

## Transformer Fault diagnosing method based on Extenics and Rough Set theory

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### Abstract

*Extenics and rough set theory are brought into transformer fault diagnosing procedure in this paper to get rid of abundant information data and to obtain more precise diagnosing result. Using the dissolved gas data as fault diagnosing attribution set, attributions which are needed for transformer fault diagnosis are predigested and preliminarily grouped by means of rough set method, and then matter element model for transformer's fault diagnosing is built. With the transformer's standard fault modes as the transformer's fault diagnosing decision set, utilizing extenics association function to calculate each fault degree, acceptance and rejection rule is defined to diagnose transformer's fault. 76 dissolved gas information data have been collected to verify the method proposed in this paper, the diagnosing results show that the correctness of diagnosing results got by this method is better than frequently used IEC three ratio methods.*

**Keywords:** *transformer, fault diagnosis, extenics, matter element model, rough set*

### 1. Introduction

Electric transformer is one of the main equipment of electric power grid; faults caused by transformer will bring about tremendous economic loss. Safely operation of transformer is a prerequisite for maintaining safety and reliability of power grid operation. The online fault diagnosing and monitoring technologies of transformer always gets great academic interests of researchers in recent years, by now the commonly employed technologies include Partial discharge method, dielectric loss testing method and Oil chromatographic analysis method [1-2] in which chromatographic analysis method is the most popular one. Because the dissolved gas in transformer oil does not bring fault part location information with it, compositive diagnosing methods which combine resolved gas analysis and analysis of other transformer electric testing data are employed to obtain more precise diagnosing result. Many intelligent data analyzing technologies are applied in processing fault information data because of their advantages in data processing. In [3], a novel fuzzy logic approach is adopted to develop a computer based intelligent interpretation of transformer faults. A multi-level decision making model for power transformer fault diagnosis based on Support Vector machine is proposed in [4]. In [5], degree of area incidence is proposed

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to diagnose transformer insulation fault. The parsimonious covering theory integrated with probability and fuzzy technique is applied to analyze power transformer malfunctions in [6]. A method of Fuzzy Petri Nets knowledge representation and its rigorous inference algorithm are proposed and applied in transformer fault diagnosing in [7]. Many fault data being processed are reduplicated and are useless for fault diagnosing, this problem has been noticed by some researchers. In [9], a new transformer fault diagnosis method based on rough sets theory and Bayesian network is presented according to complementary strategy. Based on matter-element theory in extension theory, a matter-element model is established for qualitatively describing the fault diagnosis problem of power transformer. Then, the degree of relation of tested power transformer with the faulted characteristic is calculated using the extended relation. In [10], a transformer fault diagnosing method is proposed based on rough set theory model; diagnosing rules are obtained by rough set attribution reduction. Similar efforts based on rough set theory can be observed in [11-15].

The objective of this paper is to improve transformer fault diagnosing technique by employing advanced data mining technologies to get rid of useless information data before diagnosing result is obtained and in the same time make the diagnosing results to be more precise. Based on matter element model of transformer, a new diagnosing method using rough set attribute reduction method to reduce attribution of element is proposed in this paper, in which the fault degree is calculated using Correlation function of extension theory and rule of acceptance and rejection is defined to diagnose transformer fault. Transformer fault diagnosing by this method not only does not affect diagnosing precision, instead it reduces diagnosing difficulty and speeds up diagnosing procedure. This paper is organized as follows. Section 2 introduces the basic theory of method proposed, Section 3 introduces the attribution predigesting approach and in Section 4, extenics diagnosing procedure is explained. In Section 5, several results obtained by using diagnosing method presented in this paper are listed.

## **2. Basic Theory of Transformer Fault Diagnosing based on Extenics and Attribute Predigesting of Rough Set**

How to obtain fault diagnosis result by analyzing data obtained from dissolved gas in transformer oil is an important researching field in transformer fault diagnosing. IEC three ratio methods is the most frequently applied method in actual work, and there exists no coding problem when it is employed to deal with some faults. Extenics theory is employed to analyze data from dissolved gas to diagnose transformer fault in this paper, the no coding problem can be avoided when this method is applied.

Because there exist many transformer fault modes and check testing data, and the check testing data cannot match fault modes completely, not all the testing data are needed before diagnosing. So attribution predigesting process by the means of rough set method can be applied to reduce and group testing data, the predigested data will not cause the information shortage problem when the transformer faults are diagnosed because the attribution core set which represents the cause of failure is preserved. The predigesting process eliminates useless information and information which causes confusion in the procedure of transformer fault diagnosing, speeds up diagnosing procedure and in some times avoids error diagnosis.

After the attribution reduction process, the element model of transformer is built. Using the gas content defined by [1] as base value, the content of each type of gases can be reverse deducted by employing IEC three ratio method. Referring to gas content

scopes proposed by published papers, classical domain of element model is determined. Using extennics corresponding function, the diagnosing results about the fault type of transformer and fault degree can be determined.

### 3. Attribution Predigesting based on Rough Set Theory

There are two ways to realize rough set attribution predigesting:

- ① calculate the dependency levels of one subset to another subset, use the error of these dependency levels as indicator to the importance level.
- ② calculate the equivalence relations of one subset to another subset, use the quotient of equivalence relations as indicator to the importance.

Considering the difference of predigesting results using these two methods, both of these two methods will be used to predigest attributions, and then a rule of acceptance and rejection is defined to determine the final result.

#### 3.1. Attribution Predigesting

- 1) Use the error of the dependency level as indicator to the importance level

To determine the importance level of attribution subset  $B'$  deduced from rough set attribution  $D$ , use the error of dependency levels between these two subsets to determine the importance level:

$$k(D) = r_B(D) - r_{B-B'}(D) \quad (1)$$

In which:  $B' \subseteq B$ ,  $B$  is a attribution set;  $B'$  is one sub set of attribution set;  $r_B(D)$  is dependency of  $B$  to  $D$ , the dependency calculation equation refer to [13];  $r_{B-B'}(D)$  is dependency of  $B - B'$  to  $D$ ;  $k(D)$  is value of importance level between these two attribution subsets.

- 2) Use the positive domain quotient of equivalence relations as indicator to determine importance

Build the equivalence relation between  $B$  and  $D$ , and then build the equivalence between  $B-B'$  and  $D$ , use the quotient of equivalence relations to determine the importance level of these two subsets:

$$n(D) = \frac{pos_{B-B'}(D)}{pos_B(D)} \quad (2)$$

In which:  $pos_B(D)$  is equivalence relation of  $B$  to  $D$ ;  $pos_{B-B'}(D)$  is equivalence relation of  $B - B'$  to  $D$ ;  $n(D)$  is importance level value.

#### 3.2. Accepting and Rejecting the Predigested Results

There may be two different predigesting results by using two methods referred in 3.1, a rule of acceptance and rejection is defined here.

Fault attributions before and after predigesting is shown in Table 1. Using predigesting methods proposed in 3.1 to predigest attributions of fault element set, importance level  $k_1(D)$  and  $k_2(D)$  are calculated, and two new fault attribution element Tables is formed as  $y'_{ij}(n_1)$  and  $y'_{ij}(n_2)$ , in which  $n_1$  and  $n_2$  is number of predigested conditions of  $y'_{ij}(n_1)$  and  $y'_{ij}(n_2)$ . Because  $n_1$  cannot be equal with  $n_2$ , a rule is defined to get a new fault element set attribution table  $Y'_{ij}(n)$ :

if  $n_1 > n_2$  then  $Y'_{ij}(n) = y'_{ij}(n_1)$   
 else if  $n_1 < n_2$  then  $Y'_{ij}(n) = y'_{ij}(n_2)$   
 else then  $Y'_{ij}(n) = y'_{ij}(n_1) = y'_{ij}(n_2)$

Neglect the conditions which have different attributions but the same number of attributions in two methods, because both the two methods predigest attributions rely on core attribution set, that is to say the core set used in both methods is the same core set, then other attributions must be auxiliary attributions and will have little influence to this type of fault. The fault element set selected according to this rule can satisfy requirement of transformer fault diagnosis completely.

#### 4. Extenics Fault Diagnosing

The procedure of extenics fault diagnosis is listed below:

- 1) Build the fault characteristic element of equipment
- 2) Build the condition element of equipment
- 3) Calculate the correlation function
- 4) Determine the weight coefficient
- 5) Calculate the possibility of occurrence of faults
- 6) Define the acceptance and rejection rule of fault and determine the fault

**Table 1. The Fault Attribution and its Reduction**

Before predigesting		after predigesting		
Fault type	Attribution set	Fault type	Attribution set of method 1	Attribution set of method 2
Overheating	CH <sub>4</sub>	Overheating	/	/
	C <sub>2</sub> H <sub>2</sub>		C <sub>2</sub> H <sub>2</sub>	C <sub>2</sub> H <sub>2</sub>
	C <sub>2</sub> H <sub>4</sub>		C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>
	C <sub>2</sub> H <sub>6</sub>		C <sub>2</sub> H <sub>6</sub>	C <sub>2</sub> H <sub>6</sub>
	H <sub>2</sub>		/	/
	CO <sub>2</sub>		/	/
	CO		/	/
	Totalhydrocarbon content		/	/

The weight coefficient in Step 4 is often been chosen according to experience of experts, considering the subjectivity of experts experience, rule of determining weight coefficient is modified in this paper.

##### 4.1. Determine the Weight Coefficient

Experts experience and probability of samples of fault is combined to determine the weight coefficient of probability of equipment fault, that is to reweight the experts experience using the percentage of the number of one type of fault in samples to all the number of samples of fault, the weight coefficient determined in this way avoids subjectivity of experts experience and in the same time avoids the inaccurate problem caused by insufficient of samples. The detail is listed below:

Use fault  $Y_1$  as example, the number of collected samples of transformer is  $m$ , in which number of fault caused by condition  $X_j$  is  $s_j$ , then preliminary weight coefficient can be:

$$\beta_j = \frac{s_j}{m} \quad (3)$$

The importance degree determined by experts experiences and professional knowledge are:  $\alpha_j$  ( $j=1,2,\dots,n$ ), and  $0 \leq \alpha_j \leq 1$ .

Then the final weight coefficient belongs to fault  $Y_1$  is:

$$\alpha'_j = \frac{\alpha_j \beta_j}{\sum_{j=1}^n \alpha_j \beta_j} \quad (4)$$

#### 4.1. Fault Diagnosing of Transformer using Association Function of Extenics and Attribution Predigesting of Rough Set Theory

1). Assume the number of fault equipment is  $N$ , if the fault of  $N$  is  $I_i$ , it can be represents as  $I_i(N)$ , ( $i=1,2,\dots,N$ ), and the character element set:

$$\{M\} = \{M_{ij}, i = 1, 2, \dots, N; j = 1, 2, \dots, k_i\} \quad (5)$$

$$M_{ij} = (C_{ij}, V_{ij}), (i = 1, 2, \dots, N) \quad (6)$$

$$V_{ij} = \langle a_{ij}, b_{ij} \rangle \quad (7)$$

$$V'_{ij} = \langle a'_{ij}, b'_{ij} \rangle \quad (8)$$

In which:  $V_{ij}$  is classical domain<sup>[9]</sup> when fault  $I_i(N)$  is happen, and  $V'_{ij}$  is section field about  $C_{ij}$ ;  $a_{ij}$  and  $b_{ij}$  are upper and lower limits of  $C_{ij}$ ;  $a'_{ij}$  and  $b'_{ij}$  are extension upper and lower limits.

2) Build the element set  $R_{ij}$  which describes the possible failure equipment  $N$

$$R_{ij} = \begin{bmatrix} I_i(N) & C_{i1} & V_{i1} \\ & \vdots & \vdots \\ & C_{ik_i} & V_{ik_i} \end{bmatrix} \quad (i = 1, 2, \dots, N) \quad (9)$$

3) Build the element set  $R_{ij}$  which describes the condition of equipment  $N$

$$R = \begin{bmatrix} I_i(N) & C_{i1} & v_{i1} \\ & \vdots & \vdots \\ & C_{ik_i} & v_{ik_i} \end{bmatrix} \quad (i=1,2,\dots,N) \quad (10)$$

4) Extract attribution set  $V_{ij}$  and fault element set  $M_{ij}$  to form attribution table  $y_{ij}(n)$ . Use the predigesting methods referred before to reduce fault element attribution Table and form new fault element attribution set  $Y'_{ij}(n)$ .

5) Substitute the attribution conditions of  $Y'_{ij}(n)$  into  $R_{ij}$  to form new possible failure element set  $R'_{ij}$ .

$$R'_{ij} = \begin{bmatrix} I_i(N) & C_{i1} & V_{i1} \\ & \vdots & \vdots \\ & C_{in_i} & V_{in_i} \end{bmatrix} \quad (i = 1, 2, \dots, N) \quad (11)$$

For the same reason:

$$R' = \begin{bmatrix} I_i(N) & C_{i1} & v_{i1} \\ & \vdots & \vdots \\ & C_{in_i} & v_{in_i} \end{bmatrix} \quad (i = 1, 2, \dots, N) \quad (12)$$

6) Calculate the correlation function value

$$K_{ij}(v_{ij}) = \frac{\rho(v_{ij}, V_{ij})}{\rho(v_{ij}, V'_{ij}) - \rho(v_{ij}, V_{ij})} \quad (13)$$

When  $\rho(v_{ij}, V'_{ij}) - \rho(v_{ij}, V_{ij}) = 0$  :

$$K_{ij}(v_{ij}) = \frac{\rho(v_{ij}, V_{ij})}{|V_{ij}|} \quad (14)$$

In which:

$$\rho(v_{ij}, V_{ij}) = |v_{ij} - 0.5(a_{ij} + b_{ij})| - 0.5(b_{ij} - a_{ij}) \quad (15)$$

7) Determine the weight coefficient

Method of determine the weight coefficient is described is Section 4.1.

8) Calculate the fault degree of faults

$$\lambda[I_i(N)] = \sum_{j=1}^{n_i} \alpha'_{ij} K_{ij}(v_{ij}) \quad (i=1, 2, \dots, N) \quad (16)$$

9) Determine the type of faults

Standardize faults degree [9]:

$$\lambda'[i] = \frac{2\lambda[I_i(N)] - \lambda_{\max} - \lambda_{\min}}{\lambda_{\max} - \lambda_{\min}} \quad (i=1, 2, \dots, N) \quad (17)$$

let  $\mu$  as error between arrangement in descending powers and  $\lambda'_2$ , then

$$\mu = \frac{\lambda'_1 - \lambda'_2}{\lambda'_1} \times 100 \% \quad (18)$$

Because the occasion of having triple fault in transformer is very rare, only double fault is considered. Arrange  $\lambda'$  in descending powers, assume  $\lambda_b$  as the final determined transformer fault type,  $\lambda'_m$  is the first element if the array, the fault determining rule is:

if  $\lambda'_m \leq 0$  then  $\lambda_b = 0$

else if  $\lambda'_m > 0$  &&  $\mu > 5\%$  then  $\lambda_b = \lambda'_m$

else if  $\lambda'_m > 0$  &&  $\mu < 5\%$  then ( $\lambda_b = \lambda'_m$  &&  $\lambda_b = \lambda'_{m-1}$ )

## 5. Calculation Example

A main transformer in a 220kV substation in a city of Yunnan province in China is chosen as fault diagnosing example, according to check testing data collected from years 2004~2006, the preliminary fault attribution set and diagnosing results set is listed in Table 2.

**Table 2. The Primary Fault Attributes Set and Decision Set**

Attribution set					Diagnosing result set		
num	Testing data	06 data	05 data	04 data	num	fault	Preliminary diagnosed fault
1	CH <sub>4</sub>	83.79	14.56	35.69	1	normal	normal
2	C <sub>2</sub> H <sub>2</sub>	162.68	0	0	2	Low temperature overheat	
3	C <sub>2</sub> H <sub>4</sub>	112.08	2.07	1.89	3	Middle temperature overheat	Overheat
4	C <sub>2</sub> H <sub>6</sub>	10.65	0.77	6.41	4	High temperature overheat	
5	H <sub>2</sub>	441.07	11.65	54.54	5	Low energy discharge	
6	CO <sub>2</sub>	1499.35	1282.93	2882.6	6	Low energy discharge	discharge
7	CO	766.11	438.05	1272.48	7	Low energy discharge and overheat	
8	Totalhydrocarbon content	369.2	17.4	43.99	8	High energy discharge and overheat	discharge and overheat

Take the faults type in no coding ratio method as decision set in the method proposed in this paper, predigest and group attributions in each group condition, the predigested results are listed in Table. 3.

According to guideline [1], when the content of total hydrocarbon gas in the transformer oil exceeds 150 $\mu$ L/L or the content of C<sub>2</sub>H<sub>2</sub> gas exceeds 50 $\mu$ L/L or the content of H<sub>2</sub> gas exceeds 150 $\mu$ L/L, attention should to paid and tracking analysis should be Choosing the content of C<sub>2</sub>H<sub>2</sub> as base value, according to IEC three ratio method the classical domains of CH<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub> are reverse deduced. According to [1, 9, 12], the classical domains of H<sub>2</sub>, Total hydrocarbon, CO, CO<sub>2</sub> are determined. The faults 2~4 and 5~6 in Table 2 have classic domain as 8x3 metrics and faults 7~8 have classic domain as 8x6 metrics. The diagnosing results and that determined by IEC method is listed in Table 4.

**Table 3. The Correlative Attributions of Each Kind of Fault**

Fault type	Correla-tion attribut-ion	Fault type	Correla-tion attribu-tion	Fault type	Correla-tion attribu-tion
Overheat	C <sub>2</sub> H <sub>2</sub>	Discha- rge	CH <sub>4</sub>	Overheat and discharge	CH <sub>4</sub>
	C <sub>2</sub> H <sub>4</sub>		H <sub>2</sub>		H <sub>2</sub>
	C <sub>2</sub> H <sub>6</sub>		C <sub>2</sub> H <sub>2</sub>		C <sub>2</sub> H <sub>2</sub>
	CO <sub>2</sub>		/		C <sub>2</sub> H <sub>4</sub>
	/		/		CO <sub>2</sub>
	/		/		CO

**Table 4. The Diagnosis Results**

Year	Correlation degree after standardizing							Diagnosing fault mode		
	$\lambda'(I_1)$	$\lambda'(I_2)$	$\lambda'(I_3)$	$\lambda'(I_4)$	$\lambda'(I_5)$	$\lambda'(I_6)$	$\lambda'(I_7)$	$\lambda'(I_8)$	Ext-enics	IEC
04	1	-1	-0.25	-0.74	0.23	-0.15	0.47	-0.41	1	1
05	1	-0.36	-0.58	-0.14	-0.78	-0.27	-0.25	-0.18	1	1
06	-0.89	0.68	-0.45	-0.07	0.15	0.54	0.87	1	8	6

It is shown that the diagnosing result of 2006 is different by applying IEC three ration methods and method of this paper. The fault mode diagnosed using IEC method is 6, it means high energy discharge. By using method proposed in this paper, the fault mode is high energy discharge and overheating. When scheduled maintenance was implemented in 2006, by observing the appearance of fault location and data analyzing, it is determined that the fault is high energy discharge and overheating fault, which match the diagnosing result given by method proposed by this paper.

76 dissolved gas testing data are collected and used to verify the method proposed in this paper, the diagnosing results and that got by IEC three ratio methods are listed in Table 5.

**Table 5. The Contrast of Diagnosis Results**

Number of samples			Diagnosing method	Diagnosing result			Correct percentage(%)
Single fault	Multi fault	Normal		Single fault	Multi fault	Normal	
48	4	24	Proposed method	50	10	16	89.5
187	8	0	Ext-enics method	86	88	21	86.0
187	8	0	IEC	72	0	113	69.0

It is shown that the correctness percentage of diagnosing results using method proposed in this paper is apparently higher than that by using IEC method. Also, the correctness of diagnosing result is also optimistic than that obtained by means of method proposed in [9]. The reason is that the attribution conditions used in diagnosing method is obtained from rough set reduction, not by binding attribution conditions and some kind of fault in a rigid way. Because the attribution conditions produced by different samples may be different, the predigesting method proposed in this paper will be better.

## 5. Conclusion

1) Reduce and preliminarily group the matter element attribution set and decision set using rough set method before diagnosing. In this way, confusion caused by redundant attributions can be avoided and the diagnosing procedure is sped up.

2) A transformer fault diagnosing model is built based on matter element model, and the faults occurrence degree is calculated combined with extenics correlation function, then transformer fault can be analyzed quantificationally.



3) The needing of large number of transformer faults samples is avoided by applying extenics method. By analyzing the diagnosing results of 76 transformer fault samples, the correctness of this method is verified.

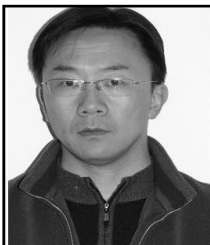
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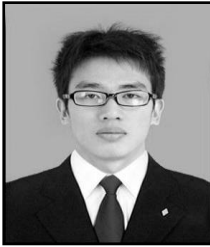
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