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Yang Liu Wenshan Yang

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Meteorological information service support system in wind park application

Yang Liu
Department of Production, University of Vaasa, Vaasa, Finland, and
Wenshan Yang
Department of Production, University of Vaasa, Vaasa, Finland and Public Meteorological Service Center, Hubei Provincial Bureau of Meteorology, Wuhan, China

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Abstract

Purpose – The purpose of this paper is to introduce a holistic decision support system based on condition-based maintenance which utilizes meteorological forecasting information to support decision-making process in services of wind power enterprises.

Design/methodology/approach – A pilot conceptual system combining with meteorological information and operations management has been formulated in this study. The proposed system provides benchmarking to support decision making directly and indirectly basing on processing meteorological information and evaluating its impact on service operations. It collects meteorological data to predict failure probabilities in different areas which need corresponding maintenance service and schedule the optimal maintenance periods. In addition, it provides meteorological forecasting and decision support in case of extreme weather events (EWEs).

Findings – The conceptual study shows that there is a connection between the meteorological conditions and failures, and it is feasible to make service decisions based on the predictions of weather conditions and their impacts to failures.

Research limitations/implications – The research presented at the present phase is not much beyond a conceptual framework. The actual implementation and all possible related practical issues will be dealt with in future research.

Practical implications – It helps decision makers to predict and identify possible categories of faults in wind turbine, make optimal service decisions to enhance the output performance of wind power generation, and take in advance emergency counteractions in case of EWEs.

Originality/value – It presents a novel concept and provides a roadmap to achieve optimal operations in wind park application through combining meteorological information system with service decision making.

Keywords Operations management, Decision support systems, Information management, Service operations, Strategic planning, Condition-based maintenance

Paper type Research paper

1. Introduction

According to Global Wind Energy Council (2012), the number of wind turbines spinning around the world by the end of 2011 is 199,064. Among that, the amount of wind turbines up and running in China is 45,894 which count 23 per cent of the total amount. That is to say, China's leadership in wind energy deployment is both an opportunity and a challenge for European and American companies to compete in

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this market and internationally. Europe remains a technology leader and is carving out the next frontier of wind energy with onshore and offshore deployments (Global Wind Energy Council, 2012). The wind energy potential of the Earth is huge and enough, in principle, to meet all the world's electricity needs. Virtually every country has sites with average wind speeds of more than 5 m/s measured at a height of 10 m, which are sufficient for using wind power to generate electricity (Sesto and Ancona, 1995).

Many of critical wind turbine faults are directly or indirectly related to weather conditions and extreme weather events (EWEs). This research intends to propose a pilot service support system which utilizes meteorological information to predict such situations which may lead to breakdowns and make it possible to take precautions in advance, and in addition to suggest other service related decisions based on condition-based maintenance (CBM), such as deciding the optimal time for maintenance during the predicted idle period. CBM is defined by a set of maintenance actions taken as a consequence of knowing the current operating status of equipment. Recent study considers it is a form of proactive equipment maintenance that forecasts incipient failures based on a real-time assessment of equipment condition obtained from embedded sensors and or external tests and measurements that are extracted directly from the equipment (Gulledge *et al.*, 2010). Many recent studies show there is direct connection between service and business performance in wind power systems and demonstrate business potential analysis that optimal service decisions based on CBM in wind park application can significantly cut down operation and maintenance costs (El-Thalji and Jantunen, 2012; Tian *et al.*, 2011; Nielsen and Sørensen, 2011), nd by implementing a successful CBM strategy can also achieve higher level of cost effectiveness (El-Thalji and Jantunen, 2012), thus improve the operation and business performance.

In many recent studies, the relationship between wind speed modelling and electricity generation from wind turbines is also studied. In fact, wind park investors are interested in long-range forecasts and simulation of wind speed for two main reasons: to evaluate the profitability of building a wind farm in a given location, and to offset the risks associated with the variability of wind speed for an already operating wind farm (Caporin and Preś, 2012). The percentage of the world's electricity that could be produced from offshore devices is estimated to be around 7 per cent by 2050, and this would employ a significant amount of people by this time, possibly around 1 million, mostly in the maintenance of existing installations (Esteban and Leary, 2012).

Optimal maintenance are affected by various factors, such as availability of resources, dependency on meteorological surrounding conditions, as well as a complex logistical process chain (Tracht *et al.*, 2013), and failure probability can be predicted based on condition monitoring data of wind energy systems (Tracht *et al.*, 2013). Based on these theories, this paper develops a holistic system which combines with meteorological information and operations management. The proposed system provides benchmarking to support decision making basing on processing meteorological information and evaluating its impact in service operations of wind power enterprises (WPEs). The concept of such decision support system is built based on years of well-established previous studies utilizing sense and respond type of continuous adjustments in decision making to achieve sustainable competitive advantage in operations strategy implementation (Liu, 2013).

The structure of this paper is as follows. Section 2 reviews the latest related studies. Section 3 introduces the research methodology. Section 4 describes the system

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structure and process in a conceptual framework. Section 5 discusses the managerial implications, research limitations and also recommendations for future research. Section 6 draws conclusions.

2. Review of related studies

2.1 Wind power as an energy source

Energy is the main intermediate strategic resource for economic development and growth in any country. This usually translates to better quality of life, and therefore it leads to higher primary energy consumption in all sectors, transportation, industry, services, household, etc. (Abulfotuh, 2007). Nowadays, the world faces a great challenge of saving our future in terms of developing renewable energy. Until now, a huge amount of the energy requirements all over the world is supplied originally from conventional energy sources like coal, crude oil, natural gas, etc. However, these patterns of energy are limited and often lead to pollution. Therefore, renewable energy resources will play an important role in our daily life in the world's future.

Renewable energy sources are those resources which can be used to produce energy again and again, e.g. solar energy, wind energy, biomass energy, geothermal energy, etc. and are also often called alternative sources of energy (Rathore and Panwar, 2007). Among the renewable energy sources wind energy is currently viewed as one of the most significant and attractive sources, which is a clean energy rather than coal, crude oil and natural gas. The outstanding characteristic of wind power is to save energy and protect environment although the intermittent character is a very critical problem.

The use of renewable energy sources is closely linked to sustainable development, because a sustainable supply of energy resources which must be used effectively and efficiently is required for it, as well as for progressing in environmental problems (Tolón-Becerra *et al.*, 2011). It is undoubtedly that sustainable development will definitely let managers handle with problems during the period of decision making.

On one hand, wind power generation is becoming more and more popular in many countries, but it differs from conventional thermal generation due to the stochastic nature of wind. Thus wind power forecasting plays a key role in dealing with the challenges of balancing supply and demand in any electrical system, given the uncertainty associated with the wind park power output. Accurate wind power forecasting reduces the need for additional balancing energy and reserve power needed to utilize wind power (Foley *et al.*, 2012).

On the other hand, the Nordic countries particularly experienced a number of EWEs during recent years and a significant number of wind power businesses were affected as a result. With the intensity and frequency of extreme weather predicted in the future, enhancing the resilience of businesses, especially WPEs which are considered as highly vulnerable, has become necessary (Wedawatta *et al.*, 2011). However, little research has been undertaken on how construction of WPEs is responding to the risk of EWEs.

2.2 Meteorological service and decision making

Traditional maintenance techniques, such as preventive maintenance is scheduled in advance of failure and usually at regular intervals which are typically determined by the analysis of historical reliability data (Gulledge *et al.*, 2010), and time-based maintenance (TBM) is labour intensive, ineffective in identifying problems that develop between scheduled inspections, and not cost-effective (Ahmad and Kamaruddin, 2012). Whereas CBM is scheduled by predicting the future status of the equipment based on operational or other characteristics. (Gulledge *et al.*, 2010). Recent studies develop optimal CBM strategy and decision for wind power applications systems (Tian *et al.*, 2011; Nielsen and Sørensen, 2011; El-Thalji and Jantunen, 2012). CBM is more efficient compared to preventive maintenance in many ways, e.g. condition monitoring and diagnostic practices have become significantly important part of offshore wind farms in order to cut down operation and maintenance costs (El-Thalji and Jantunen, 2012), and more realistic and worthwhile to apply than TBM (Ahmad and Kamaruddin, 2012). However, in wind park application it is typically hard to accurately predict with standalone meteorological data and may lead to a failure prediction. The other challenge is to enable CBM strategy to provide maintenance decisions and services at the right time i.e. maintenance is performed when it is needed and not too early and not too late, i.e. causing breakdown and downtime (El-Thalji and Jantunen, 2012). Therefore a holistic system combining the complete meteorological service and decision making is needed to increase the prediction accuracy and work together with the traditional preventive/corrective measures to provide optimal maintenance decisions.

Short-term prediction is mainly oriented to the spot (daily and intraday) market, system management and scheduling of some maintenance tasks, being of interest to system operators, electricity companies and wind park promoters (Costa *et al.*, 2008). Wind forecasting for energy generation and power system operations mainly focuses on the immediate short-term of seconds to minutes, the short-term of hours up to two days, and the medium term of two to seven days. This is because power system operations such as regulation, load following, balancing, unit commitment and scheduling, are carried out within these time frames. The science of wind power prediction is described as the application of the theories and practices of both meteorology and climatology specifically to wind power generation (Petersen *et al.*, 1997):

- Numerical weather prediction (NWP).
- In case of non-saturated power, because the wind power is equal to wind speed third cube and wind speed are much more regular than that of wind power, consequently a small wind speed error will amplify wind power errors much. It is wide and effective by using short-term wind power forecasting methods which combining NWP model with statistical models, so that we can develop operating mode for electric grid dispatching, provide support for arranging dispatch rationally, reduce the effects of intermittent power to wind power systems effectively. The wind data from now, yesterday, or last year in the same period cannot be used to predict wind in the next 24 hours, because wind is dependent on the weather, and the wind power output cannot be guaranteed at any particular time. Thus the integration of wind power into electrical grids can cause difficulties in the management of the power system (Marciukaitis *et al.*, 2008). Meteorological service.

Climate change is predicted to have a significant effect on the frequency of EWEs and the occurrence of natural disasters, such as hail, flood, tornado and thunderstorm. There is a need for facility managers to mitigate potential disruption and prepare for future events caused by natural phenomenon. Meteorological sector sends out early warnings to WPEs, using the results of real-time monitoring and weather forecasting from satellite, radar, observation stations.

The meteorological ensuring system is a derivative product which mainly involving EWE forecasting and warnings. This can prevent and mitigate climate change on

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crucial facilities and the impact of the project effectively. In current practice, however, that little risk assessment is undertaken by few organizations preparing integrated disaster management plans or business continuity plans to help them meet the challenge (Warren, 2010). As we learn more about possible climate change impacts, certain WPE protection strategies may become more desirable and feasible in management, and we can adopt strategies to minimize its negative impacts on wind power generation.

After studying how climate will change by predictions with wind power production and provide guidance in facing of EWEs, then facility managers can prepare for risk assessment and disaster plans after collecting scientific data related to the potential effects of climate change (Warren, 2010):

- Decision making.

There is relatively little research in the area of operations and service management in renewable energy sector such as wind power by utilizing meteorological information. Some notable studies connecting meteorological forecasting with renewable energy include e.g. Kaplan and Norton (2011) and Eckman and Stackhouse (2012). Changes in competitive environments have increased the importance of strategic management in corporations. Successful companies must be able to anticipate changes in operating environments and be able to react faster than their competitors (Kaplan and Norton, 2011). Earth observations are critical in enhancing the implementation of renewable energy technologies and improving energy efficiency (Eckman and Stackhouse, 2012). Other related research has been implemented by Liu *et al.* (2012). According to the research from this group, they proposed a novel wind turbine fault diagnostic method based on the local mean decomposition technology, which is a new iterative approach to demodulate amplitude and frequency modulated signals, which is suitable for obtaining instantaneous frequencies in wind turbine condition monitoring and fault diagnosis. Finally, the experimental analysis of the wind turbine vibration signal proves the validity and availability of the new method (Liu *et al.*, 2012).

Our research presented in this paper addresses this problem from a conceptual level to bridge the gap between meteorological information and decision making in service operations management. Even though this whole concept is a huge research which is still in progress, nevertheless this paper can be a pilot which leads to new ideas and opens more research paths.

3. Research methodology

3.1 Overview

There are various types of strategies for conducting research in management and social sciences. Reisman (1988) defines research strategies such as ripple, embedding, bridging, transfer of technology, creative application, structuring and empirical validation. This study uses mainly the following research strategies. Ripple is used to develop analytical models for assessing failure probabilities based on meteorological information and NWP. Embedding and bridging are used to associate the decision-making process in connection with the service needs which are based on the failure forecasts. Empirical validation is used to validate the developed theories by performing various case studies in different countries. Arbnor and Bjerke (1997) introduce three methodological approaches i.e. analytical, systems and actors. The nature of this study is to create a holistic system which is a set of components and the relations among them. Holweg (2005) applies the systems approach and contingency theory to review existing contributions and synthesizes them into a conceptual model, which is very similar to

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the nature of this work. Therefore, systems and contingency based methodological approach is proposed to carry out this work. As the main contribution of this study is the integration of meteorological information with decision making in service operations, it requires a new design in the research methodology to integrate the classic components. Kasanen *et al.* (1993) describe the constructive approach as "problem-solving through the construction of organizational procedures or models", and also propose a market-based validation for assessing this aspect of a construction. In this work the construct is the integrative holistic system and it is feasible to apply a weak market test to validate and implement the research objectives. In summary, the research methods include literature survey, descriptive conceptual analysis, analysing qualitative data based on Silverman (2001) and also quantitative data, classification by simple statistics and finally using Kasanen *et al.*'s (1993) the constructive research approach with weak market tests and pilots for implementation.

3.2 Case study

To achieve the entire objectives of this conceptual research, the empirical studies are important and numerous case studies should be carried out from different countries, and analysing them with the proposed existing analytical models and creating new analytical models for further evaluation. Therefore the selection of the case companies must be mostly representative wind park applications. The case studies will be carried out in future research.

3.3 Data collection and analysis

The data of cases in different countries are collected in the same manner: by asking senior managers or directors to answer the questionnaires. The interviewees are normally decision makers and middle management groups, who have good knowledge about the operations of their own wind parks. The interviewed high competence experts should be representative to know well the operations of the studied wind park. The data collected typically from limited and described application problems is mainly qualitative in nature and its validity and reliability can be ensured by improving the required careful documentation of the cases (Sykes, 1990, 1991). First, the managers or directors are trained to understand every item of the questionnaires correctly by interview, email or telephone. Second, after they finish the questionnaires, the answers are analysed with software. Third, the discussion with the managers or directors reveals the results and verifies the validity and reliability of the data further.

4. System description

This section develops a conceptual framework for service support in wind park application. The proposed system involves three major modules: meteorological information module, wind power prediction module and operations management decision-making module. The complete system structure and process are illustrated in Figure 1.

4.1 Meteorological information module

This module includes meteorological data collection and NWP. First, meteorological data are collected by the wind speed sensor, wind direction sensor, temperature sensor, atmospheric pressure sensor, humidity sensor etc. installed on the wind-testing tower of the targeted wind park. Through wireless communicating module, original

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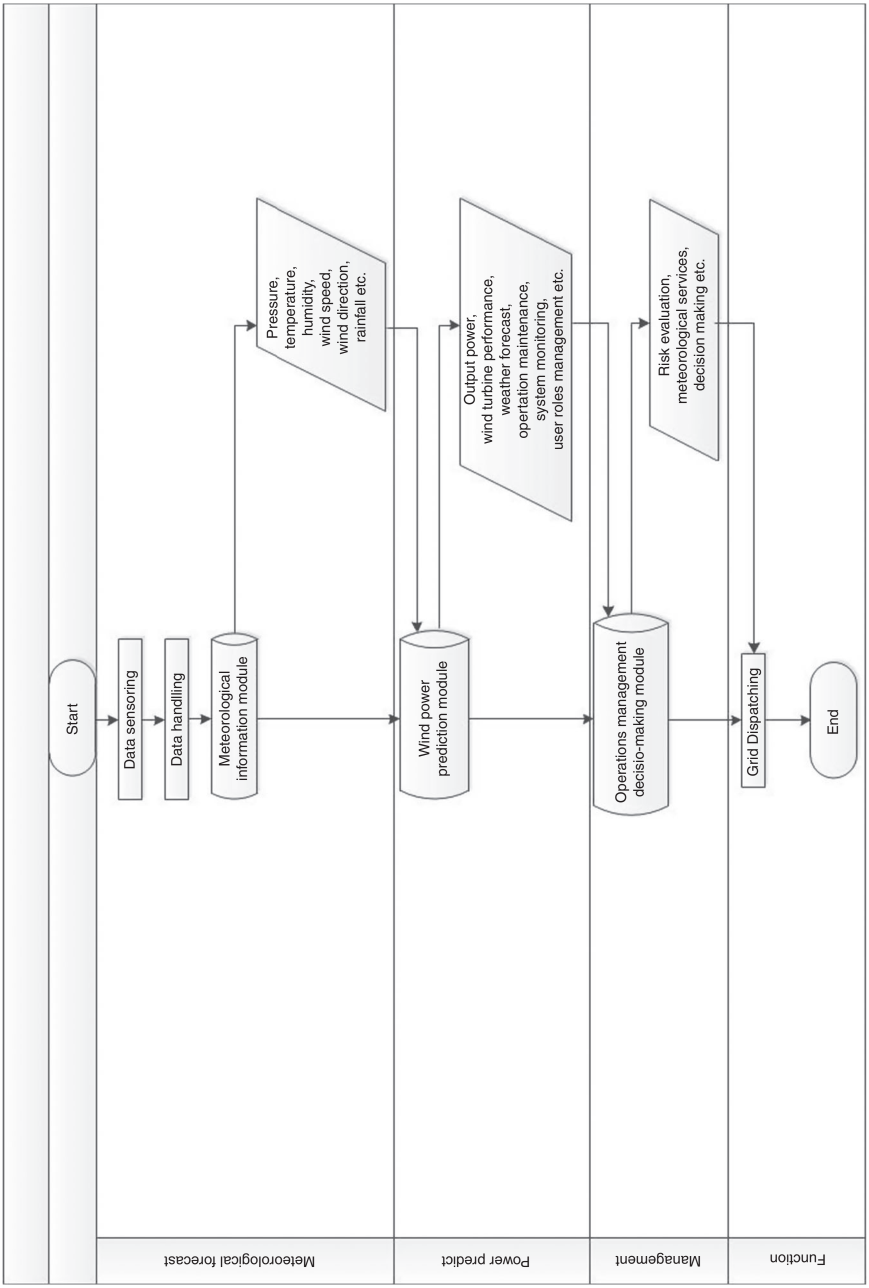

Figure 1.
System structure and process

meteorological data from the wind-testing tower is converted into a digital signal and finally transmitted to the receiving terminal. Then NWP processes the meteorological data to parameters related to wind power output. NWP is a special version tailored to predicting wind power output and is different from the version used for commercial public weather forecasts. On the other hand, it also sends early warning messages in case of EWEs and managers in WPEs can get alarming signals in advance and take countermeasures quickly. With the new forecasting system it effectively links up the NWP model geared towards very short-range forecast of severe weather system. Currently, the suit is probably one of the few operational forecasting systems that effectively combine radar information, dense mesoscale NWP model prognoses for real-time EWEs risk assessment.

The following example illustrates how this is done in reality. A mountain area site located in central China has been chosen to test the proposed theory. The site is located nearby a wind park in operation, also including a meteorological station with anemometers between 30 and 70 m. This wind-testing tower has been brought into operation since November 2011. The mountain top has a height of 700 meters and has a direct distance of 34 kilometres to the local meteorological station, which has good correlation to predict the weather conditions for the wind park. The common meteorological disasters in this location are thunderstorm, flood, drought, low-temperature freeze and continuous rain.

Measuring the maximum wind speeds in the meteorological station. The meteorological station is used to predict the 50-year wind base on annual average 10-minute maximum wind speeds. Through *t*-test to inspect the consistency for sequence of annual maximum wind speed from 1974 to 2011, it has been discovered that the values in 1982 experienced a mutation. It is necessary to correct references of maximum wind speeds from 1982 to 2011due to the diversion of the meteorological station. According to National Wind Energy Resource Evaluation Technology Provision and the type I extreme value distribution, the 50-year average ten-min maximum wind speed is 28.38 m/s.

Predicting the 50-year maximum wind speed in the wind park

$$V_{50\_max} = u - \frac{1}{\alpha} \ln\left[\ln\left(\frac{50}{50-1}\right)\right] \tag{1}$$

$$\mu = \frac{1}{n}\sum_{i=1}^{n} V_i \tag{2}$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(V_i-\mu)^2} \tag{3}$$

$$\alpha = \frac{C_1}{\sigma} \tag{4}$$

$$u = \mu - \frac{C_2}{\alpha} \tag{5}$$

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Using Equations (1)-(5), it can be calculated that the 50-year maximum wind speed is 30.5 m/s.

Predicting the 50-year extreme wind speed in the wind park. Gust factors are a ratio between a peak wind speed of some duration within a given data segment and the mean wind speed of the same segment. An optimum gust factor of about 1.4 is suggested for all types of fabric structures in general, which is an international standard value. Then it can be calculated that 50-year extreme wind speed is 42.7 m/s.

4.2 Wind power prediction module

This module utilizes the processed meteorological data to predict patterns of values related to wind power output. It is an intermediate process to obtain parameters to evaluate failure probabilities and calculate the optimal service decisions which are crucial information for the next process - operations management decision making.

The wind power prediction module calculates the predicted amount of power output during particular hours and days based on the real-time meteorological data. In order to have an accurate prediction, short-term weather forecast is important for the dynamic control of wind turbine and for minimizing the scheduling errors which impact on grid reliability and market service costs (Lerner *et al.*, 2009). Depending on their inputs, the forecast models are classified as physical or statistical or hybrid approaches. The best way is to use meteorological forecast data from NWP systems combining several prediction techniques (De Giorgi *et al.*, 2011).

The module involves real-time wind measuring, NWP, and wind power forecasting. WPEs establish the forecasting model based on NWP and historical data related to wind, and they participate in prediction and report survey to dispatch centre on time. Whether using ultra-short-term wind power forecasting or long-term wind power forecasting, they are all based on the foundation of real-time wind measuring data.

According to predicting and actual wind speed in wind parks, a mixed model of time series method and back-propagation neural networks arithmetic combining with meteorological data can be used in wind power prediction. The more accuracy of meteorological data is, the better forecasting results can be obtained. In addition, meteorological ensuring service can be provided to wind parks in the meantime.

This wind power predicting system mainly includes five parts:

(1) data collection;

(2) NWP;

(3) wind power prediction;

(4) graphical user interface (GUI) software; and

(5) predicting database.

The structure is shown in Figure 2.

- Data collection aims to select a site to set up wind-testing tower and collect wind speed, wind direction, temperature, pressure, etc. which are also the input variables of the wind power prediction module.
- NWP incorporates information representing the outer scale geophysical variability through evolving boundary conditions and by assimilating observations of the current state of the atmosphere to predict flow characteristics. In this research, NWP is responsible for dealing with all

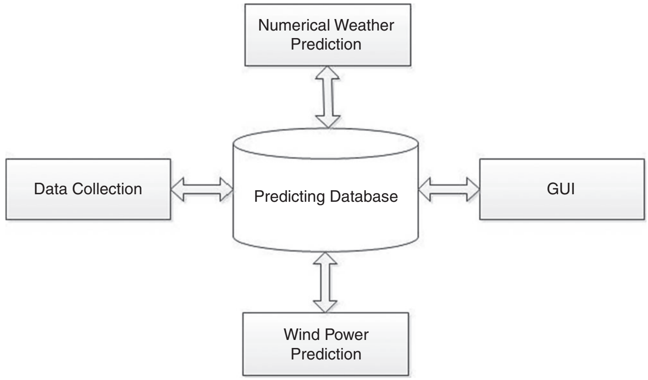

Figure 2.
Structure of wind power prediction module

collected meteorological references, adapting rational mathematical models to calculate the results of future weather.

- Wind power prediction mainly focuses on predicting wind speed and wind power output which are crucial information for the next decision-making process. Wind speed and wind direction are the most important variables. Wind power is equal to wind speed third cube and wind speed are much more regular than that of wind power, and therefore it requires accurate wind measurement.
- GUI Software deals with data transforming and interactive interfaces.

4.3 Operations management decision-making module

This module mainly utilizes the prediction data from previous process to evaluate failure probabilities in different parts of the wind turbine and calculate the optimal service decisions for the wind park operations management.

The significance of failure analysis and fault diagnosis for wind turbine results lower breakdown rate, reduced maintenance cost and time, and improves the operational efficiency and reliability (Ma *et al.*, 2012). The wind turbine is a complex system which transforms kinetic energy from wind power to electrical power. (Kostandyan and Sørensen, 2012). It consists of electrical, mechanical, hydraulic, structural and software subsystems.

Many of critical wind turbine faults are directly or indirectly related to weather conditions and EWEs. Analysis to weather related faults can reveal the causes which can be even predicted, since the weather conditions resulting faults can be predicted with meteorological information system, making it possible to take precautions in advance to prevent such situations from happening. Other service decisions such as the optimal time for maintenance during idle period can be also predicted and scheduled in advance basing on meteorological information.

Statistics show that the determining time for the fault diagnosis takes up 70 to 90 per cent of the total time, while the repair time takes up only about 10 to 30 per cent (Wang and Fent, 2004). A wind turbine can be unavailable because of planned maintenance activities or because of unforeseen failures, incidents or accidents. Analysis of predictable sources of wind turbine failures such as weather conditions can help a lot in decision making to optimize maintenance schedule and maximizes wind power output.

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Each component has different physics of failure behaviour depending on structure, shape, operational environment and many other parameters (Kostandyan and Sørensen, 2012). From the current structural characteristics of wind turbine shown in Figure 3 and its actual fault conditions, faults usually occur in parts such as gears, shafts, bearings, fastener and box.

According to real case statistics, Table I shows typical fault diagnosis related to weather conditions and the relevant actions need to be taken. The decision model can be built based on failure probabilities according to these conditions shown in Table I.

5. Discussion and future study

Based on collecting official documents, analytical results, lab experiments and hypothesis test result, this investigation discusses the possible causes of wind power system failure from these four perspectives, and presents practical suggestions for wind tower risk management and future action plans for the areas of structural design evaluation, construction and quality management, and engineering document review. By addressing study recommendations, project stakeholders can improve their risk management strategies. Construction firms can also utilize these findings to learn lessons for future reference. In terms of risk management, identifying the major causes of failure, one must understand the risk associated with these causes, and generate action plans that allow project managers to mitigate risk or employ control measures (Chou and Tu, 2011).

In addition to the conceptual design, this study has provided new insight for practical operations management in wind park application. It helps decision makers to predict and identify possible categories of faults in wind turbine and make optimal service decisions to enhance the output performance of wind power generation.

Further research is needed related to sensitivity analysis of:

(1) Wind surveys and installations have so far concerned mostly onshore sites. However, a very interesting wind potential seems to exist also in offshore, shallow water locations, where there is the advantage of better wind conditions and less environmental restrictions, although the disadvantage of more difficult access and higher installation and maintenance costs must be taken into account (Sesto and Claudio, 1998). In that situation, the seawater salinity is one critical meteorological factor which will be studied in future research.

(2) Accumulated plastic strain depending on the temperature – mean and temperature range factors. The proposed model is useful to predict damage values for solder joint in power electrical components. However, the real test data are required for the accurate model parameter estimation.

(3) In addition, operation and maintenance strategies might be developed based on the proposed approach. Especially strategies for renewable and replacement systems, where reliability updating might be implemented based on failure times.

6. Conclusions

This paper develops a conceptual system which utilizes the meteorological information for decision making based on CBM in operations and service management for wind parks, which is a form of proactive equipment maintenance that forecasts incipient failures based on a real-time assessment of various external and internal conditions obtained from, e.g. meteorological data and equipment monitoring system etc.

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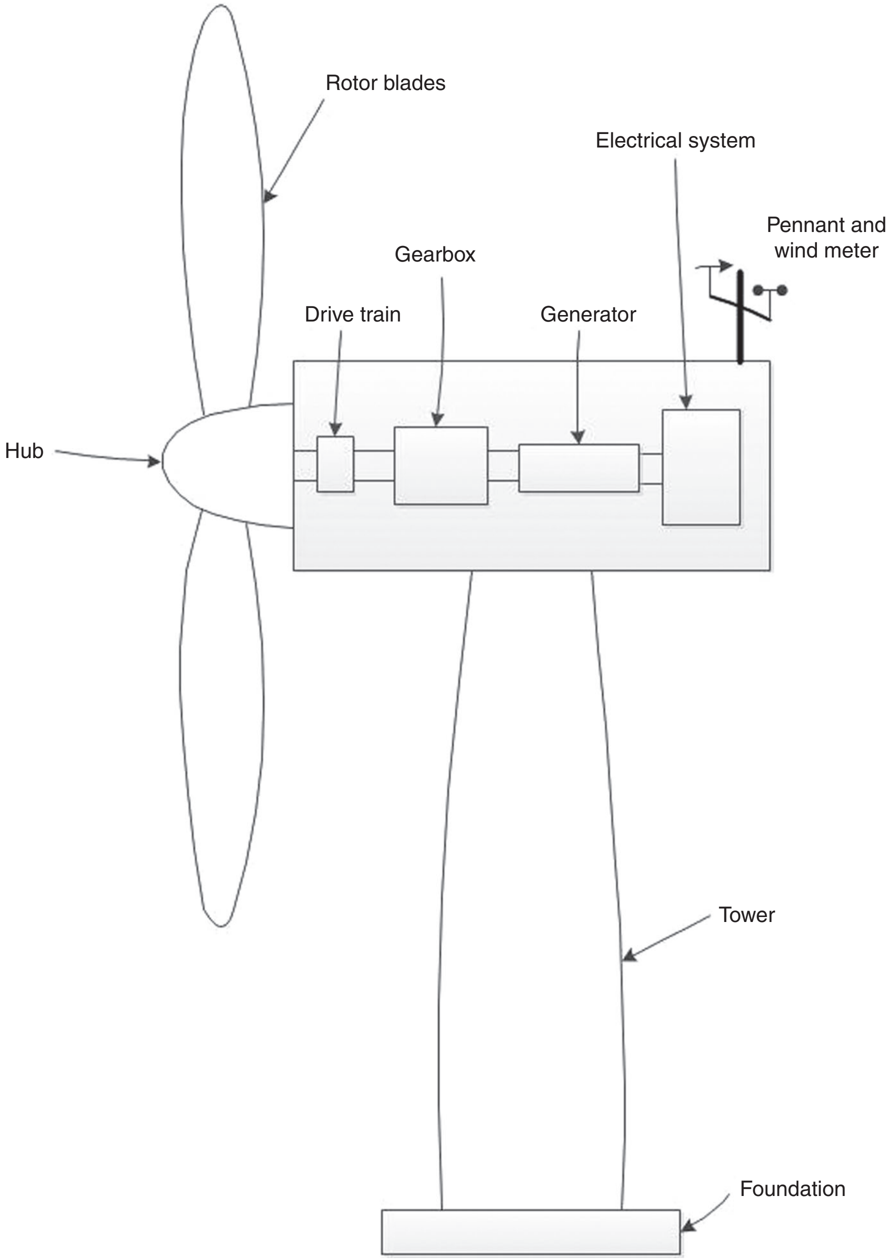

Figure 3.
Main structure of
wind turbine

Table I.
Typical failures related to weather conditions

Failure parts	Possible reasons	Weather conditions	Actions
Blade	Blade drive not ready	EWEs	Emergency stop
Rotor	Result of imbalance, blades and hub corrosion etc., brake sensor failure	Rain, snow and other hash meteorological condition	Normal stop
Gearbox	Over temperature, gearbox oil pressure too low	High temperature	Normal stop
Generator	Over speed, over temperature, bearing faults, current too high/ low, frequency sensor failure	High temperature and/or humidity	Emergency stop Normal stop
Yaw system	Yaw brake set unintentionally	Extreme changes in wind speed / direction	Normal stop
Tower	Weather or other failure may cause excessive vibration	EWEs	Emergency stop

The objective is to design an optimal service decision-making system based on CBM in wind park application to significantly cut down operation and maintenance costs and also implement a successful CBM strategy to achieve higher level of cost effectiveness, thus improve the operation and business performance. This paper bridges the gaps in current research of this area and opens up new research paths in the development of forecasting practices for service related decision making, operations and risk management of EWEs in wind parks. It has shown that through the analysis of the meteorological information, it is possible to predict harsh weather conditions which are harmful to cause faults in wind turbines. Modern NWP can provide reliable forecasts for wind parks as accurate as per quarter hour basis in the next couple of hours and also useful trend forecast up to days. By analysing the approximate time period of the 50-year maximum wind speed and extreme wind speed through EWEs forecasting, WPEs can effectively reduce and even avoid a huge number of losses in maintenance, and schedule service operations in more optimal periods. The basic idea has been already tested in a wind park in central China as depicted, but still lacks of systematic theory construction to be used as a decision support system. The implementation of this conceptual model will be dealt with in future research.

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About the authors

Dr Yang Liu has received his MSc (Tech) degree in Telecommunication Engineering and DSc (Tech) degree in Industrial Management both from the University of Vaasa, Finland. He is currently working as a full-time Senior Lecturer in Department of Information Technology at the Vaasa University of Applied Sciences, and a part-time University Lecturer in Department of

Production at the University of Vaasa, Finland. He has also been appointed as visiting professor in multiple universities in China. He has published over 50 scientific articles in refereed international journals and conferences and serves as referee in multiple leading OM/OR journals. His main research interests include evaluation and optimization of global operational competitiveness; performance analysis and enhancement in short-range wireless communications; autonomous robotics and artificial intelligence. Dr Yang Liu is the corresponding author and can be contacted at: yli@uva.fi

Wenshan Yang has received her MSc Degree in Computer Science from the China University of Geosciences, China. She is currently a PhD student in the Department of Production at University of Vaasa, Finland. Her main research area is operations management in sustainable energy.

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