Diagnosing Potentially Abnormal Attribute of Power Transformers Method

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Design Method: In this paper, the program integrates those diagnostic methods from the Big data, the ANSI/IEEE C57.104 specification, and the Key gas to develop a kind of diagnostic method in power transformer. Their main diagnostic element is the insulating oil dissolved gas, which is integrated through the "correlation coefficient" and "classical detection and estimation theory". To develop a novel method diagnoses the latent abnormality attribute of the power transformer. The new method is accomplished through clever loop control, which has been validated by repeated and extensive data testing. This method is superior to the existing traditional diagnosis method in type of latent abnormality of diagnose, and has an accuracy of 90% under the verification those actual cases obtained from Research Institute of Taiwan Electric Power Company. This method is based on the MATLAB application software to execute all steps. In addition to being easy to operate and displaying the results of test in text, it not only improves the accuracy of the diagnosis of the latent abnormal attribute inside the power transformer, but also prevents the accident of blackout equipment and affects the power supply. It can to say, it is a powerful tool for electrical equipment maintenance technicians to detect.
Design Purpose: Based on this diagnostic method to improve the accuracy of the diagnosis of the latent abnormal attribute inside the power transformer by MATLAB application software.
Design Effectiveness: The program has been tested from some actual cases to improve the accuracy of diagnosis is been risen 90% up.

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1. INTRODUCTION

The power transformer plays an extremely important role in the power system; it must be shouldered to operate efficiently and safely for a long time, depends on regular inspection and maintenance. In terms of testing, it is necessary to regularly and accurately determine the concentration of each dissolved gas in the insulating oil every year, so as to detect whether there is a potential abnormality inside the transformer and immediately eliminate it to avoid accidents affecting the power supply. The so-called concentration value of each gas in the oil, these gases are the insulating oil decomposed at high temperature by a special detection instrument "Decomposition Chromatography" (AST D 3612), which can be measured as hydrogen (H_2), methane (CH_4) , ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), oxygen (O_2), nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2) and other nine gas components, of which the total flammable gas (Total Combustible Gas, TCG) is composed of H_2, C_2H_4, C_2H_2, CH_4, C_2H_6, CO and other gases.

Because of I have worked as an electrical engineer for several decades. Every year, I must to make recommendations on the inspection and analysis of the insulating oil inside the power transformer and the maintenance of related power equipment on a regular basis. So that I discovered some disadvantage from the routine. Especially, those diagnostic methods are used in insulating oil of power transformer.

There are many diagnostic methods used in the industry today, each with their own advantages and disadvantages. After reviewing each diagnostic method, In order to improve the shortcomings of the above diagnostic methods, this paper boldly applies the correlation coefficient theory and combines the ANSI/IEEE C57.104 specification to improve its lack. this paper only summarizes three representative and high-accuracy methods of insulating oil of power transformer into a novel diagnostic method.

2. LITERATURE REVIEW

References [1,2] explain the gas concentration content of insulating oil in power transformers decomposed by "Decomposition chromatography" at under high temperature. According to ANSI/IEEE C57.104 standard specification, it is divided into four types: normal, abnormal, attention and danger. The grade range is used to determine the interval of oil quality. References [3-5] describe various diagnostic methods and introduce the advantages of the "the key gas" diagnostic method. it is through the combination of the concentration percentages of each gas in the six kinds of oil, the attribute of the latent faults inside the power transformer can be judged . Reference [6-10] describes the diagnostic techniques used by MATLAB application software. References [11,12] describe the theory of correlation coefficients, especially introduction how to applicate in mathematical. Reference [13] describes that two sets of normal and abnormal detection data are obtained from big data information, and then a "threshold value" is obtained by using the "classic detection and estimation theory" after comparing the correlation coefficient, which is used as a base for judging either normal or abnormal status. The information data provided in [14,15] described the key management for using the WBAN Security to encryption and decryption, because which are too theoretical and belong to the communication system, that are not suitable this paper in low frequency of power system. Reference [16] describes the comparison between the manufacturer's equipment testing data and the photos of the maintenance results. The above tedious calculations are all designed with MATLAB application software.

3. METHODS

3.1 Design Program

Continuing the above-mentioned references to select the best and save the quince, and then use the MATLAB software computer program to compile the Big data and ANSI/IEEEC57.104 and the Key gas method to design a high-precision diagnostic method. The development process steps are described as follows.

3.1.1 Correlation coefficient

The correlation coefficient is a measure used to measure the relationship between two sets of bivariate random variables. It is generally used to measure the correlation of two random variables X and Y, and its value should be between -1 and +1. The higher the positive value, the closer the correlation of the pairing, and the less the correlation is on the contrary. When discussing correlation coefficients, it is necessary to explore the covariance between two random variables. The corresponding sequence value of the number of variables are decided the behavior of similarity.

In this paper, the Pearson correlation coefficient theory is used as the basis for the calculation. The method for calculating the correlation coefficient value is as follows (Formula 1): x and y are variables, xi , yi are random variable number sequences, because this paper takes the gas concentrations in 6 kinds of dissolved gas of insolating oil for corresponding comparison, so n = 6, so the variable number sequences i = 1, 2, 3, 4, 5, 6. An example is given to illustrate the correlation coefficient value obtained by the calculation of the random variable number sequence value within its variance, as shown in Table 1.

$$\gamma_{xy} = \frac{\sum x_i y_i - \frac{(\sum x_i y_i)}{n}}{\sqrt{\sum x_i^2 - \frac{(\sum x_i)^2}{n}}\sqrt{\sum y_i^2 - \frac{(\sum y_i)^2}{n}}} \quad (1)$$

3.1.2 Diagnosis of big data

Based on six sets of data, represented by being divided for set A, B, C, D, E, and F respectively, all data were taken after decomposed by " Decomposition Chromatography. " and all data were verified with the actual maintenance status on - site, those result of data is right, they were been divided two kinds - abnormal and normal status. The data of set C is 100 pieces of normal status and set D is 1000 pieces of normal status, and E is 100 pieces of abnormal status. The set A is made up of set C add set D; the set B is made up of set E add set D; the set F is made up of set D add the test piece. The principle of Big data diagnosis is as follows: First, use the "correlation coefficient" to identify the two sets of distribution curves of 100,000 different correlation coefficient values (distribution interval -1 to +1) generated by set A and set B, and then use the "classic detection and estimation theory" derives the boundary point for the discrimination between set A (normal) and set B (abnormal), which is called "threshold value". Next, from the test data, the data is composed of six kinds of gas concentration values, such as H_2, C_2H_4, C_2H_2, CH_4, C_2H_6, CO, etc., and the data of "set F" is totaled to 1001 pieces, and the correlation coefficient is calculated to calculate the average of 1001 pieces. The value is compared with the "threshold value." [13] If it is greater than the threshold value, it means that the detected data

is abnormal (there is abnormality inside the power transformer), otherwise it is normal.

3.1.3 Diagnosis of ANSI/IEEE C57.104

From this diagnostic method, the concentration of dissolved each gas of each set is been diagnosed that the result of diagnosis is been classified into four levels: normal, abnormal, caution and dangerous. This paper takes the gas concentration content of the six oils in the "attention level" as the diagnostic basis for this program, which is also called flammable gas. The content data for this grade are as follows: H_2 (701), C_2H_4 (101), C_2H_2 (10), CH_4 (401), C_2H_6 (101), CO (571) in parts per million (ppm).

Then compare the concentration of each gas with the data of the detection set. If the concentration of any dissolved gas in the detection set is larger than the data in the ANSI/IEEE C57.104 of attention level, the equipment in the detection set is judged to be faulty, otherwise it is normal.

3.1.4 Diagnosis of the key gas

In this diagnostic method, H_2, C_2H_4, C_2H_2, CH_4, C_2H_6, and CO are taken from the gas concentrations in the above-mentioned nine gases as the basic diagnostic set, and then each gas concentrations are added up as denominator, and then the percentage of each gas is calculated out separately. Then it is divided into four different fault attributes, and the percentage of gas concentration in each of the six gases with different attributes is overheat for (H_2(1), C_2H_4(62), C_2H_2(0), CH_4(18), C_2H_6(19), CO (0)), Fig. 1, Corona for (H_2 (83), C_2H_4 (2), C_2H_2 (0), CH_4 (12), C_2H_6 (3), CO (0)),Fig. 2, Arc for (H_2 (62), C_2H_4 (2),C_2H_2 (32), CH_4 (3),C_2H_6(1),CO(0)),Fig. 3, and paper fiber overheating for (H_2 (2), C_2H_4 (1), C_2H_2 (0), CH_4 (3), C_2H_6 (2) , CO (92)), Fig. 4, etc. The diagnosis method is as follows: when the data of the detection set is calculated according to the above steps, then which is been compared with "correlation coefficient" in each fault attributes construction data. If correlation coefficient reaches 0.6, it is judged that the detection set of the equipment is in faulty. Otherwise it is normal.

Table 1. Values of X and Y with correlation coefficients

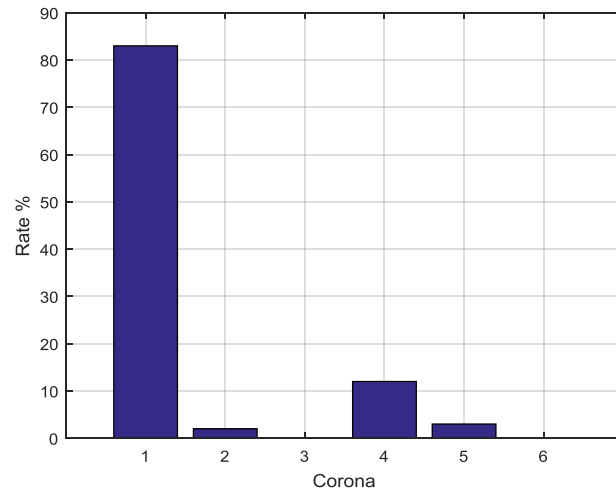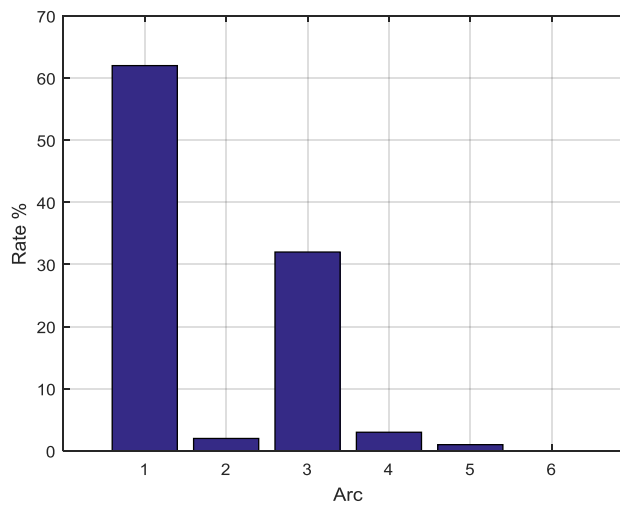| Set	H_2	C_2H_4	C_2H_2	CH_4	C_2H_6	CO	γ_{xy}
X	701	101	10	401	101	571	
Y	70	10	1	40	10	57	1
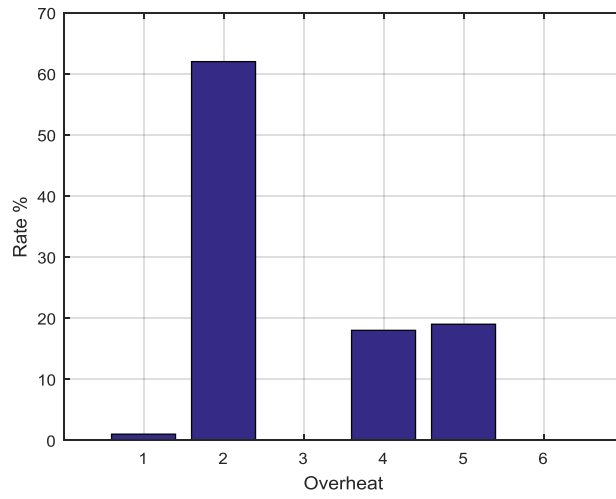
Fig. 1. Overheat

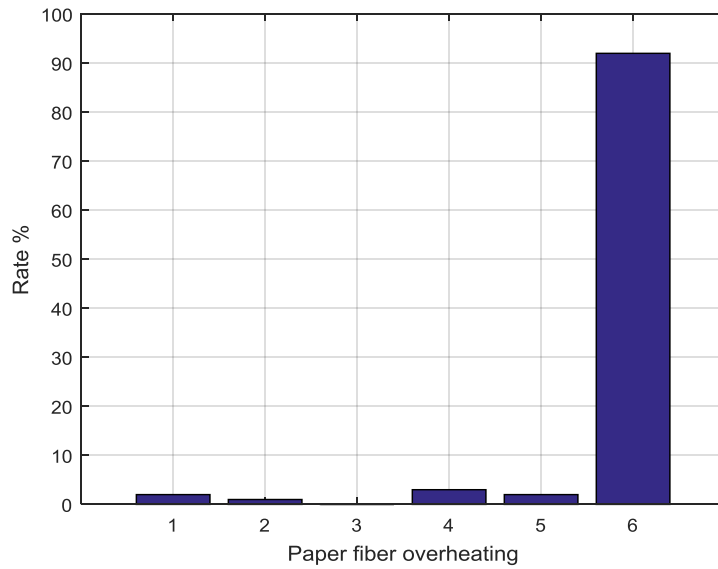**Fig. 2. Corona**

Fig. 3. Arc

Fig. 4. Paper fiber overheat

After the above three diagnostic methods have respectively diagnosed the results, the comprehensive diagnostic judgment is performed by the judgment zone to generate the diagnostic result. The operation of the judgment zone structure is to first combine the Big data with the ANSI/IEEE C57.104 diagnosis results through "AND gate", and then use the "AND gate" with the Key gas diagnosis results to obtain the comprehensive fault attribute judgment result. The schematic diagram of the diagnosis structure is as follows, shown as Fig. 5. For the above diagnostic methods, Big data diagnosis can only judge whether there is a latent fault inside the power transformer based on the concentration of each gas in the insulating oil, but cannot diagnose the fault attribute. The Key gas diagnosis method may produce a "false correlation coefficient." What is false is that the percentages of the corresponding gas concentrations in the two sets of data very similar, but the total gas content are very different. For an example: the data of each gas concentration in the data oil of set A are as follows: H_2 (701), C_2H_4 (101), C_2H_2 (10), CH_4 (401), C_2H_6 (101), CO (571) The total gas content is 1885; The data of each gas concentration in group B data oil are as follows: H_2 (70), C_2H_4 (10), C_2H_2 (1), CH_4 (40), C_2H_6 (10), CO (57), the total gas content is 188, the data is shown in Table 1.

The corresponding percentages of the two sets of gases are almost similar, but false similarity and misjudgment occur during the Key gas diagnosis process. The sum of the gas concentration values in each set is very different, so it is necessary to pay attention. In order to improve the lack of the above two diagnostic methods, the ANSI/IEEE C57.104 diagnostic methods are included in.
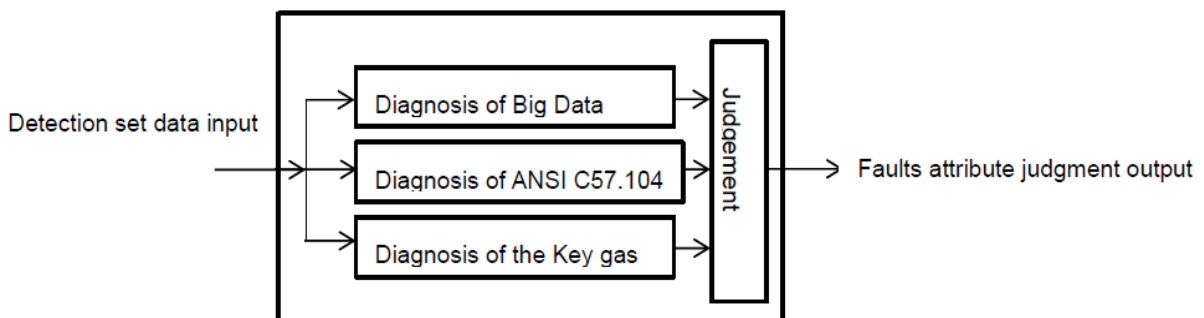

Fig. 5. Schematic diagram of the diagnosis structure

4. DIAGNOSTIC PROGRAM

The above three different diagnostic methods are designed and planned according to the schematic diagram of the diagnostic structure, and then compiled with the MATLAB application software. After repeated tests, the accurate and effective diagnostic method is finally obtained. The computer program steps will be placed in the attachment at the end of the text. In order to verify its feasibility and actually, an example is taken to as data of the test, and the results of transformer maintenance on - site are compared with the diagnostic results executed by this program. The data of diagnostic is shown as Table 2 and the results of program performer are consistent and those results, which were shown in Table 3 by the diagnostic program and power transformer maintenance on - site in Fig. 6 [16].

Table 2. Example data and photos of maintenance results to comparison with this program

H_2	C_2H_4	C_2H_2	CH_4	C_2H_6	CO	Judgment by this program	Maintenance status
1967	8323	57	8008	2013	253	Ace and Corona	Corona

Table 3. The result for diagnosis program

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Diagnosing Potentially Abnormal Attribute of Power Transformers Method: Each gas concentration data of dissolved in insulating oil T=[H_2|C_2H_4|C_2H_2|CH_4|C_2H_6|CO]; T= [1967 8323 57 8008 2013 253];

If S6 shows 1, it means an abnormality inside for being diagnosis of the Big data
S6 =   1
If S4 shows 1, it means an abnormality inside for diagnosis of ANSI/IEEE C57.104
S8 =   1
If A6 shows 1 represent the diagnosis of the Key gas, judged for overheated
A6 =   1
If B6 shows 1 represent the diagnosis of the Key gas, judged for corona
B6 =   0
If C6 shows 1 represent the diagnosis of the Key gas, judged for arc
C6 =   0
If D6 shows 1 represent the diagnosis of the Key gas, judged for paper fiber overheating
D6 =   0
If S10 show 1, the transformer needs to be repaired
S10 =   1
****

Fig. 6. The result of maintenance on-site [16]

5. VERIFY

In order to verify this diagnostic program of the accuracy and feasibility, the author obtained the detection data of each dissolved gas concentration of the transformer insulating oil in the substation from 2007 to 2013 from the Taiwan Power Company through to verify the result of the maintenance equipment on - site compare with the diagnostic results of this program are shown in Table 4.

Being compared with the status of each diagnosis method, the maintenance status on - site, and the result of diagnosis of this program, as shown in Table 5, which were 9 out of 10 verification cases and been accurately judged to

be the latent fault attribute inside the transformer, thus proving that the program is feasible and the accuracy is as high as 90%.

6. DISCUSSION

The author has served the power company for many years and served as the inspection and analysis work of the insulating oil of power transformers. The knowledge learned from another field - the correlation coefficient theory can be applied to the Key gas diagnosis method and the Big data diagnosis method to improve their respective shortcomings. This paragraph describes the advantages and disadvantages of each diagnostic method in a table, such as Table 6.

Table 4. Comparison results from maintenance and this program in actual cases

Date	H_2	C_2H_4	C_2H_2	CH_4	C_2H_6	CO	Judgment by this program	The actual condition repaired
10.5.2007	44	7	10.1	41	88	57	Normal	Normal
5.9.2010	140	21	53.8	54	79	35	Corona	Corona
3.8.2011	181	58	51.4	271	116	128	Normal	Corona
27.2.2012	113	11	36	10	2	685	Normal	Normal
9.5.2012	418	82	167	74	8	39	Corona	Corona
10.5.2012	239	787	23.7	346	78	312	Overheat	Corona
8.7.2012	48	1077	0.4	694	356	36	Overheat	Overheat
5.9.2012	1718	930	1446	884	314	199	Corona	Ace
1.10.2012	185	590	1.7	601	208	72	Overheat	Corona
23.9.2013	133	384	1.9	211	66	411	Paper fiber overheat	Overheat

Table 5. Comparison with each diagnostic methods and maintenance status and this program in actual cases

Date	ANSI/IEEE C57.104	Big data	The key gas	Maintenance status	This program
10.5.2007	1	0	0	0	0
5.9.2010	1	1	1	1	1
3.8.2011	1	1	0	1	0
27.2.2012	1	0	0	0	0
9.5.2012	1	1	1	1	1
10.5.2012	1	1	1	1	1
8.7.2012	1	1	1	1	1
5.9.2012	1	1	1	1	1
1.10.2012	1	1	1	1	1
23.9.2013	1	1	1	1	1
accuracy	80%	100%	90%	100%	90%
Features	Failed to identify abnormal properties	Failed to identify abnormal properties	False judgment	Actual state	Improve items on the left

Note: 1 means abnormal diagnosis, 0 means normal diagnosis

Table 6. Comparison of advantages and disadvantages of various diagnostic methods

Method	Advantage	Disadvantage
ANSI/IEEE C57 104	Classification & judgement of each dissolved gas concentration	Failed to diagnose fault classification attribute
The Key gas	Diagnose fault classification attribute	False diagnosis fault classification attribute
The Big data	Fault diagnosis	Failed to diagnose fault classification attribute
This paper	Diagnose fault classification attribute	-

In addition to the individual diagnostic features described above, the individual operating conditions are as follows: ANSI/IEEE C57.104 judges according to the actual concentration of each gas; For Big data, the correlation coefficient value is judged by historical cases; The Key gas is judged a graph by the percentage of each gas in the total value of the six gases to form compared with standard fault attributes graph. The method of this paper: Apply ANSI/IEEE C57.104 to delete the false judgment of the Key gas diagnosis method and then integrate the Big data to judge the fault attribute.

To sum up this paragraph, this method of this paper reduces the accuracy of Big data diagnosis in order to improve the judgment of fault attributes and display individual diagnosis results in the same table.

7. CONCLUSION

The diagnostic method of this program can effectively improve the discrimination accuracy rate from those dissolved gases in insulating oil. The results can be displayed on the report in text in a simple and easy way without the need for professionals. Among the three data sets A, B, and C mentioned in the Big data diagnosis, the threshold value (0.46) obtained by the set A and set B were directly extracted from the reference [12] in the design of this program. As for the data of set D, it must be loaded into the MATLAB operating system before executing the program to detect and diagnose. The verification data listed in this paper are all the gas concentration values after the transformer insulating oil is decomposed by the "Decomposition chromatography" on a regular basis every year. The above data are the results obtained from the inside of the transformer that were found to be abnormal and the transformer was shut down for maintenance. So that it is used as verification and comparison data, thus its credibility is very high, shown as Table 4 and Table 5 respectively.

The attribute of potential failures can be identified from the insulating oil, which is inspected regularly every year, and equipment maintenance can be carried out immediately. It can detect equipment with 90% accuracy, so that can prevent from black down, and avoid affecting the stable power supply of the power system and equipment safety. In fact, it is a powerful tool for internal detection of power transformers, and it is worth popularizing and adopting.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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APPENDIX

Executive Program

```
clear;
fprintf('***********************************************************\n')
fprintf (' Diagnosing Potentially Abnormal Attribute of Power Transformers Method')
n= 6 ;% number of gass types
m= 2022 ;% number of data sets
data = importdata('3BO.txt');
format short
fprintf (' : Each gas concentration data of dissolved in insulating oil T=[H2|C2H4|C2H2|CH4|C2H6|CO];
\n T= ')
T=input (' ');
for i=2:m;y=data(i, :);R = corrcoef(T,y);w(i)=R(1,2); w(i)>=1011;
end
T1=sum(w);avg=mean(w);r=(avg);
fprintf (' If S6 shows 1, it means an abnormality inside for being diagnosis of the big data')
S6= r< 0.46
S=[701 101 10 401 101 571];
A=[1 62 0 18 19 0];
B=[83 2 0 12 3 0];
C=[62 2 32 3 1 0];
D=[2 1 0 3 2 92];
fprintf (' If S4 shows 1, it means an abnormality inside for diagnosis of ANSI/IEEE C57.104')
S4=T(1)>=S(1) | T(2)>=S(2) | T(3)>=S(3) | T(4)>=S(4) | T(5)>=S(5) | T(6)>=S(6);
S8=S4 & S6
T1=(T/sum(T))*100;
T2=round(T1);
fprintf (' If A6 shows 1 represent the diagnosis of the Key gas, judged for overheated')
A1=corrcoef(A,T2);
A2= min(A1);
A3=min(A2);
A4=abs(A3);
A5=A4>0.6;
A6=S8 & A5
fprintf (' If B6 shows 1 represent the diagnosis of the Key gas, judged for corona')
B1=corrcoef(B,T2);
B2=min(B1);
B3=min(B2);
B4=abs(B3);
B5=B4>0.6;
B6=S8 & B5
fprintf (' If C6 shows 1 represent the diagnosis of the Key gas, judged for arc')
C1=corrcoef(C,T2);
C2=min(C1);
C3=min(C2);
C4=abs(C3);
C5=C4>0.6;
C6= S8 & C5
fprintf (' If D6 shows 1 represent the diagnosis of the Key gas, judged for paper fiber overheating\n ')
D1=corrcoef(D,T2);
D2=min(D1);
D3=min(D2);
D4=abs(D3);
D5=D4>0.6;
D6= S8 & D5
```

```
fprintf ('If S10 show 1, the transformer needs to be repaired \n ')
S9= A6|B6|C6|D6;
S10=S4 & S6 & S9
fprintf('*********************************************************\n')
```