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Analyzing bearing faults in wind turbines: A data-mining approach

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ABSTRACT

Bearings are an essential part of turbine generators and gearboxes. Dynamic and unpredictable stress causes the bearings to wear prematurely, leading to increased turbine maintenance costs, and could lead to sudden, expensive turbine breakdowns. Over temperature impacts the performance of turbine bearings. In this paper, data mining is applied to identify bearing faults in wind turbines. Historical wind turbine data are analyzed to develop prediction models for bearing faults. Such models are generated by neural network algorithms, using data from 24 turbines collected over a period of four months. Models predicting normal behavior are constructed. The performance of the models is validated on different wind turbines with over 97% accuracy. The model error residuals are analyzed using moving average windows to predict the occurrence of over-temperature events. Five over-temperature events are analyzed. The research reported in this paper has led to the prediction of faults 1.5 h before their occurrence.

1. Introduction

Wind energy is one of the most viable sources of renewable energy. The growing number of wind farms has increased the importance of their operation and maintenance [1]. Due to the variability of wind, shifting loads, and fluctuating energy demands, components of wind turbines such as gearboxes and generators are susceptible to damage. The replacement cost of failed high-value components can be high.

In the event of faults, the monitoring systems of wind turbines issue alarms. However, such alarms are usually signaled once damage to the component has already occurred. There is a need to find solutions for predicting faults ahead of time to avoid extensive damage to turbine components. Data-mining algorithms build fault prediction models using data collected by supervisory control and data acquisition (SCADA) systems. Such data—e.g., power output, gearbox bearing temperature, and generator speed—are usually acquired for over 100 turbine parameters.

Traditional condition-monitoring systems are imperfect and can be costly. Data-mining algorithms use historical wind turbine data to predict faults. Such algorithms have been successfully applied to predict faults across various wind turbine components such as: turbine blades [2], generators [1, 3], and gearboxes [4-5].

The results presented in this paper are based on data collected at twenty-four 1.5 MW wind turbines. The parameter values recorded at 10-s intervals (10 s data) over a period of four months constitute the dataset used in this current research.

2. Data description and analysis

The data used in the research have been collected from the supervisory control and data-acquisition (SCADA) systems of a large wind farm. Here, high-frequency data (i.e., 10 s) from 24 wind turbines are used to analyze bearing faults. Table 1 displays the temperature range for the turbine bearings of the generator, gearbox, and shaft. Turbines 3 and 15 are affected by over-temperature faults of generator bearing B, and thus are not considered for constructing the model of normal bearing behavior. Instead, the data from turbines 3 and 15 are used to test the abnormal behavior of turbine bearing temperature. The negative temperature readings of −273, −37, and −36 in Table 1 could be due to measurement error or they represent under temperature. Since the aim of present research is to analyze and develop models predicting over-temperature issues, data points consisting of such values are discarded. In the next section, training and testing strategies of the data-mining algorithms are discussed.

2.1. Training set selection

Modeling the normal behavior of a generator bearing requires input data with varying temperatures. Therefore, the data from

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Table 1
Turbine bearing temperature ranges.

Turbine index	Temp. generator of bearing A (°C)		Temp. generator of bearing B (°C)		Temp. of gearbox bearing (°C)		Temp. of shaft bearing (°C)	
	min	max	min	max	min	max	min	max
1	14	66	20	87	24	70	−4	36
2	13	74	16	77	22	71	−7	35
3[a]	−37	70	−37	101	−37	69	−36	36
4	−39	46	−39	64	−39	69	−38	36
5	−273	62	−273	73	−273	70	−273	34
6	−38	57	−38	73	−37	68.8	−37	34
7	−37	57	−37	69	−36	66	−36	33
8	10	43	13	62	32	67	3	37
9	−36	42	−39	49	−36	64	−35	36
10	5	42	8	48	23	68	4	36
11	6	40	15	46	26	64	0	36
12	−273	77	−273	69	−273	64	−273	32
13	−39	48	−40	52	−39	68	−38	35
14	12	52	21	76	26	69	−2	32
15[a]	−273	54	−273	107	−273	68.2	−273	34
16	8	48	12	64	25	67	−1	36
17	−37	78	−37	82	−37	70	−36	36
18	8	46	11	59	26	70	2	37
19	−37	49	−37	80.3	−36	77	−35	37
20	−39	44	−38	53	−38	65	−37	36
21	8.6	80	10	86	15	69	−8	34
22	−37	74	−37	77	−37	65	−36	34
23	−38.5	59	−38	75	−38	69	−37	36
24	−37	47	−37	47	−37	70	−36	36

[a] Of interest.

different wind turbines is used for model development. The box plot in Fig. 1 illustrates the generator-bearing temperature data from 24 wind turbines, which are highly variable. To increase the number of training examples, data from multiple wind turbines

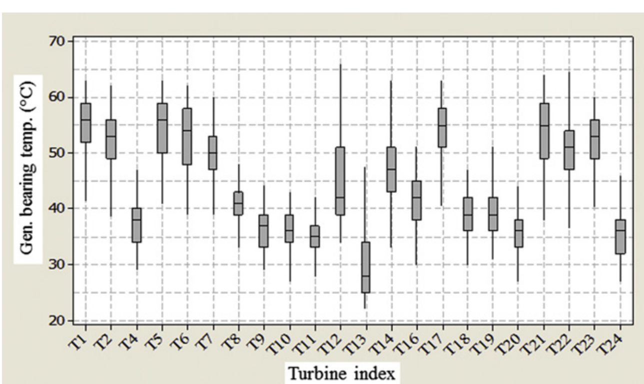

Fig. 1. Box plot of the generator bearing B temperature of 24 wind turbines.

Table 2
Description of datasets.

Dataset	Start time stamp	End time stamp	Turbines considered
Training	8/1/2009 12:00:00 AM	12/8/2009 11:59:50 PM	5–8, 12–14, 16, 19, 21–23
Testing normal behavior	8/1/2009 12:00:00 AM	10/1/2009 11:59:50 PM	1,12

have been used. The data from turbines 5–8, 13–14, 16, 19, and 21–23 constitute the training dataset.

Fig. 2 depicts the range of the generator bearing B temperature used to model normal turbine behavior (i.e., behavior not affected by faults). According to current wind turbine operation practices, the generator bearing B temperature exceeding 90 °C requires turbine shutdown for bearing lubrication. Turbines 3 and 15 have shown some abnormal bearing temperature (see Table 1) and therefore their data has been used for model validation. The characterization of the training and testing dataset is provided in Table 2.

3. Modeling normal bearing behavior

3.1. Parameter selection for model construction

To capture the normal behavior of the generator bearing, parameters impacting the bearing temperature are initially selected using domain knowledge (reduction from 100 to 50 parameters) and the final selection with data-mining algorithms. Three different data-mining algorithms—wrapper with genetic search (WGS) [6-7], wrapper with best first search (WBFS) [8], and boosting tree algorithm (BTA) [9]—have been applied to select the most relevant parameters for predicting the generator bearing B temperature. The wrapper approach uses supervised learning to select relevant parameters by performing 10-fold cross validation. Table 3 lists the 10 most relevant parameters. Eighteen different input parameters namely voltage phase A, C (VA, VC), current phase A, C (CA, CC), nacelle revolution (NR), torque (Tor), temperature generator 1 (G1T), temperature gearbox (GBT), temperature ambient (AT), temperature nacelle (TN), temperature generator cooling air (GCAT), temperature main box (MBT), temperature hub (TH), temperature control box axis 1 (TCB1), hydraulic pressure (HP), temperature top box (TBT), temperature gearbox 1 (GB1T), temperature generator 2 (G2T) are used to develop the regression models. As anticipated, various temperature parameters are found to be important for analyzing bearing temperature.

3.2. Model construction

The model for predicting the generator bearing B temperature is presented in the eq. (1).

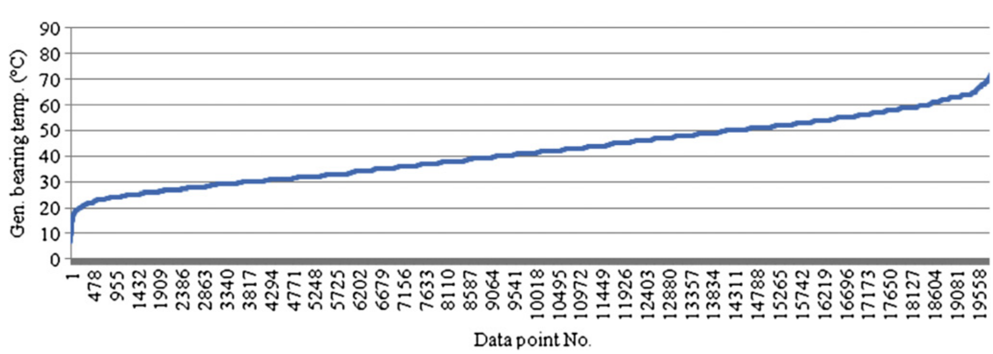

Fig. 2. The generator bearing normal temperature range.