Research Journal of Applied Sciences, Engineering and Technology 6(16): 3065-3071, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 12, 2013 Accepted: February 07, 2013 Published: September 10, 2013

Research on Wind Turbine Generator Dynamic Reliability Test System Based on Feature Recognition

[1]Bin Wang, [2]Yuemiao Wang and [3]Xinbo Chen
[1]UGS College, Yancheng Institute of Technology, Yancheng, China
[2]School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, China
[3]School of Automotive Studies, Tongji University, Shanghai, China

Abstract: Wind power resource development is increasingly becoming the focus of the current research and development in various countries' relevant scientific institutions. To make sure the secure and reliable operation of wind turbine generator, the study develops the wind turbine generator dynamic reliability test system. When the fault of gearbox and spindle occurs, their features of vibration signals are special. According to the feature recognition technology, the application of time and frequency domain model identification method has practical significance to the test system. Based on Bayesian network fault diagnosis method, the vibration feature recognition system of wind turbine generator is constructed. Finally, the paper uses GPRS technology to realize the wireless transmission of operation information. The wind turbine generator dynamic reliability test system is built based on GPRS technology to realize automatic control and remote intelligent monitoring and to ensure the safe and stable operation of wind farms.

Keywords: Bayesian network, dynamic reliability test, feature recognition, GPRS, wind turbine generator

INTRODUCTION

Energy crisis and environmental pollution have become the human survival and developing problems to be solved in the 21st Century. As a kind of clean energy, wind power has attracted worldwide attention. The main development of all countries is focus on wind power generation. At present, the development of wind turbine generator is trend to be large and complicated. In the wind power farm, wind turbine generators are with many domes of various sizes and their distribution is scattered. Generally they are far from the main control room. Along with installed capacity of wind turbine generator is large and it leads to an increased failure rate. The installed scale of wind farm continues to expand, so wind turbine generator dynamic reliability test is also more and more important. Wind turbine generator is the core of the whole system which directly affects the system performance, efficiency and quality of power supply, at the same time it is the part which is easily to break down in the system (Trudnowski *et al*., 2004). In the actual operation process, as wind turbine generators bear section wind which is complicated in the wind farm and it always works in the field, exposures under the sun and bears thunderstorm and lightning and so on, it is easily to have a variety of mechanical and electrical failures. In order to ensure the safe and stable operation of wind farms and improve the management efficiency, it needs to open up a wind turbine generator dynamic reliability test system which can satisfy the wind power generation operation requirements. The system should have perfect function and stable performance. The main goal to develop the system is for data acquisition, unit control, measurement, parameter adjustment and various cases of alarm and so on to each wind turbine generator in the wind farm (Amirat *et al*., 2007). The Research of wind turbine generator dynamic reliability test system is an attempt to research the rotating mechanical dynamic reliability testing technology.

Mechanical equipment dynamic reliability technology research has developed for nearly half a century, monitoring instruments and monitoring system research have reached for a very high level. In the field of equipment state monitoring and fault diagnosis system research and development, after several years of actual operation assessment, many companies has launched related technology products which have been used widely, such as Trendmaster 2000 system and ADRE system of Bently Navada company, CMMSl00/110 system and M800A system of SKF company, M6000 system of Scientific Atlanta company, PDS system of Westinghouse company, 5501 system of Solartron company etc., (American Wind

Corresponding Author: Xinbo Chen, School of Automotive Studies, Tongji University, Shanghai, China, Tel.: (+86) 021-69589842

Energy Association, 2008; Hameed *et al*., 2009). The development and utilization of wind resources is rapid and supporting wind power facilities are also vigorously researched. Most large wind turbine generators are equipped with corresponding test systems. Foreign on-line monitoring technology is more and more mature and they have developed a lot of special used equipment for wind turbine generator monitoring, such as Mita Teknik in Denmark developed the system WP4086, SKF in America researched the system SKF Wind Con 2.0 and so on (Ribrant, 2006; Akhmatov, 2006). They are all playing an important role in the large wind turbine generator.

The study studies the basic theory of wind turbine generator and its basic features. The transmission dynamic reliability test system based on feature recognition is according to vibration signal characteristics of turbine spindle and gearbox. The application of feature recognition technology and the principle of artificial intelligence, expert system and neural network is to having on the wind turbine generator intelligent monitoring, monitoring the dynamic reliability. According to the history fault signal and bayesian network fault diagnosis theory and method, the research constructs the wind turbine generator dynamic reliability test system. Because of the needs for remote control system in the wind farms, remote monitoring system for wind farms is studied. From the system hardware structure and overall design features, the study describes the design process and finally based on GPRS wireless network, wind farms remote monitoring system for the overall design is developed. It finally achieves the wind turbine generator automatic controlling and remote intelligent monitoring. The system helps power plant to discover and effectively eliminate hidden danger in time, improving the operation reliability of wind turbine generator, reducing the stopping loss, improving the maintenance system and reducing the maintenance cost.

LITERATURE REVIEW

At present, for the wind turbine generator dynamic reliability test technology, there are a lot of diagnosis theory and identification methods, including statistical recognition, fuzzy logic, neural network, expert system, bayesian network and so on Blmal (1994) and Long *et al*. (2008). The existing of fuzzy logic is because of the difference of objective things exist transition. Artificial neural network technology is suitable for creating intelligent monitoring and identification model because of its self-organized, learning ability and strong nonlinear ability. The expert system will make human expert knowledge and experience store in computer in the form of knowledge base and imitate human experts to solve the problem of reasoning mode and thinking process, use the knowledge and experience to make judgment and decision. The application of intelligent control technology improves the wind turbine generator reliability and working life. In consideration of the vibration of wind turbine generator part is one of the main factors, in recent years, wind turbine generator manufacturers and research departments study the optimal operation and the control rules of wind turbine generator, through the use of intelligent control technology and the machine design technology. They combine with efforts to reduce and avoid wind turbine generator operation in the ultimate load and fatigue load, which gradually becomes the main development direction of wind power control technology.

THE FAULT SIGNAL VIBRATION FEATURES OF TRANSMISSION SYSTEM

The key device of wind power generation is wind turbine generator and research and development of wind turbine generator is the core of wind power technology. Although wind turbine generator has a lot of style, generally structure and principle are the same. Wind turbine generator is mainly composed of blade, engine and tower composition. The front part of engine is wind turbine generator rotor (spindle) and spindle bearing. The inside of engine room includes generator, gear box and other major parts. The study mainly researches megawatt horizontal-axis speed-rasing wind turbine generator. Generally speaking, this kind of wind turbine generator is as shown in Fig. 1. Wind turbine generator fault has the characteristics of diversity and complexity. The same type of fault, due to different positions and conditions and other reasons, often has very big difference. The different failure showing signs sometimes have similar characteristics, so the fault diagnosis is uncertainty and fuzziness.

Mechanical vibration is a common phenomenon in engineering. When the machine has vibration abnormality, it usually appears vibration increase and causes the change of the work performance, such as impact work precision, aggravate wear, accelerated fatigue failure and so on and then causing further aggravate vibration, resulting in a vicious circle (Ramzi and Liu, 2013). By adopting the vibration analysis, the most accurate machinery could have equipment inspection and fault diagnosis, such as rotor imbalance, shaft bending, bearing looseness, shaft misalignment, movement of a friction, oil film oscillation, rotating stall and surge shaft, transverse crack, structure resonance, etc., (Booth *et al*., 2001). The typical fault of wind turbine generator transmission system is shown in Table 1.

Wind turbine generator vibration monitoring is different from other mechanical equipment and has its particularity. First of all, because of horizontal axis wind turbine generator operates in a Dozens of meters high, mechanical drive system is affected by wind disturbance and the load change is complicated, especially in some wind farms in the mountain or hill area. Air topographic is influenced by the distortion of the event, so that wind turbine generator can work

Table 1: The typical fault of wind turbine generator transmission system

Parts	Failing components	Failing styles
Accelerating gearbox	Gears	Tooth broken, tooth surface wear, tooth surface pitting, tooth surface bonding
	Rolling bearings	Spalling fatigue, wear, plastic deformation, corrosion, fracture and glue
Spindle	High-speed spindle	Misalignment, bend, unbalance
	Low-speed spindle	

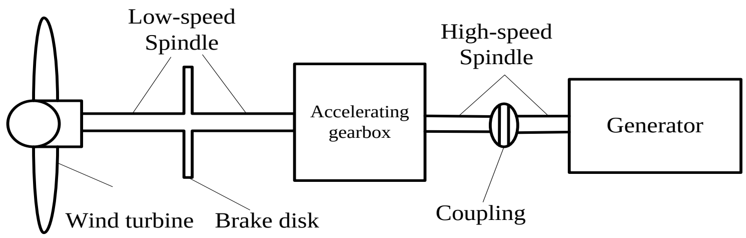

Fig. 1: The components and position diagram of transmission system

under cyclic complicated loading in the long run (Xiao, 2013). Due to the uncertainty of wind, wind turbine generator rotation speed is in the unceasing change, which makes the wind generator vibration signal analysis is more complicated. Secondly, the wind turbine generator condition monitoring is still in the stage of development, so the reference experience is very limited and it needs more exploration and practice in long time.

The feature recognition technology of vibration signal: In this rapidly developing society of information technology today, the intelligent monitoring system can't replace the experience of experts and the expert system diagnostics is in constant attention by researchers. Based on the numerical fault diagnosis methods of feature recognition have been also achieved great development, which has become a kind of important methods in field of rotating machinery fault diagnosis. The research proportion of self diagnosis method and modern intelligent, network and integrated fault diagnosis methods is rising unceasingly in recent years and has become the main development trend in the field of fault diagnosis (Zhang *et al*., 2008).

The method based on feature recognition is not only suitable for mechanical system fault diagnosis, including engine abnormal sound fault, transmission and spindle fault and so on, but also can be applied to electrical, electronic, control system and testing system. The basic steps for diagnosis are as follows. First, get diagnostic information and then make pretreatment and analysis for diagnostic information, at the same make the system state recognition to find out the cause of the problem, finally to determine the fault position. Wind turbine generator dynamic reliability test process is shown in Fig. 2.

As the analytical and processed signals have normal and abnormal division, the identification of these signals becomes the core issue of fault diagnosis and it also is the state identification of the system. Actual situation is compared to original known failure mode, after it is to be classified and then make judgment. Commonly used state recognition methods are time domain model identification method, frequency domain identification method, logic reasoning method, distance function classification, grey model correlation analysis method and method based on the pattern recognition, such as state recognition based on chaotic characteristic quantity, fuzzy recognition and neural network identification and so on. The treated analog signal has become the discrete digital signal which can be identified by computer and is also called time series. These signals can be divided into three kinds, namely random signal, periodic signal and instantaneous signal. For these signal analysis mainly adopts two kinds of method, time domain analysis and frequency domain analysis method. Figure 3 shows the wind turbine generators vibration feature recognition system framework, including the time domain model identification method and frequency domain identification method, etc.

Pattern recognition refers to the process of processing and analyzing of various forms information to represent things and phenomenon which is numerical, literal and logical, ao as to describe, recognize, classify and interpret things and phenomenon. As shown in Fig. 3, image features which are photographed by cameras will need to use pattern recognition technology. Currently pattern recognition methods used in the field of Wind turbine generator dynamic reliability test system are mainly grey model correlation analysis method, chaos identification method, fuzzy identification method and neural network identification method, etc. The present feature recognition methods still have problems such as low recognizing precision and slow speed of recognition (Srinivas and Murthy, 2007). Some methods are just to stay in the laboratory stage and they aren't gotten

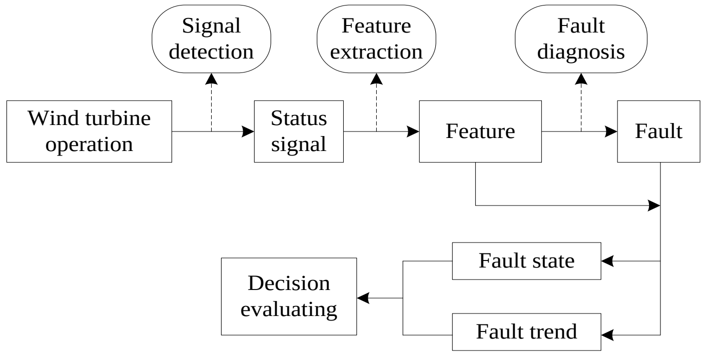

Fig. 2: Wind turbine generator dynamic reliability test process

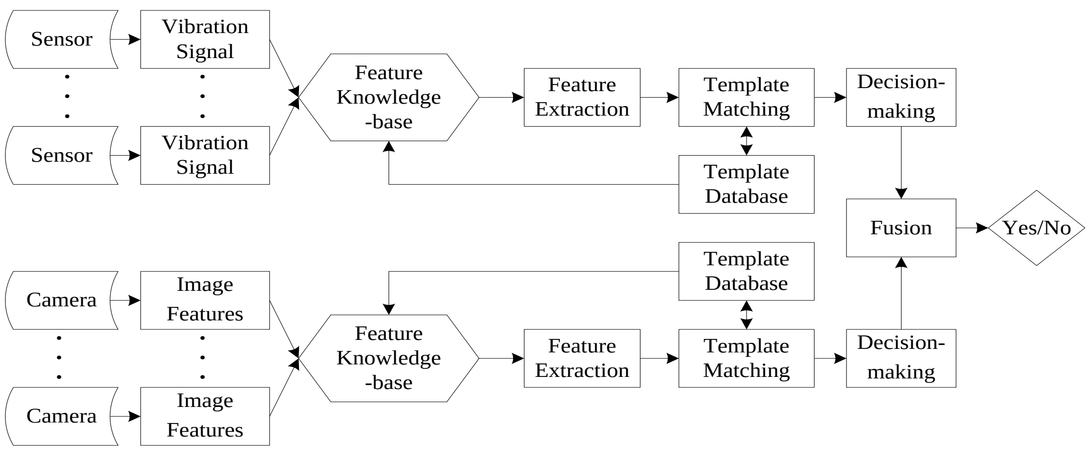

Fig. 3: Wind turbine generator vibration feature recognition system

specific application. Therefore, it needs to be further researched to give full play to its characteristics and promote the development of the automobile fault diagnosis technology.

All sorts of state recognition methods are combined with expert system. With the aid of information technology, network technology and artificial intelligence technology, product with the function of intelligent identification is developed, which makes it easy to install and operate. At present the development of some large integrated fault diagnosis test equipment has these functions, with the progress of science and intelligent technology of auto, the intelligent state recognition method will have broad development trend (Saad *et al*., 2006).

THE BAYESIAN NETWORK FAULT DIAGNOSIS TECHNOLOGY

To solve the imperfect and uncertainty problems, Bayesian network is putted forward and gotten widely attention and application in many areas. Based on the probability reasoning, Bayesian network has a lot of advantages for complicated equipment fault diagnosis. Especially in solving uncertainty and relevance factors. It has irreplaceable function (Pearl, 1988; Garcia *et al*., 2006). Bayesian network is also called belief Network. At present, in the uncertainty knowledge representation and push quantity fields, bayesian network is one of the most effective theory models (Chris and James, 2006). In the application of bayesian network to mechanical equipment fault diagnosis process, all information will be expressed in the form of different nodes and variables. The network can deal with all the nodes and variables uniformly. In constructing the bayesian network, nodes and variables can be unified in the means of processing and mechanical equipment fault diagnosis information gradually to join the network construction. Therefore, the bayesian network is more suitable for exppressing uncertain complicate problems.

Construct the basic framework of bayesian network fault diagnosis system: The research constructs a bayesian network dynamic reliability test system based on the information about the state of wind generator and associated information in the frame, the uncertain relations among the basic framework, fault nodes and fault node fault symptoms can be expressed by conditional probability. The basic framework of dynamic reliability test based on bayesian network is as shown in Fig. 4. It consists of two basic event layers and they are fault layer and fault symptom layer and causal relationship is existed in two layers.

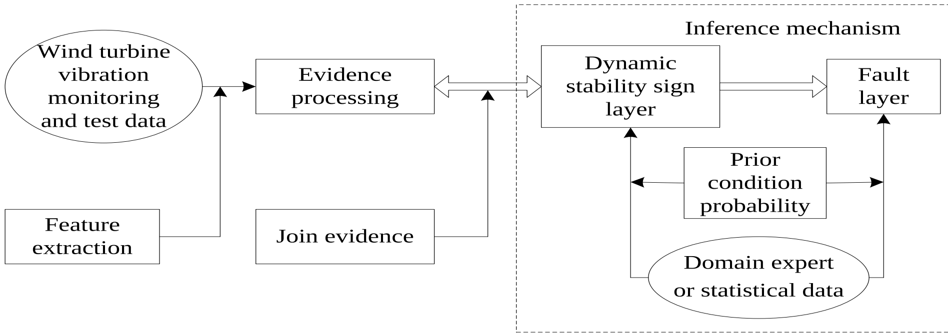

Fig. 4: The basic framework of dynamic reliability test based on bayesian network

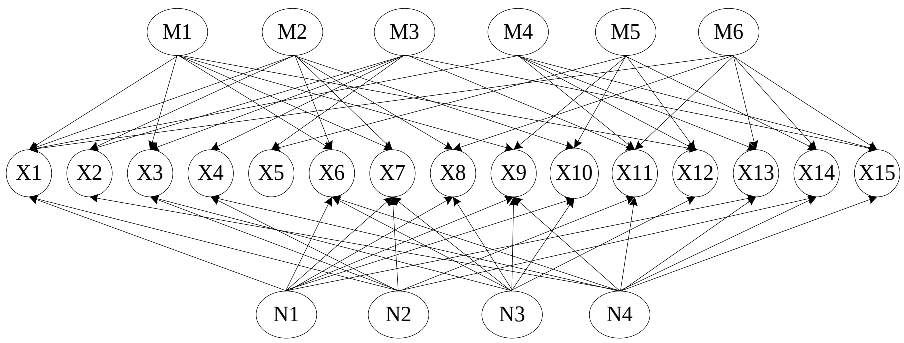

Fig. 5: The topological structure of spindle and gearbox based on bayesian networks

Fault layer is composed of different types of fault variable nodes. Such as in the spindle system, there are fault types of spindle misalignment, imbalance, action rubbing and shaft crack, etc. and they constitute failure layer together. The fault symptoms node which is directly produced by fault node constitutes a node fault symptoms layer. Usually, the selection of fault symptoms should fully reflect fault condition and identify fault types of features. Such as margin index in abnormal peak will increase obviously, so we can select margin index for a fault symptom. In the application of bayesian network to carry on the wind turbine generator dynamic reliability test, the first step is to build network topology structure composed of fault symptoms and fault layer and then get to the sharp reasoning of prior information and evidence information. Bayesian network used in wind turbine generator fault diagnosis does not require every node in the network to be complete. For any fault symptom, it doesn't have to list all fault event which may cause it to happen. Therefore, in constructing wind turbine generator bayesian network, we can only select the fault event and sign event that have a significant impact on wind turbine generator drive system.

The construction of transmission system bayesian diagnostic networks: Select several categories of common spindle faults, such as spindle unbalance, spindle misalignment, movement and static friction and spindle crack. The traditional fault diagnosis methods are difficult to accurately identify fault type and location. Selection of different signs events may directly affect the bayesian network inference results, so the choice is very important. In order to make the bayesian network be accurate and reasonable for fault diagnosis and reasoning, in view of the above four kinds of common faults, we can determine the sensitive characteristic parameters in the time and frequency domain for fault diagnosis methods, mainly including peak, mean, the Root Mean Square value (RMS), rad amplitude, kurtosis, waveform index, peak index, pulse index, margin index, kurtosis index (normal value is a fixed value) and turn frequency and power spectrum component in the 2, 3 times frequency, cepstrum amplitude, which are expressed by X1-X15.

R1~R6 are profile error, broken teeth, shaft bending, shaft imbalance, bearing fatigue spalling and pitting, housing resonance, respectively.

R1~R4 are rotor unbalance, rotor misalignment, static friction and shaft crack, respectively.

Referring to the wind turbine generator drive system structure, wind turbine generator mechanical drive system can be divided into low-speed spindle, gearbox, high-speed output spindle, shaft coupling and brake and other major parts (Fig. 5). When constructing the bayesian network system of wind turbine generator,

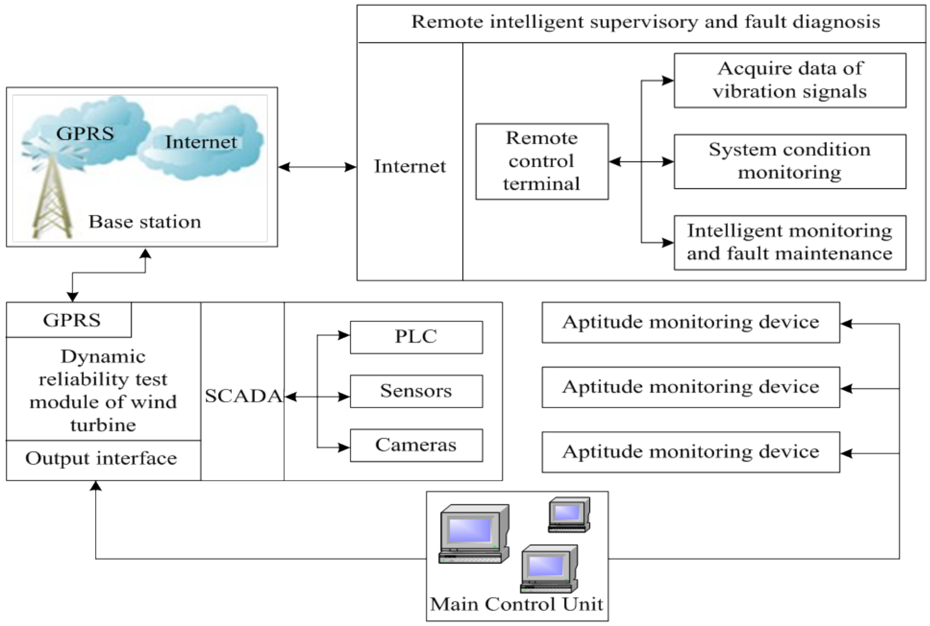

Fig. 6: Wind turbine generator dynamic reliability test system based on GPRS

we should consider extracting characteristic information which includes different rotational frequency information. Therefore, bayesian network can be established respectively to each component. And then, we can construct a bayesian network from the system to components and calculate failure rate of mechanical drive system.

WIND TURBINE GENERATOR DYNAMIC RELIABILITY TEST SYSTEM BASED ON GPRS

The full name of GPRS is General Packet Radio Service. It is the enhanced data business introduced by the ETSI in GSM phase2 and the wireless data transmission system developed by introducing new parts based on GSM communication system (Huang *et al*., 2004). The choice of communication method decides the stability and reliability of wind turbine generator dynamic reliability test system to a great extent. So choosing the right way of communication for the system is very important. The using of GPRS technology is to realize data packet sending and receiving. The user is always online and its billing is according to the flow, which quickly reduces the service cost. In the wind turbine generator dynamic reliability test system, the application of GPRS technology can monitor the operation state of wind turbine generator, acquire and transform of all kinds of operation parameters.

The control structure of wind turbine generator mainly includes main controller unit, various types of sensors, drive device, signal and communication interface and man-machine interface, etc. The wind turbine generator dynamic reliability test system based on GPRS is shown in Fig. 6. The framework of wind turbine generator dynamic reliability test system includes remote intelligent control terminal, GPRS wireless transmission module and master system module. Using PLC to realize automatic control and signal processing. Automatically control and remote fault monitoring are combined to ensure reliable operation of wind turbine generator. Concrete realization process is as follows. The system collects operating and environmental parameters of each component in wind turbine generator through the sensors. Sensors collected various parameters and transfer them to the digital quantity or analog input module of main controller unit through the signal interface. The main controller monitors operation state of turbine through acquiring various parameters and maintains communicating to other functional module. The main control system sends data to remote intelligent monitoring terminal through the ethernet interface and GPRS to test the dynamic reliability of wind turbine generator. Combining with aptitude monitoring device, the system can prevent irreparable fault.

CONCLUSION

This study established the wind turbine generator dynamic reliability test system based on feature. The fault signals vibration characteristics of wind turbine generator transmission are uncertain and fuzzy. Teature recognition technology and bayesian network fault diagnosis technology can deal with the fuzzy feature suitably. Using the sensor technology, GPRS communication, PLC control system and artificial intelligence theory constitutes a dynamic reliability test system. According to the vibration signal characteristics of the unit spindle and transmission, based on the feature recognition technology, the system tests the dynamic reliability to realize the automatic control of wind turbine generator and to remote intelligent monitoring, whose purpose is to ensure the safe and stable operation of wind farms. Wind turbine dynamic reliability test system uses mainstream test and control technology and adopts advanced intelligent control method. The later developed product will be in leading status.

ACKNOWLEDGMENT

This study was supported by the “Six Talent Peak” Project of Jiangsu Province under Grant No. ZBZZ-043.

REFERENCES

Akhmatov, V., 2006. Modelling and ride-through capability of variable speed wind turbine generators with permanent magnet generators. Wind Energ., 9(4): 313-326.

American Wind Energy Association, 2008. Global Wind Energy Market Report. pp: 13-37.

Amirat, Y., B. Bensaker and R. Wamkeue, 2007. Condition monitoring and fault diagnosis in wind energy conversion systems. Proceeding of the IEEE International Electric Machines and Drives Conference (IEMDC '07), Antalya, 2: 1434-1439.

Blmal, K.B., 1994. Expert system, fuzzy logie and neural network applications in power electronics and motion control. Proceedings of the IEEE, pp: 1303-1323.

Booth, C., J.R. Mcdonald and S.D.J. Mearthur, 2001. Forecasting and prediction app1ications in the field of power engineering. J. Inte1l. Robot. Syst., 31(1-3): 159-184.

Chris, J.N. and R.B. James, 2006. Inference in bayesian networks. Nature Biotechnol., 1: 51-53.

Garcia, M.C., M.A. Sanz-Bobi and J.D. Pico, 2006. Intelligent system for predictive maintenance application to the health condition monitoring of a wind turbine generator gearbox. Comput. Ind., 57(6): 552-68.

Hameed, Z., Y.S. Hong and Y.M. Cho, 2009. Condition monitoring and fault detection of wind turbine generators and related algorithms: A review. Renew. Sustain Energ. Rev., 3: 1-11.

Huang, X.B., J.B. Liu and X.L. Wang, 2004. On2line remote monitoring system for transmission line insulator contamination based on the GPRS net. Automat. Electr. Power Syst., 28(21): 92-99.

Long, Q., Y. Liu and Y. Yang, 2008. Applications of condition monitoring and fault diagnosis to wind turbine generators. Modern Electr. Power, 6(25): 55-59.

Pearl, J., 1988. Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference. Morgan Kaufmann Publishers, San Mateo, pp: 71-75.

Ramzi, F. and S. Liu, 2013. Fuzzy technique tracking control for multiple unmanned ships. Res. J. Appl. Sci. Eng. Technol., 5(2): 538-545.

Ribrant, J., 2006. Reliability Performance and Maintenance: A Survey of Failures in Wind Power Systems. KTH School of Electrical Engineering, pp: 59-72.

Saad, Y.Y., H. Majid, G. Subramaniam and S. Ram, 2006. Fuzzy logic control based Failure Detection and Identification (FDI) Module for Internal Combustion (IC) Engines. SAE Technical Paper 2006-01-1352.

Srinivas, J. and B.S.N. Murthy, 2007. Fault Diagnosis of Driveline System Using Response Optimization. SAE International, Paper No.: 2007-01-3727.

Trudnowski, D.J., J.M. Khan and E.M. Petritz, 2004. Fixed-speed wind generator and wind park modelingfor transient stability studies. IEEE T. Power Syst., 19(4): 1911-1917.

Xiao, Y., 2013. Instantaneous gradient based dual mode feed-forward neural network blind equalization algorithm. Res. J. Appl. Sci. Eng. Technol., 5(2): 671-675.

Zhang, L.L., J.W. Chu, T. Qiang and D. Han, 2008. Study on method of automobile fault diagnosis based on numerical feature state recognition and its application. J. Heilongjiang Instit. Technol., 3(22): 45-48.