

# Parameter Identification of Wind Power System Low Frequency Oscillation Based on Matrix Pencil Algorithm and Stabilization Diagram

Guoqiang Xie<sup>a</sup>, Benren Pan<sup>b</sup>, Lixia Xiong<sup>c</sup>, Jin Zou<sup>d</sup>, Kansheng Yu<sup>e</sup>

<sup>1</sup>State Grid Jiangxi Electric Power Research Institute, NanChang, Jiangxi Province, 330096, China

<sup>a</sup>email: xgq15@163.com, <sup>b</sup>email: 278639874@qq.com, <sup>c</sup>email: xtlsh@126.com

**Abstract**—As installed wind energy capacity increase, the low Frequency oscillation parameters may change. In order to accurately detect the low Frequency oscillation parameters, a algorithm based on the matrix pencil and stabilization diagram was proposed. It's difficult to get the order of oscillation signal, so it's necessary to find a proper method to determine the order. We calculate the order of oscillation signal stabilization diagram by using the stabilization diagram. After this, The matrix pencil algorithm is used to extract the frequency and damping of each component of system signal. In the end, the simulation results show when SNR is high, it still accurately identified the parameters in the different systems.

**Keywords**—wind turbine; low frequency oscillation; order; matrix pencil algorithm; stabilization diagram.

## I. INTRODUCTION

The stability of system is needed, as the scale of electric system is getting bigger and the capacity of single generator is becoming larger. Since the birth of interconnection large power grid, the problem of low frequency oscillation has occurred, associating with it. So the research of low frequency oscillation parameter identification has caught much attention. Some methods have been widely used in the low frequency oscillation system of electric system, such as Prone method, randomsubspace, HHT, TLS-ESPRIT, matrix pencil algorithm, etc[1-10].

Besides, it is much more important to explore new energy for the energy supply of our country, with the energy crisis becoming more and more severe. Wind energy, the mature new energy, has got great supports of our country. The influence of the stability of the system has become more obvious, along with the increase of the capacity of the wind turbine. Thus, the research of the low frequency oscillation problem of the system with wind turbine has some practical significances in [11-12]. Matrix pencil algorithm, an effective parameter identification method, not only has some identification precision used alone [10], but also has good compatibility when used with other methods[13-15]. The document [14] combined matrix pencil algorithm and wavelet to identify the parameter of synchronous motor. The result showed that the identification precision can be higher, if the two methods are combined. The document[15] improved the matrix pencil algorithm, and it was used to identify the parameter of the sub-synchronous oscillation, which can get better identification effect at last. The conclusion above shows

matrix pencil algorithm has good parameter identification effect, meanwhile, it also has great theory fusion, when combined with other methods.

Firstly, this essay used stability diagram to identify the order, and removed the noise among the signal, which will enhance the SNR(Signal to Noise Ratio). And then we processed the signal using matrix pencil algorithm to get the amplitude, damping, and the frequency of the identification signal. Finally, the simulation testing was done to identify the parameter of the analog signal, one machine system, multi-machine system signal. The results proved that the method is effective.

## II. STABILITY DIAGRAM METHOD

In the parameter identification of the low frequency oscillation, the model order determination should be done before identifying other parameters. And the stability diagram method [16] is a more severe method to identify the model's order.

The main principle of stability diagram: assuming the system is not fixed and a bigger order. Decrease it progressively, and then we can get the parameters of different orders. Identify the parameter of every order by matrix pencil algorithm and label the model parameters on the two-dimension coordinate graphs, at last the multi-group order graph can be obtained. The independent variable of the stability diagram is the frequency, and the dependent variable is the order of the system. Compare the parameter of the adjacent order. If the difference values of the adjacent order are within the scope of accepting, we can affirm that the model is stable. Due to enlarging the hunting zone of order, it will be inevitable to find false model. Along with the adding of order, the poles will almost become a straight line, which is called stable axis according to the stable model. The tolerance can be assumed as: to form stable axis, which should meet the requirements:

$$\frac{f^j - f^{j-1}}{f^{j-1}} \times 100\% < \varepsilon_f \quad (1)$$

Where  $j$  is the order of the model,  $f$  is the model frequency of every order,  $\varepsilon_f$  is the tolerance.

Stability diagram is helpful to get the true order of the signal, so it has some theory value and practical value.

## III. MATRIX PENCIL ALGORITHM

The homogeneous sampled signal  $y(k)$  with noise can

be shown:

$$y(k) = \sum_{i=1}^q A_i \exp(s_i k T_h) + w(k T_h) \quad (2)$$

Where, the  $A_i$  is the amplitude of  $i$  th component, and it can be complex number or real number;  $T_k$  is the period of the sampled signal,  $k$  is the sampling number,  $w(k)$  is the noise. The range of the value of  $i$  is  $k/4 \sim k/3$ , if making Hankel matrix  $\mathbf{Y}_{(k-l) \times (l+1)}$  for the sampled signal[8].

And then analyzing  $\mathbf{Y}$  by SVD, we can get  $\mathbf{Y} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^H$ . In the practice, we pay more attention to the front bigger characteristic value of  $\mathbf{\Sigma}$ . Choose the  $q$ th bigger characteristic value  $z_i$  to make the  $\mathbf{\Sigma}_1$ , and  $z_i$ ' corresponding right eigenvector  $\mathbf{v}_i$ , to make  $\mathbf{V}' = [\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_q]$ .  $\mathbf{V}_1$  and  $\mathbf{V}_2$  stand for the first line and the last line of the deleted matrix  $\mathbf{V}'$ , respectively, the names of those are  $\mathbf{Y}_1 = \mathbf{U}\mathbf{\Sigma}_1\mathbf{V}_2^H$ ,  $\mathbf{Y}_2 = \mathbf{U}\mathbf{\Sigma}_1\mathbf{V}_1^H$ . It can be proved that the relationship of generalized eigenvalue and the characteristic root:

$$s_i = \ln(\sqrt{z_{ri}^2 + z_{ii}^2}) + j \frac{z_{ri}}{\sqrt{z_{ri}^2 + z_{ii}^2}} \quad (3)$$

So, if the generalized eigenvalue is solved, we can get the amplitude and the characteristic root of the identification signal  $y(k)$ :

$$\mathbf{Y}_1 \mathbf{u} = z \mathbf{Y}_2 \mathbf{u} \quad (4)$$

$A_i$  can be got through the follow linear system of equations:

$$\mathbf{y} = \begin{bmatrix} 1 & 1 & L & 1 \\ z_1 & z_2 & L & z_q \\ M & M & O & M \\ z_1^{k-1} & z_2^{k-1} & L & z_q^{k-1} \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ M \\ A_q \end{bmatrix} = \mathbf{Z} \mathbf{A} \quad (5)$$

Solve it by least square method:

$$\mathbf{A} = (\mathbf{Z}^H \mathbf{Z})^{-1} \mathbf{Z}^H \mathbf{y} \quad (6)$$

#### IV. DESIGN STEPS

1) Firstly, identify the order of the signal by stability diagram, than we can get the signal component, after knowing the order of the system;

2) And then, identify parameters of low frequency signal, such as the amplitude, damping, frequency, and so on, by matrix pencil algorithm;

3) Demonstrate the validity of this method, by three groups Simulate Signal.

#### V. SIMULATION ANALYSIS

**Analog Signal Analysis.** Assuming the low frequency oscillation is linear combination of sinusoidal signal (oscillation mode), the frequency of which is stable and the

amplitude changes according to the index law. Then the random noise can be expressed as:

$$y(k) = e^{-0.2t} \cos(2\pi f_1 t) + e^{-0.5t} \sin(2\pi f_2 t) + w(t) \quad (7)$$

Where,  $f_1=1.5\text{Hz}$ ,  $f_2=1.0\text{ Hz}$ . The signal of the simulation is digital, and the frequency is 200Hz. The variance of the noise is 0.04.

To study the effect of this method, the noise is brought in, which is shown in the following figure. And then we analyzed the simulation to make the result be more persuasive. The contrast method adopted is the least square method rotation invariant technology (TLS-ESPRIT).

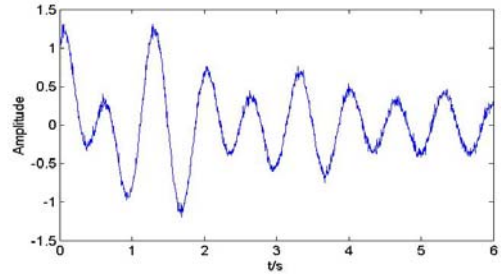


Figure 1. The simulated signal with noise

Obviously, the oscillation frequency and damping factor can be gained through TLS-ESPRIT. The result of the identification can be seen from the first 3 lines of the Tab.1. It can be known from the following table that the maximum relative error of the damping ratio adopting the matrix pencil is 1.0%; the maximum relative error of the damping ratio adopting TLS-ESPRIT is 2%.

TABLE I. PARAMETERS OF LOW FREQUENCY OSCILLATION MODEL FUNCTIONS

Method	modality	f/Hz	damping ratio	amplitude
LS	1	1.5002	-0.2045	1.0054
TLS	2	1.0019	-0.4965	1.0098
MP	1	1.4995	-0.1980	0.9982
MP	2	0.9998	-0.5026	1.0084

The figures of the table above are the result of simulation, where the SNR=27.9dB. The algorithm of the fifth column is the parameter error without adding filtering wavelet. Apparently, the method adopted by this essay is a little better than the contrast method, when the signal to noise ratio reaches 27.9dB.

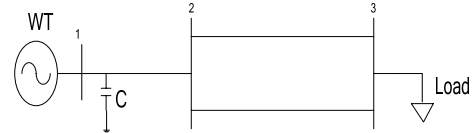


Figure 2. One Machine-Infinite Bus System

#### VI. ONE MACHINE-INFINITE BUS SYSTEM ANALYSIS

The capacity of the wind turbine is 275kVA, the voltage is 480V. The load changed abruptly at 0.2s, varying from 50kW to 75kW. The main parameter of the asynchronous

wind turbine: the stator resistance  $R_s=0.016$ , the stator inductance  $L_{ls}=0.06$ , rotor resistance  $R_r=0.015$ , rotor inductance  $L_{lr}=0.06$ , magnetic inductance  $L_m=3.5$ , inertia time constant  $H=2s$ , damping factor  $F=0$ , damping factor  $p=2$ , the capacity of capacitance is  $75kVar$ , and the wind speed is  $10m/s$ .

TABLE II. PARAMETERS OF LOW FREQUENCY OSCILLATION MODEL FUNCTIONS

Method	modality	$f/Hz$	Damping ratio	amplitude
MP	1	1.6920	-2.0549	12.5877
MP	2	0.5822	-0.9807	22.9714
MP	3	0	-0.0006	200.1929

Under the circumstance of microvariations, the system parameters of one machine system are shown in the table above, and there are two oscillating components and one direct component. The direct component is stable operation power. The oscillating component is generated by the step change of the load. The oscillating and direct component can also be found in the displayed value of the stability diagram.

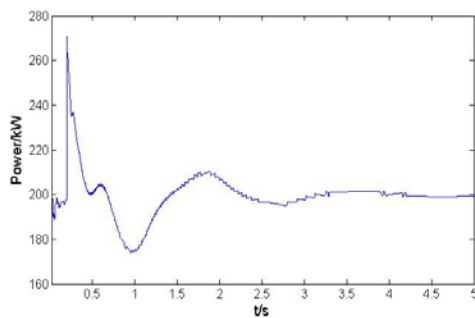


Figure 3. The Oscillatory Power of One Machine - Infinite Bus System

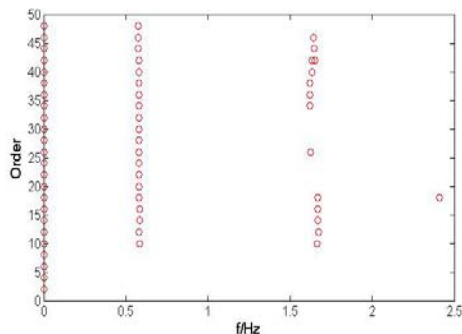


Figure 4. The Oscillatory Power of Stabilization Diagram

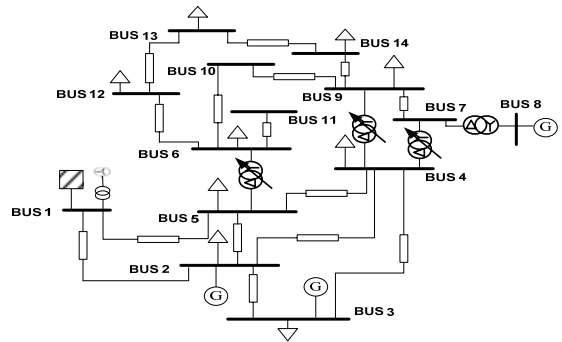


Figure 5. Schematic diagram of IEEE 5 Machine 14 Bus

### VII. IEEE 5 MACHINE 14 BUS ANALYSIS

The schematic diagram of IEEE 5 machine 14 bus can be seen in Figure 5. The double feedback wind turbine was connected to the bus, and the capacity of the wind turbine is  $600MVA$ . The load changed abruptly at  $1s$ , and the main parameters of the double feedback wind turbine: the stator resistance  $R_s=0.001$ , the stator reactance  $X_s=0.01$ , rotor resistance  $R_r=0.01$ , rotor inductance  $X_r=0.08$ , magnetic inductance  $X_m=3$ , inertia time constant  $H=6kWs/kVA$ .

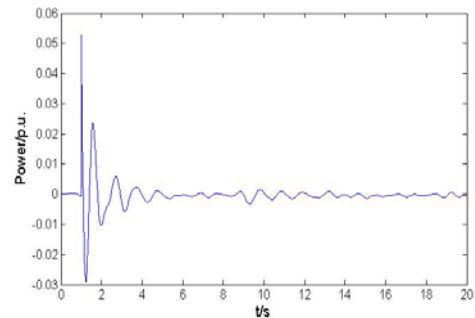


Figure 6. The Oscillatory Power of IEEE 5 Machine 14 Bus

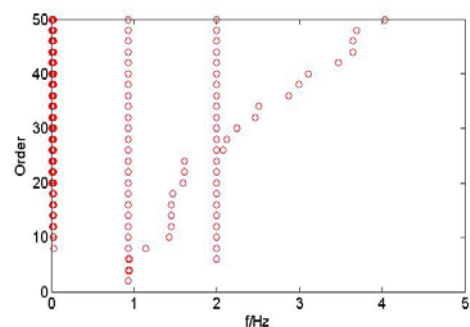


Figure 7. The Transmission Power of Stabilization Diagram

TABLE III. PARAMETERS OF LOW FREQUENCY OSCILLATION MODEL FUNCTIONS

Method	modality	$f/Hz$	Dampingratio	amplitude
MP	1	1.9683	-0.6809	0.0450
MP	2	0.9478	-0.1615	0.0180
MP	3	0	-0.0142	0.0010

Under the large disturbance circumstance, the parameters of IEEE 5 Machine 14 Bus are shown in the above table, and there are two oscillating components and one direct component. The oscillating component is generated by the short circuit. The stability diagram can also demonstrate the oscillating and direct component.

### VIII. CONCLUSION

The Matrix Pencil Algorithm has been used to identify the parameter of the low frequency oscillation of the electrical system including wind turbine. The advantage of this method is that it can avoid iterations can get high identification precision in the acceptable calculated amount.

1) The algorithm used in this essay can also process the nonlinear steady signal and then online non-stationary signal, which can obtain excellent result.

2) To provide reference for PSS, the stability diagram can be used to identify the order during the normal operation of the system, or under the circumstance of little disturbance, then the low damping pattern and model parameters can be identified through matrix pencil algorithm.

Furthermore, due to the matrix pencil algorithm's high speed, and the stability diagram's widespread use, it can offer a method used for reference on-line analysis of the low frequency oscillation the electric system with wind turbine.

### REFERENCES

- [1] WANG Hui, SU Xiao-lin. Several improvements of Prony algorithm and its application in monitoring low-frequency oscillations in power system [J]. Power System Protection and Control, 2011, 39(12): 140-145. (in Chinese)
- [2] LI Tian-yun, YUAN Ming-zhe, LI Jun-qiang et al. Method of modal parameter identification of power system low frequency oscillation based on EMD and SSI [J]. Power System Protection and Control, 2011, 39(8): 6-10. (in Chinese)
- [3] GUO Rui, WANG Xiu-pang, GUO Shan-shan et al. Analysis of Low Frequency Oscillations Using HHT Method [J], Proceedings of the CSEE, 2006, 26(14):24-30 (in Chinese)
- [4] ZHAO Li-jie. Application of Prony algorithm based on EMD for identifying model parameters of low-frequency oscillations [J]. Power System Protection and Control, 2009, 37(23): 9-14, 19. (in Chinese)
- [5] Wang Nana, Liu Dichen, Liao Qingfen et al. Identification of the Dominant Inertial Mode Based on EMD-TEO and Signal Energy Method [J]. TRANSACTIONS OF CHINA ELECTROTECHNICAL SOCIETY, 2012, 27(6): 198-204. (in Chinese)
- [6] Deng Jixiang, Ou Xiaogao, Yao Tianliang. Detection of the Dominant Inertial Modes Based on Wavelet Energy Coefficient [J]. TRANSACTIONS OF CHINA ELECTROTECHNICAL SOCIETY, 2009, 24(8): 141-146. (in Chinese)
- [7] Li Xun, Gong Qingwu, Jia Jingjing et al. Atomic Sparse Decomposition Based Identification Method for Low-Frequency Oscillation Modal Parameters [J]. TRANSACTIONS OF CHINA ELECTROTECHNICAL SOCIETY, 2012, 27(9): 124-133 (in Chinese)
- [8] Yang Dechang, Christian. Rehtanz Li Yong et al. Application of "Individual" and "Ensemble" Integration Method in Low Frequency Oscillation Analysis [J]. TRANSACTIONS OF CHINA ELECTROTECHNICAL SOCIETY, 2012, 27(9): 133-139 (in Chinese)
- [9] ZHANG Jing, XU Zheng, WANG Feng et al. TLS-ESPRIT Based Method for Low Frequency Oscillation Analysis in Power System [J]. Automation of Electric Power Systems, 2007, 31(20): 84-88 (in Chinese)
- [10] WANG Jing-yu, YU Ji-lai. Matrix pencil method of oscillation modes identification in power systems [J]. Proceedings of the CSEE, 2007, 27(19): 12-17. (in Chinese)
- [11] LI Yuanyuan, QIU Yuefeng, MASHIYING et al. Impact of Grid-Connected Wind Turbine Generators on Small Signal Stability of Power Grid [J]. Power System Technology, 2012, 36(8): 50-56. (in Chinese)
- [12] LI Yuanyuan, QIU Yuefeng, MASHIYING et al. Low Frequency Oscillation Damping Characteristics of Power System with DFIG [J]. Journal of Shenyang University of Technology, 2013, 36(1): 1-6. (in Chinese)
- [13] ZHU Rui-ke, LI Xing-yuan, ZHAO Rui, et al. Application of Matrix Pencil Algorithm in Synchronous Machine Parameters Identification [J]. Automation of Electric Power Systems, 2012, 36(6): 52-55. (in Chinese)
- [14] ZHANG Yu-hui, CHEN Feng, LI Hui-min et al. Parameter identification of synchronous machine based on wavelet transform and matrix pencil algorithm [J]. Power System Protection and Control, 2012, 40(9): 87-92. (in Chinese)
- [15] LI Kuan, LI Xingyuan, ZHAO Rui. Detection of Subsynchronous Oscillation in HVDC Transmission System Based on Improved Matrix Pencil Method [J]. Power System Technology, 2012, 36(4): 42-46. (in Chinese)
- [16] Chang Jun, Zhang Qi-wei, Sun Li-min. Application of stabilization diagram for modal parameter identification using stochastic subspace method [J]. Engineering mechanics, 2007, 24(2): 39-44