

Identification of Excitation Parameters Based on TLS - ESPRIT

Guoqiang Xie¹, li Zou², Kansheng Yu¹, Jin Zou¹, Zhicheng Wang¹ and Xiaozhi Gui¹

¹State Grid Jiangxi Electric Power Research Institute, Nanchang, Jiangxi Province, 330096, China
²Jiangxi Technical College of Manufacturing, Nanchang, Jiangxi Province, 330095, China

Abstract. In order to accurately detect excitation system parameters, this paper presents an algorithm based on the TLS-ESPRIT. The matrix pencil algorithm is used to extract the frequency and damping of each component of system response. So it's necessary to apply the Laplace transform for s function of excitation system. After getting the Laplace transform of a function $f(t)$, as mean as impulse response for excitation system. Then the magnitude and phase of each component of impulse response are estimated by least squares method, thus achieving the excitation system parameters. In the end, the simulation results show when SNR is between 35dB to 30dB, it still accurately identified the parameters.

Keywords: Excitation system; Parameter identification; TLS-ESPRIT.

1 Introduction

As excitation control system is an important regulating part of modern power system, the obtaining of the parameters of excitation model accurately plays an important role in the stability of the system. Therefore, the research on parameter identification of excitation system has always been paid attention to by people. Nonlinear methods such as correlation identification method, improved genetic algorithm, and improved particle swarm optimization have been fully used in parameter identification of power system excitation system^[1-5].

TLS - ESPRIT is different from the traditional Prony algorithm in that it has the certain ability to eliminate noise. That's why that relevant scholars have studied the parameter identification problems related to the power system and have made some achievements^[6-8]. Document^[9] has the functions of extracting fundamental wave and eliminating noise, and can achieve high precision extraction of signal parameters. The conclusion shows that this method can achieve high identification accuracy. Document^[10] uses multi-pole recovery method to improve TLS - ESPRIT to obtain accurate actual frequency, and applies polynomial fitting method to improve amplitude estimation to obtain high-precision amplitude detection. The above results show to some extent that TLS - ESPRIT not only has excellent parameter identification effect, but also has achieved good results in many fields.

In this paper, the IEEE / ST1A model is taken as the prototype, and the corresponding simplified model is

obtained by being appropriately simplified based on the prototype. Then laplace transform is performed on the transfer function of the excitation model to obtain the impulse response function of the system. Then, the basic principle of the total least squares rotation invariant technique is introduced, the modal information of the excitation model is identified, and the parameters of the excitation system are obtained according to the characteristics of the system itself. The final simulation test shows that the total least squares rotation invariant technique has a certain anti-noise capability.

2 Mathematical model of excitation system

There are many kinds of excitation models in practice. Based on IEEE / ST1A model, this paper makes appropriate simplification. The following is a schematic diagram of the excitation model that this paper needs to identify:

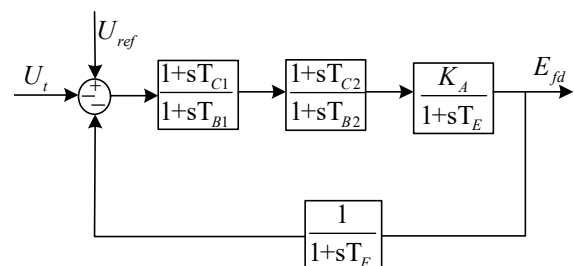


Figure 1. The figure of excitation system.

Sort diagram 1 into the form of a transfer function:

$$W(s) = \frac{K_A(1+sT_{C1})(1+sT_{C2})(1+sT_F)}{K_A(1+sT_{C1})(1+sT_{C2})(1+sT_E)(1+sT_{B1})(1+sT_{B2})(1+sT_F)} \quad (1)$$

Expand that polynomial in formula (1) to obtain the following transfer function:

$$W(s) = \frac{b_3s^3 + b_2s^2 + b_1s + b_0}{s^4 + a_3s^3 + a_2s^2 + a_1s + a_0} \quad (2)$$

In which:

$$a_3 = \frac{1}{T_F} + \frac{1}{T_E} + \frac{1}{T_{B1}} + \frac{1}{T_{B2}}, \quad a_0 = \frac{1 + K_A}{T_F T_{B2} T_{B1} T_E}$$

$$a_2 = \frac{K_A T_{C2} T_{C1}}{T_F T_{B2} T_{B1} T_E} + \frac{1}{T_{B1} T_E} + \frac{1}{T_{B2} T_E} + \frac{1}{T_F T_E} + \frac{1}{T_{B2} T_F} + \frac{1}{T_{B1} T_F} + \frac{1}{T_{B2} T_{B1}}$$

$$a_1 = \frac{K_A (T_{C1} + T_{C2})}{T_{B1} T_E T_{B2} T_F} + \frac{1}{T_E T_F T_{B1}} + \frac{1}{T_E T_F T_{B2}} + \frac{1}{T_{B1} T_F T_{B2}} + \frac{1}{T_E T_{B1} T_{B2}}$$

$$b_3 = \frac{K_A T_{C1} T_{C2}}{T_{B2} T_{B1} T_E}, \quad b_0 = \frac{K_A}{T_{B2} T_{B1} T_E T_F}$$

$$b_3 = \frac{K_A (T_{C1} T_{C2} + T_F T_{C2} + T_{C1} T_F)}{T_{B2} T_{B1} T_E T_F}$$

$$b_1 = \frac{K_A (T_{C1} + T_{C2} + T_F)}{T_{B2} T_{B1} T_E T_F}$$

Expand the form as shown in formula (2) into partial fractions. The form is as follows:

$$W(s) = \sum_{i=1}^4 \frac{A_i}{s - s_i} \quad (3)$$

Performing laplace transform on formula (3) can obtain the impulse response function of the excitation system:

$$y(t) = \sum_{i=1}^4 A_i e^{s_i t} \quad (4)$$

After obtaining the time domain response function of the excitation transfer function, the total least squares rotation invariant technique can be used to identify the excitation parameters. The following will briefly introduce the total least squares rotation invariant technique.

3. TLS - ESPRIT principle

ESPRIT algorithm is a kind of signal parameter estimation algorithm based on subspace technology. The

principle of TLS - ESPRIT algorithm is mainly divided into the following five steps.

Step 1: taking N sample data signals $y(k\Delta t) = x(k\Delta t) + n(k\Delta t)$.

In which: $k=1, 2, 3 \dots N$.

The Hankel matrix is constructed according to the data matrix. Hankel matrix

$$Y = \begin{bmatrix} y(0) & y(1) & \dots & y(M-1) \\ y(1) & y(2) & \dots & y(M) \\ \vdots & \vdots & \ddots & \vdots \\ y(L-1) & y(L) & \dots & y(N-1) \end{bmatrix} \quad (5)$$

In the formula: $L > P, M > P, L + M - 1 = N$.

Here, P is greater than or equal to twice the number of real sinusoidal components in the data to be detected.

Step 2: singular value decomposition of matrix γ : $Y = U \Sigma V^T$. The diagonal elements of Σ are in descending order of the singular value $\xi_1, \xi_2 \dots \xi_{\max(L,M)}$ of the matrix γ .

Step 3: divide V into signal sub-space V_1 and noise sub-space V_2 according to the value of singular value, and then $V = (V_1 V_2)$ Only process the sub-space V_1 . Denote matrix V_1 whose first and last rows are deleted by V_3 and V_4 respectively. Considering the noise and other interference in the signal, we can get the following expression:

$$(V_3 + e_1) = (V_4 + e_2) \phi \quad (6)$$

Step 4: according to the method of total least squares: the optimal solution sought makes equation (6) hold. The solution process is as follows:

1) Build a matrix $[V_3, V_4]$, and perform singular value decomposition,

$$[V_3, V_4]_{(M-1) \times 2p} = U_{(M-1) \times (M-1)} \Sigma_{(M-1) \times 2p} V_{2p \times 2p}$$

2) Divide V into 4 $P * P$ matrices, i.e. $V = \begin{bmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{bmatrix}$, to result in $\phi_{ils} = -V_{12} V_{22}^{-1}$.

Step 5: find ϕ_{ils} 's characteristic value λ_k ($k=1, 2, \dots, p$). Construct a vandermonde matrix of the characteristic value. Then the amplitude of each component in the signal can then be estimated. The formula is as follows:

$$S = (\lambda^T \lambda)^{-1} \lambda^T Y \quad a_k = 2|S| \quad (7)$$

Among them, the a_k denote the corresponding amplitudes.

4. Parameter solution

The system parameters a_i and b_i ($i = 0, 1, 2, 3$) are obtained by using the total least square rotation invariant

technique. The remaining problem is how to convert these parameters into the parameters of the excitation system.

Given that obtaining parameters b_i ($i = 0, 1, 2, 3$), by observing the corresponding factorization form of the transfer function numerator of formula (2), solve the equation composed of numerators. Its form is shown by the numerator of formula (1):

$$b_3s^3 + b_2s^2 + b_1s + b_0 = 0 \quad (8)$$

After factorization of equation (10), make an appropriate transformation to result in:

$$K_A(1 + sT_{C1})(1 + sT_{C2})(1 + sT_F) = 0 \quad (9)$$

It is not difficult to obtain the corresponding characteristic roots λ_i ($i = 1, 2, 3$). If the algebraic relationship between T_{C1} , T_{C2} and T_F is known in advance, one-to-one correspondence between them and the characteristic roots can be obtained.

After obtaining T_{c1} , T_{c2} and T_F , substitute it into the expression of B_0 , and get:

$$T_E T_{B1} T_{B2} = \frac{K_A}{b_0 T_F} \quad (10)$$

Substitute expression B_0 into the expression of A_0 to obtain the expression of K_A :

$$K_A = \frac{b_0}{a_0 - b_0} \quad (11)$$

After expanding the denominator of equation (1), the following equation can be obtained:

$$\frac{1}{a_0 - b_0}(s^4 + a_3s^3 + a_2s^2 + a_1s + a_0) = 0 \quad (12)$$

Observing the denominator of equation (1), it is not difficult to see that the coefficient consists of two parts, and now the main concern is the latter half, i.e. the part containing T_{B1} , T_{B2} , T_E and T_F . Because the first half is known, the two can be separated and the equation containing only the second half is written as follows:

$$\frac{1}{a_0 - b_0}s^4 + \frac{a_3}{a_0 - b_0}s^3 + c_2s^2 + c_1s + 1 = 0 \quad (13)$$

In which:

$$c_2 = \frac{a_2 - b_0 T_{C1} T_{C2}}{b_0 - a_0}, c_1 = \frac{a_1 - b_0(T_{C1} + T_{C2})}{b_0 - a_0}.$$

After solving the corresponding equation of equation (13), the corresponding characteristic root is obtained. When the algebraic relationship between T_{B1} , T_{B2} , T_E and T_F is known, it is not difficult to obtain relationship between the characteristic root and the parameter T_{B1} , T_{B2} , T_E and T_F .

5 Design procedure

1) Firstly, the excitation model of the system is sorted out and transformed into the impulse response function of the system through laplace transform.

2) Secondly, the total least squares rotation invariant technique is used to identify the system's characteristic root, amplitude and other parameter values.

3) After obtaining information such as characteristic roots, the corresponding parameter values of the excitation function are obtained through the properties of the transfer function of the excitation system.

6. Simulation analysis

The main parameters of the system described in diagram 1 are: $T_{C1}=1.0$, $T_{C2}=0.1$, $T_F=0.01$, $T_{B1}=8.0$, $T_{B2}=0.033$, $T_E=0.03$, $K_A=200$.

When a certain white noise is added to the impulse response of the excitation system, the system will have certain randomness. After analysis by using the total least squares rotation invariant technique, it is found that there will be some differences in the results of the parameters identified each time. In order to avoid the randomness brought by the noise, the Monte Carlo method is used for reference to perform multiple calculations and save the results of each calculation. After the calculation, perform the arithmetic mean value for all the data to obtain the required system parameter value.

6.1 Influence of noise on identification results

In order to study the anti-noise performance and identification accuracy of TLS - ESPRIT, taking IEEE / STA 1 model as an example, compare the calculation accuracy and analysis results of the total least squares rotation invariant technique after 250 times of calculation under different signal-to-noise ratios. See in diagram 2.

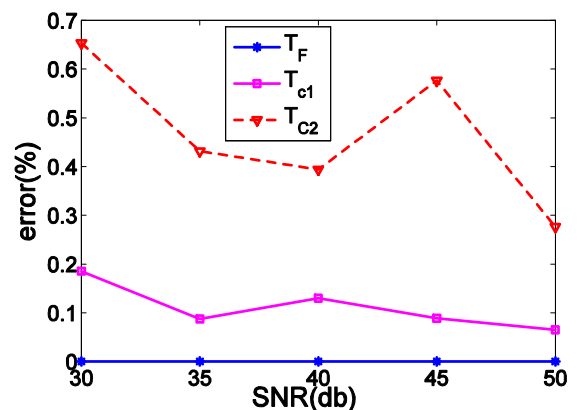


Figure 2. At different signal to noise ratio, the mean error of the parameter identification.

From diagram 2, it is not difficult to see that the error of identification parameters generally decreases with the increase of SNR, which is consistent with the actual identification law. However, some fluctuations occurred in the diagram may be related to the insufficient times of calculations so that the randomness of the system cannot

be completely suppressed.

6.2 Influence of calculation times on identification results

The conclusion drawn from diagram 2 is that the randomness of the system is caused by systematic errors. However, the main suppression method in this paper is realized through multiple calculations. Therefore, it is necessary to consider the influence of calculation times on system errors.

Diagram 3 shows the error curves of identification parameters under different calculation times when the signal-to-noise ratio is equal to 40. When the calculation times of the system are less than 80 times, the error of the system parameters shows certain fluctuation. When the number of calculations is greater than 80, the fluctuation decreases to some extent. When the calculation times of the system gradually increase, the suppression effect on the calculation error of the system is relatively enhanced.

Certainly, how to choose appropriate times of calculations is also a problem that needs to be considered. It is not only impossible to calculate too much and take too much time, but also to obtain higher identification accuracy for the system.

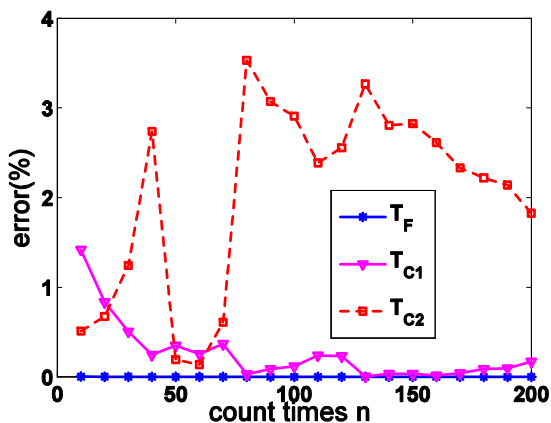


Figure 3. At different count times, the mean error of the parameter identification.

7 Conclusion

In this paper, TLS - ESPRIT is applied to the parameter identification problem of excitation system. The advantage of this method is that it does not need much iteration and there is no convergence problem. But it also can obtain higher identification accuracy under applicable times of calculation.

This paper mainly discusses the identification problem under white noise. Whether there is the same rule for other noises needs further experimental confirmation.

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