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MODERN TECHNIQUES OF WIND TURBINE CONDITION MONITORING

Miloš Milovančević *
Mašinski fakultet, Niš
Dr Boban Anđelković
Mašinski fakultet, Niš

The wind power industry has experienced a large growth the past years. The growth mainly focus on a growing market, better economical conditions for wind power because of political decisions and the development of large wind turbines and offshore farms. A goal is to increase reliability for turbines. The topic is even more important for offshore farms where service is difficult and expensive.

Applied condition monitoring techniques on sub system level (gearbox, pitch mechanism, i.e.) are producing useful information about the wind turbine. Normally this information is only used at the level of safeguarding. Exceeding of the alarm levels often simply results in a wind turbine shut down and waiting for remote restart or repair. By application of more advanced methods of signal analysis, focused on trends of representative signals or combination of signals, significant changes in turbine behavior can be detected at an early stage. Because the approach is based on general turbine parameters, the information will also be of a global nature, so specific diagnostics cannot be expected. Thus, system for wind generator transmission gear vibration monitoring has been developed.

Keywords: wind turbine, maintenance, control

INTRODUCTION

The wind power industry has experienced a large growth in the past years. The growth mainly focuses on a growing market and the development of large wind turbines and offshore farms. The technical availability of wind turbines is high; this has mainly to do with a fast and frequent service and not with good reliability or maintenance management. Earlier, many wind power manufacturers tried to put the high service costs on insurance companies but they are not willing to play this game anymore. Hence, the wind power manufacturer must pay the service costs on its own as long as the turbines are within the warranty or service contract. Reliability for existing turbines must increase. The topic is even more important for offshore farms where service is difficult and expensive.

Thus, the answers for the wind power industry are condition monitoring systems (CMS). Such systems, commonly used in other industries, continuously monitor the performance of the wind turbine parts e.g. generator, gearbox and transformer, and help determine the best time for a specific maintenance work. At the moment several companies are developing and testing such systems. The systems aim at private owners that use wind turbines from many different manufacturers, hence the CMS systems must work for wind turbines from many different manufacturers. At the moment it seems that no systems show satisfying results and they seem to be too expensive to buy compared to what they do for the separate turbine. It must be investigated how these CMS systems can support the wind power user.

The further step could be to implement Reliability Centered Maintenance (RCM) as a part of CMS. A RCM method is a structured approach that focuses on reliability aspects when determining maintenance plans. The method defines efficient maintenance plans by e.g. prioritizing critical components and through the choice of maintenance tasks.

To understand the wind turbine's needs when it comes to the maintenance process a general knowledge about the wind turbine was needed. By looking into how the business views wind tur-

*Mašinski fakultet, Aleksandra Medvedeva 14, 18000 Niš; milovancevic@masfak.ni.ac.rs

bines, its components and CMS and how they view certification and standardization knowledge for what they want was found.

Through investigating how CMS could be applied to Reliability Centered Maintenance (RCM) and how this has been performed earlier in e.g. hydropower, a general knowledge was reached. Definitions of failure, availability and maintenance were necessary to come to an understanding about RCM and further on about RCM as a possible tool for wind power.

To get an understanding about CMS and what it can do, condition monitoring with vibration analysis and oil analysis has been studied in detail. The component that seems to fail the most is the gearbox; it has therefore been studied in a basic way and with condition monitoring as a focus [5].

GLOBAL CONDITION MONITORING TECHNIQUES

Application of this approach does not require additional investments in hardware. Only development costs are involved. Although it cannot be expected, that the results will be very specific, information which give an indication that something might be wrong can already be very valuable. In literature, some references have been found however, concrete results are not available. This means that long term development will be necessary.

Pitch mechanism

The pitch mechanism is one of the most vulnerable systems in a wind turbine. Following the development of larger wind turbines, the importance of the pitch mechanism will increase because:

- The pitch mechanism is part of the safety system for large wind turbines
- Pitch adjustment is of increasing importance for power control and load reduction provisions

Nowadays condition monitoring of this system is restricted to the individual performance of the servo motors themselves at the level of detection of maximum current. However model based condition monitoring of all three servo-systems is a promising possibility in this situation. Model based condition monitoring is suitable for non-stationary operation. The process I/O signals are used for diagnosis of the system, see Fig. 1.

The diagnosis can be based on the residual of the process and estimator output signals (see Fig. 2). In this situation, a constant model is used. The difference between the output of the system and the output of the model can be monitoring. Trend analysis of this residue can be used to detect changing characteristics of the system.

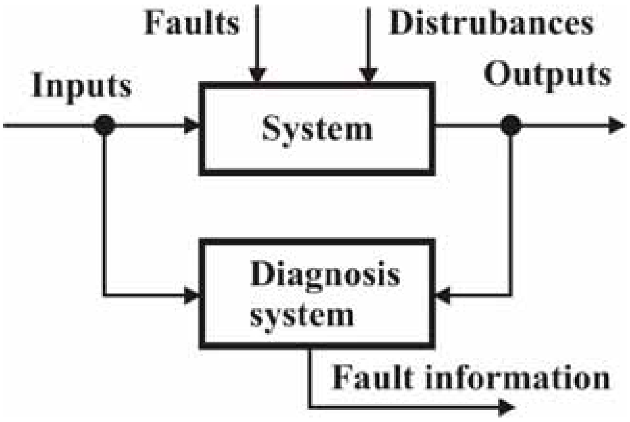

Fig. 1. Principle of model based fault detection

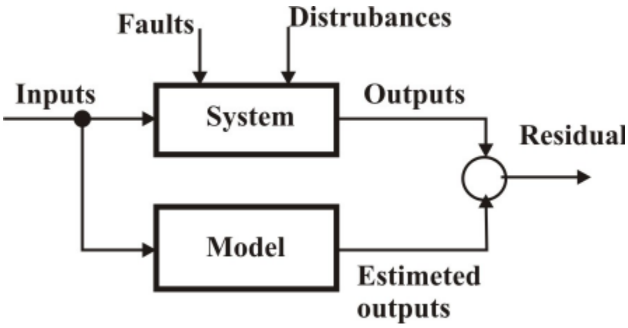

Fig. 2. Fault estimation based in residual

Another possibility of model based fault detection is continuous estimation of the model parameters, based on the measured I/O values and to monitor the trends in the parameters (see Fig. 3). The performance strongly depends on the accuracy of the estimation procedure. The number of I/O signals and the measurement accuracy of these signals are of importance to be able to detect changes in trends in an early stage.

Because the application of this technique is very specific for this application, the algorithms should be developed. This requires specific knowledge of the system, the control and model development. On the other side the application of the technique in a real wind turbine does not or hardly require addition hardware and sensors [6].

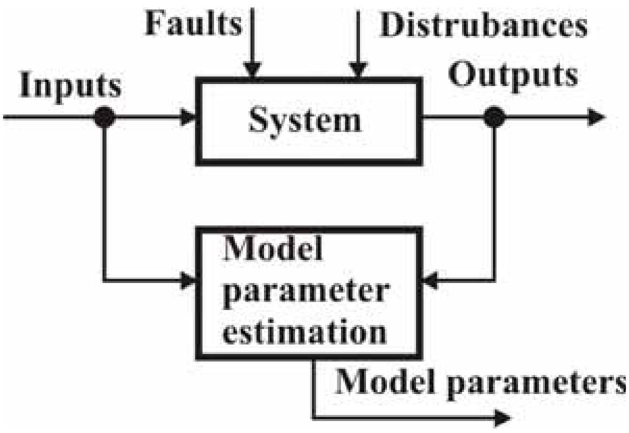

Fig. 3. Fault estimation based on model parameters

Gearbox

The importance of monitoring the condition of the gearbox is obvious. Also for wind energy, specialized companies supply special systems adapted for wind turbines (SKF, Pruftechnik, Gramm&Juhl, Schenck).

The fault detection is often based on frequency analysis and level detection for certain frequency bands. Based on the level of amplitudes, status signals can often be defined and generated. Presented diagram of fault detection based on FFT analyses presented on Fig. 4 is a product of newly developed software for vibration signal acquisition and analyses. Vibration diagrams a) and b) are gearbox vibrations in the state of good working order. Spectrums c) and d), are vibrations that indicate appearance of dynamic forces in gearbox due to gear wear process. Presented vibration spectrum is result of acquired vibration using, two axes accelerometer ADXL311 that is specially customized for vibration monitoring. Software for data acquisition and signal analyses is created by applying axiomatic design [3, 4]. Entire hardware is designed on PIC microcontroller bases and represents completely new micro-configuration for vibration monitoring [1, 2]. Basic signal characteristic (resolution, stability and repeatability) were laboratory tested on signal generator Tektronix dpo403. Analyses of exploitation results of newly developed configuration have proven that strict industry requirements can be fulfill completely by applying PIC technology.

The effectiveness of these systems is yet not evident.

Due to the non stationary operation, it appears to be difficult to develop effective algorithms for early fault detection, especially for variable speed operation. Practical experience builds up very slowly, because component degeneration is fortunately a slow process, and additional information about turbine loads and operational conditions are only fragmentarily available.

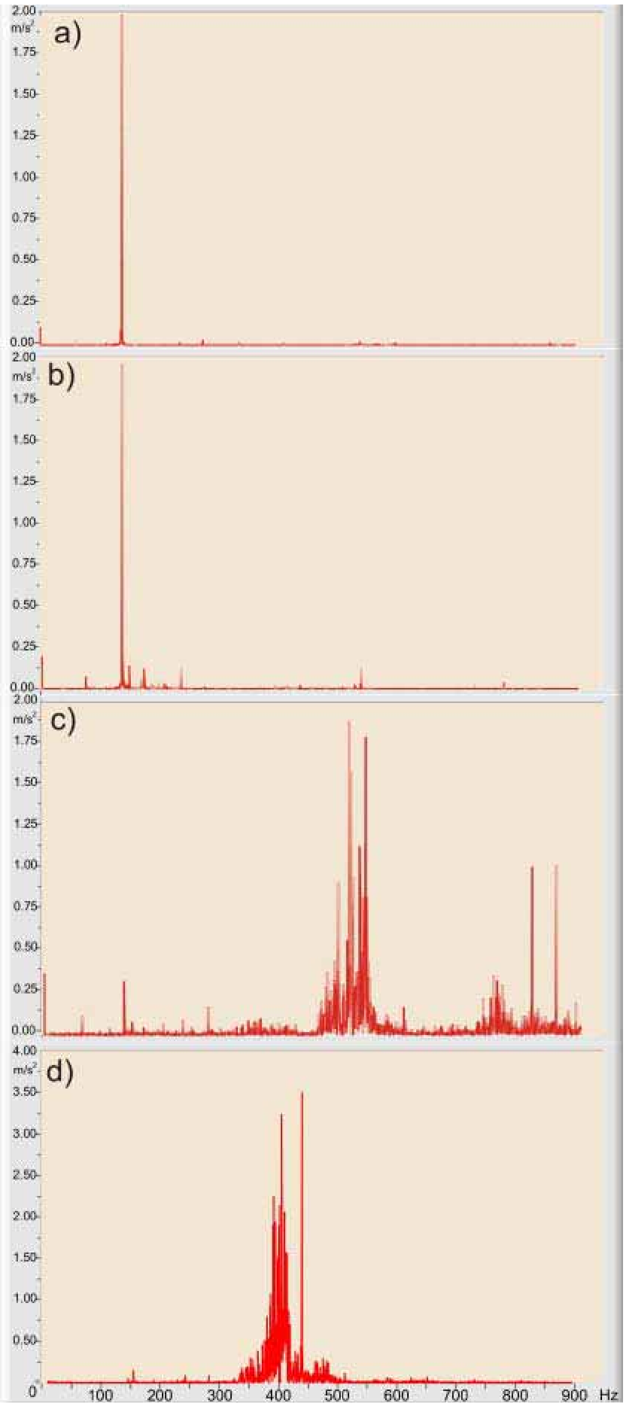

Fig. 4. Example of fault detection based on FFT

Blade monitoring

There are already some practical examples of blade monitoring. LM for instance has a system available, which operates completely, stand-alone and which is focused on detecting excessive vibration levels and sending messages to the company. The system uses acceleration sensors. The system has mainly been used for prototyping but was intended to be widely applied for stall regulated turbines in the 600 kW range.

NGUp has a sensor available, which was developed by blade manufacturer Aerpac. This sensor is based on a proportional proximity sensor, in combination with a bar mechanism. This system was developed for the same purpose as the LM sensor.

Although the LM system as well as the Aerpac sensor already have a track record, application of fiber-optic measurement techniques are foreseen as the most promising.

WIND TURBINE CONTROL

In constructing wind turbine control and safety systems one is soon aware of a couple of rather important problems. These problems pose special demands on the systems, because they have to function in the complex environment of a wind turbine. The first problem is common to all control and safety systems: A wind turbine is without constant supervision, apart from the supervision of the control system itself. The periods between normal qualified maintenance schedules is about every 6 months, and in the intervening 4,000 hours or so the control system must function trouble-free, whether the wind turbine is in an operational condition or not. In almost every other branch of industry there is a much higher degree of supervision by trained and qualified staff.

On factory production lines, operatives are normally always present during production. For example, in power stations the system is constantly supervised from a central control room. Should a fault or breakdown occur, rapid intervention is possible and, as a rule, one has always some sort of good impression of what has actually happened in any unforeseen occurrence? However a wind turbine must be able to look after itself and in addition have the ability to register faults and retrieve this stored information concerning any special occurrence, should things possibly not go exactly quite as expected. The high demands on reliability require systems that are simple enough to be robust, but at the same time give the possibility for necessary supervision. The number of sensors and other active components need to be limited as far as possible; however the necessary components must be of the highest possible quality. The control system has to be constructed so that there is a high degree of internal control and to a certain degree the system must be able to carry out its own fault finding. The other problem most of all relates to the safety systems. A wind turbine, if not controlled, will spontaneously over speed during high wind periods. Without prior control it can then be almost impossible to bring to a stop. During high wind, a wind turbine can produce a much higher yield than its rated power. The wind turbine blade rotational speed is there fore restricted, and the wind turbine maintained at the rated power, by the grid connected generator. If the grid connection is lost, by reason of a power line failure or if the generator for some other reason is disconnected, while the wind turbine is in operation, the wind turbine would immediately start to rapidly accelerate. The faster the speed, the more power it is able to produce. The wind turbine is in a run – away condition.

The following diagrams (Fig. 5, Fig. 6) dramatically illustrates run – away in high wind. The first graph shows the power curve for the 600 kW wind turbine as a function of the blade

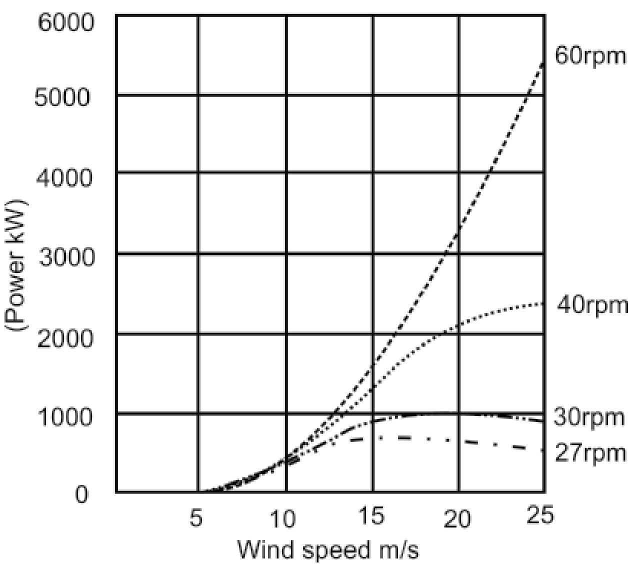

Fig. 5. Power curves depends of wind speed and wind turbine angular velocity

rotational speed. The bottom curve illustrates the normal power curve controlled by the generator, at a blade rotational speed of 27 rpm. The three other curves show power production at 30 rpm, 40 rpm and 60 rpm.

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Most wind turbine owners are familiar with the normal keyboard and display unit used in wind turbine control. The computer is placed in the control cabinet together with a lot of other types of electro-technical equipment, contactors, switches, fuses, etc. The many and varied demands of the controller result in a complicated construction with a large number of different components. Naturally, the more complicated a construction and the larger the number of individual components that are used in making a unit, the greater the possibilities for errors. This problem must be solved, when developing a control system that should be as fail-safe as possible.

To increase security measures against the occurrence of internal errors, one can attempt to construct a system with as few components as possible. It is also possible to build-in an internal automatic “self-supervision”, allowing the controller to check and control its own systems. Finally, an alternative parallel back-up system can be installed, having more or less the same functions, but assembled with different types of components.

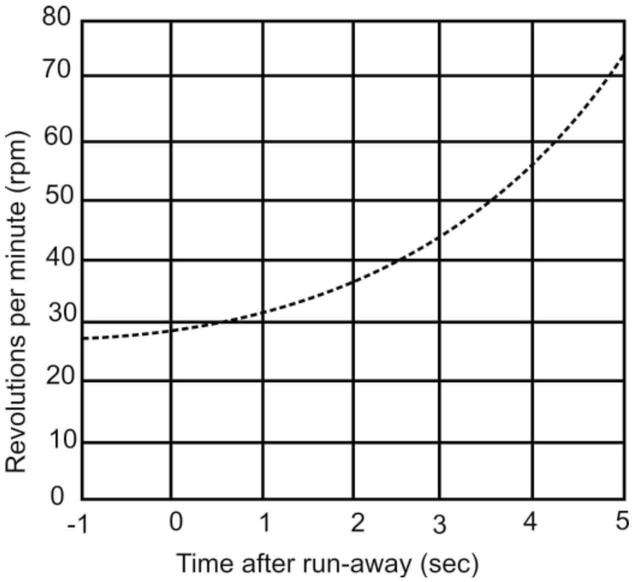

Fig. 6. Revolution per minute in run-away state

On the 600 kW Mk. IV wind turbine, all three principles are used in the control and safety systems. These will be further discussed one at a time in the following. A series of sensors measure the conditions in the wind turbine. These sensors are limited to those that are strictly necessary. This is the first example of the targeted approach towards fail-safe systems [7]. One would otherwise perhaps think, as we now have access to computers and other electronic devices with almost unlimited memory capacity, that it would merely be a matter of measuring and registering as much as possible. However this is not the case, as every single recorded measurement traduces a possibility for error, no matter how high a quality of the installed sensors, cables and computer. The choice of the necessary sensors is therefore to a high degree a study in the art of limitations.

CONCLUSIONS

Before condition monitoring can be applied successfully for wind energy, at least the following items should be solved. Wind turbine control systems incorporate an increasing functionality. Some of the functions come very close to condition monitoring. With relatively low costs, some more intelligence can be added, which makes early fault detection based on trend analysis possible. Apart from safeguarding, trending of wind turbine main parameters (power, pitch angle, rotational speed, wind velocity, yaw angle) can give global insight in the operation in the turbine. In other industries, condition monitoring provisions are normally separate systems, apart from the machine control and safe guarding functions. The monitoring is often focused on a very limited number of aspects. For wind turbines however, the system to be monitored is rather complex and the margins for investments are small. The number of systems is very high. So when existing systems are used, the adaptation should not only be focused on the dynamic load behavior, but also on streamlining the system and integration. Also, we have concluded that PIC microcontroller is good choice in wind generators vibration monitoring. Further research is going to be focused on development of other monitoring techniques for mechanical system based on PIC microcontrollers.

NOTE:

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SAVREMENE TEHNIKE MONITORINGA STANJA RADNE ISPRAVNOSTI VETRO-GENETARORA

Industrija vetro-generatora je u fazi značajnog razvoja poslednjih nekoliko godina. Rast industrije je prvenstveno okrenut ka razvoju tržišta, zato što bolji ekonomski uslovi za korišćenje snage vetra uglavnom zavise od političkih odluka u vezi sa korišćenjem obnovljivih izvora energije odnosno izgradnje farmi vetrogeneratora. Osnovni cilj je da se poveća nivo pouzdanosti vetrogeneratora. Ovo je naročito značajno u slučajevima, koji su i najčešći, kada su vetrogeneratori udaljeni od naseljenih mesta te je njihovo servisiranje komplikovanao i skupo.

Monitoring sistemi kod vetro-generatora uglavnom podrazumeva praćenje globalnog stanja sistema. Primena savremene metodologije analize signala, koja je uglavnom fokusirana na analizu trenda signala i analizi značajnih promena signala može da odredi vreme nastanka otkaza. U cilju određivanja stanja radne ispravnosti prenosnika vetro generatora razvijen je nov mikrokontrolerski sistem za monitoring vibracija.

Ključne reči: vetro-generatori, održavanje, kontrola

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