Forecast of Faults in a Wind Turbine Gearbox

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Abstract— **The maintenance costs associated with wind turbines assumes an important weight in the operation of wind parks. The main objective of wind farms operators is to run their parks most economically, to increase their profits. An adequate maintenance planning is essential to an effective operating costs reduction, compared with traditional maintenance techniques.**

Tools to detect the onset of mechanical and electrical faults in wind turbines at a sufficiently early stage are very important for well planned maintenance actions, because these actions can reduce the outage time and can prevent bigger faults that can lead to machine outage.

The amount of information obtained from SCADA systems of wind farms is huge. The use of neural networks to deal with all the information and try to detect faults in some equipment in a early stage is a promising technique.

***Keywords*— Condition monitoring, fault detection, gearbox, neural network, wind turbine.**

I. Introduction

Faults are problems that must be prevented at any cost in any equipment and specifically in a wind turbine. First, because a fault resolution implies, normally, the displacement of specialized staff (maintenance teams) to the wind park. On the other hand. if a fault exists, it can lead to the stopping of the machine and, in this situation, it is necessary to add the costs associated to the outage and, consequently, the costs of the energy not produced , to the costs associated to the reparation of fault.

Failure rate applied to the equipment of a wind turbine follows the known bath curve, where the fault rate tends to increase when close to the limit of useful life of the equipment. Fig. 1 presents the bath curve which represents the evolution of failure rate.

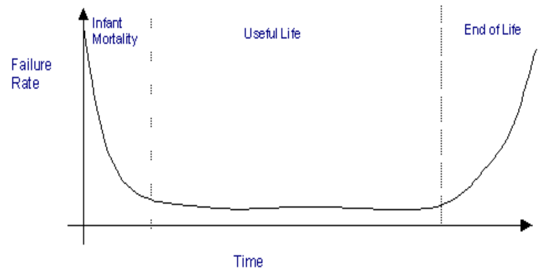

Fig. 1. Failure rate evolution [1].

As consequence, operation and maintenance costs increase significantly. Operation and maintenance costs can account for 10-20% of the total production cost of energy for a wind project [2]. For these reasons it is important to minimize, the maintenance costs, without disregard the reliability of the wind turbines.

It is important to invest in new preventive maintenance methods, to reduce costs and increase the efficiency and the profits.

To implement this new method of earlier detection of faults in the gearbox of wind turbines information gotten from SCADA system and information of the service reports made by the maintenance teams will be used. To deal with this big amount of information neural networks techniques are applied. All data used in this paper is real and obtained from a real wind park equipped with 13 wind turbines of 2 MW, with gearboxes, in the North of Portugal.

II. Gearbox

The gearbox, if it exists, is one of the main components of a wind turbine and is placed in the nacelle between the rotor and the generator. Its main function is to adapt the blades rotational speed to the rotation speed of the electric generator.

There are several types of gearboxes, but the planetary gearboxes are the most usual in applications to wind turbines. Although more complex, have some advantages in terms of size and weight.

This type of gearbox is composed of a central gear and multiple gears around, usually three. Fig. 2 shows a gear box of this type.

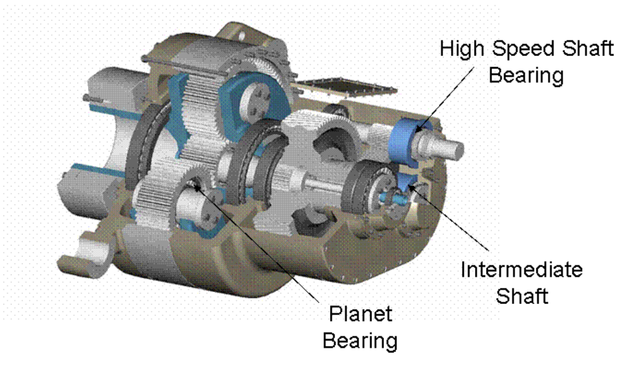

Fig. 2. Planetary gearbox [3].

The central gear wheel rotates at speed imposed by wind turbine blades while, three smaller gears are increasing the speed. The axis associated with the highest speed level is the one that will be coupled to the electric generator.

Gearboxes usually do not break down during the first years of operation. Gearboxes applied to wind turbines in the power range between 1.5-3 MW, were developed by experience obtained in smaller gearboxes used in other industrial equipment. Inspections made from the first three years of operation show, however, that wear of equipment normally leads to serious faults, which cause major repairs, or even its replacement after a few years [4].

A major failure in the gearbox is a serious problem, because of the equipment cost of and the means required for replacement and associated downtime of the wind turbine.

Gearbox is a device purely mechanical, with lots of rotating parts. The main causes of breakdowns occur, usually due to lack of lubrication, wear of materials, failures of bearings and gears teeth break.

Faults in the gears are usually preceded by bearing failures. This phenomenon may seem incomprehensible, since the bearings that are used in gear boxes, are not subject to strong efforts, compared to the cogwheels, which are subject to sliding, contact and bending efforts. The bearings can, however, be affected by small particles earned by oil used to lubricate, derived from the wear of parts, that could be the explanation of the failure [5].

Typically, the gearboxes failures are not due to manufacturing errors. However, they can occur due to the use of materials of lower quality, which later lead to the appearance of cracks in the body of the box. This was the major problem occurred to the gearboxes of wind turbines of the wind park used to develop this research work.

III. Neural networks application

The application of neural networks (NN) is dependent on the number of measurements and on their quality. Greater the quality data set, greater the quality of the results will be. If a year's measurements is used the data set is very large and can be used for learning, test and validation of the NN. The main goal is to understand which measurements are important to use as input of the NN, because some measurements can have a weak influence on the process and this only contributes to wasting computational time.

Wind turbines have a lot of sensors measuring important information of its behavior. Depending on the turbine kind and producer, several measurements are made and saved in the wind park central computer or in the control centre, if it exists. Measurements are normally 10 minutes average values and can hide important information. In this particular Portuguese wind park, the measurements saved are: time and date, wind speed, pitch angle, generator rpm, power, frequency, phase currents and voltages and 16 temperatures of several equipments of the wind turbine. These 16 temperatures are very important, important because they can hide a lot of information about the component's behaviour. For the specific wind turbines in which the study is undergoing, collected temperatures are summarized in Table I, and from those 16 temperature measurements, some of them were used as input of the developed method to prevent faults in the gearbox of the wind turbine. The method used to choose the most important measurements was based on several aspects such as correlation analysis, behavior analysis and delay between measurements.

For a good fault detection approach it is necessary to develop very accurate models, based on a series of measures that effectively represents the normal operation of wind turbine.

TABLE I.
Temperature measurements made in the wind turbine

	Component
Temperature 1	Environment
Temperature 2	Hydraulics
Temperature 3	Gear Oil
Temperature 4	Generator
Temperature 5	Slip Ring
Temperature 6	Bearing
Temperature 7	Hub Control
Temperature 8	Nacelle
Temperature 9	Top Control
Temperature 10	Busbar
Temperature 11	Spinner
Temperature 12	Transformer L1
Temperature 13	Transformer L2
Temperature 14	Transformer L3
Temperature 15	Generator Bearing
Temperature 15	Cooling Water

With the objective of monitoring the gearbox and to try to prevent faults in the important wind turbine component it was necessary to analyse the behavior of temperature of the gear oil (Temperature 3).

The neural network model developed to detect faults in the gearbox is composed by 1 input layer, 1 hidden layer and 1 output layer. The input layer is composed by 4 inputs that are the average power produced, the average environment temperature, the average bearing temperature and the average nacelle temperature. In the output layer is the gear oil temperature. Fig. 3 shows the architecture of the network used

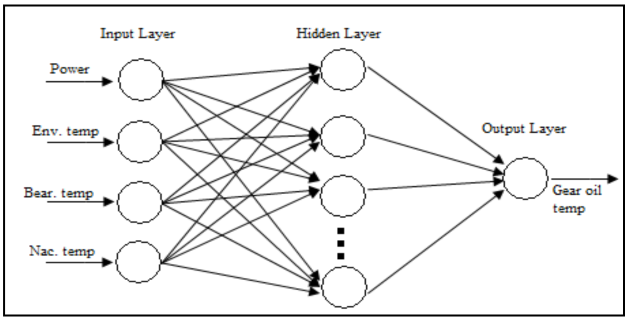

Fig. 3. Neural Network architecture.

The criterion used to evaluate the performance of the model is the reduction of the mean square error (MAE), given by the equation.

$$MAE = \frac{1}{n} \sum_{i=1}^{n} \sqrt{e_i^2} \qquad (1)$$

where e_i represents the error between the real generator temperature and the estimated one and n is the number of estimations made by the neural network.

A MAE greater than 2ºC indicates that something wrong has occurred in the gearbox.

IV. Results

To implement the neural network two software's were used, the *SPSS Clementine* and the *Matlab Neural Network toolbox*. To train, test and validate the neural network was used 1 year of measurements.

The objective was to predict the gear oil temperature based on the inputs referred in the previous section.

After training the neural network with almost 1 year data the same interval of data was used to evaluate the performance of the NN.

The wind park used to make this study started its activity in 2004 and has 13 wind turbines of 2 MW, each equipped with double fed induction generators.

Out of the 13 machines, nine of them had problems with the gearbox that led to the substitution of that component. Seven of the problems were due to cracks in the body of the box.

Next tables will show the results of simulations made by the application of the neural network model developed to detect faults in the gearbox of the wind turbines.

Will be presented, on Table II, the results of the MAE obtained for a wind turbine with no problems in the gearbox. Table III shows the results for a wind turbine with a fault in the gearbox [6].

Simulations were made for 3 years of operation of the wind park.

TABLE II.
SIMULATION FOR A WIND TURBINE WITH NO PROBLEMS

	2006	**2007**	**2008**
Jan	1.163	1.107	1.193
Feb	2.315	1.630	1.458
Mar	5.276	1.279	1.240
Apr	0.958	No data	1.353
May	1.171	1.288	1.393
Jun	1.134	1.377	1.412
Jul	1.199	1.346	1.509
Aug	1.441	1.411	1.383
Sep	1.142	1.403	1.355
Oct	1.320	1.621	2.066
Nov	1.090	1.363	2.353
Dec	1.020	1.459	2.169

As is possible to see from Table II, MAE is generally always lower than 2ºC. In March of 2006 there is a high value, which can indicates that something is wrong with the gearbox.

A maintenance team was called to check out a high alarm temperature reached by the gearbox oil. The service report drafted by the maintenance team indicates that the oil pump gear box was defective.

Analysing the values in the table is possible to see that the problem occurred with the oil pump was detected in February, i. e., one month in advance.

From October of 2008 the MAE is higher than 2ºC, value used as trigger alarm. Service reports made by the maintenance teams in the end of 2008 reports some leaks in the gearbox. Those leaks were considered normal for that kind of equipment and are not due to cracks in the body.

Table III shows the MAE simulation results obtained with the application of the developed neural network model to a gearbox with problems.

TABLE III.
SIMULATION FOR A WIND TURBINE WITH PROBLEMS

	2006	**2007**	**2008**
Jan	1.056	1.156	1.194
Feb	1.006	1.597	1.264
Mar	1.065	1.272	1.412
Apr	1.046	No data	2.157
May	1.025	1.244	1.742
Jun	1.080	1.207	2.282
Jul	1.113	1.640	2.574
Aug	1.051	1.639	3.374
Sep	1.190	1.851	2.137
Oct	1.176	1.850	2.664
Nov	1.143	1.584	2.447
Dec	1.015	1.391	2.437

The analysis of the results presented in Table III is possible to verify that during the years of 2006 and 2007, the MAE indicator shows normal values, concluding that the gear box is working correctly. Also the service reports drawn up during that period do not indicate any serious failure in equipment [6].

In June 2008, the MAE reached high values and remained so until December of the same year. In December, the gearbox was replaced due to leaks of oil caused by cracks in the body of the box. As is possible to see, the method developed for the detection of faults in the gearbox detected the failure with six months in advance, because since June 2008 Mae indicator presents high values, indicating something wrong with the equipment [6].

V. Conclusions

The study presented show that is possible to model the normal operation of the gearbox using neural networks.

The developed tool based on neural networks is a valid tool and can be useful to make an early detection of failures in the gearbox device. Although the results presented refer to problems arising in the past, it is possible to use the same method with online measurements as a way of bringing to our attention some future faults in wind turbines components. The results presented were applied to the gearbox but the same method can be applied to other equipment of the wind turbine with the main goal of make an earlier detection of faults in other important components of the wind turbine.

In [8] the same method was applied to the detection of faults in the electrical generator and results obtained were very good. Major faults in that equipment were detected 4 months in advance.

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