The extraction and application of fault characteristic vector for lower vacuum of condenser in 1000MW unit

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Abstract. In this paper the failure sets and symptom sets of the problem for a 1000MW unit were determined. On the basis of distinguishing the precipitous decline and slow decline of vacuum, the calculation model of the state quantization value of every symptom parameter was established and the fault characteristic vector of the lower vacuum of the condenser was obtained by the simulation test of the unit. Based on BP neural network, the fault diagnosis model of condenser was established, and the low vacuum fault of the unit was diagnosed. The results show that the fault diagnosis of condensers can be used in the actual unit operation according to the fault theory domain feature vector of 1000MW unit.

1 Introduction

The fault diagnosis of condenser system is a branch of fault diagnosis of thermal power unit, and low vacuum of condenser is the most frequent and complicated fault [1].Early power station operators are based on operational experience to determine the cause of condenser failure. From 1990s [2], some scholars began to research low vacuum of condenser through intelligent technologies such as fuzzy mathematics [3] [4], the BP neural network, grey correlation method [5], the fault tree model [6], genetic algorithm, integrated diagnosis method [7], etc. The core of these methods is to establish the mapping relationship between the low vacuum fault sets and symptom sets by using different diagnostic methods to determine the cause of the vacuum-induced drop [9]. However, the diagnosis is based on the establishment of fault characteristic vectors, which is the relationship between the cause of the malfunction and the signs of change in online monitoring data. Due to the variety of operation modes of the units, the structure, performance of the thermal equipment and thermal system are complicated. The faults have dynamic time-varying characteristics and the degree of faults can be large or small [9]. The common method of extracting theory domain eigenvectors such as the field operation experience, the theoretical analysis of the condenser fault [1], there are always some limitations, and fault theory domain feature vectors should be fixed combined with specific equipment and systems for different units. However, the existing literature does not give a detailed method of establishing the fault characteristic vector of the condenser instead of giving the result that the symptom appears (the characteristic value is taken as 1) or not (the characteristic value is taken as 0). Therefore it is necessary to study the establishment of the theory domain feature vector of low vacuum fault in condenser.

In this paper, a 1000MW unit is taken as an example. Through several experiments on simulation, the threshold value of the symptom parameter is obtained, and the fault diagnosis is verified on the actual unit.

2 Fault symptom set of condenser

Due to the difference of structure, equipment and systems for units, the condenser fault symptom set is not the same. The unit studied in this paper is an ultra-supercritical intermediate reheat condensing steam turbine (N1000-26.25MPa/600℃/600℃), which is four-cylinder and four-row steam construction with 8 stage steam extraction. The condenser is double back pressure N-54000 type, double shell, single flow, surface type, horizontal arrangement, which equips with two EVMA250 type vacuum pumps. The cooling water system is equipped with two 2600VZNM circulating water pumps. The condenser low vacuum fault symptom sets are shown in Table 1.

Table 1. Symptom set of condenser

Items	symptom parameter	Items	symptom parameter
B1	Vacuum of condenser A	B16	Electricity of vacuum pump A
B2	Vacuum of condenser B	B17	Electricity of vacuum pump B
B3	Electricity circulating pump A	B18	Outlet pressure of condensate pump A

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B4	Electricity circulating pump B	B19	Outlet pressure of condensate pump B
B5	Water resistance of condenser	B20	Outlet pressure of circulating pump A
B6	Differential expansion of low pressure cylinder rotor	B21	Outlet pressure of circulating pump B
B7	Motor electricity of condensate pump A	B22	Filter screen pressure of pre-condensate pump A
B8	Motor electricity of condensate pump B	B23	Filter screen pressure of pre-condensate pump B
B9	Water level of low-pressure heater 7#	B24	Inlet water temperature of low-pressure heater 8#
B10	Water level of low-pressure heater 8#	B25	Outlet water temperature of low-pressure heater 8#
B11	Temperature rise of circulating water	B26	Outlet water temperature of low-pressure heater 7#
B12	Heat transfer difference of condenser	B27	Outlet water temperature of steam-water separator A
B13	Condensate depression of water	B28	Outlet water temperature of steam-water separator B
B14	Water level of condenser hot well A	B29	Electricity of steam-water separator A bypass pump
B15	Water level of condenser hot well B	B30	Electricity of steam-water separator B bypass pump

The online monitoring parameters are divided into normal, increased, and decreased cases. The quantified values of the characteristic parameters that defined the symptoms are 0.0, 0.5, and 1.0, respectively. In other words, the state quantification value of the symptom parameter Bj can be determined by Formula (1).

$$B_j = \begin{cases} 0.0 & normal \\ 0.5 & increased \\ 1.0 & decreased \end{cases} \tag{1}$$

3 Characterization of the symptom parameter

Generally there are two kinds of characteristic methods for symptom parameters [10]: The first one judge the positive and negative rate values of change about the parameters per unit time. The advantage of this method is that it is very sensitive to the faults in the initial stage of the fault, but it is lack of a stable maintenance. The second one is based on the deviation and threshold of the parameter operating value and the expected value. The advantage is that the symptom can be maintained for a long time, but the determination of the deviation and the threshold are more complicated.

For the fault that causes the vacuum to decline sharply and the unit to trip, it is necessary to discover and take corresponding remedial measures in time. Therefore, the corresponding symptoms should be characterized by the positive and negative rate values of change about the parameters when a fault occurs in the unit. For the fault that causes the vacuum to decline slowly, it can be characterized according to the deviation and the threshold of the parameter operating value and expected value when corresponding symptom parameters change slowly.

3.1 Fault identification causing precipitous and slow decline in vacuum

For example, various failures of low vacuum occurred in the unit simulator when the unit operates under condition of 700MW. The degree of vacuum of condenser A and condenser B is monitored, and the magnitude of change rate for the average value to time is used as a criterion for judging whether or not malfunction causing precipitous decline in vacuum. The test results are shown in Table 2.

Table 2 The fault symptom set of condenser

Items	Fault parameter	rate of change (a)	Items	Fault parameter	rate of change (a)
A1	Leakage of water pipe at low pressure heater 7#	0.0070	A6	Circulating pump B tripping and jury pump disconnecting	0.0028
A2	Leakage of water pipe at low pressure heater 8#	0.0135	A7	Leakage of vacuum system	0.4668
A3	Circulating pump A tripping	0.0263	A8	The vacuum breaker opening	1.1794
A4	Circulating pump B tripping	0.0263	A9	Circulating Water interrupting	1.6411
A5	Circulating pump A tripping and jury pump disconnecting	0.0028			

The change rate of the faults A8 and A9 is much greater than the other faults under conditions of 700MW, and the experimental results are the same under other conditions according to Table 2. Therefore, it can be confirmed that the faults A8 and A9 cause a precipitous decline in vacuum, while the remaining faults are faults causing a slow decline in the vacuum. In actual operation, the average value about the minimum value of the change rate with precipitous decline and the maximum value of the change rate with slow decline is the defined value(about 0.8):

$$\begin{cases} a \geq 0.8 & rapid \quad drop \\ a < 0.8 & slow \quad drop \end{cases} \tag{2}$$

3.2 Method of determining deviation about symptom parameter

For the fault with slow decline, the expression of symptom parameters is based on deviation and threshold. Noting the parameter running value, the expected value and the deviation value is X, X0 and Y, respectively. Deviation Y has two kinds of calculation methods:

Method One: $Y_1 = X - X_0$ (3)

Method Two: $Y_2 = \left(X - X_0\right)/\left|X_0\right|$ (4)

The first method is the absolute amount of deviation, which result in missed sentence easily because of large deviation calculated. On the other hand, method 2 calculates the relative deviation concentrated on [-1, 1], which can avoid the occurrence of missed judgement and is more conducive to comparative judgment. Therefore, the second method is chosen to calculate the deviation of the operating value and the expected value of the symptom parameter.

4 Fault characteristic vector

4.1 Fault characteristic vector causing slow decline in vacuum

Table 3 The quantification value of symptom state parameter in A1-A7

symptom parameter	Range of deviation	State of symptom parameter	Quantification value
B1、B2	Y≤0.0002	increase	0.5
	Y>0.0002	decrease	1.0
B9、B10	Y<-0.1	normal	0.0
	-0.1≤Y≤0.1	increase	0.5
	Y>0.1	decrease	1.0
other	Y<-0.001	normal	0.0
	-0.001≤Y≤0.001	increase	0.5
	Y>0.001	decrease	1.0

For faults causing a slow vacuum decline, the symptom parameters are characterized according to the deviations of the parameter operating values from the expected values and the threshold values calculated by formula (3). Under the normal operating conditions of the unit 700MW, the symptom parameter deviation value of A1-A7 can be calculated. And then, it can be determined the thresholds for each symptom state corresponding to the faults A1-A7, and define the scope of the symptom parameter deviation from the deviation values of the symptom parameters. The quantification value of the symptom parameters according to equation (1) is shown in Table 3.

The quantification value of each symptom parameter is established by performing a failure test under 700 MW operating conditions in table 4. The same fault tests were performed for other conditions. The quantification value of the symptom reference state obtained according to formula (1) was completely consistent with Table 3 although different deviation under other conditions.

4.2 Fault characteristic vector causing precipitous decline in vacuum

Faults A8 and A9 would cause a precipitous decline in vacuum, and they will be tested separately under 700 MW conditions. The change rate of each symptom parameter relative to time can be calculated. And then, it can be determined the state threshold of each symptom parameter corresponding to the occurrence of faults A8 and A9, and define the scope of the symptom parameter deviation from the change rate. The parameter quantification values A8 and A9 obtained by formula (1) are shown in Table 4.

Table 4 The Quantification value of symptom state parameter in A8 and A9

range	State of symptom parameter	Quantification value
a≤-0.5	normal	0.0
0.5≤a	increase	1.0
-0.5<a<0.5	decrease	0.5

The quantification value of each symptom parameter is established by performing a failure test under 700 MW operating conditions in table 4. The same fault tests were performed for other conditions.

The condenser low vacuum fault feature vector set applied to any conditions of the unit can be established according to Table 3 and Table 4, as shown in Table 5.

Table 5 The fault theory domain feature vector set of 1000MW condensing unit

symptom	A1	A2	A3	A4	A5	A6	A7	A8	A9
B1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
B2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
B3	0.5	0.5	0.0	1.0	0.5	0.5	0.5	0.5	0.0
B4	0.5	0.5	1.0	0.0	0.5	0.5	0.5	0.5	0.0
B5	0.5	0.5	0.0	0.0	0.5	0.5	0.5	0.5	0.0
B6	0.0	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.5
B7	0.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5
B8	0.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5
B9	0.0	1.0	0.5	0.5	0.5	0.5	0.5	1.0	1.0
B10	0.0	1.0	0.5	0.5	0.5	0.5	0.5	1.0	1.0
B16	0.5	0.5	0.5	0.5	0.0	0.5	0.5	0.5	0.5
B17	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.5	0.5
B18	1.0	0.0	0.5	0.5	0.5	0.5	0.0	0.5	0.5
B19	1.0	0.0	0.5	0.5	0.5	0.5	0.0	0.5	0.5
B20	0.5	0.5	0.0	0.0	0.5	0.5	0.5	0.5	0.0
B21	0.5	0.5	0.0	0.0	0.5	0.5	0.5	0.5	0.0
B22	0.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5
B23	0.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5
B24	0.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5
B25	1.0	0.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5

B11	0.0	1.0	1.0	1.0	0.5	0.5	1.0	0.5	0.5	B26	1.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5
B12	1.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	B27	0.5	0.5	1.0	1.0	1.0	0.5	0.5	0.5	0.5
B13	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	B28	0.5	0.5	1.0	1.0	0.5	1.0	0.5	0.5	0.5
B14	0.5	0.5	1.0	1.0	0.5	0.5	1.0	0.5	0.5	B29	0.5	0.5	0.5	0.5	0.0	0.5	0.5	0.5	0.5
B15	0.5	0.5	1.0	1.0	0.5	0.5	1.0	0.5	0.5	B30	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.5	0.5

5 Test of fault diagnosis for low vacuum of condenser

A BP neural network was used to establish a condenser fault diagnosis model based on the fault symptom vector set of the condenser of a 1000 MW unit in Table 7.

The BP neural network input layer corresponds to the state quantification value of the symptom parameters, the number of nodes is 30; the output layer corresponds to a low vacuum fault level, and the number is 9. The ideal range of neurons in the hidden layer is [20, 49]. The neural network topology with the smallest mean-square error is selected: 30-40-9 by comparison.

The circulating pump A is tripped under 550MW condition. The symptom set feature vector corresponding to the new condition is obtained by formula (1)、formula (3)、 table 4 and table 5 according to the monitoring parameters:

[B]=[1.0，1.0，0.0，1.0，0.0，0.5，0.5，0.5，0.5，0.5，1.0，0.0，1.0，1.0，1.0，0.5，0.5，0.5，0.5，0.0，0.0，0.5，0.5，0.5，0.5，0.5，1.0，1.0，0.5，0.5]

Inputting to the trained BP neural network, the output vector of the network is:

[A]=[0.0003，0.0061，0.9805，0.0157，0.0025，0.0090，0.0048，0.0001，0.0076]

The maximum output value of the network is 0.9805 corresponding to A3. Compared with the fault set of low vacuum in table 2, it can be known that the fault occurred is the trip of the circulating pump A. The diagnosis result is consistent with the fault setting, which indicates that the fault theory domain characteristic vector of the 1000 MW unit according to the simulator test can be used for the fault diagnosis of the condenser in the actual unit operation.

6 Conclusions

(1)In view of the difference of descent speed in the vacuum when the condenser low vacuum occurs, two different symptom parameter calculation methods are selected to establish the calculation model, and the vacuum degree relative to time is determined by the simulation test of the unit simulator. It is discriminated a malfunction causing precipitous decline in the vacuum whether or not the rate exceeds 0.8.

(2)For the fault causing a slow vacuum decline, the symptom parameter is calculated by the state threshold from the relative deviation between the parameter operating value and the expected value, then the state quantification value of the symptom parameter is obtained; for the fault causing a precipitous vacuum decline, the calculation method is obtained by comparing the magnitude of the change rate of the parameter with respect to time. According to this method, the state quantification value of the symptom parameter can be calculated.

(3)The symptom vector set of the low vacuum fault for the condenser of the 1000 MW unit was obtained according to the tests and calculations of (1) and (2). The result of condenser fault diagnosis model established by BP neural network is accurate. It shows that the fault symptom vector set for the condenser of the 1000 MW unit in this paper can be used to diagnose the condenser low vacuum problem during the actual unit operation.

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