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SCIENCE DIRECT®
Computers in Industry 57 (2006) 552–568
COMPUTERS IN INDUSTRY
www.elsevier.com/locate/compind

SIMAP: Intelligent System for Predictive Maintenance Application to the health condition monitoring of a windturbine gearbox

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Accepted 9 February 2006
Available online 13 June 2006

Abstract

SIMAP is the abbreviated name for the Intelligent System for Predictive Maintenance. It is a software application addressed to the diagnosis in real-time of industrial processes. It takes into account the information coming in real-time from different sensors and other information sources and tries to detect possible anomalies in the normal behaviour expected of the industrial components. The incipient detection of anomalies allows for an early diagnosis and the possibility to plan effective maintenance actions. Also, the continuous monitoring performed allows for an estimation in a qualitative form of the health condition of the components. SIMAP is a general tool oriented to the diagnosis and maintenance of industrial processes, however the first experience of its application has been at a windfarm. In this real case, SIMAP is able to optimize and to dynamically adapt a maintenance calendar for a monitored windturbine according to the real needs and operating life of it as well as other technical and economical criteria. In particular this paper presents the application of SIMAP to the health condition monitoring of a windturbine gearbox as an example of its capabilities and main features.

Keywords: Predictive maintenance; Maintenance effectiveness; Health condition; Diagnosis; Artificial intelligence

1. Introduction

The use of wind is one of the most attractive new sources of energy at the present moment, as can be seen by the growing installation of windfarms all over the world. Windturbines are relatively young machines where the application of a correct maintenance strategy would be very important for the protection of their future life, productivity and profitability [1]. The current practice of maintenance applied to the existing aerogenerators is based on periodical or preventive maintenance actions recommended by their manufacturers. These are good and general guidelines for the maintenance of aerogenerators, however they do not focus on the specific characteristics of the real and local life of them such as: weather conditions at the location, stress by over-load, hours continuously working, etc. These factors determine the particular life and health of each aerogenerator and for this reason the maintenance applied has to also take them into account. In order to do this, a predictive maintenance plan is the best option to guarantee the long life of the new investments in aerogenerators due to the maintenance actions which are applied according to the real and specific health conditions of every aerogenerator during its life and not only based on general guidelines.

When thinking about a predictive maintenance strategy for aerogenerators, it is important to remark that windturbines are quite new machines using an important number of sensors able to supply information to different controllers in order to perform the best control and efficient operation of them. The information collected by the sensors of aerogenerators for control purposes can also be used for monitoring the health condition of their different components and to apply a predictive maintenance plan. According to this, no new investment in sensors is required in order to perform an effective windturbine predictive maintenance strategy because all the aerogenerators include a set of sensors from the manufacturer for different aspects of the control of their elements. The information from these sensors can also be used as main information source for a predictive maintenance plan.

This paper presents the architecture of a new predictive maintenance system, called *SIMAP*, based on artificial

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doi:10.1016/j.compind.2006.02.011

intelligent techniques. Its predictive maintenance strategy can be applied to any industrial system or equipment and its main goal is to find the most appropriate time to carry out the needed maintenance actions both from a component health condition and an incipient failure diagnosis perspectives. The new and positive aspects of this predictive maintenance methodology have been tested in windturbines. *SIMAP* is able to create and dynamically adapt a maintenance calendar for the windturbine that it is monitoring. The criteria followed are set up according to the real needs and operating life of the windturbine. This process is performed on-line and is different from the traditional scheduled maintenance plan based on fixed time intervals following the manufacturer criteria which do not focus on the real operation conditions of the aerogenerators. According to this, SIMAP implements the main aspects of an e-maintenance approach in a computer network such as local and remote continuous monitoring and diagnosis of the main components of the aerogenerators, maintenance actions planned according to the current and historical information collected, distribution of the on-line diagnosis and maintenance workload in different modules interconnected through a computer network and finally, different levels of warnings for the operator. This predictive maintenance system has been developed and applied to a windfarm owned by a Spanish wind energy company called *Molinos del Ebro*, *S.A*.

This paper provides in Section 2 an overview of the main features and architecture of SIMAP and, in Sections 3–9, presents the capabilities of SIMAP applied to a particular case of a windturbine, which is the possible failures in a gearbox and how SIMAP works in real-time to detect and diagnose anomalies in this component, to evaluate its health condition and to plan predictive maintenance actions.

2. SIMAP: objectives and architecture

The principal tasks performed by *SIMAP* are the following:

- Continuous collection of data coming from different sensors installed in the aerogenerator and meteorological towers.
- Continuous processing of the information collected in order to evaluate on-line the health condition of the aerogenerator components and also to detect if some symptoms of degradation or anomalies are present or could become present [3]. Both *health condition evaluation* and *incipient fault detection* are based on *normal behaviour modelling* (that is, in absence of failures) of the aerogenerator components. Thus, previously *normal behaviour models* were obtained using real data in order to characterize the normal dynamics of the representative variables of each component without any failure, taking into account both the different operation conditions of the components. SIMAP is working on-line taking current measurements from the process and evaluating the prediction of values from the models. The comparison between measured and predicted values of particular variables permits the incipient fault detection and the health condition evaluation for:
  a. *Diagnosis of the root causes* of the symptoms detected.
  b. *Failure risk forecasting of the aerogenerator components* according to their actual health condition.
  c. *Dynamical maintenance scheduling* based on the machine condition, its environmental conditions and the aerogenerator production plan. Maintenance scheduling pursues to interfere the least possible with the production plan in order to maximize the aerogenerator availability and, also, to minimize the maintenance costs required. Other technical criteria considered are:
    - the failure risk of the aerogenerator components, estimated on-line based on their health condition;
    - the criticality of the components;
    - the maintenance actions efficiency to solve or mitigate the failure or degradation diagnosed;
    - the variable maintenance resources as well as the different relations among maintenance actions (precedence relations, compatibility relations, etc.).

  Effectiveness of the maintenance actions applied according to the change observed in the health condition and degradation of the components affected by these maintenance actions. This measurement will allow for both technical and economical comparisons of possible different maintenance strategies to be applied, as well as maintenance actions performed during different time periods.

These tasks are organized in a modular architecture presented in Fig. 1 around the following six main modules:

- ***Normal Behaviour Models***. These models are able to predict on-line the normal behaviour (or reference behaviour) expected for each windturbine component, according to its current working and environmental conditions. These models are created mainly by means of *artificial neural networks* due to their ability to model dynamic non-linear industrial processes [4,5].
- ***Anomalies Detection Module***. Its main goal is to detect possible anomalies in components by means of the results given by the normal behaviour models. Thus, by comparing for each component, its normal behaviour estimation with its real behaviour, both a *normal behaviour deviation degree* as well as an *estimation certainty degree* are obtained. These are used to recognize an anomaly present and the certainty of it [6–10].
- ***Health Condition Assessment Module***. Its function is to evaluate on-line the health condition of each windturbine component as well as the general windturbine health condition. This function is performed by means of the results given by the normal behaviour models [11].
- ***Diagnosis Expert Module***. Its main goal is to identify the possible failure modes that are present or developing in a windturbine component before this component faults in an irreversible way (for this reason, these detection and diagnosis tasks are called incipient) [12]. In order to reach this objective, this module employs a *fuzzy expert system* [14,15] able to represent in a flexible way both the knowledge and the uncertainty involved in this reasoning process, that is, mainly