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An Extraction Method of Key Mode for Wide-band Oscillation in Power Electronic-based Power Systems

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***Abstract*—With the development and popularization of power electronic-based power systems, the wide-band oscillation becomes more and more serious around the world. In order to better represent and describe the wide-band oscillation, this paper presents a mode extraction method for the wide-band oscillation in the modern power electronic-based power systems. The effective value (RMS) representation is developed from the instantaneous value representation to observe the oscillation more intuitive. Based on the matrix pencil algorithm and active power data, the typical oscillation mode information can be extracted such as oscillation frequency, damping ratio, residue, and the eigenvalue. The effectiveness of the proposed method has been verified through the case study according actual oscillation measurement data.**

***Keywords*—mode extraction; wide-band oscillation; power electronic-based power systems; RMS; matrix pencil algorithm**

I. INTRODUCTION

Recently, renewable energy power generation is developing rapidly all over the world. It's thought that by 2021, the global installed capacity of photovoltaic(PV) will be 733GW, and the wind power will be 713GW[1]. With the quick increasing of renewable energy proportion, the characteristics of the power system have changed profoundly, driven by the large-scale adoption of electronic power converters for renewable generation[2][3]. The power electronic-based power system comes into being. However, the power electronic converter is still relatively new for the legacy power grid, which paves the way towards modern power grid with high flexibility and improved efficiency, yet it also poses new challenges to the stability and power quality of the power system[4].

The special wide timescale control dynamics of converters can result in cross coupling with both the power grid and the power electronic equipment, which may lead to the oscillations

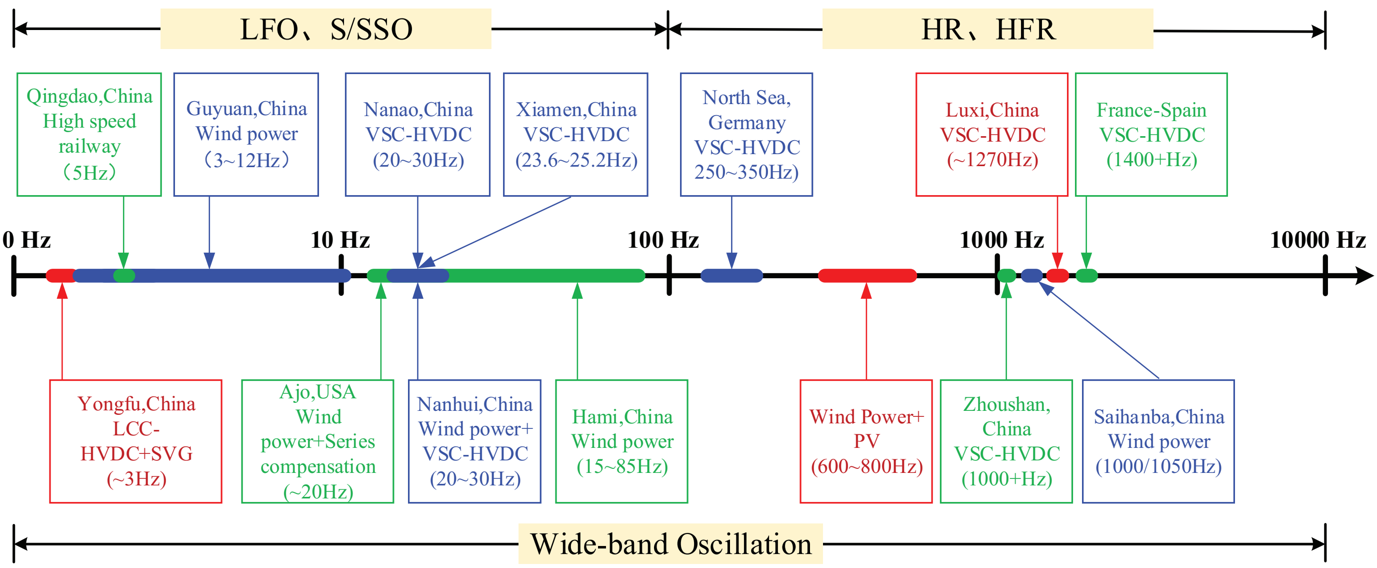


Fig 1 The statistical of wide-band oscillation in power electronic-based power systems

across a wide frequency range[5]. With the development and popularization of power electronic-based power systems, this issue becomes more and more serious. A number of incidents have been reported with the grid integration of renewables, VSC-HVDC and electrified transportation[6]–[9], as shown in Fig.1, where the undesired low frequency oscillation(LFO), sub/sup-synchronous oscillation(S/SSO), harmonic resonance(HR), or high-frequency resonance(HFR) caused disruption to the power supply. Such oscillations have the following characteristics: (1) the oscillation frequencies range from 2Hz to 2kHz, which has broadband frequency properties; (2) the oscillation mechanism involves the interaction of converters, generator sets and AC/DC power grid, whose influence factors are complex.

There have been growing interests in identifying the causes of wide-band oscillation in the power electronic-based power systems[10]-[13]. Previous studies mostly have made inspections from the modeling, mechanism analysis and suppression, but researches which are related to phenomena representation and data mining are not heavy. The familiar representation technology such as instantaneous value waveform, spectral analysis has no longer satisfied all requirements on wide-band oscillation in power electronic-based power systems[14].

Therefore, the effective value(RMS) representation for wide-band oscillation is presented in this paper. Then, this paper elaborates an extraction method based on matrix pencil algorithm for key oscillation mode information, which can provide the oscillation frequency, damping ratio, residue, and the eigenvalue. Lastly, the effectiveness of the proposed method has been verified through the case study according actual oscillation measurement data.

II. THE DATA MINING AND MODE EXTRACTION METHOD

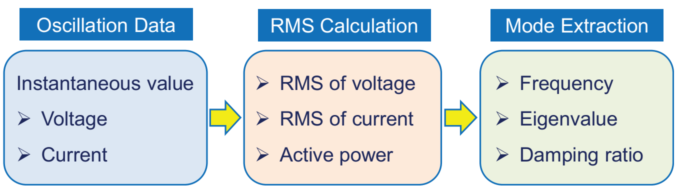


Fig.2 The flow chart of the data mining and mode extraction

The flow chart of the data mining and mode extraction is shown in Fig.2. Initially the wide-band oscillations in power electronic-based power systems usually are recorded in the form of instantaneous value. Then, the effective value of voltage, effective value of current and active power can be obtained by effective value(RMS) calculation. The effective value presentation can provide other valuable information, which could help us a better understanding of wide-band oscillations. After that the extraction of key oscillation mode can proceed depending on the RMS data obtained in the previous step.

There are some methods for the mode extraction, in which the Matrix Pencil(MP) algorithm has the merits of simple calculation and high calculation efficiency as an useful method for signal processing and parameter estimating[15], converting the special characteristic of signal to the relation of matrix, which transfer the nonlinear problem to the matrix decomposition through matrix pencil constructed from sampled data. Specific steps are as follows:

(1) Hankel Matrix constructing

First **Y** is decomposed:

$$\mathbf{Y}=\mathbf{U}\Sigma\mathbf{V} \tag{1}$$

where **U** and **V** is unitary matrix and Σ is diagonal matrix of singular values.

(2) Singular value decomposition, determining the maximum number of modes

(3) Calculating the key information of the mode (eigenvalue, oscillation frequency, damping ratio, residues, etc.)

$y(t)$ denotes the output of the system, when discrete sampling, the system can be expressed as:

$$y(k)=\sum_{i=1}^{n} R_i z_i^k, k=0,1\cdots N-1 \tag{2}$$

In which, n is the order number of the system, which is not a definite value for a real system, and N is the number of the sampled point.

R_i is the residue of the mode:

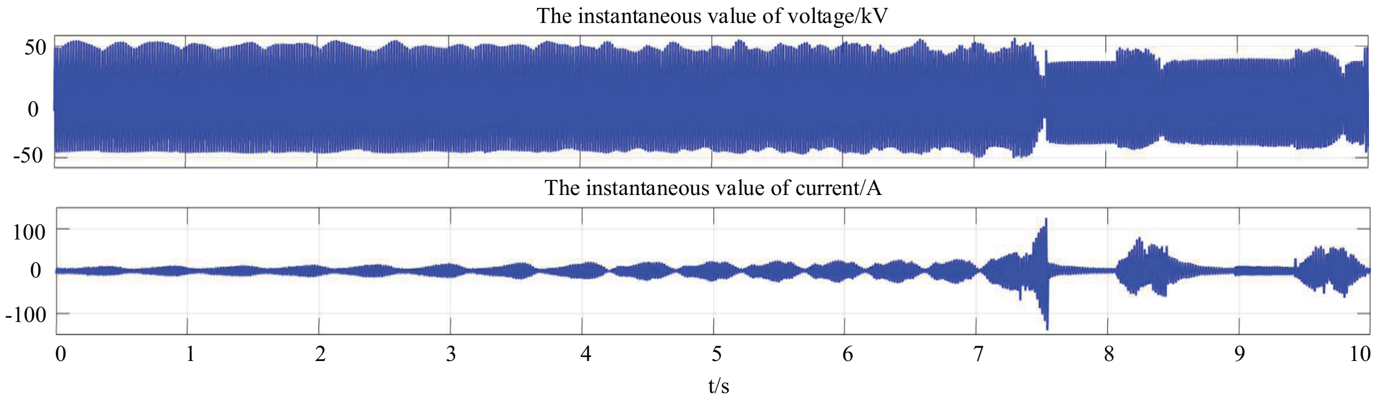
$$R_i = A_i e^{j\theta_i} \tag{3}$$

The eigenvalue is:

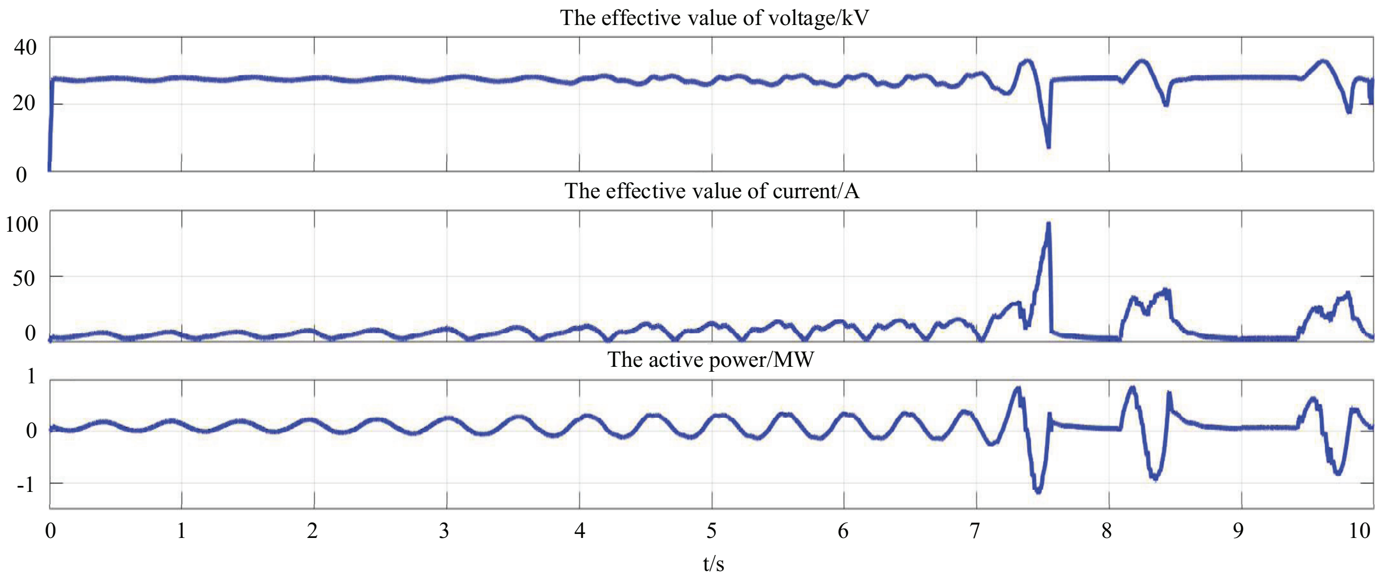
$$\lambda_i = a_i + j2\pi f_i \tag{4}$$

When the eigenvalue is a real number, it corresponds to a non-oscillation mode, and if the eigenvalue is a complex number, it corresponds to an oscillation mode.

Based on the matrix pencil algorithm and active power data, the typical oscillation mode information can be extracted such as oscillation frequency(f), damping ratio, residue, eigenvalue, and so on. Damping ratio expresses the decay rate of the oscillation amplitude, which also can show the effective of the system damping. If the damping ratio is greater than 0, the mode is stable, and the greater the damping ratio, the stronger the damping for the oscillation. Damping ratio equaling to 0 indicates critical stability. If damping ratio is less than 0, the mode is unstable. Residue represents the initial amplitude and angle. The amplitude of residue can express the initial energy of the oscillation signal. Thus, the dominant mode of the system can be recognized through the maximum of the residue. From the above, the oscillation mode and damping of the power electronic-based power systems can be got, which will also help us better represent and describe the wide-band oscillations.



(a) The instantaneous value of voltage and current



(b) The effective value and active power

Fig.3 The instantance value and effective value(RMS) representation of typical oscillation waveform

III. The Case Study

In this section, a piece of actual measurement data from the oscillation in China Railway High-speed power supply system is selected as the case, whose instantaneous value of voltage and current are shown in Fig.3(a). It can be seen that the instantaneous value envelope of the voltage and current waveforms present low-frequency periodic oscillation. Meanwhile, the oscillation of the voltage and current are simultaneous and related. When the voltage waveforms fluctuate, the associated current will fluctuate in the similar frequency.

Then on the basis of the effective value (RMS) calculation, the relevant parameters, such as effective value of voltage, effective value of current and active power, can be obtained as shown in Fig.3(b). The RMS representations of typical oscillation waveform show that the effective value can help us better understand the oscillation. The RMS waveforms can be approximated as the instantaneous value envelopes in the aspect of oscillation representation. And the fluctuation of the active power changes in the same way as the effective value of current and voltage. In particular, this phenomenon can be regarded as a kind of low-frequency power oscillation according to the low-frequency periodic oscillation of active power. The oscillation frequency is approximate to 2Hz from the first part(0~7s) of the active power waveform, and the later part(7~10s) is about 0.7Hz.

After that, the active power is divided into 3 parts, which are 0~4s, 4~7s and 7~10s, so that the mode extraction can be carried out based on Matrix Pencil algorithm respectively.

A. Mode extraction based on the active power from 0s to 4s

The waveform of active power from 0s to 4s is shown in Fig.4. According to Matrix Pencil calculation, the extraction results of key oscillation mode information can be obtained, as illustrated in Table I.

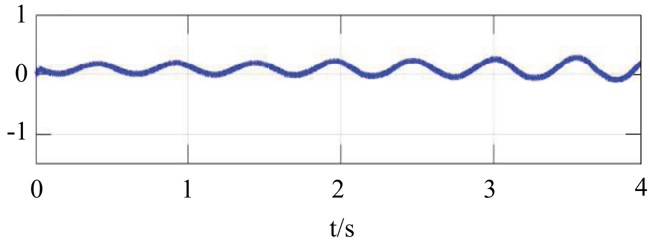


Fig.4 The waveform of active power/MW from 0s to 4s

TABLE I. THE EXTRACTION RESULT OF KEY MOED INFORMATION

No.	*f*/Hz	Damping ratio/%	Residue	Eigenvalue
1	**1.9**	**-1.1**	**10056-j50126**	**0.14+j12.97**
2	1.7	42.8	2328+j6741	-5.07+j10.70
3	0.4	53.0	2430-j4504	-1.67+j2.68

According to the definition of residue, with bigger residue comes bigger initial amplitude of the oscillation mode, the modes in Table I are in descending order according to the module value of the residue. Combined with damping ratio, it can be concluded that the first line is the dominant mode, whose damping ratio is less than 0 and close to 0. The oscillation frequency is 1.9Hz. From this it can be deduced that the mode is an increasing oscillation or approximate persistent oscillation, and the growth trend is very slow. These conclusions coincide with the oscillation tendency in Fig.4, which can verify the effectiveness of the proposed method.

B. Mode extraction based on the active power from 4s to 7s

The waveform of active power from 4s to 7s is shown in Fig.5. Similarly, the extraction results of key oscillation mode information can be calculated, as illustrated in Table II.

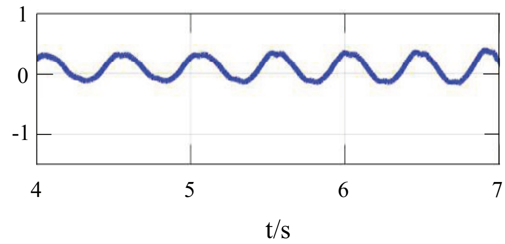


Fig.5 The waveform of active power/MW from 4s to 7s

TABLE II. THE EXTRACTION RESULT OF KEY MOED INFORMATION

No.	*f*/Hz	Damping ratio/%	Residue	Eigenvalue
1	**2.0**	**-4.3**	**125757+j80246**	**0.54+j12.50**
2	2.2	-4.9	-19954+j55	0.68+j14.04
3	1.3	9.4	-2680+j3520	-0.75+j7.89

Based on Matrix Pencil calculation, the mode extraction results show that the first line is the dominant mode, whose oscillation frequency is 2.0Hz and damping ratio is -4.3%. Compared to the second line, the residue of the first line is bigger. It can be indicated that the oscillation dominated by this mode is approximate persistent oscillation, which is in accord with the oscillation tendency in Fig.5.

C. Mode extraction based on the active power from 7s to 10s

The waveform of active power from 7s to 10s is shown in Fig.6. Similarly, the extraction results of key oscillation mode information can be counted, as illustrated in Table III.

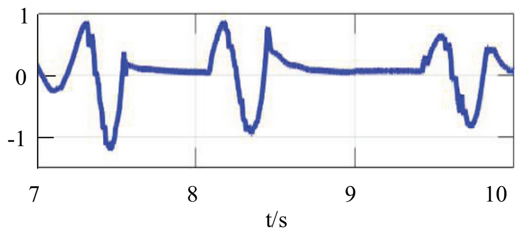


Fig.6 The waveform of active power/MW from 4s to 7s

TABLE III. THE EXTRACTION RESULT OF KEY MOED INFORMATION

No.	*f*/Hz	Damping ratio/%	Residue	Eigenvalue
1	2.2	4.3	-343895-j94839	-0.60+j14.02
2	1.3	2.5	-85811+j109277	-0.22+j8.61
3	**0.7**	**-1.9**	**-9935-j37521**	**0.10+j4.94**

It can be seen that there are three main oscillation modes. The damping ratio of the first two mode are greater than 0, so these two modes represent the oscillation convergence, which will be reduced progressively to zero in the system. The damping ratio of the third mode is -1.9%, thus it can be concluded that the third line is the dominant mode. The oscillation frequency is 0.7Hz, which is in keeping with the oscillation tendency in Fig.6. Extraction results show that the proposed method is still applicable for the relatively complex oscillation and can precisely extract the key oscillation mode information.

IV. Conclusion

This paper presents an extraction method of key mode for wide-band oscillation in the modern power electronic-based power systems. Firstly, developed from the instantaneous value representation, the effective value (RMS) waveform can be approximated as the instantaneous value envelopes in the aspect of oscillation representation, which could help us a better understanding of wide-band oscillation. Based on the matrix pencil algorithm and active power data, the typical oscillation mode information can be extracted such as oscillation frequency(f), damping ratio, residue, eigenvalue, and so on, which will also help us better represent and describe the wide-band oscillation. Finally, the effectiveness of the proposed method has been verified through the case study according actual oscillation measurement data. Meanwhile, extraction results show that the proposed method is still applicable for the relatively complex oscillation and has a good adaptability.

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