OPEN ACCESS

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Neural Network Controlled Primitive Fault Analysis and Monitoring of Wind Turbine Gear Box

B. Raja Mohamed Rabi, Kanimozhi Kannabiran

Abstract*: The problem considered in this paper is minimization of operational and maintenance costs of Wind Energy Conversion Systems (WECS). A continuous condition monitoring system is to be designed for reducing these costs. Hence preliminary identification of the degeneration of the generator health, facilitating a proactive response, minimizing downtime, and maximizing productivity is made possible. The inaccessibility of Wind generators situated at heights of 30m or more height also creates problem in condition monitoring and fault diagnosis. This opens up the research on condition monitoring and fault diagnosis in WECS (blades, drive trains, and generators). Therefore different type of faults, their generated signatures, and their diagnostic schemes are discussed in this paper. The paper aims in validating the application of neural networks for the analysis of wind turbine data, so that possible future failures may be predicted and rectified earlier.

***Index Terms*: Condition monitoring, Drive train, Generator, Primitive Fault diagnosis, Wind Energy Conversion Systems.**

I. INTRODUCTION

Renewable energy source is an alternative for dwindling fossil fuels[1-4].The future electric generation is going to depend on wind energy conversion techniques. The focus of wind power growth in the past years is on market growth, economic conditions of wind power and the technical advancement of wind turbines and offshore farms. Reliability of turbines used in off shore farms has to be increased as their service is difficult and expensive. The quantitative growth of wind farms rated capacity, and its demographic availability makes it possible to be operated similar to traditional power plants. But the problem faced compared to traditional power plants is controllability of wind farms. The problem can be reduced by predicting power output of wind plants so that to economic power dispatch is achieved. The state of wind power system is analyzed by number of sensors and measurement equipment attached to wind turbines. These information saved in the master computer at Wind Plant is sent to the control unit. The operators in control unit have to analyze the data and identify the symptoms of turbine problem . The wind farm has many machines and each machine can send signals to the to the control unit. The master computer unit has a database of several measurements categorized based on the make and producer of the wind turbine. In this research a wind plant at Tirunelveli with 22 wind turbines of 10 MW was studied and, the data collected are are: Time and date ;Wind speed; Pitch angle; Turbine speed ; Power; Frequency; Current and voltages; temperature. SCADA (supervisory control and data acquisition) systems is implemented to collect above data on an average of 5 minutes interval. Normally during availability of wind turbines produce power and power is drained to the grid. Due to the increased amount of power produced by latest techniques grid integration should be well organized and monitored by the system operator. To compete with other traditional power plants more research has to be done towards improving the reliability and life time of the wind turbines [5].As SCADA is being used in wind turbine systems predictive maintenance strategies has to be evolved. Maintenance guidelines for wind turbine has been given by manufacturers, but more strategy has to be chalked out for prediction of real life problems. [6]. This paper provides the use of neural networks to detect problems in wind turbine components. In Section 2 it will present the base of this study, the most common failures of wind generators and in the wind park. Gearbox description will be done in Section 3 will focus on the selection of important measurements to be used on the neural network. Section 4 will present some results of the application of neural networks to the detection of failures in the wind turbine gearbox.

II. MATERIALS AND METHODS

Wind energy generation is flourishing in the past decades. The estimated value of installed wind capacity in 2003 was around 50000 MW, and it has exceeded 95000 MW in 2008 . The estimated r target is to achieve 15 % of the world's electricity from wind power by 2020. The present research interest is harvesting wind energy for electric power generation and the scenario is dragged towards the cost-effective utilization of wind energy for quality and reliable power supply. The remarkable development of wind turbines capacity is from 20KW to 2 MW in the past few years , and more number of larger wind turbines are being designed [7].

Revised Manuscript Received on 30 July 2019.

* Correspondence Author

B. Raja Mohamed Rabi*, Department of Mechanical Engineering, Sethu Institute of Technology, Kariapatti, Tamil Nadu, India.

K.Kanimozhi, Department of Electrical and Electronics Engineering, Sethu Institute of Technology, Kariapatti, Tamil Nadu, India.

A. *Availability*

Reliability of wind turbine is measured by the measurand availability. This is a combination of the time during which interruption has occurred ie.outage time and the frequency of interruptions. In [8], availability is defined as the probability that the component or system is capable of functioning at a time t.

The availability is defined as

$$A = \frac{MTF}{MTF + MTR} \qquad (1)$$

where MTF is mean time to failure and MTR is mean time to recovery.

B. *Maintenance*

The goal of turbine maintenance is to enhance the component's desired performance by regularly monitoring the component [9]. The regular maintenance provides so many desirable solutions to the system. The classification of maintenance are preventive and corrective maintenance [10]. In preventive maintenance work is done before occurrence of failure and in corrective maintenance work is done after occurrence of failure. Scheduled and condition-based maintenance are categories of preventive maintenance. A time schedule is to be developed depending on number of units for implementing scheduled maintenance [11]. Scheduled maintenance elements are lubrication, tightening bolts, changing filters, and validating safety equipment. Maintenance performed based on performance and/or parameter monitoring and following actions is called as Condition-based maintenance.

C. *Failures*

In modern wind plants installed with human operated control units fault detection techniques are essential. The parameters considered for diagnosis are the prevention of major components failures, performance of wind generators and vibration characteristics that allows for condition-based maintenance schemes to increase maintenance intervals [12]. The three types of faults occurring in a wind generator are electrical faults, electronic faults and mechanical faults. The electrical faults are not periodical and are unexpected. In the wind plant considered for research work problems occurred in the generator and led to its replacement. The problem was a short circuit in the rotor winding. Electronic faults are periodical and have a higher occurrence frequency compared to electrical faults. These kinds of problems occur frequently in sensors and in electronic cards. The faults in electronic components faults can be caused by changes in weather conditions and atmospheric effects. When lightning hits the towers the electronic components break and are damaged. The solution left out is replacement. A number of sensors are fitted in a wind generator. Time required to repair sensor components is very less but the fault occurrence rate is very high. These component faults can lead to standstill condition in wind turbine. The next types of fault is the mechanical fault. This occurs in the gearboxes, turbine blades and hydraulic system. Cracks in The gearboxes are too often cracked leading to reduction in oil pressure. Hence turbine blades are damaged due to weather changes. Wind turbine Blade system is a very important component. The size

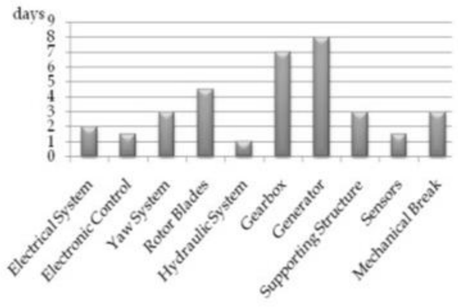

Figure 1 Typical Downtime per failure

of towers and blades, determines wind bearing capacity, hence strongest winds are captured by increasing width and height of blades. But in contradiction the turbine blades experience continuous vibrations and centrifugal forces making this component the weakest mechanical link in the system.The mean time required to repair faults occurred in wind turbine equipment is shown in figure 1. It is inferred from figure 2 that the components causing turbine downtime are blade system, gearbox and the electrical generator. Therefore regular monitoring and maintenance is to be done to those components by the condition monitoring system.

Considering a real wind farm, equipped with 22 wind generators of 10 MW each for half yearly monitoring, some inferences about turbine downtime fault are arrived. The causes of faults that led to the standstill condition of machine were divided into five groups: NTP (not planned), PLN (planned), NFT (network fault), STP (short time planned) and OTC (other causes).The NTP outages covers unplanned causes , say sudden replacement of damaged equipment, faulty communications, increase in generator temperature and other equipment. In case of PLN is the sudden stops are already scheduled for planned maintenance of the wind turbines. In the NTF group all halts caused by the electrical grid are embedded. The examples in real time scenario are activation of maximum or minimum voltage in the substation and high currents in the generator caused by electrical network problems.

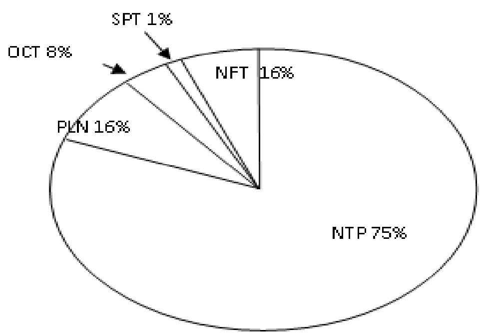

Figure 2 Occurrence of fault in percentage

In case of STP stops are made by the outage time caused by software upload and adjustments in parameters of turbines control systems made by maintenance teams. The causes that led to wind turbine stop due to weather conditions, lightening, strong winds, etc. are grouped in the OTC group.

From above analysis it is inferred that not planned actions contribute to 80% of the stopped time of a wind. The other groups also are accounted to the stopping of the machine. Fig. 2 shows the occurrence of fault in percentage. From figure 2 it is arrived that unexpected reasons are mostly the cause of stopping of a wind turbine. Therefore early detection of faults in wind turbines is very essential because it creates platform for better maintenance. The strategies for repair can prevent major problems in other components. For this reason condition monitoring systems are very important tools for the early detection of faults.

III. DATA MEASUREMENT FOR FAULT ANALYSIS

The turbines used in wind farm considered for research comprises of gear boxes. The function of gearbox is to increase the speed from low speed rotor to high speed generator and hence it is placed between these two parts. Neural networks (NN) are a valid tool to make the detection of failures in some wind turbine equipment . An important premise in order to apply neural networks is to have a large set of data. This set of data will be used for processing, supervising and checking of the neural network. The derived data quality determines the quality of results obtained.

A. *Gear Box*

There are several types of gearboxes and some types of configurations. For the case under study, gears are planetary and parallel axles. The advantages of this type of gearbox are the efficiency increase and the extremely low speeds provide the possibility to deliver high reduction ratios and the transmission of higher torque, the high reliability due to the distribution of stress among different bearing components . Fig. 3 shows an example of gearboxes used by the wind turbine of the park. The parts of gearbox in which faults occur are the gear tooth and bearing. Due to contaminants in oil and high speed generator bearing failure occurs in higher rates. For the wind farm used as base of this study, the most common fault identified in the gearbox were cracking and consequent leakage of oil in gear box. Of all the machines of the wind farm, only two had problems in the teeth and seven had problems in the gearbox body. For that reason, it was decided to develop a tool to try to forecast this kind of problem. The quality of the lubrication is linked with the durability of the gearbox. High temperatures can disrupt the stability of lubricant oil leading to degraded system performance and finally lifetime of components are degraded. Fluid suffering high temperatures can experience permanent deterioration. Low temperatures can damage the temperature stability of lubricant just as much as high temperature. The viscous nature of lubricant oil increases and eventually reaches the saturation point .Hence the oil coaxes and flow is affected leading to serious problems. For that reason oil temperature cannot be too high because that reduces the durability and the quality of

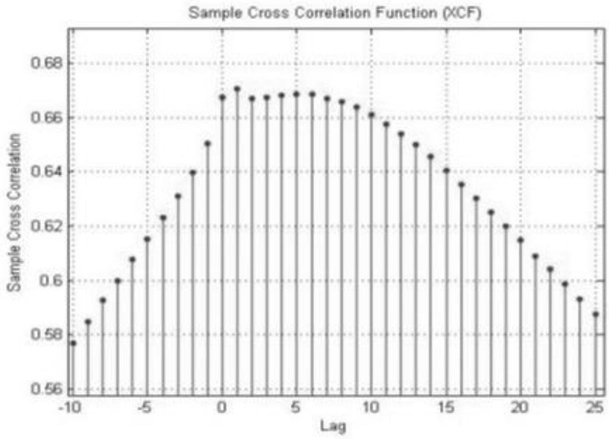

Figure 3 Cross correlation between measurements' of two wind turbines

the oil, and cannot be too lower because it increases the viscosity of the oil hurting the lubrication. In the wind turbines used for the study, oil temperature is maintained between 38 ºC and 62 ºC. When the temperature goes out of the limits, something wrong is happening.

B. *Neural Network Measurements*

An important premise in order to apply neural networks (NN) is to have a large set of data. The processed data aids in supervisory learning and checking of the neural network states. As it was said in the first section that there are more than 20 kinds of measurements saved in the control centre, but it is important to know if all of them are needed for the neural network. The method used to choose the input measurements was the analysis of the dispersion curves to see the correlation between measurements. Fig. 3 shows an example of correlation between two measurements of the wind turbine.

All correlated measurements must be used in the NN application, but some of them have a similar behavior and therefore bring no added value to the process, causing waste of computational time. As a way of reducing computational time, is necessary to do a behavior study of measurements, trying to eliminate measurements with the same time behavior and in that way, reduce the measurement set that will be used as input of the NN application. One other important characteristic that must be taken into account is the delay that some measurements have on others. For instance the influence of generated power can be delayed two or three periods of time (t) on the temperature of the gear oil.

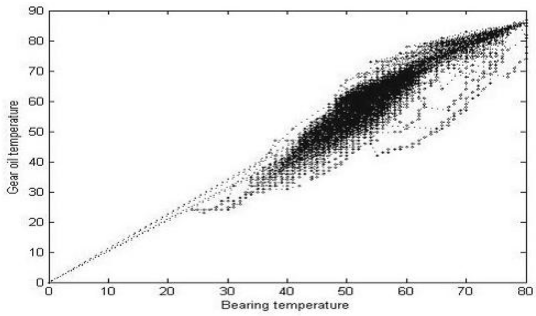

Figure 4 Dispersion Graphic

It has to be verified if the model outputs occur at the same time (t) after occurrence of model inputs. In some cases the output takes long time to settle due to inertia, after applying input. A cross correlation was made between measurements to validate the results. Two synchronous measurements ie. input and output occurring at same time produce zero maximum cross-correlation. When measurements are not synchronous with a non-zero maximum cross-correlation inertial output is produced. Fig. 4 depicts an example of that.
After doing this study to choose the inputs of the neural network, the following variables are chosen ,

- Power generated (t-1)
- Environment
- temperature (t-3)
- Bearing temperature (t)

C. *Application of Neural Network*

The topology of the neural network used is in Fig.5 and the influence of each input in the output in Fig. 6.The performance of the model is evaluated by the reduction of the MSE (mean square error), given by the equation

$$MSE = \frac{1}{n}\sum_{i=1}^{i=n} e^{2}{}_{i} \qquad (2)$$

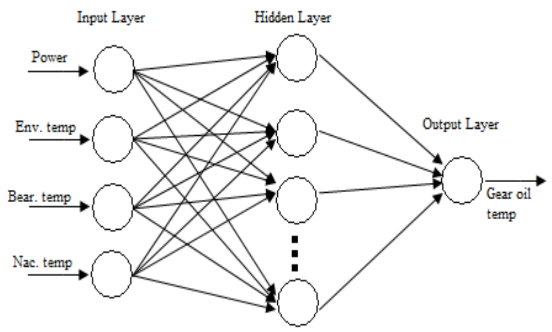

Figure 5 Neural Network Schematic Model

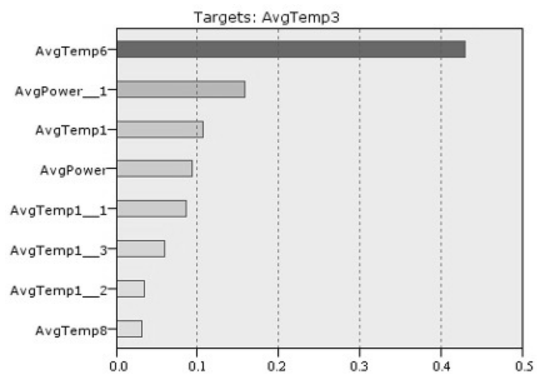

Figure 6 Influence of inputs

IV. RESULTS AND DISCUSSION

Neural Network toolbox in MATLAB is used for software implementation. The training methodology adopted for training the neural network is quick method. Here thumb rule and data characteristics are needed to choose the network topology. Data overtraining has to be avoided, hence separate training data sets and testing data sets are created model building. Accuracy of the trained data sets are determined from test data. Data sets are equally divided for training and validation. The network training comes to an end state on reaching the optimal trained state. Finally the program will generate the optimal neural network.

A. *Training Results*

The number of epochs, which indicates the training speed, can be used as criteria. Data collected half yearly was used to train, validate and test the neural network model. After the neural network training process, the objective is to compare the predicted gear oil temperature with the real gear oil temperature and investigate the differences trying to list the differences with probable causes. The model had detected a strong deviation between occurred gear oil temperature and the gear oil temperature estimated by the neural network model in a very specific period of time The lighter color represents the real gear oil temperature and the darker color represents the provision made by the neural network model.
Analyzing the maintenance service reports during the period of occurrence of the fault, it was possible to confirm that maintenance team was working in the turbine, trying to troubleshoot a problem in the gear oil system. Analyzing the results of comparison between estimated temperature of oil used in gear obtained by the neural network model and the real gear oil temperature, it is possible to observe that behavior of the machine diverges from the estimated one. With less oil in the gearbox, due to the oil leakage, temperature of the remaining oil increases. For that reason the real oil temperature registered in that time period is always higher than the oil temperature estimated by the model. This can be understood as a signal of a fault in the gearbox. The monitoring tool developed was also tested for detection of one problem occurred in a cooling hose system of the gearbox. The maintenance team reported a problem in the gear oil hose Problem detection was made in advance of two days because of the predicted results given by optimal neural network. The results obtained by the NN based monitoring tool proved that the developed method presented here can be used to make primitive detection of failures in the gearbox equipment.

V. CONCLUSION

The findings of study carried out shows that NN is an appropriate tool to detect primitive failures in wind turbine equipment. The model was validated with real data from a wind mill at Tirunelveli. The results obtained infer that although the study refers to past problems the same methodology combined with online measurements may be used to predict future faults. The research results discussed were validated with the gearbox data, but the same NN model can be used for primitive fault detection of faults in wind turbine components such as the electrical generator. \

VI. ACKNOWLEDGMENT

The authors would like to thank the management and Principal of Sethu Institute of Technology for their continuous support.

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AUTHORS PROFILE

Dr. B. Raja Mohamed Rabi,is a Professor, of Department of Mechanical Engineering in Sethu Institute of Technology. He completed his BE in Mechanical Engineering department at RVS College of Engineering and Technology. He completed his M.E in CAD at Madras University .He has completed her Ph.D at Anna University His research interests are artificial intelligence, Machine Design, Renewable energy and Optimization. He is a member in ISTE and IAENG.

Dr. K. Kanimozhi,is a Professor, of Department of EEE in Sethu Institute of Technology. She completed her BE in EEE department at Thiagaraja College of Engineering.She completed her M.E in Applied Electronics at Anna University. She has completed her Ph.D at Anna University Her research interests are artificial intelligence, Renewable energy and Power Electronics. She is a member in ISTE and IAENG.