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Circuit Fault Detection of an AC Stable Power Supply Based on a Data Driven Method

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When the circuit fault detection of an AC stable power supply based on data driven is studied, the AC stable power circuit acquisition system, composed of the intelligent controller, signal conditioning module and data sensor, is adopted to collect the data of the AC stable power circuit. The circuit fault detection method based on principal component analysis is used to construct an original observation matrix according to the acquired AC stable power circuit data. The co-variance matrix of the original observation matrix is carried out using singular value decomposition, and the singular value and eigenvalue are decomposed into the residual subspace and principal component space, the observation matrix, constructed according to the new AC stable power circuit data, is then projected into the residual subspace and the principal component space. When the statistic value of the new observation matrix is larger than that of the original observation matrix, the circuit is judged to be faulty, otherwise the circuit is normal. The simulation results show that this method can accurately detect the specific fault circuit of an AC stable power supply, and it takes less time to detect the faults of each circuit. Moreover, after completing the circuit fault detection of an AC stable power supply, the service life of the AC stable power supply increases, which can improve the economic benefits of the AC stable power supply.

Keywords: data driven; stable AC; power circuit; fault detection; observation matrix; principal component analysis

1. INTRODUCTION

The continuous development of industrial technology has made enterprises pay more attention to the safe operation of factory equipment. Instruments and equipment working with an AC stable power supply will cause serious economic losses in case of failure [1]. Therefore, the timely detection and accurate detection of the circuit failure of the AC stable power supply will play an important role in improving the service life of the instruments and equipment of the enterprises and improving the economic benefits of the enterprises.

Nowadays, there are many ways to detect the circuit fault of an AC stable power supply. The circuit fault detection method of an AC stable power supply based on the fractal theory detects the fault through the fractal number of phase voltage, phase current and module current. Due to the complex data collection process, the obtained fractal number of voltage and current may contain errors, which leads to errors in fault diagnosis [2]. The circuit fault detection method of an AC stable power supply based on Wavelet Transform combines the Wavelet Transform with fuzzy reasoning to realize fault detection according to the wavelet energy spectrum characteristics of various fault interference signals detected, this has the disadvantages of insignificant energy spectrum characteristics and fault judgment errors [3]. Due to the widespread application of data mining and machine learning technologies, the application of the data-driven method in the field of fault diagnosis has gradually deepened. The principal component analysis method in data-driven technology can accurately detect a specific circuit, and it is a fault detection method with high use value. In this paper, the principal component analysis method in data-driven technology is used to detect the circuit fault of an AC stable power supply, this can obtain high-precision circuit fault detection results while reducing the probability of fault error detection.

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2. THE METHODS OF CIRCUIT FAULT DETECTION

Currently, there are three fault detection methods based on data-driven technology; statistical learning, knowledge learning and signal analysis. In this paper, the statistical learning method is used to detect the circuit fault of an AC stable power supply. The statistical learning method is used to extract valuable statistical data from the data generated during the operation of the AC stable power supply [4], and realize the circuit fault detection by observing the change of valuable statistical data. The statistical learning method covers a variety of multivariate statistical methods, such as principal component analysis, independent component analysis and partial least squares [5]. This paper mainly studies the specific application of principal component analysis in the circuit fault detection of an AC stable power supply using the data-driven method.

2.1 The Data Acquisition of a Power Circuit

The circuit acquisition system of an AC stable power supply includes the LCD, extended USB interface, intelligent controller (with the MSP430F149 chip as the core), signal conditioning module and data sensor [6], among which the intelligent controller is a single-chip microcomputer with high performance and low power consumption. The chip is surrounded by multiple precision hardware multipliers, A/D converters, DCO internal oscillators and parallel output ports. The intelligent controller completes the acquisition and decision-making control of the data of the AC stable power supply circuit, and the controller uses the A/D converter in the MSP430F149 chip to collect the circuit data and implement the data processing.

The design of the power circuit data acquisition and processing program based on MSP430F149 is the key to achieving power circuit data acquisition. The MSP430 chip includes a built-in multi-channel analog-to-digital converter, in which the ADC13 realizes the conversion of a circuit data analog signal to a numerical signal [7], and the ADC13 completes the acquisition of the circuit data analog signal using the timing interruption method, and the MSP430F149 initialization can complete the ADC13 initialization [8]. The MSP430F149 initialization procedure is as follows:

Invalid ADC_init(Invalid)

{

Unsign int I,

P7Sel|=1X8F; // P7.0 ∼ P7.7 are configured as AD input function

AD13CTL1=ADC13open+SHT0_2+REFopen+REF2_6V;

// Open ADC module, the sampling holding period is 4 times of the sampling period;

// Open internal reference voltage 26V

For (i=0, i is less than 29000, i ++) delay 18ms (open the internal reference voltage)

ADC13CIL1=SHP+ConSEq_1+SHS_1

// The signal source of the power circuit comes from the output channel of the timer and the single conversion mode of the sampling channel;

ADC13MCTL1-NCH_1+SREF _2

// The selected AD channel is 1, and vref is a positive reference voltage

// AVSS, same as below

ADC13MCTL2=NCT_2+SREF_2

ADC13MCTL3=NCT_3+SREF_2

ADC13MCTL4=NCT_4+SREF_2

ADC13MCTL5=NCT_5+SREF_2

ADC13MCTL6=NCT_6+SREF_2

ADC13MCTL7=NCT_7+SREF_2+EOS

_ENT()'// Turn off the main switch

ADC13IE=1X1F.// ADC13 can be interrupted

TACCR1=1700-1; // Preset sampling frequency

TACTL=TACLR|MC_2|TA SSEL_2,

// Select SMCLK timer clock, increase technology mode

ADC12CTL1|=ENC, // ADC implementation conversion

}

After the MSP430F149 initialization is completed, the ADC sampling timing interruption working mode is used to carry out the circuit data analog signal acquisition [9]. The AC stable power circuit data acquisition program is shown in Figure 1:

2.2 The Circuit Fault Detection Method Based on Principal Component Analysis

The principal component analysis method was initially used for high-dimensional data processing. When this method is used for circuit fault detection and diagnosis, the power circuit data is stored on the principal component with a large variance [10–12]. The difference and the correlation between the data were judged by the projection of a new power circuit data in the principal component space to realize the accurate detection of a circuit fault. The principal component analysis method using power circuit data for fault detection includes two parts: offline model establishment and fault online detection [13]. In the offline stage, the principal component analysis model is constructed based on related equipment and historical data to get the principal component space and the residual subspace. The on-line fault detection uses the principal component analysis model to analyze and process the newly acquired power circuit data [14], in order to obtain the fault detection results. The process of fault detection of an AC stable power circuit by principal component analysis is as follows:

(1) Standardize the original AC stable power circuit data obtained by observation [15], and transform each observation data sample into a standard vector with the variance of 1 and the mean of 0.

$$\mathrm{L} = \begin{bmatrix} l_1^T \\ l_2^T \\ \vdots \\ l_m^T \end{bmatrix} = \begin{bmatrix} l_{11} & l_{12} & \cdots & l_{1n} \\ l_{21} & l_{22} & \cdots & l_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} & \cdots & l_{mn} \end{bmatrix} \in R^{n\times m} \tag{1}$$

Among them, is the matrix of the AC stable power circuit data, obtained by observation. The number of

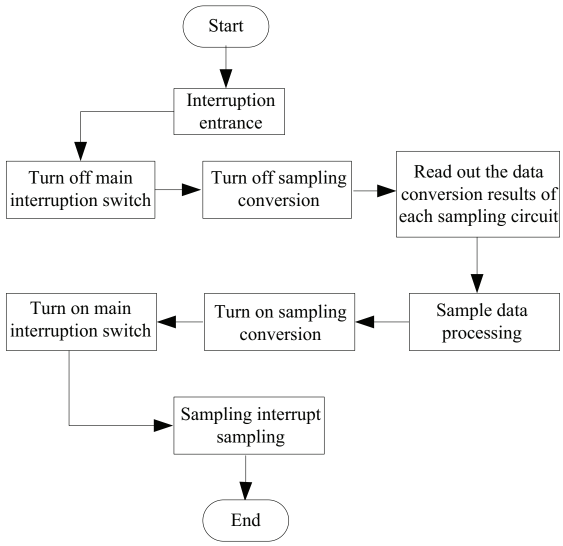

Figure 1 The Data Acquisition Program of an AC Stable Power Circuit.

observation samples and variables are represented by m and n. R is the constant set. T is the sampling period.

(2) Calculate the co-variance matrix Φ of data matrix L, as shown in Formula (2):

$$\phi = \frac{1}{m-1} L^T L \tag{2}$$

(3) Perform singular value decomposition on Formula (2), and arrange the obtained feature values reasonably.

$$\phi = \frac{1}{m-1} L^T L = P \Lambda P^T \tag{3}$$

$\Lambda = diag(\beta_1, \beta_2, \ldots, \beta_n), \beta_1 \geq \beta_2 \geq \ldots \beta_n$ exists in Formula (3). β is a constant.

(4) The singular value and eigenvalue P can be decomposed into residual subspace and principal component space, respectively, as shown in Formula (4):

$$P = \left[P_{pc} P_{\text{res}} \right], \Lambda = \begin{bmatrix} \Lambda_{pc} & 0 \\ 0 & \Lambda_{\text{res}} \end{bmatrix} \tag{4}$$

(5) In the process of circuit fault detection, a new observation data vector Z needs to be projected onto the residual subspace and the principal component space. There is:

$$\bar{z} = P_{pc}^T z, \bar{\bar{z}} = P_{\text{res}}^T z \tag{5}$$

The statistics SPE and T^2 are used to detect the power circuit state, and the two statistics are expressed as follows:

$$\begin{aligned} SPE &= \bar{\bar{l}}^r \bar{\bar{l}} = l^T P^{\text{res}} P_{\text{res}}^T l \\ T^2 &= \bar{l}^T \Lambda_{pc}^{-1} \bar{l} = l^T P_{pc} \Lambda_{pc}^{-1} P_{\text{res}}^T l \end{aligned} \tag{6}$$

Formula (8) and Formula (9) can be used to determine the value range of statistics SPE and T^2:

$$\begin{aligned} SPE\_Threshold &= \theta_1 \left(\frac{v_a \sqrt{2\theta_2 f_0^2}}{\theta_1} + \frac{\theta_2 f_0 (f_0 - 1))}{\theta_1^2} + 1 \right)^{\frac{1}{f_0}} \\ T^2\_Thershold &= \frac{\delta(m^2 - 1)}{N(m - \delta)} F_a(\beta, m - \delta) \end{aligned} \tag{7}$$

Formula (8) is the statistical value of the initial observation matrix SPE, where v_a is the deviation value of the normal distribution at $1 - a$. Formula (9) is the statistical value of the initial observation matrix T^2, where $F_a(\delta, m - \delta)$ is the degree of freedom of the F distributed at $\delta, m - \delta$. The results of $f_0 = 1 - \frac{2\theta_1\theta_3}{3\theta_2^2}$ and $\theta_i = \sum_{j=\delta+1}^{n} (\beta_j)^i$ are also in the formula. θ_i and f_0 are the number of power connection circuits and the resistance of power circuit respectively.

(6) Fault circuit judgment: if SPE_New is larger than SPE_Threshold or T^2_NEW is larger than T2_Threshold, the circuit can be judged to be faulty at this time. SPE_New and T^2_NEW are the statistical values of the new observation vector. Otherwise, the circuit is normal without fault.

3. EXPERIMENTAL ANALYSIS

In order to verify the strong practical significance of the circuit fault detection of an AC stable power supply based on the data driven method, the method proposed in this paper is used to detect the circuit fault situation of a large-scale AC stable power supply in a factory. The size of the selected AC stable power supply in the field is 220V, which is connected with multiple circuits. The experiment compares the circuit fault detection methods of the AC stable power supply based

Table 1 The Fault Data Diagnosis Results of Data Sensor.

The name of the circuit	Fault location /m	False rate/%	Under report rate/%
A	(148–165); (220–260)	2.1	0.4
B	—		
C	—		
D	(965–975)	0.9	0
E	—		
F	—		
G	—		
H	(310–365); (812–820)	1.5	0
I	(710–740)	0.4	0
J	—		
K	—		
L	—		
M	(518-521)	0.2	0
N	—		
O	—		
P	—		
Q	—		
R	—		
S	(399-415); (498-539)	1.5	0
T	—		

on Wavelet Transform and fractal theory with the method in this paper. The practical value of the method in this paper can be judged by comparing which of the three methods can accurately detect the specific faulty circuit and how quickly each method detected the circuit fault.

In the experiment, there are 20 circuits connected to the selected AC stable power supply, and their names are set as circuit A to circuit T, respectively. The three methods are used to simulate and analyze the fault circuit results and they are compared with the actual fault results of the circuit. The fault data diagnosis results of the power transmission circuit collected by the method proposed in this paper are shown in Table 1. The fault circuit results simulated and analyzed by the three methods and the actual circuit fault results are shown in Table 2:

From Table 2, it can be seen that during the actual operation process of the AC stable power supply, faults may occur in different connecting circuits. It also can be seen from Table 2 that in the circuit fault detection results using the method in this paper, only the detection circuit K and circuit P are inconsistent with the actual detection results, and the accuracy of the circuit fault detection results is 90%; while the number of correct detection circuits using Wavelet Transform method and fractal theory method is 13 and 9 in the 20 connecting circuits, and the detection accuracy is 65% and 45% respectively, much lower than that of the method proposed in this paper. Therefore, it shows that when detecting the circuit fault of the AC stable power supply, the method of this paper can accurately determine which circuit has a fault in the power connecting circuits, and provide convenience for the subsequent fault repair.

In the experiment, on the basis of verifying the circuit that can be detected by the method proposed in this paper, the speed of accurate fault detection should also be verified. In the experiment, Circuit E and Circuit F in Table 2 are taken as examples, because all three methods detect that there is no fault in the two circuits. In order to obtain accurate fault detection time, the experiment is carried out under the condition that the AC stable power supply runs continuously and stably for different times. Table 3 presents the amount of time taken to detect a circuit fault using the three methods:

In order to highlight the influence of the continuous and stable operation time of the AC stable power supply on the time taken to detect a circuit fault, the data results in Table 3 are presented in Figure 2 and Figure 3:

From the curve in Figure 2, it can be concluded that there is a great difference among the time taken between the three methods when they are used to detect the fault of Circuit E. According to the data in Table 3 and Figure 2, with the increase of the operation time of AC stable power supply, the time for fault detection by the method in this paper has a small change, with the change range between 1.35 ms and 1.47 ms; whereas the time of fault detection based on the Wavelet Transform method increases with the increase of power supply operation time, and the lowest and highest detection time are 1.36 ms and 4.98 ms respectively, with the maximum difference of detection time being 3.32 ms, this shows that the stability of this method is not high when it is used to detect circuit fault. The time taken using the fractal theory to detect the fault in Circuit E is higher in the shorter power supply operation time, but even with the increase in operation time, the time of fault detection does not change significantly.

It can be concluded from the curve in Figure 3 that when the three methods are used to detect the fault of Circuit F, the time of fault detection based on the Wavelet Transform method is positively related to the operation time of the power supply, and the fault detection based on fractal theory takes the longest time, this demonstrates that the method in this paper is more efficient when used to detect the circuit fault of long-operating AC stable power supply.

Table 2 The Circuit Fault Detection Results.

The name of the circuit	The method proposed in this paper	Wavelet Transform	Fractal theory	The actual circuit fault
A	Yes	Yes	No	Yes
B	No	Yes	No	No
C	No	Yes	No	No
D	Yes	No	No	Yes
E	No	No	No	No
F	No	No	No	No
G	No	No	No	No
H	Yes	No	No	Yes
I	Yes	No	No	Yes
J	No	No	Yes	No
K	Yes	No	Yes	No
L	No	No	Yes	No
M	Yes	Yes	No	Yes
N	No	No	No	No
O	No	No	No	No
P	No	Yes	No	Yes
Q	No	Yes	Yes	No
R	No	Yes	No	No
S	Yes	Yes	Yes	Yes
T	No	No	Yes	No
Fault detection accuracy%	90%	65%	45%	—

Table 3 The Time Taken to Detect a Circuit Fault by Three Methods (ms).

The operation time of AC stable power supply /min	Circuit E			Circuit F		
	The method proposed in this paper	Wavelet Transform	Fractal theory	The method proposed in this paper	Wavelet Transform	Fractal theory
50	1.35	1.36	2.55	1.23	1.54	2.67
100	1.35	1.42	2.45	1.24	1.68	2.74
150	1.36	1.47	2.57	1.25	1.73	2.63
200	1.42	1.62	2.64	1.31	1.79	2.55
250	1.47	1.84	2.54	1.28	1.86	2.64
300	1.43	2.05	2.64	1.33	2.14	2.75
350	1.43	2.35	2.74	1.24	2.25	2.71
400	1.38	2.51	2.64	1.29	2.38	2.62
450	1.44	3.11	2.54	1.31	2.57	2.57
550	1.37	3.54	2.75	1.32	2.84	2.35
600	1.44	4.02	2.84	1.36	3.24	2.64
650	1.46	4.35	2.67	1.28	3.55	2.57
700	1.38	4.84	2.84	1.24	3.64	2.84
750	1.36	4.95	2.75	1.22	3.57	2.88
800	1.42	4.98	2.67	1.26	4.22	2.67

In order to verify that the method in this paper can accurately detect the specific fault circuit and the detection efficiency, three methods are used to evaluate the service life of AC stable power supplies. An evaluation mechanism is used to analyze the service life of some large AC stable power supplies in this plant. After three methods are used for circuit fault detection, 12 experts from an engineering equipment company analyze the service life of the batch of AC stable power supplies. The results are shown in Table 4.

In order to highlight the change in the service life of AC stable power supply after the circuit fault detection using the method in this paper, the data results in Table 4 are presented in Figure 4:

From the data in Table 4 and the curve in Figure 4, three methods are used to detect the circuit of an AC stable power supply, this can accurately predict the expected service life of

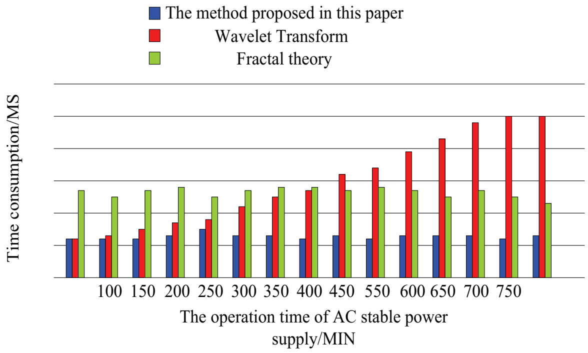

Figure 2 The Time Taken to Detect a Fault in Circuit E.

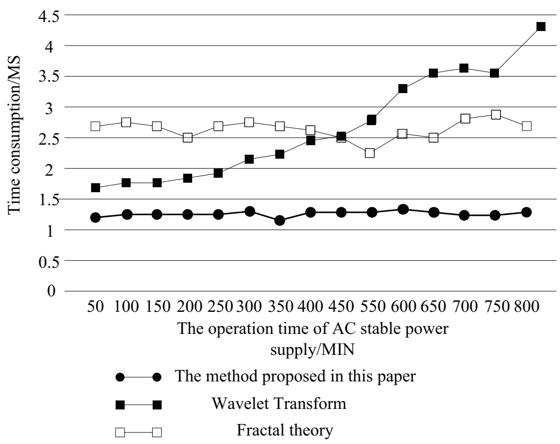

Figure 3 The Time Taken to Detect a Fault in Circuit E.

Table 4 Estimation Results of Service Life of AC Stable Power Supply.

Number of experts	The method proposed in this paper (year)	Wavelet Transform (year)	Fractal theory (year)
1	7.0	3.5	2.0
2	7.0	4.0	1.5
3	7.5	4.0	1.5
4	7.0	4.0	1.5
5	7.0	3.0	1.5
6	7.0	3.5	2.0
7	7.5	3.0	2.0
8	8.0	4.0	2.0
9	7.5	4.0	2.0
10	7.5	3.0	1.5
11	7.5	3.5	1.0
12	7.0	3.0	1.0

power supply, in order to remind the management to replace the power supply in a timely manner. Through the detailed analysis of the curve in Figure 4, it can be concluded that each expert uses the method in this paper to detect the circuit fault, and analyzes that the shortest service life of the power supply is 7 years, and the longest service life is 8 years; experts using the wavelet analysis method to detect faults concluded that the shortest and longest service life of power supply is 1 year and 2 years respectively, much lower than the time detected by method in the paper. Experts using the fractal theory to detect the circuit fault concluded that the expected service life of the power supply is 3 to 4 years. The results show that if this method described in this paper is used for circuit fault detection, the AC stable power supply has the longest service life and the highest economic benefit.

4. CONCLUSION

The circuit of a normal and stable AC power supply provides the foundation for the stable operation of a power supply. In this paper, the circuit fault detection of an AC stable power

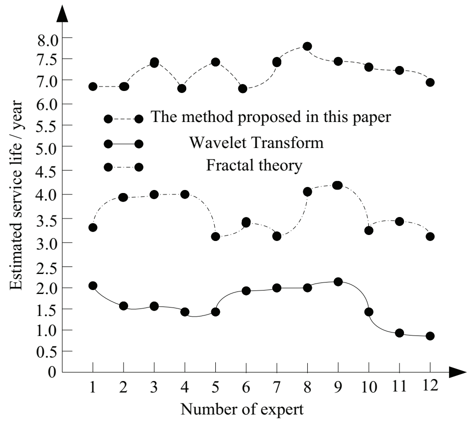

Figure 4 Evaluation Results Service Life of Power Supply.

supply based on the data-driven method is proposed; this method can accurately detect whether the circuit in the power supply has a fault and decrease the time needed for fault detection, and is the core of the design of the AC stable power supply. Principal component analysis in data-driven technology can accurately detect a specific circuit, which can improve the service life of the AC stable power supply and is a high-value fault detection method.

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