracted, and then the automatic extraction of the historical state of the protection device and the calculation of the coefficient of the state-transfer matrix are completed. Using Markov state space model method, the probability of each state that can be monitored by protection device was calculated, and the state of protection is evaluated. Finally, the operation data of CSC-101B protection device are selected as an example. The correctness and effectiveness of the method for evaluating the state of the protective device are verified.

1 Introduction
The current evaluation of relay protection operation status is mainly based on the regulations [1, 2] of the relay protection state maintenance evaluation regulations, and the basic data of the operation status of the reaction protection device are manually collected, as well as the defect data found in the dynamic records of patrol, maintenance, protection actions etc. According to the reliability factors and calculation methods of protection components given in the evaluation regulation, the state evaluation analysis of relay protection devices at the management level is carried out, and the state evaluation method of relay protection that meets various requirements is developed [3]. The characteristics of offline state evaluation and analysis work are as follows: (1) manual collection of data, manual analysis of data, manual calculation of reliability, or input of data used for state evaluation into the relay protection state reliability analysis software system to realise part of the automatic state evaluation function, which is in the stage of controlling the preliminary state evaluation of relay protection devices in the operating power grid at the management level; (2) The realised relay protection self-checking information or online monitoring system information (intelligent station network analyser information or guarantee system information) is not fully utilised as a data source for analysing the reliability of relay protection devices and systems, and the division of protection device states is not comprehensive [4–6]; (3) The real-time performance is poor, and the real-time performance is generally conducted once every 2 to 3 years according to the evaluation rules, so that only the working state of each protection device operating in the power grid can be understood macroscopically; (4) The work mainly depends on the participation of personnel, which shows a large workload and some work difficulty. With the expansion of the power grid, this mode of reliability analysis at the management level requires a lot of manpower and capital, and cannot ensure the real-time control of the reliability of the protection device.

Here, the information derived from the security information system is used as the data source for online monitoring. According to the actual operation information, the state information that can be monitored by the operation of the protection device is extracted. According to the real-time monitoring data file information, the real-time extraction of the historical state information of the protection device and the real-time calculation of the transfer matrix coefficient are completed; the state evaluation calculation is carried out by using a Markov model, and the probability of occurrence of each state that can be monitored by the protection device is calculated, wherein the probability of occurrence of the normal operating state is taken as a reliability index predicted by the protection device.

2 Information extraction
The status that can be monitored by the operation of the protection device refers to: according to the real-time operation data collected by the security system, and linking the configuration file developed by the third-party application software to the inside of the protection device through the interface standard, information that can directly reflect the abnormal operation state of the protection device is obtained [7]. According to the position of the protection device and the risk caused by the abnormal operation information, the state space that the protection device can monitor is determined, and then the information in the real-time collection information file is screened.

When determining the status that the protection device can monitor, it is required that the status elements must be independent events. Since the protection device self-check or event configuration file provides the following: fixed value, area code of fixed value, soft platen, device parameters, protection measurement, hard platen, action element, operation alarm, disturbance data description, fault information, and other information are mutually independent abnormal events. However, if the collected operation abnormal information is directly used as the state element, there is a large amount of space, and because the information definition is not uniform, it is not conducive to reliability prediction, so it is used to classify the operation abnormal information of the protection device into parts. When screening status elements, it is necessary to sort out the protection event information provided according to the research requirements of the relay protection device and protection system status maintenance project, filter out the field information that does not need to be analysed and the information that does not reflect the function, performance, and reliability of the protection device and the system, so that the sorted data are clearer, and serve as the
original characteristic quantity for researching the relay protection device and system evaluation status.

The basis for screening effective information is: according to the above filtering conditions, only the information reservation that has a direct impact on the function loss or performance degradation of the protection device and the protection system, as well as on the reliability degradation of the protection device and the protection system, will be considered, and the content information such as the response setting value, the setting value area code, the soft pressing plate, the device parameters, the protection measurement, the hard pressing plate, the action element, the disturbance data description, and the failure information will be deleted. Screening out information that can directly reflect the abnormal running state. According to historical data, 15 kinds of states that can be monitored by protection devices are sorted out, namely, functional hardware failure, Software failure, abnormal data, abnormal start, power failure, communication failure, abnormal current measurement and acquisition, configuration error, fixed value error, abnormal acquisition of switching value, abnormal output, abnormal voltage measurement and acquisition, operation not confirmed, and clock synchronisation failure is normal.

Specific screening information is shown in Table 1. Establishing a database through a state screening table, then obtaining fault information of real-time message response corresponding to a configuration file (SCD), linking the fault information to the database for classification, and accumulating and recording the duration of the state. The flow chart is shown in Fig. 1.

### 3 Markov model

The precondition of Markov state-space model is: the state space events generated in the random process must be random events, i.e. the value of the state-space transition matrix element is a certain value, which is to say, the probability of occurrence of events in the state space is subject to exponential distribution [8]. Since the occurrence and recovery of the abnormal information of the protection device collected by the security information system belong to random events and meet the conditions of Markov homogeneous random process, it meets the requirements of Markov state-space model.
Fig. 2  Line protection CSC101B Markov state transition diagram

Not all of the 15 types of states that can be extracted by the security system can be detected for specific protection devices, so it is necessary to dynamically generate basic state space for specific protection devices based on the states that can be monitored by the protection self-checking information/events. For example, the space that the line protection CSC 101b device is actually configured to be able to monitor includes: abnormal current measurement and acquisition, communication failure, software failure, functional hardware failure, abnormal voltage measurement and acquisition, configuration error, operation not confirmed, wrong setting value, abnormal acquisition of switching value, abnormal output, and abnormal data. Plus the normal operating state, 12 basic state spaces can be determined. Its state space is shown in Fig. 2.

Where \( \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8, \lambda_9, \lambda_{10}, \lambda_{11} \) represent the transfer coefficient from the normal state to each fault state, respectively, \( \lambda_{12} \) represents the transfer coefficient from the state to the previous state, respectively, \( \lambda_{13} \) represents transfer coefficients of the respective fault states to the normal state. In order to fully describe the actual state of the protection device, this paper uses the improved index of comprehensive real-time acquisition of the number of state transitions, i.e. the calculation formula of state transition coefficient \( \lambda_n \) is the corresponding number of state occurrences / statistical time value \( 10^{-6} \).

3.1 No state calculation method occurred

For states that did not occur during the statistical period, the state transition coefficient is calculated according to the aging failure probability of the products [9], that is, the occurrence probability of the state of the operating equipment is predicted according to the aging failure probability of the faults contained in the state of the similar products, and the specific algorithm determines the specific algorithm according to the conditions of the known data:

(1) If there are a large number of aging samples, the aging failure rate of the existing equipment can be evaluated according to the life distribution of the samples. If there are a large number of samples in practice, the annual product failure rate can be obtained through statistics when the product is running, and the product life can be regarded as a discrete random variable. The aging failure rates of the products for 1 year, 2 years, 3 years, … n years (n is the end of the life cycle) are: \( r(1), r(2), r(3), \ldots, r(n) \), prediction of aging failure rate in m-years \( R[m] = [1 - r(1)] [1 - r(2)] [1 - r(3)] \ldots \ [1 - r(m)] \), in which the \( K \)-year has been normal operation, predict the aging failure rate indicator for the next year, according to \( R(t) = [1 - r(K + 1)] [1 - r(K + 2)] [1 - r(K + 3)] \ldots [1 - r(t)] \).

(2) If the product life follows the normal distribution, the value of aging failure rate at time \( t \) is calculated. If there is no sample data mentioned above, it can be calculated according to the life of the product satisfying \( F(u, \sigma^2) \), where \( u \) is the life value of the product (the life value of the product provided by the manufacturer) – is the variance of the life of the product and the function of the probability density function of failure.

\[
N(0, 1) = \frac{1}{\sqrt{2\pi}} e^{-u^2/2}
\]

(2)

Thus \( Z = (t - u)/\sigma \), \( n(u) \) is converted into a standard normal form, and the value of variance can be calculated by looking up the normal distribution table, and passed after determining the parameters of \( N(u, \sigma^2) \).

\[
F(t) = \int_0^t f(t) \, dt
\]

(3)

\[
R(t) = 1 - F(t)
\]

(4)

The aging failure rate index of \( R(t) \) at time \( t \) can be calculated.

(3) If the product life cycle obeys Weibull distribution [10]. Since the distribution function of the normal distribution cannot be expressed by the elementary function, the above method of calculating the aging failure index \( R(t) \) needs to look up the table every time, which is not conducive to calculation. Therefore, Weibull distribution is used to fit to obtain the function of \( R(t) \). Non-negative random variable \( t \) density function

\[
f(t) = \eta \beta \left(\frac{t - t_0}{\eta}\right)^{\beta - 1} e^{-\left(\frac{t - t_0}{\eta}\right)^{\beta}}
\]

(5)

where \( \beta \) is the shape parameter; \( \eta \) is a scale parameter; \( t_0 \) is the position parameter, and the cumulative distribution function can be obtained by integrating it.

\[
F(t) = 1 - e^{-\left(\frac{t - t_0}{\eta}\right)^{\beta}}
\]

(6)

Since the life value of the product obeys the normal distribution rule, the life distribution function \( f(t) \) of the product can be obtained. Obtaining three point values from the life value can form three equations, i.e. substituting \( f(t1), f(T2), f(T3) \), solving \( \beta, \eta, t_0 \) and bringing it into the following formula

\[
R(t) = 1 - F(t) = F(t) = 1 - e^{-\left(\frac{t - t_0}{\eta}\right)^{\beta}}
\]

(7)

The reliability value of the product at any time can be calculated to obtain the aging failure rate value. For example, if the life expectancy of the product is set at 10 years, and \( T \) is the number of years that the manufacturer provides for the product life, the reliability of the product without aging failure at time \( t \) can be calculated according to the following formula :  

\[
R(t) = e^{-\left(\frac{t - t_0}{\eta}\right)^{\beta}}
\]

(8)

The aging failure rate \( R(t) \) of the fault contained in this state is its corresponding state transition coefficient. Note that the above (2) and (3) can only calculate the aging failure rate \( R(t) \) value when the manufacturer provides \( u \) values and \( \sigma \) values. If \( u \) and \( \sigma \) values of the product are not provided, then a basic aging distribution curve is drawn up based on the statistical data of the same type and model of equipment, and the basic aging curve is corrected to obtain the \( u \) and \( \sigma \) values of the product.
3.2 Markov state-space model

First, the states that did not occur during the statistical period are screened, and the state transition coefficient is calculated according to the above method. A Markov state-space matrix is established in combination with other monitored state transition coefficients (see (9)). Stay matrix $p = [p_0, p_1, p_2, \ldots, p_9, p_{10}, p_{11}]$, which indicates the probability of occurrence of the corresponding state. The residence matrix and the Markov state-space matrix satisfy to form a linear equation set.

Since these 12 states are independent states that form a complete solution space, the sum of the probability of solution space is 1, that is (see (10))

$$
\sum_{n}^{11} \lambda_n = 1
$$

In combination with the above equations, the matrix of linear equations is expressed as (see (12)). The probability value of occurrence of each state can be calculated by using the gauss elimination. The availability $a = P_0$ of the line protection CSC 101B device indicates the probability of occurrence of a normal operating state, and the probability of occurrence of each fault state prediction is $p_1, p_2, \ldots, p_9, p_{10}, p_{11}$, respectively.

### 4 Case analysis

Taking the line protection CSC 101B as an example, the analysis of the data derived from the guarantee system confirms that the software failure, functional hardware failure, configuration error,
The state transition coefficient is calculated by the way of product aging failure probability through the historical data collected in advance. The rest of the state transition data is calculated according to the actual situation of the message. Select a point in time as the statistical starting time, and then establish a Markov model to calculate the probability of occurrence of each state at the beginning of the statistical calculation. The calculation results of the starting point state evaluation are shown in Table 2.

The probability of occurrence of each state in the state space included in the protection device is as shown in Fig. 3.

### Table 2  CSC101B state assessment data during statistics

| State space element | Number of state occurrences | Cumulative time of status, ms | Probability of occurrence of state space prediction |
|---------------------|----------------------------|-------------------------------|-----------------------------------------------|
| (1) abnormal current measurement and acquisition | 1 | 100 | 0.000085 |
| (2) communication failure | 2 | 20 | 0.000173 |
| (3) software failure | 0 | 0 | 0.00001 |
| (4) functional hardware failure | 0 | 0 | 0.00001 |
| (5) abnormal voltage measurement and acquisition | 1 | 120 | 0.000087 |
| (6) configuration error | 0 | 0 | 0.00001 |
| (7) operation not confirmed | 0 | 0 | 0.00001 |
| (8) fixed value error | 0 | 0 | 0.00001 |
| (9) abnormal acquisition of switching value | 3 | 500 | 0.000257 |
| (10) abnormal output | 0 | 0 | 0.00001 |
| (11) data exception | 5 | 5000 | 0.00049 |
| Normal | | | 0.9889 |

1. Accumulating and adding the abnormal information corresponding to the abnormal class as statistical data of the state space elements of the fault mode of the class; 2. The occurrence probability calculated by the state space element of the abnormal class is taken as the probability of occurrence prediction of the state; 3. During the statistical period, the protection device will generally start counting from the last scheduled check to the current accumulated time unit ms, and can also randomly select the specified statistical time.

### Fig. 3  Protection device status of each state probability diagram

The probability of occurrence of each state in the state space included in the protection device is as shown in Fig. 3.

### 5 Conclusion

Here, the state of the protection device is divided by the information of the guarantee system, and the probability of state occurrence is calculated by Markov model. At the same time, the probability of state failure that did not occur during monitoring is corrected by the way of aging failure probability. Results of the study:

(1) Can intuitively, conveniently and accurately complete the online prediction of the operation reliability of the relay protection device, and timely grasp the operation reliability status of the relay protection device.

(2) At the same time as a supplement to the current management offline status assessment. A new method for on-line monitoring status evaluation of relay protection is realised, which provides status data support for relay protection status maintenance work and improves the accuracy of relay protection system actions and the reliability of power system operation.

### 6 References

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