Study on Chaos Neural Network Prediction Method for Rotating Machinery

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Abstract: Aiming at the operating condition of rotating machinery possessing nonlinear characteristics the nonlinear prediction method based on chaos neural network is studied to guarantee the safe and reliable operation and achieve scientific maintenance. The trend prediction model is constructed, the data acquisition and condition monitoring way are introduced and the related test verification and analysis based on chaos neural network prediction method are made. Chaos neural network prediction method colligates the advantage of chaos and neural network, obtaining good forecasting results with small prediction errors

Keyword: rotating machinery, Condition Monitoring, Chaos Neural Network, prediction

1 Introduction

Rotating machinery is the most widely used mechanical equipment in industry, usually various faults influence the normal operation of the machinery and even some faults cause severe accident with heavy economic losses. In order to ensure safe and reliable operation of the equipments and achieve scientific maintenance, the trend prediction study of machinery developing condition is of great importance [1].

Rotating machinery is a complex, multi-layer, mechanical system. There is not only the difference of structure and function among the subsystems in the layers, but also very complex coupling relationship among the subsystems. From the view of time evolvement of mechanical systems, it can be considered as a complex nonlinear power system. For long term prediction for the conditions (failure) in a nonlinear, complex mechanical system, there is "sensitivity problem of initial conditions". That is, for the same complex mechanical system, there is small difference of its initial operating conditions (state); but when the system has operated for a period, there is maybe large difference between its operating conditions and performance.

Aiming at the operating condition of rotating machinery possessing nonlinear characteristics the stack gas turbine units in the petrochemical industry is used as application object to study chaos neural network prediction method.

2 condition monitoring

2.1 research object

Stack gas turbine is the special turbine for catalytic cracking plant in the refinery, work done with its expansion by the thermal and pressure energies in the regeneration gas is converted into the mechanical energy, the power from the stack gas turbine is used to drive main fans or motors, and the purpose of energy recovery is achieved.

To know the operations of the units, especially the vibration and axial displacement of the units, the units is provided with vibration and displacement transducers (mainly non-contact eddy current transducer), vibration monitoring and protection system (such as Bentley 7200, 3300, 2500 and Schenck 4000). The configuration performing the monitoring is shown in the figure 1, which is also the overview of the units. The selected transducers are conventional transducers such as Bentley dual-channel vibration monitor unit 3300/16 XY/GAP.

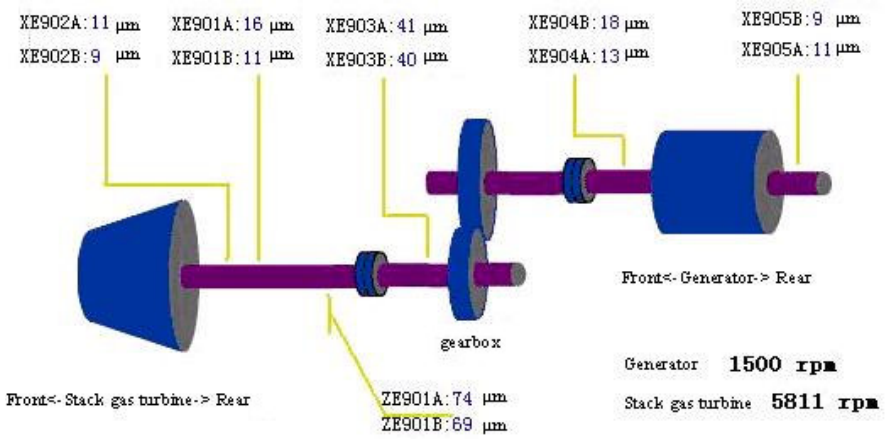

Figure 1 Overview of stack gas turbine units monitoring configuration

2.2 Data collection and condition monitoring

With the development of the Internet and Web technologies, real-time transmission of monitoring data via the Internet and Web has become the hotspot of the research gradually. Using the platform based on the remote monitoring and diagnosis center server and rotating machinery monitoring system can actually realize remote monitoring and management of the units. The sensitive monitoring concept is used in the monitoring system. Firstly, sensitive monitoring of vibration alarm in the units is to distinguish the frequency divisions of the vibration. It is not only for the alarm of total vibration value or the vibration itself, but also for alarm of any change in the vibration. Secondly, sensitive monitoring for the alarm limits of frequency divisions in the vibration from the units is obtained by means of learning the historical data statistics of the units itself. The system stores the data in the event-driven way, that is, the storage of historical data of operations doesn't determined by time. Only when an alarm of the operations of the units occurs, i.e., when an event occurs, the historical data are be saved.

The online actual data of stack gas turbine units is acquired from monitoring system installed in the enterprise. Then, the data are real-time transferred to the center server for remote monitoring and diagnosis. The center server consists of large data server, special software, Monitoring system is modular, networking monitoring and diagnosis platform for the plant. The system takes charge of data collection, analysis and processing; meanwhile, it solely takes charge of transferring the data to remote monitoring center.

Data server implements the data exchange with monitoring system, acquires real-time, historical and start/stop data from the monitoring system, obtains original buffer output signal of the vibration or obtains original vibration signals directly from vibration transducers, performs the conditioning and collection of signals, generates and stores useful data such as the start/stop data, performs the storage and management of data.

Instant distribution of real-time data is performed according to the requests of the user-end. Its purpose is to reduce the burden of network transmission as low as possible, achieve the effective utilization of network resource. Historical and start/stop data can be directly written into the database. Real-time, historical and start/stop data in the operation conditions data server in the remote monitoring and control center can be obtained via the network. Table 1 gives the data at 20:07, April 12, 2005 obtained remotely.

Using the data transmission technology based on the B/S structure can easily obtain remote monitoring diagnosis services via the Internet, supporting and achieving the condition inspection and maintenance. B/S structure has the advantages of easy operation, maintenance, upgrade, and lower maintenance costs.

Table 1 data at 20:07, April 12, 2005

Factory: Branch company of Petrochemical	Sub-station: No.2 station of No.3 catalytic shop		Keyphase: No.1 main fan	
Time: 2005-4-12 20:07	Sampling period: points of 8 cycles: 32		Speed: 6200rpm	
Channel No.	Total vibration value:	HHL:	HL:	Waveform
XT-7101	5.5	90	72	-0.58
	0.5x: 0.1∠21			-0.53
	1x: 2.1∠208			-0.86
	2x:1.0∠185			-0.94
	⋮			⋮
XT-7102	9.5	90	72	-2.57
	0.5x: 0.3∠146			-4
	1x: 7.5∠187			-2.14
	2x: 1.2∠42			-2.33
	⋮			⋮
⋮	⋮	⋮	⋮	⋮

3 chaos neural network prediction method

3.1 Chaos theory

The chaos is an important theoretical basis of modern nonlinear science. Chaos is apparently unpredictable behavior arising in a deterministic system because of great sensitivity to initial condition. In the power system, if any two adjacent initial points diffuse in the exponent way, their future conditions is unpredictable. Therefore, the system is chaos. The discrete of chaos is generally represented as chaos time series in which abundant dynamics information of the system is contained.

When using the chaos time series analysis method, phase space reconstruction is the basis of chaos time series analysis [2]. It is put forward by Packard and Takens. It introduces the chaos theory into nonlinear time series analysis. With theoretical analysis and numerical methods, it proves that state space reconstruction is capable of remaining geometric invariance of the original nonlinear power system. It establishes the basis using testing method to research high-order nonlinear power system. The persons including Takens introduce the method performing the phase space reconstruction of chaos time series $x=\{x_i \mid i=1,2,\cdots,N\}$ using delay coordinate method. Phase type distribution of *m* dimension phase space is shown in the table 2.

Where, m is embedding dimension, τ is time delay, M=N-(m-1)τ is the number of points in the phase space. Takens theorem has proved that reconstructed power system is equivalent topologically to original power system if embedding dimension m≥2d+1 (where, the d is the dimension of system dynamics).

Table 2 Phase type distribution of *m* dimension phase space

$x(t_1)$	$x(t_2)$	$\cdots$	$x(t_j)$	$x(t_n-(m-1)\tau)$
$x(t_1+\tau)$	$x(t_2+\tau)$	$\cdots$	$x(t_j+\tau)$	$x(t_n-(m-2)\tau)$
$x(t_1+2\tau)$	$x(t_2+2\tau)$	$\cdots$	$x(t_j+2\tau)$	$x(t_n-(m-3)\tau)$

…	…	…	…	…
$x(t_1+(m-1)\tau)$	$x(t_2+(m-1)\tau)$	…	$x(t_j+(m-1)\tau)$	$x(t_n)$

3.2 Forecasting theory of neural network

In the recent years, artificial neural networks (ANN) have been successfully applied in many fields. The advantages of the ANN are: large-scale parallel structures, distributed storage and parallel processing of information, good self-adaptability, self-organization and fault-tolerance, as well as strong learning, memory, association and recognition functions. The applications of the ANN provide the operation monitoring and trend forecasting of large units with new ideas [3].

Performing the trend forecasting of mechanical and electrical system with the neural network is the process that maps the historical data of time series into future data through neural network.

Neural network is a high-dimension nonlinear system. According to Kosmogorov theory, if the number of nodes of its hidden layer can be set randomly, one three-layer neural network can achieve any accuracy of function mapping approximation.

The main working of establishing the forecasting neural network model is to determine the structure of neural network and training network weight. The basis of BP algorithm theory is solid, the process of derivation is strict, and the versatility is strong. At present, it is one of the most common methods in training neural network.

3.3 chaos neural network forecasting method

Thanks to parallel processing of neural network and powerful nonlinear mapping capacity, that is, it can integrate processing methods and tools of many nonlinear signals, unknown power system can be learning by it, and then perform the forecasting and control. Because of deterministic regularity in the chaos time series, this regularity comes from nonlinear, it represents the correlation of time series in the time delay state space. This makes the system seem to have certain memory capacity; meanwhile it is difficult to express this regularity by using general analytical method. But this information processing mode is just what neural network can provide.

Construct three-layer chaos time series forecasting system based on the BP neural network. BP neural network structure is shown in Figure 2. The size of each layer in the neural network (i.e., the number of neuron), depends on the specific conditions of chaos time series. The number of first layer inputs is equal to the saturated embedding dimension of reconstructed phase space of chaos time series.

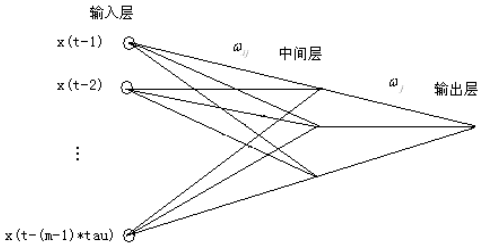

Figure 2 Three layers of neural network structure

Detailed procedures of chaos time series forecasting of BP network are as follows:

(1) Establishing the BP network: calculate embedding dimension (m) according to chaos time series, and the number of neurons of first layer inputs is expressed in the m.

(2) Learning phase: orderly input the M-1 value series after phase space reconstruction. Obtain an output result by the feed process, and compare this result with target model. If there is any error, perform back propagation process immediately, and correct the network weight to reduce the error. Forward output calculation and reverse weight correction shall be performed alternately, until the errors are controlled within the allowable range.

(3) Forecasting phase: list No. M value series to neural network, now the output is the actual forecasting value of the series.

Using the chaos time series forecasting method of the BP network, research the data series in 2005, YT7701A channel, No.1 station stack gas turbine units, No.3 catalytic shop, Petrochemical No.103 Stack gas turbine units. In the chaos time series phase space reconstruction of 1D scalar, select delay time τ and embedding dimension m using the G-P algorithm of embedding dimension. Process the vibration displacement data, evaluate the intensity. Perform the wavelet noise reduction to eliminate the interference component, and then perform the phase space

reconstruction and calculate associated dimension. Calculate the dimension d according to the G-P algorithm, and obtain appropriate embedding dimension m according to the Takens theorem [4].

Let τ= 6, begin to try from embedding dimension m=2, get: m=2, d=0.7468; m=3, d=0.9281; m=4, d=1.0643; m=5, d=1.0987; m=6, d=1.1038. As shown in the figure 3, using the G-P method, evaluate the lnC(r) and ln(r) relationship of associated dimension.

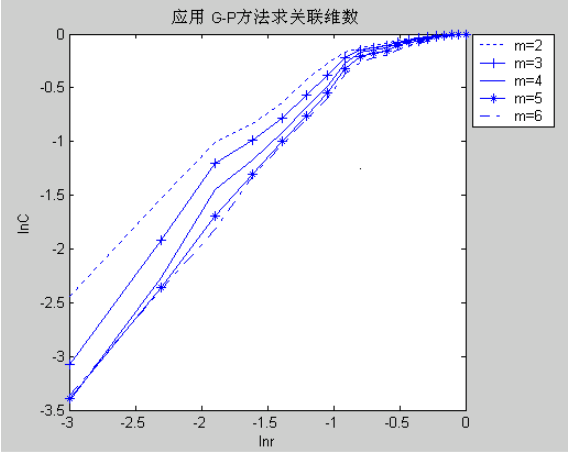

Figure 3 Evaluate associated dimension using the G-P method

From the figure, we can see when m=5 and m=6, the curves are overlapped. This means that the d converges on the stable value 1.0987 with the increase of the m. It indicates that the system under the consideration isn't a random system. The embedding dimension of attractor given by the above calculations of time series is 5, and associated dimension is d=1.0987. That is, chaos analysis of the data shows: associated dimension d=1.0987, saturated embedding dimension m=5, have chaos. By constructing three layers of BP network, perform the chaos time series forecasting. The results are shown in the table 3.

Table 3 Forecasting results of chaos BP network

forecasting value	Actual value	Error %
7.1085	7.0318	1.091
7.1086	7.1758	0.936
7.2452	7.0742	2.417
7.0236	7.1832	2.221
7.0287	6.9554	1.054
7.1590	7.1173	0.586
7.0231	7.0291	0.085

4 Conclusions

This paper uses the stack gas turbine as research object. By using the platform based on the remote monitoring and diagnosis center server and rotating machinery monitoring system, achieve the remote monitoring of the units. The researched prediction method based on the chaos neural network, combine the advantages of both chaos and neural network. The forecasting errors are small, and good forecasting results have been obtained.

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