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WIDE-AREA INTELLIGENT PROTECTION SYSTEM BASED ON GENETIC ALGORITHM

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Abstract: *This article brings forward a wide-area intelligent protection system based on abundant power network information by analyzing the practical application of wide area protection and further combining it with the recent development of power network. The system works with main protection system and strengthens the capability of power system relay protection and simplifies the backup protection. This paper also gives the decision-making and working mode of a new intelligent protection including the principle of state correlation wide-area protection and the principle of fault identification based on genetic algorithm. A fault mathematical model based on genetic algorithm is developed. The results of the simulation test prove that the validity and good fault-tolerance capabilityof the model proposed.*

Keywords: *Wide-area intelligent protection, power network information, backup protection, genetic algorithm, fault-tolerance capability*

1 INTRODUCTION

In early 2008, an extremely heavy ice disaster attacked the south regions of China, which caused a long-time power failure in large-scale. During this course of power grid disaster, communication system became disfunctional due to the ice disaster, which made a further negative influence on power dispatching, monitoring and relay protection system. As a result, they were partially or completely disabled. Especially for the damage of longitudinal communication channel, the key information was lost and the main protection capability was reduced and even was forced to quit from running [1][2], which made the transmission line stop. Furthermore, it made a heavier ice cover and made easier collapse and broken bridge accidents. Finally, the vicious circle broadened the power cut range.

Within the current development of power system, it is difficult to cope with huge complicated power network and to stabilize the damaged backup protection caused by a big power cut accident, which is related to some special problems (such as weak running ability under complicated conditions, false relay actions cased by big charge transformation, and improvement of the functions of relay protection of power system). In these conditions, wide-area protection based on Wide-Area Measurements System (abbr. WAMS) - a feasible method has been established to solve the above power network problems [3]-[6]. It has a distinct advantage of fully using the provided information by wide-area synchronous measure technology. Most wide-area protection is based on the ideal state of getting accurate information and researching a principle of using wide-area information to judge the fault. Although many achievements have been obtained [7][8], there are still some disadvantages in practical applications. ①it is hard to completely ensure the effectiveness of the distributed wide-area information collection, communication, long-distance and anti-interference measures, especially when the communication channel is damaged by natural disaster that causes partial information lost or is sent to the decision-making

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level. From the existed relay protection principle, under the situation of lack or mistake information, the general operation will stop the machine. ②the wide-area protection principle based on some single kind of information fails to effectively use the integrate advantage that all electric quantity in power system are connected with each other [9]-[12].

It is hard to guarantee the distributed information collection anti-interference measurements, and it is possible to appear false information or wrong judgment in the collection port. The wide-area quality of information collection determines that the wide-area criterion must have strong fault-tolerance capability. However, it is not the main point of used fundamental research of wide-area protection theory. Meanwhile, it is necessary to find out the hidden logical connection among all kinds of real-time information that can reflect power network faults and improve sensitivity as well as its reliability. Therefore, it is necessary to find out the support of artificial intelligent technology. GA (genetic algorithm) is a kind of adaptive heuristic global searching probability algorithm, which can search multiple points at the same time in solution spaces and make the solution optimal in the whole area [13]. Nowadays, GA has been used in the research of power system [14][15]. However, its mathematic model emphasizes on the distribution of network fault diagnosis. The collected power network can reflect more information, which is not suitable for transmit electricity network relay protection area. Based on the past research, this article puts forward a new wide-area protection principle based on GA. We build mathematic model and further validate it with simulation.

2 WIDE-AREA INTELLIGENT PROTECTION

2.1 Decision-Making Module of Wide-Area Intelligent Protection

The distributed information collected by wide-area protection will cause a lack of ability of anti-interference on bad dates. Therefore, it is necessary to adopt a set of decision-making system with strong fault-tolerance ability as main criterion. In addition, we need to fully use the logical connection among fault information in power network so that wide-area protection can make right decision under the condition of collected information lack or aberrance. Besides, the choice of a set of wide-area protection theory based on state association as assistant criterion is important, which make system more reliable and quicker. There is a complement between main criterion and clear logic assistant criterion. This article provides an artificial intelligent criterion based on GA. GA is based on evolution theory and uses genetic combination, genetic aberrance and natural choice and other design methods, which make it simple universal, strong robustness and high fault-tolerant.

To reduce the communication burden of two sets of decision-making units, we try to choose the input information, which includes intra-regional main protection (line and bus), circuit breaker failure protection action state information, breaker state information and fault direction information.

2.2 Working Mode of Decision-Making Module

Decision module collects the connotative logical relationship among information so that it can give a fast evaluation on the information statue. The evaluation process has the same pace with the decision process and improves the reliability of system. Figure 1 indicates the logical controlling relationship in decision module, in which F represents logical estimated errors and K represents the highest fault-tolerance.

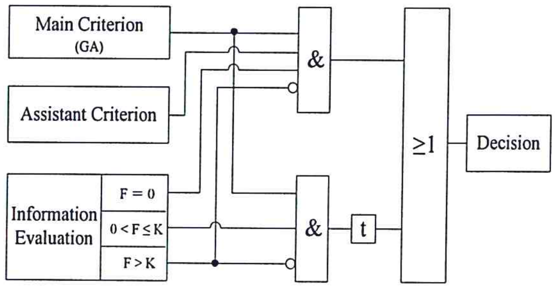

Fig.1 Decision-making Logic

The role of the information evaluation module is to do quick logic identification about the receiving information of the power network, including following logic issues: ① the absence of protection information; ②reflection of the logic conflict between information of the same elements under the redundancy situation. F corresponds to the logic detect result, K is related to the protecting area range and associating fault information of selected power network.

2.3 Cooperation between Wide-Area Intelligent Protection and Current Protection System

The main goal of wide-area intelligent protection is to improve backup protection and try to cooperate with the current main protection. According to the literature report [16], we can use fiber network to realize wide-area current differential protection. As a result, the highest delay of network communication, 24ms, is calculated by simulation software Network Simulator. However, the state value of this system is far less than

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the communication traffic of wide-area current differential protection. Considering the delay influence caused by the calculation time of decision-making unit and other situation, the reflection time on fault must be less than 100ms, which is faster than current backup protection. Due to the adoption of distributed redundant direction and state information, this system can locate the fault in the exact place and make up with main protection based on the theory of current differential or pilot direction. At the same time, if the main protection have to quit from running owning to some exceptional reasons, or it is locates on the areas without double main protection, it can be configured as the second main protection.

In wide-area protection system, the complicated setting coordination problem of traditional backup protection can be avoided.· So after the right location on faults by decision-making unit, wide-area intelligent protection system can realize the following action strategies:

1) If the main protection fails in action, speed up the backup protection action.

2) When the protection unit on fault circuitry is completely invalid, shorten the action time for remote backup protection.

3) For the system without circuit breaker failure protection, when the breaker fails, shorten the action time for remote backup protection, which has similar effect as circuit breaker failure protection action.

3 PROTECTION PRINCIPLE BASED ON STATE ASSOCIATION

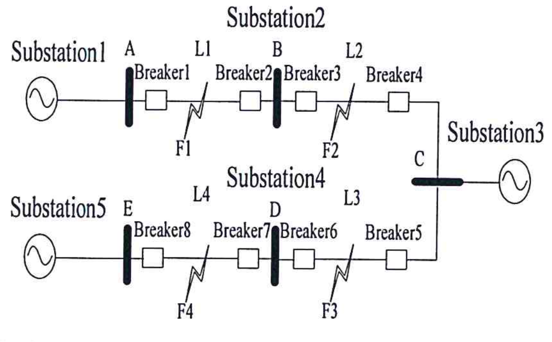

Fig.2 Framework of Regional Power Network

We make F1 as a single phase earth fault, which is used as an example to explain the principle of wide-area protection. The real-time topology of power network is the basis of fault location for the topology of circuitry which will change on the situation of fault, examine and repair or newly join circuitry and substation. Preserved original circuitry topology picture, the wide-area protection decision-making unit will modify the topology of protected areas in time according to the receiving breaker stature information.

According to the Fig.2, the state signal matrix can be described as the following if the breakers are closed (1 as close, 0 as disconnection):

Breaker1、Breaker2···Breaker8

$$A=\begin{bmatrix}1 & 1 & 1 & 1 & 1 & 1 & 1 & 1\end{bmatrix} \tag{1}$$

A real-time incidence matrix is concluded as:

$$\begin{array}{c} \text{Line } 1 \quad 2 \quad 3 \quad 4 \\ B=\begin{bmatrix}1 & 0 & 0 & 0\\ 1 & 1 & 0 & 0\\ 0 & 1 & 1 & 0\\ 0 & 0 & 1 & 1\\ 0 & 0 & 0 & 1\end{bmatrix} \begin{array}{l}\text{Substation } 1\\ \text{Substation } 2\\ \text{Substation } 3\\ \text{Substation } 4\\ \text{Substation } 5\end{array}\end{array} \tag{2}$$

On the basis of real-time fault direction information, we assume that "1"represents the positive result of direction component and "-1" represents the reversing result of direction component, and further assume that the result of direction component under the fault of F1 can be received under the situation. The direction component has complete right judgment, which is explained in Tab.1:

Tab.1 Estimation Results of Direction Elements

	Line 1	Line 2	Line 3	Line 4
Substation 1	1	\	\	\
Substation 2	1	-1	\	\
Substation 3	\	1	-1	\
Substation 4	\	\	1	-1
Substation 5	\	\	\	1

Take place of the corresponding elements by putting the calculated result of direction component into the incidence matrix of system structure, and get the corresponding result matrix is:

$$R=\begin{bmatrix}1 & 0 & 0 & 0\\ 1 & -1 & 0 & 0\\ 0 & 1 & -1 & 0\\ 0 & 0 & 1 & -1\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{3}$$

Additional results of the same row vector, the corresponding circuitry of component 2 is the wrong circuitry. Therefore, we get a judgment that circuitry 1 has faults.

There is no complicated data calculation for the discriminating principle based on state relation, and it is exact and fast, but it has a high request on the state information reliability. The right judgment and collected information integrality of direction components have straight effects on the decision and it still has certain localization under the wide-area protection system referring to more transformer substations.

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4 THE FAULT DISCRIMINATING PRINCIPLE BASED ON GA

The critical thing for the application of GA for the power system relay protection is the establishment of a reasonable math module for network fault. Compared to distribution net, transmission network is a configured by multi-power as well as the more important components, more kinds of configured protection and more complicated action strategies bring certain difficulties to establish right math module. To make sure the speed that the discrimination system responds to the faults, the information needed is the same as the wide-area collected. The realization process of fault location through GA will be stated as following:

4.1 Gene Coding

Generally, GA does not directly manage the parameters of fault space but code the optimizing parameters. Because the 0、1 digit strings correspond to two kinds of states of system equipments (0 is the normal state, and 1 is the fault state), the parameters can be coded to binary digit string which express the decision-making solution of the wide-area intelligent protection. The decision-making solution of figure 2 can be described as:

0	0	0	0	0	0	0	0	0

Bus A B C D E; Line 1 2 3 4

4.2 Establish Fitness Function

During the process of genetic operation, the solution function is evaluated by fitness function. The choiceness of solution with good performance can be passed down to next generation. The fitness of each unity of group according to the fitness function can be calculated, which will provide evidence to the choice of group revolution. The main method of design fitness function is to transform the objective function to appropriate fitness function. The fitness function constructed by this article is expressed as following:

$$Fi(X)=\sum_{j=1}^{N}\left|A_j-A_j^*(X,C)\right|+\sum_{k=1}^{S}\left|F_k-F_k^*(X,C)\right| \qquad (4)$$

N is the total number of main protection and circuit breaker failure protection, M is the number of system components and S is the direction component number of fault;

X: a M-dimension vector, X_i expresses the state of ith component (0 is the normal state, and 1 is the fault state); A: a N-dimension vector, A_j expresses the real state of jth protection (0 is no action, and 1 is action); $A^*(X,C)$: a N-dimension vector, $A_j^*(X,C)$ expresses the expected state of jth protection. If the jth protection should act, $A_j^*=1$, or $A_j^*=0$。F、$F_k^*(X,C)$: the expression is similar to A、$A^*(X,C)$， they represents the real state and expected state of S direction components respectively in this system. If the jth direction is forward, $F_j^*=1$; and if it is reverse, $F_j^*=-1$； if it is an invalid judgment, $F_j^*=0$. It is assumed that the current direction from mother line is forward.

C: a N-dimension vector, C_j expresses the real state of jth breaker(0-non-trip，1-trip).

Formula(4) is consisted of two parts. Under the expected relationship between breaker state and equipment state as well as the former part with protection action information and the later part with fault direction information, these two parts make fitness function. In some sense, the circuit breaker failure protection startup in former part is expected to makeup the arithmetic, which is beneficial to approach the best. Because the circuit breaker failure protection is configured in the current 220kV or higher main line, this kind of expected function is intensively discussed here.

In addition, formula (4) is a problem about minimum. In favor of the solution of GA, formula (4) is transformed into a function of seeking maximum:

$$Fi(X)=V-\sum_{j=1}^{N}\left|A_j-A_j^*(X,C)\right|-\sum_{k=1}^{S}\left|F_k-F_k^*(X,C)\right| \qquad (5)$$

V is a constant greater than N+S.

4.3 Protection State Expectation Function

When we locate the power network fault, the process of solving the best solution of this math model is a kind of optimal process of approaching the protection action expected value of equipment information confirmation to the protection action information of collection termination from each transformer substation. The protection state expectation function is related to the concrete network topology, breaker state, protection configuration and action strategies. Referring to fig.2, the expectation function is given as following:

Assume the voltage grade of line is 220kV, referring to fig.2, A、B、C、D、E represent bus, L1~L4 represent line, which are corresponding to X_i (i from1

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to 9), breaker1 to breaker8 are corresponding to C_i (i from1 to 8); at the same time, we use subscript m to represent the bus protection or main protection of line, bf represents the circuit breaker failure protection。 A_i (i from 1 to16) are corresponding to all sixteen protections， A_m、B_m、C_m、D_m、E_m、$L1_{Am}$、$L1_{Bm}$、$L2_{Bm}$、$L2_{Cm}$、$L3_{Cm}$、$L3_{Dm}$、$L4_{Dm}$、$L4_{Em}$、B_{bf}、C_{bf}、D_{bf}。 F_i (i fromCB1 to CB8) are corresponding to all eight fault direction information， F_{CB1}、F_{CB2}、F_{CB3}、F_{CB4}、F_{CB5}、F_{CB6}、F_{CB7}、F_{CB8}。

The function establishment has a direct effect on the fitness function establishment. The expectation action function should reflect the protection action cooperation principle. The main protection expectation function has an easier and more general expression:

$$A_i^*(X,C) = X_j, \begin{cases} j=i, & 1 \le i \le 5 \\ j=[(i+6)/2], & 6 \le i \le 13 \end{cases} \quad (6)$$

In this expression, [] is an integral function.

Generally, confirmation of circuit breaker failure protection and the expectation state of fault direction is more complicated than the expectation state confirmation of main protection as these two expected states can be related to multi-components and multiple protection state (in this model, only considering the related parts to main protection). The specific expectation function is as following:

$$A_{14}^*(X,C) = X_6 A_7 (1-C_2) \,||\, X_7 A_8 (1-C_3) \quad (7)$$

$$A_{15}^*(X,C) = X_7 A_9 (1-C_4) \,||\, X_8 A_{10} (1-C_5) \quad (8)$$

$$A_{16}^*(X,C) = X_8 A_{11} (1-C_6) \,||\, X_9 A_{12} (1-C_7) \quad (9)$$

$$F_1^*(X,C) = X_6 + X_7 + X_8 + X_9 \quad (10)$$

$$F_2^*(X,C) = X_6 - X_7 - X_8 - X_9 \quad (11)$$

$$F_3^*(X,C) = -X_6 + X_7 + X_8 + X_9 \quad (12)$$

$$F_4^*(X,C) = X_6 + X_7 - X_8 - X_9 \quad (13)$$

$$F_5^*(X,C) = -X_6 - X_7 + X_8 + X_9 \quad (14)$$

$$F_6^*(X,C) = X_6 + X_7 + X_8 - X_9 \quad (15)$$

$$F_7^*(X,C) = -X_6 - X_7 - X_8 + X_9 \quad (16)$$

$$F_8^*(X,C) = X_6 + X_7 + X_8 + X_9 \quad (17)$$

In the expressions, || represents logic or.

4.4 GA Flow

The population size should abide the principle of guaranteeing the diversity of GA population and relatively faster constringency speed. Starting from initial random population, arithmetic do the evolution operations including selection, crossover and mutation. Tournament selection is used to calculate the reasonable crossing and variance probability according to the simulation. In this article, we set the size of population as 50, the initial crossing operation probability as 0.8, the variance probability as 0.03. The constringency condition of finish is that the optimal individual fitness value of population that reaches maximum. The GA flow is presented as fig.3:

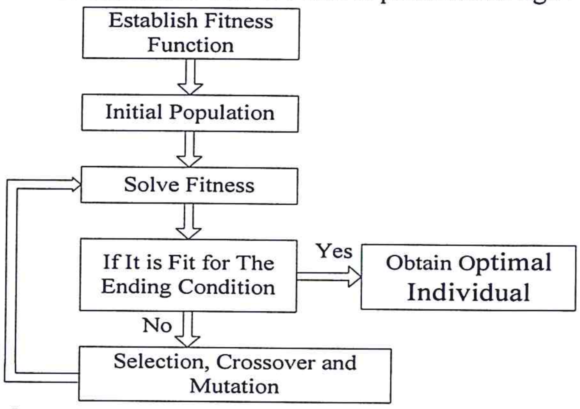

Fig.3 Flow Chart of Genetic Algorithm

5 SIMULATION ANALYSIS

By using the model and arithmetic of this article, the simulation test has been made on the location application of the judgment system based on GA and Matlab is chosen as the simulation tool. Establishment of simulation model is also achieved referring to fig.2 power network. In this model, there are nine protected equipments (it the equipment is fault, the value is 1, or it is 0). The simulation input includes protection action information (for each group, input the first line 1- 16 bits), breaker state value (for each group, input the first line 17- 24 bit) and fault direction information (for each group, input the second line). As a result, the information includes 32 bits. The test result is presented as table 2, 3.

Tab.2 Results of Faults Simulation

1	Input	000001100000000000000000 11(-1)1(-1)1(-1)1
	AG Output	000001000
	Ass Output	Line 1
2	Input	000001100000000000000000 11(-1)1(-1)111
	AG Output	000001000
	Ass Output	Line 1,4
3	Input	000001100001000000000000 11(-1)1(-1)111
	AG Output	000001000
	Ass Output	Line 1,4

Tab.3 Results of GA Fault-Tolerance Simulation

F	3	4	5	□6

Decision	Right	Right	Right	Maybe Wrong

In table 2 group 1, 2, 3 record the judgment depending on the main protection action information and the fault direction information. For group 2, 3, there are information aberrance on one or two bits respectively. The simulation result indicates that when the collection information is totally right, both the main criterion of GA and the assistant criterion of state association can make a right judgment. However, when there is any aberrance in the collection information, the assistant criterion of state association will give a false judgment. On the contrary, the main criterion of GA can still get a right decision solution, which shows its high capability of fault-tolerance and the advantage of GA in fault judgment.

Table 3 shows the decision-making simulation result when the network has greater F values. In this arithmetic, there are line fault and six group signals, which include two direction components, two breaker states and two groups of main protection action information, among which the worst input condition is that all six groups of signals are completely wrong. We can see that this system has a tolerance of at least five wrong inputs (32 inputs together). So in this scale of network, it is necessary to take relative less value of K, which makes K equal or less than 5 in order to make the system more reliable.

6 CONCLUSION

The present paper brings forward a wide-area intelligent protection system based on wide-area power network information and double decision-making units. This protection system can cooperate with the current main protection and the backup protection, which strengthens the relay protection. There are there main features as following:

(1)Introduction of the artificial intelligent criterion unit based on GA which has high collection information fault-tolerance and greatly improve the serious effects on the system reliability owing to communication problems. Because the new-style protection system uses limited wide-area information, the application of artificial intelligent technology will greatly increase the protection level of protection system.

(2)The action speed of this set of wide-area intelligent protection system is between the existed main protection and the backup protection. This system has higher sensitivity and better reliability, which can form good compliment to the main protection.

(3)By judging the power network information in the protection area, this set of protection system makes action decision globally, which can realize the action strategy that can not be done by the traditional protection system based on local information. Therefore, the complicated setting coordination problem of traditional backup protection can be avoided.

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BIOGRAPHY

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