Fault Diagnosis for Power Grid Systems Based on Rough Set and Bayesian Network

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Abstract. In terms of the uncertainties and incompleteness of alarm information in power grid fault diagnosis, this paper proposes a fault diagnosis method based on rough set combined with Bayesian network. Using the ability of rough set to reduce knowledge and process indeterminate information and mine fault information hierarchically, using the attribute reducing method based on cognizable matrix and information entropy, the optimal attribute reduction combination is extracted. Finally, by means of the reduction decision table formed by optimal attribute reduction combination, the Bayesian network model is built for parallel reasoning of each region, and the nodal probability is trained to achieve fault diagnosis. The experiment proves that this method can diagnose the fault rapidly and accurately, and has strong fault tolerance and adaptability.

Introduction

The method of accurate and rapid power grid fault diagnosis is of great significance to the modern power grid operation, which is an important means to guarantee the reliability of power supply[1]. Power system fault diagnosis is the process of fault identification based on various kinds of information. In recent decades, domestic and foreign scholars have put forward a series of fault diagnosis methods, including artificial neural network[2-3], Petri net[4-5],expert system[6]and so on.

There are two main problems of the fault diagnosis for SOE(Sequence Of Events) alarm information: on the one hand, when a circuit breaker or relay protection device alerts false refusing action and error information transmission channel breaks, it will lead to alarm information missing or error diagnosis deviation; On the other hand, the alarm information should be dealt with after failure within a certain time interval, otherwise the fault has nothing to do with the alarm information, and it will be hard to identify the event interval[7-8].

In terms of the complexity of power grid, this method utilizes rough set theory to optimize the attributes of decision table and extract diagnosis rules, and takes advantage of Bayesian model to maximum a posterior probability of fault groups, thus getting the fault elements.

Rough Set Theory

Rough set theory is a kind of new mathematical tools to deal with uncertain and imprecise problems, and the most significant characteristic of it needs to provide no prior information out of data collection to solve the problems, such as the required prior probability in statistics and the membership degree of fuzzy focus, which can effectively analyze and deal with imprecise and incomplete data and then discover the implicit knowledge, reveal the potential regularity[9].

In rough set, we define quad $IS = (U, Q, V, F)$ as a decision table. U is the theory field, and Q is the set of properties, which is composed of condition attribute C and decision attribute D, while $C \cap D = \Phi$, $C \cup D = Q$. V is the attributes domain set, and V is equal to $\bigcup_{q \subset Q} V_q$ while V_q is the range of values of q. $f: U \times Q \to V$ is the function of decision table.

Rough set theory describes the characteristics of objects by a two-dimensional decision table. According to the decision table formed by existing data, it uses the knowledge of rough set to remove redundant condition attributes, thus excluding redundant condition attributes from complex decision table and achieving the minimal condition attributes decision table[10].

After the reduction, the decision table will be an incomplete decision table, and it only contains those necessary condition attributes values in decision-making. But it has all the knowledge of original knowledge system so as to effectively simplify the knowledge and obtain minimal diagnostic rules. The specific algorithm steps could be considered in the references[11].

Bayesian Theory

If the event A_1, A_2,..., and A_n are incompatible, and these events are inevitable events, that is, $A_1 + A_2 + ... + A_n = U$ (inevitable events). All events should satisfy:

$$P(B) = \sum_{i=1}^{n} P(A_i)P(B \mid A_i) \quad (1)$$

This is the so-called probability formula.

According to the conditional probability formula, we could deduce that:

$$P(A_i \mid B) = \frac{P(A_i)P(B \mid A_i)}{P(B)} \quad (2)$$

$$P(B)P(A_i \mid B) = P(A_i)P(B \mid A_i) \quad (3)$$

$$P(A_i \mid B) = \frac{P(A_i) \mid P(B \mid A_i)}{\sum_{i=1}^{n} P(A_i)P(B \mid A_i)} \quad (4)$$

The physical meaning of the Bayesian formula is that test event B always occur at the same time with one of all the incompatible events. If we have already known the probability $P(A_i)$ of an event A_i before the test and the conditional probability $P(B \mid A_i)$ (i is equal to 1, 2,..., n) after a test event B happens, we need to calculate the probability of each event like A_1, A_2,...,A_n.

Bayesian network is a directed cyclic graph, in which each node represents a random variable, and the edge between nodes represents the direct dependency relationship between variables. Each node is attached with a probability distribution, while root node is attached with a marginal distribution and the non root node is attached with conditional probability distribution. Joint probability distribution of decomposition can reduce the complexity of the probability model, while the introduction of the Bayesian network did not further reduce the complexity, so Bayesian network is straightforward and easy modeling.

In Bayesian network, the node without directed arc input is called root node, which should be determined the prior probability; the node with directed arc input is called child node, and the the node with directed arc output is called parent node. For each child node the conditional probability under different status of the parent node should be determined.

The connection of a certain power grid system is shown in figure 1, including four regions:*Sec1*, *Sec2*, *Sec3*, *Sec4*, *A*, *B* and *C* represent for bus lines. *CB1*, *CB2*, *CB3*, *CB4*, *CB5* and *CB6* represent for circuit breakers. A_p, B_p and C_p respectively represent for bus protectors.

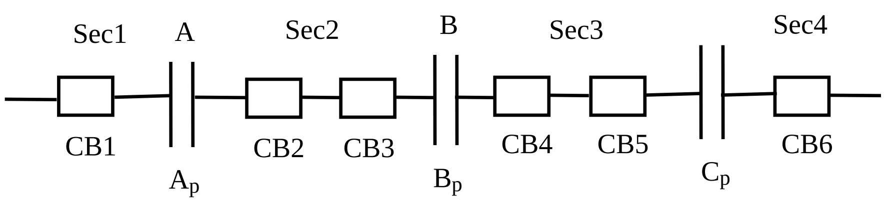

Fig.1. A Certain Power Grid

Learning from the definition of Bayesian network, we can get the Bayesian network model of the fault zone. The collection of various nodes F is equal to {*CB1* and *CB2*, *CB3*, *CB4*, *CB5*, *CB6*, *A*, *B*, *C*}. The collection of alert protection information D is equal to {*CO1* and *CO2*, *CO3*, *CO4*, *CO5*, *CO6*, A_p, B_p, C_p}. Collection E represents for the casual relationship of alarm information after element fault protection. So we can get the Bayesian network model of power grid of figure 1, which is shown in figure 2.

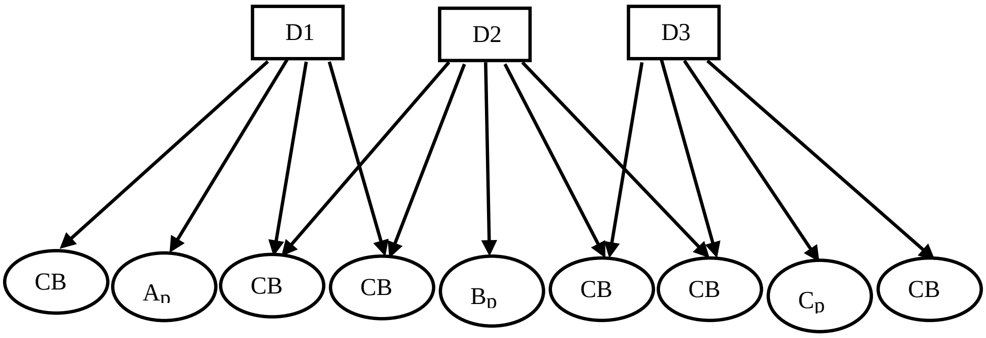

Fig.2. Bayesian Network Model

Probability Calculation of Fault Hypothesis

We use H to represent for fault hypothesis, and it contains possible combinations of all the suspicious fault components. To find out which group state of suspicious components has the maximum posterior probability to explain the protection action information.

$$Bel(H_1) = \max \alpha \prod_j \lambda(D_j | F, K) \prod_{i:F_i=F_i^+} \pi_i \prod_{i:F_i=F_i^-} (1-\pi_i) \tag{5}$$

The a in the formula is a normalization constant. $\lambda(D_j|F,K)$ is the credibility of the observed protection behavior D_j under the condition of given fault hypothesis H_1 and all switch behaviors. $\prod_{i:F_i=F_i^+} \pi_i$ is the prior probability of all the failure element sets of Fault hypothesis H_1; $\prod_{i:F_i=F_i^-} (1-\pi_i)$ is prior probability of no failure element sets of Fault hypothesis H_1[12];

Analysis of Example

Utilizing the proposed method, author makes experiments to analyze the example with the tool of Java and Matlab. In the figure 3 of local power grid, there are 2 bus lines, 4 transformer, 4 circuits and 3 power areas. In the local power grid, bus differential protection (*BR1*,*BR2*) is the main bus protection. Current protection (*OR1*,*OR2*,*OR3*) is the backup protection of bus. Distance protection (*DR1, DR2*, *DR3*, *DR4*) is the protection of line *L1* and line *L2*. Current protection (*OR6*, *OR7*) is the protection of line *L3* and line *L4*. Transformer differential protection (*TR1*, *TR2*) is the main protection of transformer *T1* and transformer *T2*. Current protection (*OR2*, *OR3*, *OR4, OR5*) is the backup protection of *T1* and *T2*. Transformer current protection (*TR3*, *TR4*) is the main protection of transformer *T3* and transformer *T4; CB* represents for circuit breakers.

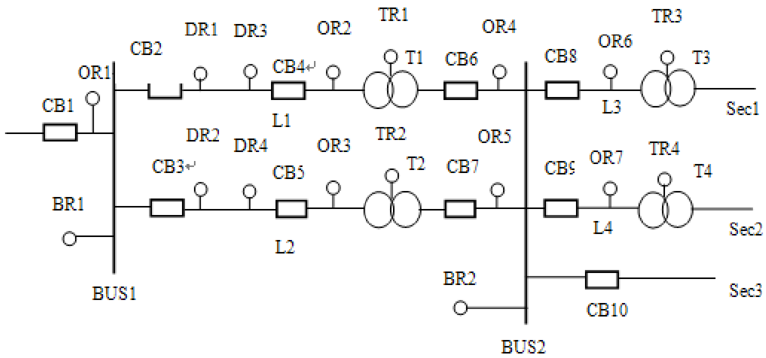

Fig.3. Local Power Grid Diagram

According to the algorithm of attribute reduction based on differential matrix put forward by Skowron[13], we can get the reduction decision table of all kinds of faults.

According to the 2009 protection action times[14], we can count the prior probability and use the formula of fault hypothesis to get the failure elements with the failure probability .

Preset the fault location and get the results of the diagnosis as shown in table 1 according to the fault information. When the fault information is missing or not the core attribute (such as sample 3, 6), we can get the correct diagnosis (the probability of the location of the assumed failure diagnosis is also high); When part of the core attribute information is missing or something goes wrong (sample 2), we can still get the correct diagnosis (the probability of the location of the assumed failure diagnosis is not very high); When the core attribute information is lost and other attributes information is right (sample 5,7,9), we can also get the right diagnosis (the probability of the location of the assumed failure diagnosis is low, but the failure probability of it ranks high); When some faults information is missing or wrong(sample 8), the diagnosis of fault zone with the highest probability is not the assumed fault area, but the probability of assumed fault zone is generally in the top few, thus achieving the purpose of providing the dispatcher with auxiliary decision-making.

Table.1. Power Grid Fault Diagnosis Result

No	Assumed location	OR1	OR2	OR3	OR6	OR7	OR8	DR3	DR4	TR1	TR2	TR3	TR4	BR1	BR2	Fault Location Possibility
1	Bus1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	Bus1 0.819 NO 0.096
2	Bus1	0	0	*	*	*	0	0	0	0	0	0	0	1	0	Bus1 0.669 NO 0.079 L3 0.079 L4 0.079
3	L2	1	0	0	0	0	0	0	1	0	0	0	0	0	1	L2 0.783 Bus1 0.104
4	L2	0	0	0	0	0	0	0	*	0	0	0	0	0	*	L2 0.238 NO 0.238 Bus1 0.119 Bus2 0.119 T1 0.119 T2 0.119
5	T1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	T1 0.820 NO 0.096
6	T1	0	1	0	0	*	0	0	0	1	0	1	0	0	0	T1 0.794 T3/Sec1 0.171
7	T1	0	*	0	0	0	0	0	0	*	0	0	0	0	0	T1 0.423 NO 0.211 Bus1 0.106 Bus2 0.106 T2 0.106
8	T1	0	1	0	0	*	1	0	0	0	0	0	0	0	0	Sec3 0.664 T1 0.176
9	T4/Sec2	0	0	0	0	0	0	0	0	0	0	0	*	0	0	T4/Sec2 0.254 NO 0.254 Bus1 0.127 T1 0.127 T2 0.127

According to the analysis of experiment results, we can conclude that the diagnostic method can help get more reasonable results. Compared with the proposed algorithm in the references[14-16], our algorithm has the following advantages:

1. With making full use of the knowledge reduction of rough set and Bayesian network pattern classification ability, this diagnosis method is of high accuracy.
2. It uses membership function to deal with the relationship between protection and elements, which dynamically expresses the process of "element fault-protection action-breaker trip-cut off the connection between the fault components and protection".
3. Use the method of Bayesian theorem to calculate the probability of diagnosis results. It enables to give the most likely failure location.

Conclusion

This paper proposes a power grid fault diagnosis method based on Bayesian network and rough set. In view of the complexity of power grid, it has strong adaptability and flexibility. Due to the combination of rough set theory and Bayesian network, this method deeply excavates alarm information knowledge. And it uses probability to analyze the wrong protection action, thus improving the diagnosis accuracy of this method under the condition of error and missing of fault alarm information. Examples show that this method has the ability to process the uncertainty of power grid fault diagnosis problems in time and space, thus improving the accuracy.

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