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Study on the Time Domain Identification Method for Low-order Modal Parameters of AACSR/EST Conductors using Improved RDT-ITD Method

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Abstract: Conductor low-order modal parameters are most important to study wind-induced vibration phenomenon for transmission lines. But there is still a lack for the effective test method to obtain these parameters. In this study, a improved RDT is obtained by proposing a new random sampling triggering condition, which is more advantaged for the limitations of the number of triggering points and the crossing threshold value than the traditional threshold level crossing triggering condition. Then, a time domain identification method for conductor low-order modal parameters is put forward by using the improved RDT-ITD method and introducing the digital filtering method and the averaging method, which is more effective to obtain these parameters under the condition of the natural excitation. Finally, two types of AACSR/EST conductors, AACSR/EST-500/230 and AACSR/EST-400/180, usually used in the large-crossing engineering are presented as examples to identify their low-order modal parameters to verify the feasibility of this method.

Key words: Low-order modal parameters, RDT-ITD method, time domain identification method, conductor wind-induced vibration

INTRODUCTION

Wind-induced vibration (Diana *et al*., 1982) has become a main danger (Zhu *et al*., 2009) to the safe and stable operation (Zheng, 1987) of power grid. According to different frequency, the form of wind-induced vibration can be divided into three kinds: The aeolian vibration (5-100 Hz), subspan oscillation (1-5 Hz) and galloping (0.5-3 Hz). Damping characteristic is the most important parameter that affects the vibration characteristic of conductor (Richardson, 1995). Factors that affect the damping characteristics are very complicated but there is no useful theoretical calculation method on the determination of damping coefficient both at home and abroad, mainly through experiment to get it. At present, the research achievements were mainly about the damping characteristics of conductors in higher frequency under the condition of Aeolian vibration, research on the low-order modal parameters' characteristics is less, which severely restricted the development of theory and control technology of wind-induced vibration. In this study, the random decrement method was improved and stochastic sampling trigger condition was established due to the wind-induced vibration is generally weaker and the signal acquisition has a limited capacity. Then, time domain identification method for conductor low-order modal parameters is put forward using improved RDT-ITD method. Finally, two types of conductors, AACSR/EST-500/230 and AACSR/EST400/180, are presented as examples to identify their low-order modal parameters.

METHODS

Time domain modal parameter identification method based on environment excitation (Xu *et al*., 2002) usually includes in two key areas: The reasonable processing for response signal and efficient application of recognition algorithm. Currently there are two ways for signal processing: one is to extract the free attenuation signal directly from the response signal, known as the Random Decrement method (RDT) (Asmussen, 1997); the other is Natural Excitation technology (NExT) (James *et al*., 1995), the cross-correlation function and impulse response function between two response points has a similar expression, this relationship was used to process response signal. Modal parameters Identification Algorithm include Eigen system Realization Algorithm (ERA), (He and Qin, 2009; Juang and Pappa, 1985), Stochastic Subspace Identification (SSI) and Ibrahim Time Domain (ITD) (Ibrahim, 1986).

In this study, the random decrement method was improved and stochastic sampling trigger condition was established due to the wind-induced vibration is generally

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weaker and the signal acquisition has a limited capacity. Then, time domain identification method for conductor low-order modal parameters is put forward using improved RDT-ITD method.

Research on trigger condition using random decrement method. Random decrement technique was first put forward by Cole (1968), its basic thought was established on the basis of the superposition principle of linear system (Bedewi, 1986), it means that for structural random response, two parts of deterministic and stochastic response will be separated under certain conditions and then rule out the portion of the random using statistical average method, filter the determinate of free decay signal.

In the practical application of the random decrement technique, the arithmetic average of the sub signal serves as the estimate value for random decrement function. General expression is as follows:

$$\hat{D}_{XX}(\tau) = \frac{1}{N}\sum_{i=1}^{N} x(t_i+\tau)\Big|T_{x(t_i)} \quad (1a)$$

$$\hat{D}_{YX}(\tau) = \frac{1}{N}\sum_{i=1}^{N} y(t_i+\tau)\Big|T_{x(t_i)} \quad (1b)$$

Among them, N is the number of intercepted signal or trigger points of random decrement function, $T_{x(t)}$ ` $T_{y(t)}$ are the trigger condition for random decrement function, X (t) and Y (t) are random process, $\hat{D}_{XX}(\tau)$, $\hat{D}_{YX}(\tau)$ are the random decrement function and mutual random decrement function. The amount of wind excitation is usually weak in actual conductor structure and the change is bigger, so the selection process of traditional random decrement trigger condition is more troublesome and improper selection will cause the signal distortion; In addition, under the condition of limited sampling for wind vibration response signal, the traditional random decrement trigger condition cannot guarantee enough average number for sub signal, so that affect the identification accuracy. According to these two problems, random decrement function was expanded on the basis of traditional level crossing triggering condition, then the x (τ) has arbitrary values (Liu *et al*., 2007; Nie *et al*., 2009).

That is:

$$\hat{D}_{XX}(\tau) = \frac{1}{N}\sum_{i=1}^{N} \gamma\cdot x(t_i+\tau)\Big|T_{x(t_i)} \quad (2a)$$

$$\hat{D}_{YX}(\tau) = \frac{1}{N}\sum_{i=1}^{N} \gamma\cdot y(t_i+\tau)\Big|T_{x(t_i)} \quad (2b)$$

Among them:

$$\gamma = \begin{cases} 1 & T_{X(t)}(X(t)\ge 0) \\ -1 & T_{X(t)}(X(t)<0) \end{cases}$$

On this basis, the random sampling trigger condition was proposed. First, the length of the random response data was known as T, between the time interval [0, T], execute the random sampling by any probability distribution, the sampling frequency was a given average number of N. Using a simple uniform distribution, for example, get the sampling sequence $\tilde{t}_i$, i = 1,···,N and the distribution density of this sequence is:

$$p(\tilde{t}) = \frac{1}{T}, \quad 0\le \tilde{t} \le T$$

$$T_{X(t)} = \begin{Bmatrix} \begin{Bmatrix} 0\le X(\tilde{t}) < \max(X(t)) \\ \min(X(t)) \le X(\tilde{t}) < 0 \end{Bmatrix}, \\ -\infty \le \dot{X}(\tilde{t}) < +\infty \end{Bmatrix} \quad (3)$$

At the same time, in Eq. 2:

$$\gamma = \begin{cases} 1 & T_{X(t)}(0\le X(\tilde{t}) \le \max(X(t))) \\ -1 & T_{X(t)}(\min(X(t)) \le X(\tilde{t}) < 0) \end{cases} \quad (4)$$

ITD method: ITD is the method which use free response sampling data to establish the mathematical model of characteristic matrix, eigenvalue and eigenvector is obtained through solving equations of the characteristic matrix, then modal parameters are obtained from characteristic solution, this method was called a single input and multi-output modal identification method. ITD method has a satisfactory accuracy for identifying of the modal frequency but the recognition accuracy will be impacted when there is a big noise. ITD method has higher identification accuracy for modal frequency than that of modal damping. In order to improve the identification precision of modal damping, dual least squares method was put forward by Cooper (1996), the corresponding recognition matrix is as follows:

$$A = \frac{1}{2}\left\{\left[\bar{\Phi}\Phi^T\right]\left[\Phi\Phi^T\right]^{-1} + \left[\bar{\Phi}\bar{\Phi}^T\right]\left[\Phi\bar{\Phi}^T\right]^{-1}\right\} \quad (5)$$

Among them, the characteristic matrix A meets $A\Phi = \bar{\Phi}$, Φ and $\bar{\Phi}$ are the time course matrix of free attenuation signal using random decrement technique. Set characteristic root of matrix A is $\alpha_n+\beta_n J$ and then the nth order modal frequencies and modal damping will be obtained:

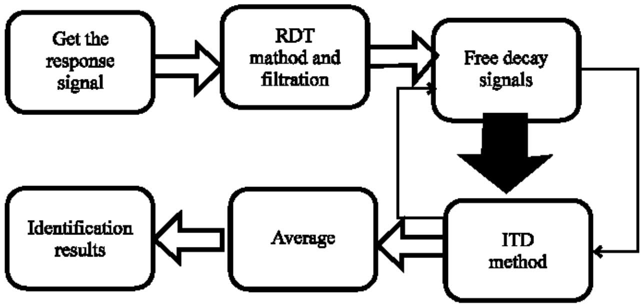

Fig. 1: Process for conductor low-order modal parameters identification

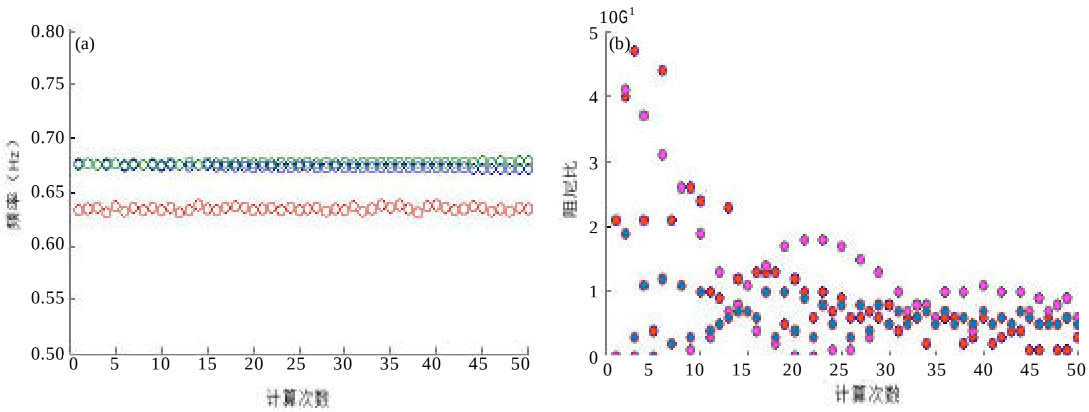

Fig. 2(a-b): Results of first order frequency (0.635 Hz) and damping ratio (0.0000625) for conductor of AACSR/EST-500/230

Table 1: Results of modal parameters for the two types of conductors

Order	1	2	3	1	2	3	4
Frequency (Hz)	0.635	1.760	2.868	0.663	1.863	3.209	4.355
damping ratio (10^{-3})	0.625	0.311	0.099	0.505	0.148	0.373	0.124
Conductor type	AACSR/EST-500/230		AACSR/EST-400/180				

$$P_n = \frac{1}{2\Delta t}\ln\left(\alpha_n^2 + \beta_n^2\right), \quad Q_n = \frac{1}{\Delta t}\left(\arctan\left(\frac{\beta_n}{\alpha_n}\right)\right)$$
$$\omega_n = \frac{1}{2\pi}\sqrt{P_n^2 + Q_n^2}, \quad \xi_n = \frac{P_n}{\sqrt{P_n^2 + Q_n^2}} \qquad (6)$$

Identification process of low order modal parameters for conductors: Low order modal parameters identification procedures were developed based on the research of the identification method, the process was shown in Fig. 1. First of all, select the appropriate random decrement the trigger condition according to the different sampling signal, get a better free attenuation signal using the random decrement method and appropriate filter processing; Then, identify the modal parameters for free attenuation signal samples many times using ITD method; Finally, average the modal parameter identification results to get the final recognition result.

Low order modal parameters identification for conductors: Two types of conductors, AACSR/EST-400/180 and AACSR/EST-500/230, using in large crossing lines were selected to test to identify their low-order modal characteristics, with in improved RDT-ITD method. Test conditions are as follows: (1)Test span: 147 m (2) Loading ways: Forced excite from one end to simulate natural incentives (3) Response signal measurement: Acceleration sensor.

Modal parameters test for conductor of AACSR/EST-500/230: According to the experimental sampling data of response signal, low-order modal characteristics of the conductor was identified using improved RDT-ITD method, frequency and damping ratio of the first three orders in vertical orientation were analyzed. Figure 2 and 3 shows part of the corresponding recognition result.

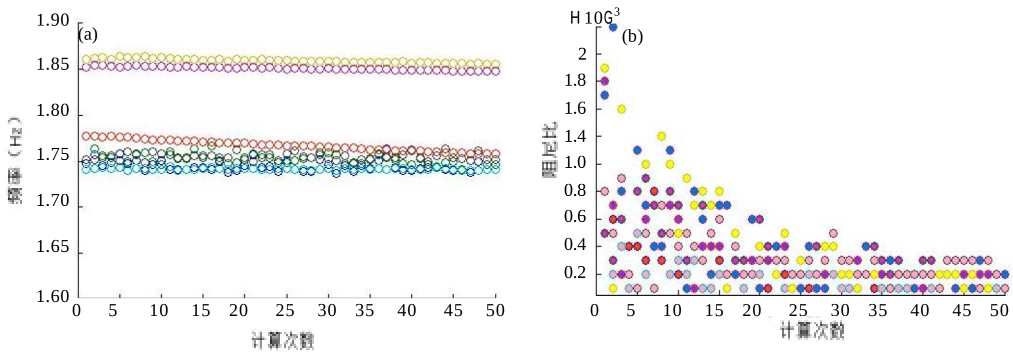

Fig. 3(a-b): Results of second order frequency (1.760 Hz) and damping ratio (0.0000311) for conductor of AACSR/EST-500/230

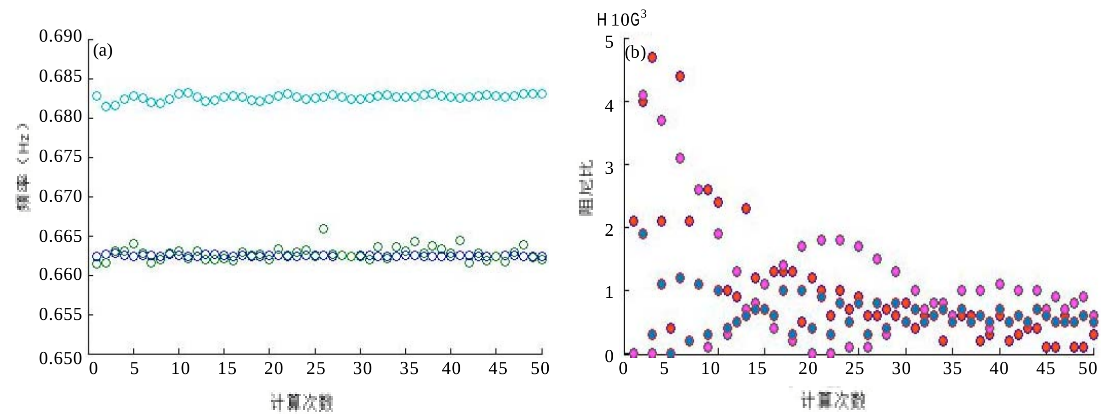

Fig. 4(a-b): Results of first order frequency (0.663 Hz) and damping ratio (0.0000505) for conductor of AACSR/EST-400/180

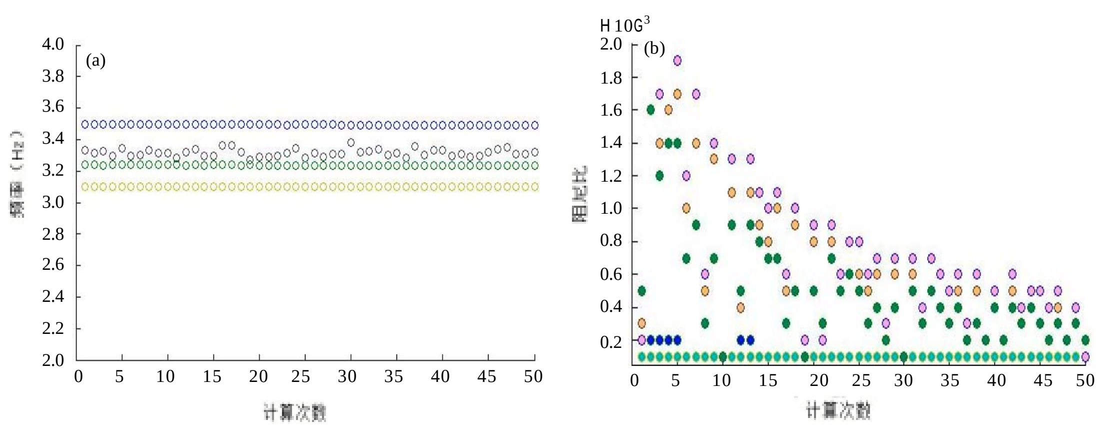

Fig. 5(a-b): Results of third order frequency (3.209 Hz) and damping ratio (0.0000373) for conductor of AACSR/EST-400/180

Modal parameters test for conductor of AACSR/EST-400/180: Frequency and damping ratio of the first four orders in vertical orientation were analyzed in the same way. Figure 4 and 5 shows part of the corresponding recognition results.

Table 1 shows the identification results of low-order modal parameter based on different trigger conditions for the two types of conductors, respectively. From the calculation result we can see that the conductor frequency identification results are more stable; but the damping ratio identification has certain dispersion, the final result should be obtained through statistical average processing.

CONCLUSION

According to environment excitation characteristics of transmission line conductor structure and actual situation of response signal collection, low-order modal characteristic identification method for conductor structure was proposed based on improved RDT-ITD method. This method was verified through test calculation; the results show that the method proposed in this study can give a better recognition result of modal parameters in low frequency and getting some conclusions as follows: (1) It is feasible that using improved RDT-ITD method to identify low-order modal parameter of conductor structure under the condition of environmental incentives. (2) Trigger points can be given in advance under the random sampling trigger conditions, for structural response signals, when sampling sample is small and there is insufficient data, this method can be used to obtain ideal results. (3) The results are more precise and have higher stability when using improved RDT-ITD method to identify modal frequency; The inaccuracy of damping ratio identified by this method has certain fluctuation but final result can be obtained through statistical average. (4) The choice of the sampling frequency has a significant impact for identification inaccuracy of damping ratio; in order to improve the recognition accuracy, lower sampling frequency should be chosen as far as possible.

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