Project title	Load and risk based maintenance management of wind turbines
Project number	TG 5-1
Organisation	Chalmers University of Technology, Electric Power Engineering
Project leader	Ola Carlson
Other participants	Pramod Bangalore (PhD student)
Report for	2011-10-01 – 2016-09-30
Participating companies	Göteborg Energi, Stena Renewables, Gold Wind, Greenbyte

Project description

The main aim of this project was to increase the availability of wind turbines while reducing the overall costs of maintenance.

Below is a short summary of the project:

1) An artificial neural network (ANN) model was proposed which utilizes data stored in the SCADA system for early detection of faults in critical components of the wind turbine.
2) An automated procedure to decide and update the training data set was proposed; the proposed procedure enables the selection of individual training data sets for each wind turbine.
3) Data filtering methods were presented to clean the often noisy SCADA data in order to create robust ANN models.
4) A statistical outlier detection approach was proposed to analyze the signals from the ANN model, and to decide the threshold for anomalous operation.
5) Case studies were performed to validate the ANN-based condition monitoring methodology with data from real wind turbines.
6) A maintenance management framework–the Self-Evolving Maintenance Scheduler–was proposed. The SEMS frameworks provides guidelines for utilization of data from different sources for maintenance optimization.
7) A mathematical model for maintenance optimization referred to as Preventive Maintenance Problem with Interval Costs (PMSPIC) was utilized to create optimal maintenance schedules considering age based failure rate models.
8) Modifications in the original PMSPIC model were proposed to enable condition based preventive maintenance scheduling utilizing the condition based failure rate models.
9) A case study was performed to show the application of the condition based preventive maintenance optimization routine applied along with the ANN based condition monitoring method within the proposed maintenance management framework.

Results

A statistical analysis was performed on the maintenance reports for 28 onshore wind turbines rated 2 MW. The result from analysis of around 800 maintenance reports showed that the gearbox and generator are critical components in the wind turbine, which accounts for a considerable portion of the total downtime.

An ANN based condition monitoring methodology was created, which utilizes the measurements stored in SCADA for an early detection of faults in the components being monitored. Figure 1 presents the output from the ANN-based condition monitoring system for a wind turbine, which had recorded a failure in the gearbox bearing. The system was able to detect the fault in the gearbox bearing in advance, providing an opportunity to plan the replacement activity.

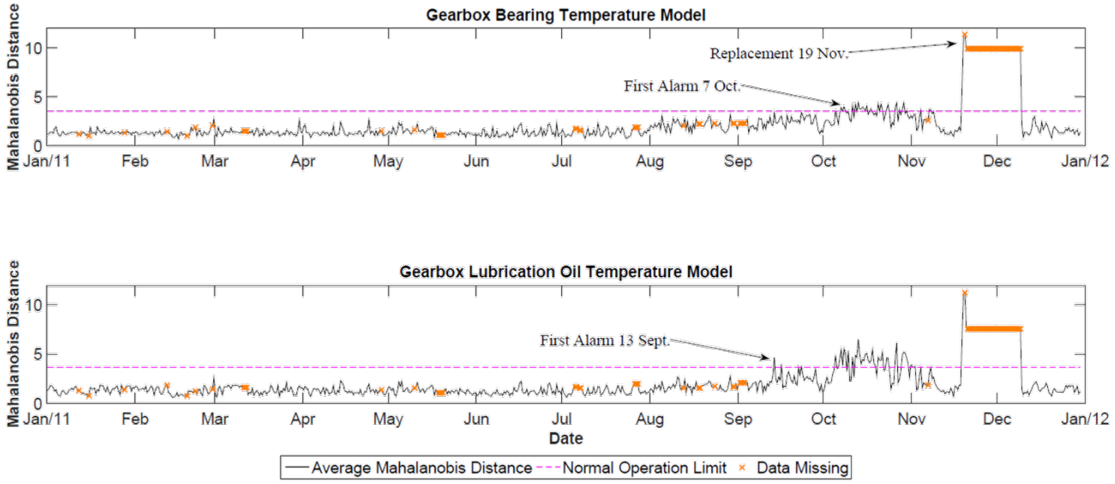

Figure 1 Output from the ANN-based condition monitoring system for a wind turbine with gearbox bearing fault

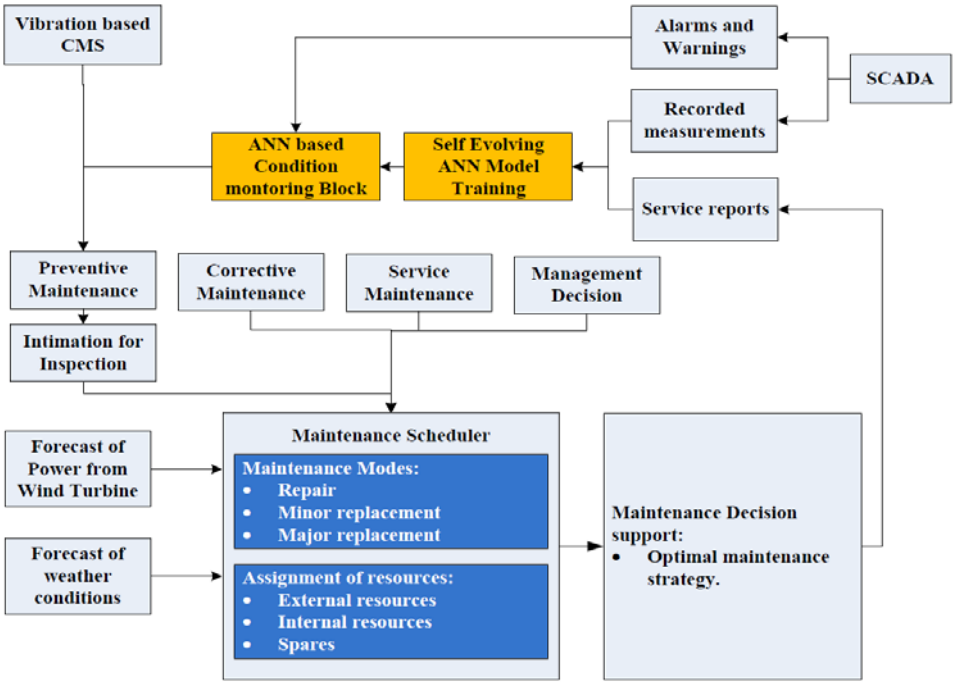

Figure 2 SEMS maintenance management framework

A maintenance management framework, referred to as SEMS (Self-Evolving Maintenance Scheduler), was proposed, and is presented in Figure 2. The SEMS framework incorporates the indication of failure from various CMS systems in order to plan maintenance activities. The SEMS framework also considers opportunities to perform maintenance on other components in order to optimize the total maintenance cost over the entire life of the wind turbine.

The preventive maintenance scheduling problem with interval costs (PMSPIC) mathematical model was utilized to provide the initial optimized preventive maintenance schedule with age based failure rate models. Modifications in the PMSPIC model were suggested to enable condition based maintenance scheduling in real time and considering the signals from condition monitoring systems. Figure 3 presents

the output from the PMSPIC based scheduler for a case study, where the indication of deterioration in the gearbox was obtained in month 20.

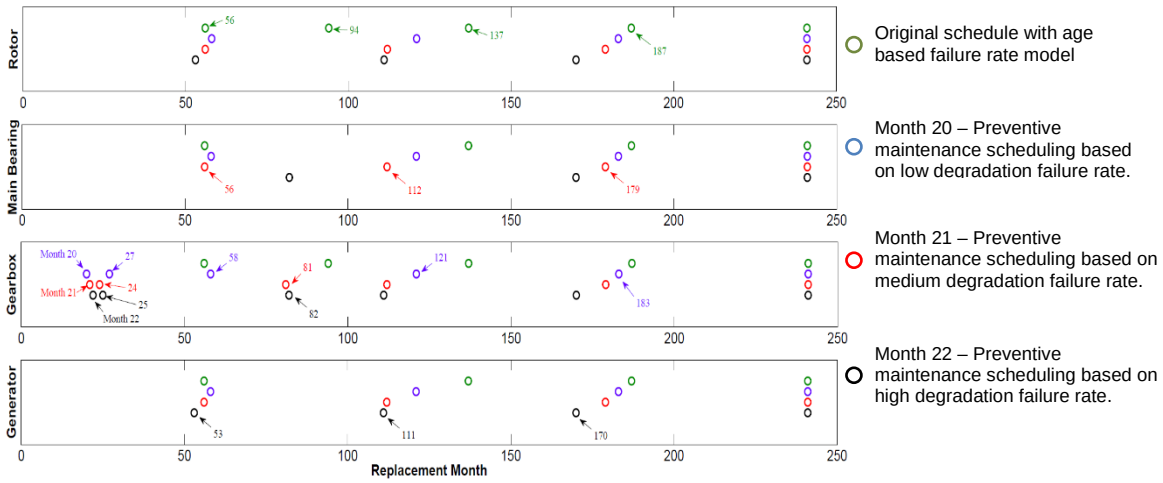

Figure 3 A typical output of an optimized maintenance schedule based on condition based failure rate model for a test wind turbine

Fulfilment of SWPTC's goals

This project contributes towards SWPTC's goal of increasing the availability of wind turbines while reducing the maintenance costs. The aim is to develop a maintenance strategy based on measured information about the conditions of the components, and the costs associated with performing maintenance. Such a strategy will aid in effective maintenance, lower downtimes and lowering total costs.

Deviations from project plan

No deviations from the project plan.

Publications

- P. Bangalore and L. B. Tjernberg, "An approach for self evolving neural network based algorithm for fault prognosis in wind turbine," in *PowerTech (POWERTECH), 2013 IEEE Grenoble*, 2013, pp. 1-6.
- P. Bangalore and L. B. Tjernberg, "Self-evolving neural network based algorithm for fault prognosis in wind turbines: A case study," Probabilistic Methods Applied to Power Systems (PMAPS), Durham, 2014.
- P. Bangalore, "Load and Risk Based Maintenance Management of Wind Turbines", Licentiate Thesis, Dept. of Energy and Environment, Chalmers University of Technology, Gothenburg, Sweden, 2014.
- P. Bangalore and L. B. Tjernberg, "An Artificial Neural Network Approach for Early Fault detection of Gearbox Bearings," IEEE Transactions on Smart Grid, vol.6, no.2, March 2015, pp.980-987.
- Simon Letzgus, " SCADA-Data Analysis for Condition Monitoring of Wind Turbine Components", Masters Thesis, Dept of Energy and Environment, Chalmers University of Technology, Gothenburg Sweden, 2015.
- Daniel Karlsson, " Wind Turbine Performance Monitoring using Artificial Neural Networks", Masters Thesis, Dept of Energy and Environment, Chalmers University of Technology, Gothenburg Sweden, 2015.
- P. Bangalore, S. Letzgus, D. Karlsson, and M. Patriksson, "A SCADA data based condition monitoring method for wind turbines, with application to the monitoring of the gearbox", submitted to Wind Energy, June 2016.
- P. Bangalore, and M. Patriksson, "Analysis of SCADA data for early fault detection, with application to the maintenance management of wind turbines", submitted to Renewable Energy, August 2016.

- P. Bangalore, S. Letzgus, and M. Patriksson, “Analysis of SCADA data for early fault detection with application to the maintenance management of wind turbines”, presented at Cigre Session 46, Paris, August 2016.
- P. Bangalore, “Load and Risk Based Maintenance Management of Wind Turbines”, Doctoral Thesis, Dept. of Energy and Environment, Chalmers University of Technology, Gothenburg, Sweden, 2016.

External activities

- Participation in IEAwind -Task 33 ‘Reliability Data: Standardizing data collection for wind turbine reliability and O&M analyses’. The aim of the task is to develop standardized procedures for wind turbine maintenance and reliability data collection.
- Participation in Nordic Wind Operation and Maintenance (NWOM) meetings. The network aims at connecting researchers and industry in Nordic countries, working in the topic of operation and maintenance of wind power plants.
- Visit to Gold Wind facility in Beijing.