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Reliability Evaluation Model of Safety Measures for Protection Device Maintenance Opreating Based on Goal Orientation

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Abstract

Aiming at lack of general Reliability Evaluation that exists in executing safety measures for protection device maintenance operating with relying on habit and showing diversity, this paper gives a general reliability evaluation model of second safety measures by using of two dimensions on reliability and complexity and point to the specific maintenance task, it shows optimal method which gives improvement to present working method. The model takes count of the habit from maintenance firm, its application can be feasible.

Keywords: reliability; complexity; secondary safety measures; relay protection; function link

Introduction

The relay protection system, as the first line of defense, plays an important role in the safe operation of the power grid. The substation relay protection system is an integrated system where different protection devices are interconnected through secondary circuits based on their specific functions. Due to the connection between the secondary equipment in maintenance status and the operating equipment among the secondary circuit, it is easy to cause misoperation of the operating equipment. Therefore, measures need to be taken before the maintenance operation to prevent accidents. This is the main purpose of the secondary safety measures implemented before the maintenance of relay protection equipment. The effectiveness of implementing secondary safety measures will directly affect the prevention of accidents. The current secondary safety measures and operation methods have greatly difference due to different operation methods and maintenance habits, or experiences. How to evaluate the effectiveness for different secondary safety measures becomes particularly important. References [1] and [2] have improved some specific secondary safety measures for smart substations. References [3-5] describe the implementation strategy of secondary security measures for intelligent stations. A large number of literature [6-12] involve the application system and proofreading methods of secondary safety measures. Currently, studies on secondary safety measures have not involved the evaluation strategies and methods for the performance of secondary safety measures. This article focuses on the study of evaluation methods for the reliability of secondary safety measures at the system level.

Functional link of secondary safety measures

The main methods used in the current secondary safety measures

The fundamental purpose of executing secondary safety measures before maintenance work for relay protection equipment is to take effective measures to prevent misoperation of the operating protection device caused by maintenance worsk, to prevent misoperation events of the circuit breaker (including accidental tripping of the operating circuit breaker, mistripping the opposite side circuit breaker during line protection check, and the operating protection to misoperate the maintenance circuit breaker), and to prevent accidents such as the damage to testing instruments and equipment. Secondary safety measures do not take into account any abnormal situations that may occur in other auxiliary secondary devices, such as monitoring systems, fault recorder devices, fire alarm systems, and on-line monitoring systems.

The causes of accidents during secondary equipment maintenance are analyzed and summarized as follows: 1. Misinput current into the TA secondary circuit of the running protection device to result protection devices misoperate. 2. The maintenance equipment is not completely isolated from the running protection secondary circuit during the maintenance process, which may cause incorrect operation of the running protection device. 3. Wrong connecting secondary wire causes equipment damage or other abnormalities and may lead to electric shock. 4. The TV secondary circuit may experience reverse charging during power out. 5. The live TV secondary circuit may experience short circuits and the TA secondary circuit may experience secondary opened. The basic principle of preventing these accidents is to disconnect the secondary circuit that connects the maintenance equipment to the running equipment for isolation. Preventive measures also include preventing accidental contact the secondary circuit by applying isolation signs and taking short-circuit measures to prevent opens in the live TA secondary circuit.

For conventional stations, the secondary system security measures can be summarized into the following seven categories:

A. Disconnection/connection operation of Phoenix terminal connecting strap.
B. Short-circuit/disconnection operation of terminal blocks.
C. Disconnection/connection operation of secondary circuits.
D. Operation of pressure plates.
E. Operation of air switches.
F. Operation of optical fiber links.
G. Isolation identification for wrong contact.

The implementation methods of safety measures form a set of safety measures types:

$$SM = \{s_i \mid i \in (A, B, C, D, E, F, G)\}$$

For smart stations, the secondary circuits of conventional stations are converted into virtual terminals [3], and there are no physical links associated different from conventional stations. Therefore, none of the forward text showed safety measures A, B, and C applies to smart stations. The operation of the pressure plate is based on the maintenance mechanism and characteristics of the intelligent station [3, 4], which can be divided into GOOSE receiving soft pressure plate, GOOSE sending soft pressure plate, SV input /output soft pressure plate, interval input /output soft pressure plate, maintenance status hard pressure plate, and remote operation hard pressure plate. The focus of this article is on the analysis and discussion of conventional stations, and no specific analysis or discussion will be conducted on smart stations for the time being. However, the theoretical methods gived in this article are equally applicable to smart stations, with the only difference being the change in relevant parameters.

Functional link criteria in secondary safety measures

During the maintenance of secondary equipment, causing various accidents is possible.as mentioned earlier, the fundamental purpose of implementing secondary safety measures is to take effective measures to prevent accidents caused by human factors during maintenance. There are multiple methods for implementing secondary safety measures, What methods, where to do and frequency of implementation are specific rather than arbitrary. Based on the characteristics of secondary safety measures implementation, the concept of functional links is introduced. The so-called functional link refers to the combination of a series of safety measures and quantities formed by using the safety measures in the set of SM to prevent a specific event during the implementation of secondary safety measures. For example, in the periodic inspection test of 500kV transformer protection, the mis-tripping of the operating circuit breaker will be an event that needs to be prevented. There are various possibilities for the occurrence of this event, such as the worng input of the outlet pressure plate to trip the operating circuit breaker. and the human error of shorting the secondary tripping terminal during maintanence. Therefore, measures such as disconnecting the outlet pressure plate, dismantling the secondary tripping wire. and making to prevent misoperation isolation marks on the secondary tripping terminal blocks. This will form a joint body to prevent the occurrence of this event and constitute a functional link to prevent mistripping the operating circuit breaker. If one of these measures is not implemented, the accident that was prevented is not effectively prevented and there is a loophole, which is called functional link failure. This is the implementation criteria for secondary safety measures based on functional links.

The basis for the division of functional links

Based on the characteristic about implementation of secondary safety measures and statistical analysis of reliability evaluation data, functional link division is carried out according to the following principles:

Classify based on the specific roles and functions of the secondary circuits that caused the safety incidents, and on the basis of individual maintenance of protective equipment. In special cases, different protection devices within the same cubicle may share their common pressure plates and terminal blocks without exclusive units, this case should be considered as one functional link.2. The protection function is the same but the object is different, which should be considered as a functional link. For example, for main transformer protection equipment with 3 / 2 wiring, preventing the circuit breaker from being mis-tripped is a definite function. However, there are many operational circuit breaker might be mis-tripped, such as the bus coupler and the section breaker, however it should be considered as one functional link for mis-tripping the operation breaker. The implementation of measures requires operations on several affected objects, but the increase in the amount of operations only affects their complexity but effectiveness. 3. The safety measures taken for outdoor equipment, such as circuit breaker terminal boxes, mechanism boxes, and PT terminal boxes, are based on individual devices (terminal boxes and mechanism boxes). Current and voltage circuits in different equipment, if designed to fulfill the same function, even if they involve different protective devices, should be considered as one functional link and no longer be classified as separate functional links based on specific protective devices. However, if the measures are aimed at different functionalities, they should be regarded as different functional links. 4. For the operating relay protection equipment, the misoperation maintenance circuit breaker is based on each circuit breaker and forms a functional link. There are several operating protection devices that can misoperate this circuit breaker should belong to one functional link for misoperation maintenance circuit breaker, and the amount of operating protection devices involved only affects its complexity.

Reliability evaluation model for secondary safety measures based on goal orientation

Principles for reliability evaluation of secondary safety measures

The main principle of reliability evaluation of secondary safety measures is to quantitatively evaluate the impact of the implementation of secondary safety measures under ensuring safety. The probability of misoperation of various safety measures in the set SM involves the reliability of safety measures execution [13-16], which naturally also involves the performance of the measures. The functional link is a union of security measures and will also involve reliability issues. Therefore, the reliability of safety measures implementation is an indicator that needs quantitative evaluation. The more security measures each functional link performs, the better the effectiveness of accident prevention and the higher the safety factor. The more times certain safety measures (such as dismantling secondary lines) are repeated, the higher their safety factor. But as the safety factor continues to improve, it also means an increase in the amount of operations and complexity. The higher the complexity, the more reverse operations there will be during the secondary safety measures recovery process after the maintenance operation is completed. The probability of safety measures misrecovery or missed recovery accidents is higher, the safety factor is lower, and the risk is higher. Based on this, considering the relationship between reliability and complexity, evaluation is conducted from the two dimensions of safety measures execution reliability and complexity. Similarly, it can be determined that there will be an optimal safety operation method for any maintenance operation.

Obtaining parameters related to secondary safety measures

If there are n functional links in the secondary safety measures for a certain maintenance operation. If the row vector of matrix S_{7n} represents the 7 security measures corresponding to the set SM, and the column vector represents each functional link.

$$S_{7n} = \begin{bmatrix} l_{11} \cdots l_{1k} \cdots l_{1n} \\ l_{21} \cdots l_{2k} \cdots l_{2n} \\ l_{31} \cdots l_{3k} \cdots l_{3n} \\ l_{41} \cdots l_{4k} \cdots l_{4n} \\ l_{51} \cdots l_{5k} \cdots l_{5n} \\ l_{61} \cdots l_{6k} \cdots l_{6n} \\ l_{71} \cdots l_{7k} \cdots l_{7n} \end{bmatrix} = [L_1 \cdots L_k \cdots L_n]$$

For the element l_{jk} of S_{7n}, when its value is 1, it indicates that the k-th functional link has executed the j security measure operation, and vice versa, it means the j security measure has not been executed. Therefore, a matrix with only 0 and 1 values for each element of S_{7n} is called the security execution matrix.

The value of S_{7n} has constraints: each functional link has at least one security measure execution operation, that is, at least one element has a value of 1. Otherwise, if all are 0, it will cause a functional link failure event, which is not allowed to occur. This is called the constraint condition of safety measures, and is represented as follows:

$$\sum_{j=1}^{7} l_{jk} > 0 \qquad (1)$$

Assuming the probability of human error operation as p[16], for a certain safety measure in the set SM, then 1-p is the probability of its correct execution, denoted as ck for the reliability of the safety measure operation. At present, there is no exact statistical indicator for misoperation in the set SM, and only the empirical values are given as follows:

c1:0.94, c2:0.92, c3:0.92, c4:0.95, c5:0.97, c6:0.97, c7:0.98, represented as the reliability array of safety measures:

$C_k = [c_1 ,..., c_7]$

For operations other than C in SM, its operating object is a state. But for the operation such as dismantling the wiring, it involves dismantling both sides of the wiring, and there are also differences in dismantling one side or both sides during on-site execution. Therefore, this type of operation belongs to a dual state variable, denoted as A (a1, a2), which has four operating states {00, 01, 10, 11}. If the value of ck is for reliability of a single operation, the corresponding reliability for the four variables is:{0, ck, ck,2ck-ck2}[15].

Each functional link may perform several Si tasks, each Si being independent of each other. If it indicates the occurrence of a functional link failure event, then A indicates the success of the functional link event. If all Si can cause event A to occur, its relationship is a parallel system, as shown on the left side of Figure 1; If the combination of several items in Si leads to the occurrence of event A, its relationship is a series system, as shown on the right side of Figure 1.

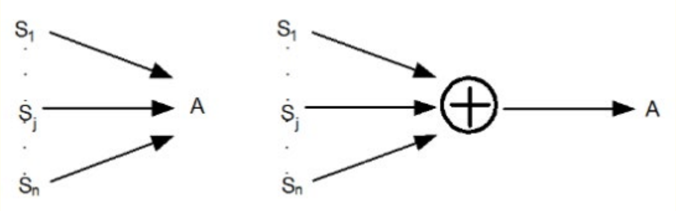

Figure 1: Parallel and series System drawing about mutual independent event.

$$r_{k-op} = 1 - \prod_{j=1}^{7} (1 - l_{jk} c_{jk}) \qquad (2)$$

$$r_{k-op} = \prod_{j=1}^{7} l_{jk} c_{jk} \qquad (3)$$

If there is a combination of parallel and series systems in a certain functional link, the calculation formula is shown in (4):

$$r_{k-op} = 1 - \prod_{i=n}^{7} (1 - l_{ik} c_{ik})(1 - \prod_{j=1}^{n} l_{jk} c_{jk}) \qquad (4)$$

In order to improve reliability on site, there are situations where a certain safety measure is repeatedly executed multiple times. For example, during work for replacing the line protection devices, secondary safety measures need to be taken to prevent accidental for misinputing current into the operating TA for busbar protection device. SA measures in SM are adopted in the circuit breaker mechanism box and busbar protection canbinet, respectively. The two measures are parallel systems, and their reliability parameters can be calculated according to formula (1).

Each functional link in S_{7n} will get a specific reliability parameter value $r_{k\text{-op}}$ noted as following, and the reliability parameter values of each functional link in the entire S_{7n} will form a one-dimensional array of reliability for secondary safety measures.

$$R_C = \left[r_{1-op}, \ldots, r_{k-op}, \ldots, r_{n-op} \right]$$

Goal oriented principle

For different types of maintenance operations, the functional links they contain may vary. The types of security measures adopted for the same functional link, namely the values of elements in S_{7n} also differ. For example, for the annual routine inspection of the transformer protection equipment, for a functional link such as tripping the operating CB by mistake, the execution measures that can be taken include disconnecting the Phoenix terminal connection, dismantling the secondary tripping wire, disconnecting the outlet pressure plate of the protection device, and labeling the corresponding tripping secondary wire on the terminal strip to prevent misoperation. However, for the replacement of the transformer protection equipment, there also have probability to trip the operating CB. Due to the need for a complete replacement of the protection device cabinet, all measures taken for all components inside the cabinet are meaningless, leaving only the dismantling of the secondary line. Therefore, the values of certain quantities of S_{7n} need to vary depending on the type and nature of the task. Secondly, for different types of tasks, the values of elements in S_{7n} have specificity, that is, the values of certain l_{jk} are certain and not arbitrary. For example, the safety measures for preventing misinput current into the operation TA for protection equipment do not involve measures for pressure plates and air switches, and l_{4k} and l_{5k} must be 0.

Similarly, for the routine inspection of protective equipment without power outage, SB measures must be taken for the current circuit, and this value cannot be set to 0. The above conditions are referred to as the constraint conditions for safety measures, which can be represented by equation (5).

$$l_{jk} : \{ l_{jk} \in S_{7n} \mid (l_{jk} = 1) \cap (l_{jk} = 0) = \phi \} \qquad (5)$$

In summary, the value of element in S_{7n} is correlated with the type of maintenance operation, which is the goal oriented principle of secondary safety measures. As mentioned earlier, it is constrained by equations (1) and (5).

Calculation of the complexity of secondary safety measures

At present, there is no mature method for calculating the complexity of equipment operation in the power industry that can be used for reference. The calculation method of operational complexity in the field of computer science can be referred to, and the Halstead method in this field can be used to calculate the operational complexity of secondary security measures [17, 18].

The Halstead method calculates program complexity based on the number of operators and operands on the statement lines in the program, and obtains the program complexity by formula (6).

$$M = (N_1 + N_2)\log_2(n_1 + n_2) \qquad (6)$$

In the formula, n_1 and N_1 respectively represent the number of different operators that appear in the program and the total number of all operators that appear; n_2 and N_2 represent the number of different operands that appear in the program and the total number of all operands that appear. The specific complexity related parameters are statistically calculated as follows:

Consider Si as an operator, with input/outlet pressing plate, and dismantling/connection (short sealing/unpacking) all considered different operators. The anti misoperation isolation label is a single operation, so there are a total of 13 types of operators. Treat the object that Si actually operates on as an operand. Different operands refer to the different types of operands. The calculation of the total number of operations should be based on the actual number of security measures performed, and the complexity should be calculated according to this method by counting the number of operations performed for each step:

For example: In the routine inspection of 220kV line protection equipment, the mistripping of the operating circuit breaker and protection plate used for starting the failure protection of busbar protection belong to different types of operation numbers. The protection plate used for starting the failure protection is divided into A, B, and C three-phase, belonging to the same type of pressing plate, and the number of operations is counted as 3. In the dismantling measures, dismantling the secondary line of the startup failure and dismantling the secondary line of the tripping outlet belong to different types of operating objects. The number for disconnecting the three-phase integrated PT secondary air switch is noted as 1, and disconnecting the three-phase independent PT secondary air switch is 3. Disconnect the three-phase Phoenix terminal connections of n number of CT(current transformers), which belong to the same type of operation object. Due to phase separation operation, the number of them is 3n. After the same type of security measures for a functional link mentioned earlier are executed multiple times, the number of operands increases while the type of operands remains unchanged. After the same type of security measures for a functional link mentioned earlier are executed multiple times, the number of operands increases while the type of operands remains unchanged. Making anti misoperation isolation labels only serves as a barrier and reminder. The number of operands is calculated based on the corresponding anti misoperation isolation labels made by different objects, and the types of operands are no longer divided, that is, the type of operands is 1. According to the above method, obtain the complexity parameter of S_{7n}.

$$W_C = \{W_{c1}, \ldots, W_{c7}\} = \{3, 6, 4, 3, 2.5, 2, 1\}$$

It is also necessary to consider different Si has different complexity in their operation process. For example, the corresponding anti misoperation isolation measures do not involve operating any components and only provide label, which has lower complexity. For the operation of secondary disassembly and wiring, it is necessary to carefully check the drawings and actual secondary circuit, which is highly complexity. Therefore, for the different elements Si in the SM set, their complexity operation weights should be considered, differentiated processing should be carried out, and the N_2 value should be corrected. Based on experience, the corresponding Si weight set is defined as follows:

After considering the weight, the correction formula is:

$$N_2' = \sum W_{cj} \bullet n_k \qquad (7)$$

Reliability evaluation model for secondary safety measures

The reliability parameter evaluation parameter R_S of the safety measures for the entire secondary maintenance operation is the sum of the squares of the values of each functional link in n R_C:

$$R_S = \sum_{k=1}^{n} r_{k-op}^2 \qquad (8)$$

Set the following reliability evaluation function for secondary safety measures:

$$F(l_{jk}) = \frac{w_1 R_S}{w_2 M} \qquad (9)$$

In the formula, w_1 and w_2 are the weights of reliability and complexity, respectively. Before determining the weight, in order to eliminate the impact of different levels of reliability and complexity, normalization should be carried out separately.

$$R_S' = \frac{R_S}{R_{S-max}} \qquad (10),$$

$$M' = \frac{M}{M_{max}} \qquad (11)$$

In the equation, $R_{S\text{-}max}$ is the R_S value after setting all l_{jk} to 1 under the constraint conditions. Finding the maximum value of M_{max} is complex. As discussed earlier, a measure of a functional link to improve reliability can be repeated several times. If the maximum value can only be determined based on experience, a limit on the number of repetitions can be set, and the experience limit is taken as 3. Based on experience, there is usually a possibility of repetitive execution in SA and SC, so they are calculated three times. There are various methods for determining weights, such as expert scoring and tolerance method. In order to avoid the influence of human factors, tolerance method is used to determine weights.

Calculate tolerance:

$$\alpha = \frac{R_{S-max} - R_{S-min}}{2}, \quad \beta = \frac{M_{max} - M_{min}}{2} \qquad (12)$$

Calculate weight:

$$w_1 = \frac{1}{\alpha^2} \quad , \quad w_2 = \frac{1}{\beta^2} \qquad (13)$$

Similar to the previous calculation methods for $R_{S\text{-}max}$ and M_{max}, $R_{S\text{-}min}$ is the l_{jk} value corresponding to selecting the smallest C_{jk} value in each functional link under constraint conditions, set to 1, and the R_S value when all other values are 0. Obviously, M_{min} is set to 1 for the least complex term under constraint conditions, while all others are set to 0, indicating the M value under the condition of no repeated execution of measures. The function $F_{max}(l_{jk})$ is a function of S_{7n}. According to the l_{jk} different values of l_{jk}, there are extreme values. According to the iterative method of , its extreme value $F_{max}(l_{jk})$ can be obtained. The evaluation principle of the entire secondary safety measure is to consider the degree of deviation between the function value and the extreme value [19], and the following evaluation formula is given:

$$\left(1 - \frac{F_{\max}(l_{jk}) - F_j(l_{jk})}{F_{\max}(l_{jk})}\right) \times 100 \qquad (14)$$

The value of l_{jk} is only 0 and 1, so its solution is a 0-1 programming problem [20, 21]. The methods for solving 0-1 programming problems include traditional methods such as implicit enumeration and exhaustive method, as well as new intelligent algorithms such as improved discrete particle swarm optimization algorithm. The optimization model established in this article has a small scale and is suitable for solving using implicit enumeration method. The implicit enumeration method determines whether a combination of independent variables is the optimal solution by continuously exploring the value of variables based on the information obtained during the solution process and the objective function and constraint conditions. The solution of $F_{max}(l_{jk})$ requires the use of the functional link matrix S_{7n}, although the objective function's independent variable is l_{jk}, the independent variable should meet the constraint conditions of formula S_{7n}. The extreme value is solved through continuous iteration of the value of the independent variable, and the solution flowchart is shown in Figure 2.

Example analysis

Taking the annual inspection of the protection of a 220kV line with dual configuration in a conventional substation with dual bus connection type (primary equipment outage maintenance and no related secondary system work) as an example, the reliability of its secondary safety measures is evaluated using the described method. Based on the analysis of the relevant secondary systems and the existing work methods, there are the following functional links:

1. Preventing to misinput current into Bus operation; 2. A set of line protection to prevent abnormal operation of PT secondary circuit; 3. B set of line protection to prevent abnormal operation of PT secondary circuit; 4. A set of line protection prevents to start false the failure protection for busbar protection; 5. The B set of line protection prevents to start false the failure protection for busbar protection; 6. A set of circuit protection mistransmission circuit breaker on the opposite side; 7. B set of line protection mistransmission opposite side circuit breaker; 8. Prevent mistransmission of operation protection and maintenance of circuit breakers. Thus the S_{7n} matrix formed is:

$$S_{7n} = \begin{bmatrix} L_1 & L_2 & L_3 & L_4 & L_5 & L_6 & L_7 & L_8 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \end{bmatrix}$$

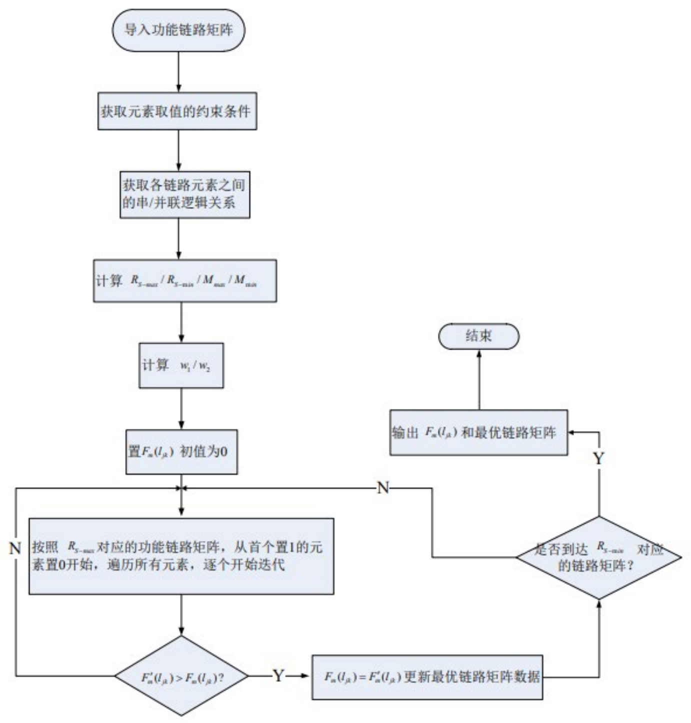

Figure 2: Flow chart of solving extreme value.

The description of the above measures is as follows:

Functional link L1: Disconnect the CT Phoenix terminal strip for busbar protection in the circuit breaker mechanism box, and mark the terminal strip with anti misoperation markings. Constraints:

$$c = \left\{ l_{ik} = 0 \mid k \in (2,4,5,6) \right\}$$

Disconnect the terminal strip and label it as a parallel system for misoperation prevention.

Functional links L2 and L3: Disconnect the PT secondary voltage air switch in the protection screen, and mark the terminal block with preventing misoperation markings. Constraints:

$$c = \left\{ l_{ik} = 0 \mid k \in (2,4,6) \right\}$$

The air switch and terminal strip shall be labeled as a series system with anti misoperation markings.

L4 and L5: Disconnect the busbar protection failure circuit protection pressing plate inside the protection screen, and mark the terminal block with preventing misoperation markings. Constraints:

$$c = \left\{ l_{ik} = 0 \mid k \in (2,5,6) \right\}$$

Disconnect the pressure plate from the terminal strip and mark it as a series connection system to prevent misoperation.

L6, L7: The measures taken include: exiting the differential protection pressure plate, exiting the remote tripping function pressure plate, and disconnecting the longitudinal protection channel optical fiber. Constraints:

$$c = \{ l_{ik} = 0 \mid k \in (1,2,3,5,7) \}$$

All three measures are parallel systems.

L8: dismantling the busbar protection tripping secondary line from the line protection screen, constraints:

$$c = \{ l_{ik} = 0 \mid k \in (2,5,6,7) \}$$

The relevant parameters are calculated as follows:

$$R_C = [0.99, 0.95, 0.95, 0.93, 0.93, 0.99, 0.99, 0.92]$$

Reliability parameter values:

$$Rs = 7.3215$$

n1：6，N1：15，n2:10，N2'：79，M:376, M_{max}：1 578.6, $M_{\min}$:72.6481, $R_{S-\max}$：7.840 8, $R_{S-\min}$:6.88 34,RS':0.933 8,M':0.238 2, α :0.4787, β :752.956,w1:4.3639, w2:1.763 9 × 10-6。

$$(1-\frac{F_{\max}(l_{jk})-F_j(l_{jk})}{F_{\max}(l_{jk})})\times 100 = 59.23$$

The optimal link matrix corresponding to $F_{\max}(l_{jk})$ optimization：

$$S_{7n} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \end{bmatrix}$$

Reliability evaluation parameters:

$$F_{\max}(l_{jk}) : 1.6375 \times 10\text{-}7,$$

Evaluation score:

$$(1-\frac{F_{\max}(l_{jk})-F_j(l_{jk})}{F_{\max}(l_{jk})})\times 100 = 59.23$$

Through the analysis of the evaluation results of the case, there are several differences between the existing secondary safety measures and the optimal construction method formed by this method: 1. For security measures with parallel connections in functional links, from the perspective of improving reliability and complexity, one measure can be implemented without repeating multiple measures. Therefore, there is no safety measure for parallel connection in the optimized functional link. This is manifested in two aspects: ① when the anti misoperation isolation sign can be effective, no other measures will be taken; ② Mistripping the circuit breaker on the opposite side only takes the measure of disconnecting the optical fiber with the lowest complexity. 2. For the operation of mistripping maintenance circuit breakers during operation protection, the optimal performance is achieved by disconnecting the outlet pressure plate. Because the current maintenance measures usually do not include operational protection within the scope of maintenance, and currently only involve the removal of secondary lines from equipment within the scope of maintenance. This operation has a high complexity. From an optimization perspective, the relevant operation protection should be considered within the scope of measures, and the operation of disconnecting the outlet pressure plate of the operation protection transmission maintenance circuit breaker should be carried out. The executed operation should be marked with anti misoperation isolation signs. 3. The safety measures of disconnecting the phoenix and connecting the pieces should replace the safety measures of dismantling the secondary line. According to the current enterprise standard requirements of State Grid Corporation of China, the tripping outlet of the protection device adopts Phoenix terminal connection. Therefore, many safety measures for dismantling secondary lines can be replaced by disconnecting Phoenix terminal connection.

The optimization results of the example can provide an improvement plan for the implementation of secondary safety measures for the current routine 220kV line protection inspection operation.

Conclusions

This article focuses on the diverse forms of secondary safety measures implemented in the maintenance of relay protection equipment in current substations, lacking effective standards and evaluation basis. The implementation of safety measures neglects the issue of complexity. Based on the basic theory of reliability, a reliability evaluation system for secondary safety measures is constructed from two dimensions: reliability and complexity of secondary safety measures. The specific work is carried out in the following aspects:

Based on the basic theory of power system reliability, the main principles for evaluating the reliability of secondary safety measures are introduced by analyzing the probability of human error operations in secondary safety measures and the impact of the complexity of safety measures operation; 2. Proposed the concept of secondary security measures functional link, pointed out the problem of target oriented in functional link, and provided the division principles of functional link; 3. The Halstead method was used to calculate the complexity of secondary safety measures, and a calculation method for the parameters related to the complexity of secondary safety measures was proposed; 4. A systematic reliability evaluation model for secondary safety measures has been constructed, and an optimization plan for the existing secondary safety measures has been proposed after considering both reliability and complexity in execution.

The reliability evaluation model for secondary safety measures proposed in this article is an evaluation standard formed based on two dimensions of reliability and complexity, using the tolerance method to determine the weight model of reliability and complexity. Currently, production units attach greater importance to the reliability of secondary safety measures. Based on this, the application unit can adopt artificial methods to set the weights of reliability and complexity according to the actual situation, making it more inclined towards the operation and maintenance habits of the application unit. Therefore, the theoretical method proposed in this article has practical application value.

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