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Substation Fault Diagnosis Based on Rough Sets and Grey Relational Analysis

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Abstract

As the 750kV substation has the characteristics like incomplete information, uncertain diagnosis result and dual protection configuration, a fault diagnosis method of substation with redundant protection configuration based on rough sets and grey relational analysis is proposed. In this method, the diagnosis decision table which takes advantage of information about wave-recording devices and two protective devices is constructed and simplified, and the minimal reduction can be obtained by using knowledge acquisition method based on rough set; Based on the point, the comparative sequence and reference sequence is established. Through the use of grey relational analysis, the grey relational grade of attributes and failure rate of suspicious fault components is determined in the reduction table, and furthermore obtain a certain diagnosis result. The result shows that the proposed method is effective.

***Keywords**: 750kV substation, redundant protection, fault diagnosis, rough sets, gray relational analysis*

1. Introduction

The 750kV grid is an important delivery channel of wind and solar power in Gansu and Xinjiang, the safety and reliability of substation is of great significance to ensure its stable operation. That grid [1-2] uses dual protection configuration and two protective devices are in parallel operation and redundant, in which the 750kV substation plays an important role and includes 750kV, 330kV and 66kV line. Once a fault occurs, huge alarm information resulted from the complexity of line is sent to control center. So it is very necessary for an operator to detect the fault quickly and accurately, locate and recover it. Hence, it is very important to study fault diagnosis system of substation.

Consequently, various fault diagnosis methods [3-6] are proposed by foreign and domestic scholars like bayesian, fuzzy theory, petri nets, and neural networks. These methods have their own characteristics and have been used as well, but mostly can not get a satisfying result with incomplete information. Therefore, some methods to deal with incomplete information effectively have been applied to grid fault diagnosis in recent years, like grey relational analysis and rough sets. In transformer fault diagnosis, the grey relational analysis (GRA) [7-8] has been used, which can dig out the fault information of oil gas by means of statistical methods. While in [9] the diagnosis model based on rough set (RS) has been proposed, which can deal with incomplete information better and use the reductions and rules to detect the fault. Afterforward, a method [10] combined rough sets with graph theory has been put forward, in which the use of fault decision diagrams and its adjacency matrix can identify the core attributes of decision table quickly. However, there are still some limitations: 1) it exist incomplete fault-information; 2) it also can not obtain a certain diagnosis result.

Based on the point, a method combined rough sets with grey relational analysis is proposed. It takes advantage of information about wave-recording devices and two protective devices and can obtain the minimal reduction by using knowledge acquisition method based on rough set. Through the use of grey relational analysis, the grey relational grade of attributes and failure rate of suspicious fault components is determined in the reduction table, and furthermore obtain a certain diagnosis result.

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2. Rough Sets and Grey Relational Analysis

2.1. Rough Sets

Rough sets [11] can deal with imprecise, inconsistent and incomplete information effectively, even discover a potential relationship in data and get useful knowledge in order to obtain a brief expression obout knowledge, known as information systems which is represented by $S = \langle U, A, V, f \rangle$. Where U is a non-empty finite set of objects called universe. A is a non-empty finite set of attributes, $A = C \cup D$, where C is the condition attribute and D is the decision attribute. $V = \underset{a \in A}{U} V_a$ for any $a \in A$, V is set of attribute value and V_a is called the domain of attribute a. $f : U \times A \to V$, where f is an information function and is given information value to each attributes of each objects. The attribute-value table is called the decision table. In which all condition attributes are not necessary, but are redundant and removing these attributes will not affect the original decision-making ability. So the redundant condition attributes will be removed through the reduction so as to achieve knowledge simplified.

2.2. Grey Relational Analysis

Definition 1. $X_0 = (x_0(i) \mid i = 1, 2, \cdots, m)$ denotes the reference sequence. $X_j = (x_j(i) \mid i = 1, 2, \cdots, m; j = 1, 2, \cdots, n)$ is the *comparative sequence.* And $\gamma(X_0, X_j)$ denotes the grey relational grade and can be expressed as:

$$\gamma(X_0, X_j) = \frac{1}{m} \sum_{i=1}^{m} \gamma(x_0(i), x_j(i)) \tag{1}$$

Where $\gamma(x_0(i), x_j(i))$ is the grey relational coefficient.

Definition 2. P_j is the failure rate of suspicious fault components in decision attribute. p_i denotes the failure rate of condition attribute with respect to decision attribute. $p_i \in P_j, (i = 1, 2, \cdots, m)$, and can be expressed as:

$$p_i = \frac{\gamma(x_0(i), x_j(i)}{\sum_{i=1}^{n} \gamma(X_0, X_j)} \tag{2}$$

$$P_j = \sum_{i=1}^{m} p_i \tag{3}$$

3. The Fault Diagnosis Method Based on Rough sets and Grey Relational Analysis

In this method, it takes advantage of information about wave-recording devices and two protective devices and the redundant information of decision table is removed. Consequently the minimal reduction can be obtained by using knowledge acquisition method based on rough set. Afterward, the grey relational grade of attributes and failure rate of suspicious fault components is determined in the reduction table by using grey relational analysis, and furthermore obtain a certain diagnosis result. The method which combines rough sets with grey relational analysis is on the base of the integrated view to deal with incomplete and uncertain information, and furthermore obtain a certain diagnosis result.

3.1. Knowledge Acquisition Based on RS

3.1.1. Decision Table Constructed

A. The discretization of continuous attributes

The discretization of continuous attributes [13] is that sets several discrete points in a specific domain and the domain of attribute is divided into a few discrete intervals. And then the attribute-value of each interval is represented by the different symbols or integer values. Figure

2 shows fault voltage waveforms of 750kV wusheng substation. In figure, mutation positions of high voltage side U_n of the second main transformer are considered as discrete points of continuous attributes. Therefore, the domain of attributes is divided into three discrete intervals, like premutation, mutation and mutation recovered. In which "0" represents the attribute-value of premutation and mutation recovered, while "1" is the attribute-value of mutation.

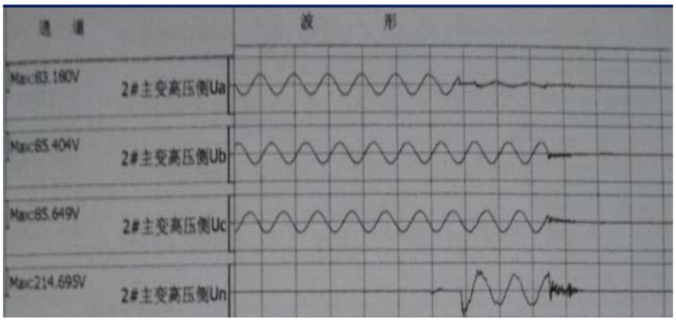

Figure 1. The Wave-recorded Information of 750kV Wusheng Substation

B. Decision table

The protective configurations of 750kV substation are as follws: the line protection uses an integral dual-configuration in the main and backup protection; the breaker failure protection is provided by its auxiliary protection devices; the remote trip protection uses an integral dual-configuration; the bus protection uses dual-configuration. The local connection scheme of 750kV WuSheng substation shows is shown in Figure 2 and the components is shown in Table 1, including two lines, two buses, three circuit breakers and fifteen protective devices that consist of four line protective devices, four bus protective devices, three breaker auxiliary protective devices and four remote trip protective devices. Therefore, the acted information of protection and breaker and the discretized wave-recorded information are considered as condition attributes, while the suspicious fault components is consided as decision attributes. In addition, the decision table which considers the action principle of protection and the fault samples is determined as shown in Table 2. Where “1” denotes that the breaker is opened or the protection operates and “0” indicates that the breaker is closed or the protection does not operates. The subscripts 1 and 2 are the first and second protection of components. And FR is wave-recording devices.

Table 1. The Component

The name of Components	The symbol
Wugu No. 2 line	L1
Wuhai No. 1 line	L2
Circuit breaker	CB3371、CB3370、CB3372
330kV No. 3 bus	B3
330kV No. 4 bus	B4
Wugu No. 2 line protection	$ML1_1$、$ML1_2$
Wuhai No. 1 line protection	$ML2_1$、$ML2_2$
Breaker auxiliary protection	A1、A0、A2
330kV No. 3 bus protection	$MB3_1$、$MB3_2$
330kV No. 4 bus protection	$MB4_1$、$MB4_1$
Wugu No. 2 line remote trip protection	$RL1_1$、$RL1_2$
Wuhai No.1 line remote trip protection	$RL2_1$、$RL2_2$

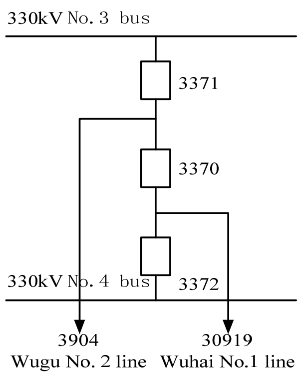

Figure 2. Local connection scheme of 750kV WuSheng substation

Table 2. The Decision Table of the Fault Diagnosis

U	$ML1_1$	$ML2_1$	$MB3_1$	$MB4_1$	$RL1_1$	$RL2_1$	A1	A0	A2	3371	3370	3372	$ML1_2$	$ML2_2$	$MB3_2$	$MB4_2$	$RL1_2$	$RL2_2$	FR	F
1	0	1	0	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	1	L2
2	0	1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	L2
3	0	0	0	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	L2
4	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	L2
5	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	L2
6	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	L2
7	1	0	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	1	L1
8	1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	L1
9	0	0	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	L1
10	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	L1
11	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	L1
12	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0	L1
13	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	B3
14	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	B3
15	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	B3
16	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	B3
17	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	B3
18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	B3
19	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	B4
20	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	B4
21	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	B4
22	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	B4
23	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	B4
24	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	B4

3.1.2. Attribute Reduction of Decision Table

The Attribute Reduction [14-16] is to get rid of unnecessary condition attributes in decision table and remains the same of knowledge representation and classification ability. Through ROSE reduction tool Based on heuristic reduction algorithm, the minimum attributes reduction set {CB3370, CB3372} can be obtained. Then each attribute of the reduction is consider as a data unit and the uncertainty of this data unit can be expressed as:

$$\rho = \frac{\text{The number of the same value of a data unit}}{\text{The total number of attribute values of a data units}} \quad (4)$$

According to Equation (4), calculate the uncertainty of each data unit. And the reduction and the uncertainty of the minimum attributes are shown in Table 3.

Table 3. The Reduction and the Uncertainty of the Minimum Attributes

U	3370 The value of attribute	The uncertainty of attrbute	3372 The value of attribute	The uncertainty of attrbute	F
1	1	0.5	1	0.5	L2
2	1	0.5	1	0.5	L2
3	1	0.5	1	0.5	L2
4	1	0.5	1	0.5	L2
5	1	0.5	1	0.5	L2
6	1	0.5	1	0.5	L2
7	1	0.5	0	0	L1
8	1	0.5	0	0	L1
9	1	0.5	0	0	L1
10	1	0.5	0	0	L1
11	1	0.5	0	0	L1
12	1	0.5	0	0	L1
13	0	0	0	0	B3
14	0	0	0	0	B3
15	0	0	0	0	B3
16	0	0	0	0	B3
17	0	0	0	0	B3
18	0	0	0	0	B3
19	0	0	1	0.5	B4
20	0	0	1	0.5	B4
21	0	0	1	0.5	B4
22	0	0	1	0.5	B4
23	0	0	1	0.5	B4
24	0	0	1	0.5	B4

3.2. Fault Diagnosis Based on Grey Relational Analysis

3.2.1. The Comparative Sequence and Reference Sequence

On the Basis of the number of the fault components in decision attributes, the data in Table 3 can be invided into four boxes. Like the first box is {1, 2, 3, 4, 5, 6}, the second is {7, 8, 9, 10, 11, 12}, the third is {13, 14, 15, 16, 17, 18}, and the fourth is {19, 20, 21, 22, 23, 24}. Select the largest uncertainty of boxes to be reference sequence and then obtain $X_0=(0.5,0.5)$. Calculate the boxes data by using the mean value method and can be obtained comparative sequence which can be expressed as:

$$X_i=\begin{pmatrix}0.5 & 0.5\\ 0.5 & 0\\ 0 & 0\\ 0 & 0.5\end{pmatrix}$$

3.2.2. Calculation grey relational grade [17-18]

According to Equation (1), calculate the grey relational grade of comparative sequence and reference sequence, in which the grey relational coefficient can be expressed as:

$$\gamma(x_0(i),x_j(i))=\frac{\min\limits_j\min\limits_i|x_0(i)-x_j(i)|+\zeta\max\limits_j\max\limits_i|x_0(i)-x_j(i)|}{|x_0(i)-x_j(i)|+\zeta\max\limits_j\max\limits_i|x_0(i)-x_j(i)|} \quad (5)$$

Where $|x_0(i)-x_j(i)|$ is the absolute difference between $x_0(i)$ and $x_j(i)$ at the point i, $\min\limits_j\min\limits_i|x_0(i)-x_j(i)|$ is the smallest difference, $\max\limits_j\max\limits_i|x_0(i)-x_j(i)|$ is the biggest difference, and ζ is the recognition coefficient, $\zeta\in[0,1]$. When ζ=0.5, the error is the smallest, so it takes 0.5.

4. Results and Discussion

Case: When a fault occurred on Wuhai No. 1 line, the first and second protection operate, the auxiliary protection of 3372 and 3370 breaker operates, and 3372, 3370 breaker trip. Through calculation, 0.75, 0.5, 0.25 and 0.5 are the failure rate of suspicious fault components in decision attribute respectively, like Wuhai No. 1 line, Wugu No. 2 line, 330kV No. 3 bus and 330kV No. 4 bus. In which Wuhai No. 1 line is the actual fault component and is consistent with the case results. Compared with the diagnosis method based on rough sets, the result is shown in Table 4. It is demonstrated that the proposed method not only takes advantage of information about wave-recording devices and two protective devices, but also obtain a certain diagnosis result.

Table 4. The Comparative Result of the Different Diagnosis Methods

The dignosis methods	The dignosis resluts
RS	Wuhai No. 1 line, Wugu No. 2 line, 330kV No. 4 bus
RS+GRA	Wuhai No. 1 line

5. Conclusion

As the 750kV substation has the characteristics like incomplete information, uncertain diagnosis result and dual protection configuration, a fault diagnosis method of substation with redundant protection configuration based on rough sets and grey relational analysis is proposed. The method which combines rough sets with grey relational analysis is on the base of the integrated view to deal with incomplete and uncertain information. In this method, it takes advantage of information about wave-recording devices and two protective devices and the minimal reduction can be obtained through rough set. Afterward, the grey relational grade of attributes is determined and the failure rate of suspicious fault components can be obtained in the reduction table by using grey relational analysis. The result shows that the proposed method is effective.

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