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Control chart monitoring of wind turbine generators using the statistical inertia of a wind farm average

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A B S T R A C T

A method for monitoring wind turbine generators (WTG) using data provided by the SCADA system is proposed. This method relies mainly upon comparing one WTG with the average of all remaining WTGs on a wind farm. Because environmental conditions on a wind farm are roughly the same over its entirety, the difference between each WTG and the average of the remaining WTGs on the wind farm is constant over time. The statistical inertia of averaged conditions for the entire farm provides a good yardstick for WTG monitoring. The results of monitoring four aspects of a WTG are presented here: these are electrical energy produced; tower vibration; nacelle yaw; and gearbox temperature. Control charts are used to detect abnormal behaviour. With regard to the electrical energy produced, one accidental activation of a curtailment algorithm was found. For tower vibration, we describe an application for the detection of rotor imbalance. For yaw, an example showing detection of nacelle drift is covered. Lastly, for gearbox temperature, the proposed methodology succeeded in detecting an issue two months prior to failure. We have included limitations as to the minimum wind farm size required in order to use the wind farm average. A centralized control chart is also proposed.

1. Introduction

During the life time of a Wind Turbine Generator (WTG), many events can affect its performance. These events can be classified according to the time scale on which they occur. Faults such as blade-angle asymmetry or generator over-speed generally affect the produced electrical energy for hours. Downtime resulting from changing or repairing a principal component such as a main bearing or a gearbox can last for days, even weeks [1]. Other events such as blade erosion build up over months and years. The effect of such events on power output can also be divided in two categories: events that partially reduce the production (e.g.: icing, blade erosion) and others that stop the WTG (e.g.: faults, downtime for repairs). Preventing these events or limiting their duration is an important aspect of wind farm operation and maintenance (O&M).

The ageing of WTGs is now a timely topic for the wind industry, since many wind farms in Canada and around the world have been in service for decades. With time, failure of components is more frequent and underperformances can appear. Some authors are reporting a performance reduction rate of approximately 1.5% per year [2]. Also, some operators are even considering the option of repowering, as their farms are getting closer to the end of their planned lifetimes, or as new WTG models, significantly larger than the ones built decades ago, become available [3]. Thus, various monitoring method are used to improve availability of WTGs and to achieve condition based maintenance. The ageing of the wind farms also motivates interest in the great amount of data available for the development of monitoring tools.

The objective of this paper is to propose a data-driven method to monitor wind farm WTGs base on the long term, which is also robust and suitable for the industry. Here, control charts are used for the generation of alarms. Unlike most other monitoring methods, the proposed methodology can be used to monitor a wide range of WTG components or aspects. It is also simple to understand and use: no advanced knowledge in data mining or modeling is required. Thus, the proposed methodology is suitable for industrial applications. Furthermore, this method allows for the monitoring of various aspects of a WTG simultaneously, with the help of a centralized control chart. This method is suitable for medium and large wind farms (more than 25 WTGs). Since the number of units per wind farm is constantly rising, this method is can be applicable

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to most cases.

First, previous work on the monitoring of WTGs will be reviewed. Then the proposed method will be detailed, followed by the results of its application to industrial wind farms. The method used here for monitoring a wind farm is based on comparing a single WTG with the average of the other WTGs on the same wind farm. The effectiveness of this approach will be demonstrated by means of four separate industrial study cases.

2. Literature review

One way of increasing the reliability and availability of wind energy is by monitoring WTGs. With proper monitoring, failures can be avoided and their consequent down-times limited, all of which increases availability. Maintenance can be planned efficiently, and replacement parts can be ordered before failure occurs. There are various ways of performing the monitoring of a WTG. These can be classified as follows: condition monitoring systems (CMS); Supervisory Control and Data Acquisition (SCADA) monitoring; power curve monitoring; and fault prediction.

2.1. Condition monitoring systems

Condition monitoring systems (CMS) involve the use of additional sensors that evaluate the health of WTG components. They are often based on vibration analyses and use methods such as wavelet analysis or Fourier transformations. They can achieve great precision by predicting the failure of a component months before it happens [4] [5] [6]. However, installing additional sensors can be costly in large wind farms [7]. CMS may also include oil analysis, thermography, shock pulse methods, acoustic emissions and ultrasonic techniques, as reviewed in Ref. [5].

2.2. SCADA monitoring

SCADA monitoring is the monitoring of a WTG using the data provided by its SCADA system and does not need the use of additional sensors [7]. This monitoring method is limited by the data SCADA provides. Often it is component temperature that is analyzed via SCADA monitoring [8]. In some cases, models are used in order to predict component behaviour [4] [9] and in other cases, the monitoring can be based on the signal itself (mean values, standard deviation, slopes, root mean square, spectrum, etc.) Power curve monitoring can be viewed as a subset of SCADA monitoring.

Power curve monitoring is based on the relationship between wind speed and power output. A change in behaviour of a WTG may be reflected by its power curve [10] [11] [12] [13]. This method of monitoring can be powerful for the detection of small, progressive underperformances [14].

However, power curve monitoring relies upon measurement of wind speed. According to IEC (International Electrotechnical Commission) 64100-12-1 [15], wind speed shall be provided by a met mast in order to assess the performance of a WTG as a function of freestream speed. But since wind farms have only a few met masts, nacelle wind speed is used instead in power curve monitoring. In fact, the important point is to obtain a reliable, repeatable and representative wind speed measurement. Therefore, the power curves, using nacelle wind speeds, can be used for monitoring. However, a major flaw in power curve monitoring is that any change in nacelle anemometry can create a considerable shift in the power curve. Fig. 1 illustrates a change in nacelle power curve following various changes in nacelle anemometry. These power curves were obtained with the bin method described in IEC's 64100-12-1 standard, while using nacelle anemonetry [15]. A noteworthy difficulty while monitoring a WTG's components using power curve monitoring, is that often, their failure will be seen in the power output after a critical point is reached.

2.3. Fault monitoring

Another type of monitoring is the prediction of faulty behaviours in a WTG. As defined by Ref. [16], a fault occurs when a parameter of a system deviates from standard conditions, such as blade angle asymmetry, component over-temperature or generator over-speed. Operational data are analyzed by means of complex algorithms in order to predict or even avoid the shutdown of the WTG [17] [18] [19] [20] [21] [22]. Faults monitoring methods can be classified into two categories: model-based and signal-based [16]. In the first case, a model is used to predict the value of a parameter and the predicted value is compared to the observed value in order to find abnormal behaviours. For the signal based approach, features of the signal are studied. These features may be in the time domain (mean, root mean squarre, gradient) or frequency domain (spectrum) [16] [23]. Fault monitoring also includes fault-tolerant control, where a system analyses the severity of the fault and takes appropriate action (compensation, controller reconfiguration, etc) [16].

Fault prediction is especially important for offshore wind farms, where access to the WTG is more difficult than onshore wind farms. High frequency data (~1 Hz) must be available for use in predicting faults; often, additional sensors or complex models, or algorithms are used as well. The types of conditions the control system of a WTG uses in order to detect faulty behaviour requires input to remain above a certain threshold for a few seconds or minutes. Some work has also been done on the development of a WTG controller that can be optimized according to the conditions of the WTGs subset in order to avoid faults. Used components or component subsets may act differently from their nominal behaviour and thus, the optimal control strategy should be revised [22]. For more on fault monitoring and diagnosis, see Refs. [16] and [23].

The monitoring methods detailed above can all be useful in the O&M of a wind farm. Operators might consider using a combination of these methods, as each evaluate the condition of a different aspect of their WTG, based on different criteria.

3. Data source

The data used to develop and test the proposed method was taken from five industrial wind farms located in Canada. All the WTGs were the same model and were MW class and pitch regulated. Each wind farm contained over 50 WTGs. While the data was recorded at a frequency of 1 Hz, ten-minute averages are used. This averaging limits the noise in the signals and is the norm in the wind power industry, as suggested by the IEC standard [15]. The database has been in service since 2009, which is of interest for long-term monitoring. No CMS were installed on the WTGs. Available values included wind speed; yaw; ambient and nacelle temperatures; blade pitch angle; principal-component temperatures (generator, gearbox and main bearing); rotor and generator rotation speed; power output; tower vibration; and state of the WTG (online, repair, maintenance, curtailment, etc.) Because there was no measurement of principal-component vibration, monitoring methods using these values could not be used. Extreme values corresponding to obvious instrumentation malfunction have been removed from the database. Fig. 2 illustrates the data available and the data acquisition process. Here the acquisition and archiving system is the PI system from OSISoft. There is a local server in each wind farm, linked with an Internet connection to a main server. This redundancy allows to archive data even in the eventuality of connection losses with the main server and the on-site server. The

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