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WindMT: An integrated system for failure detection and maintenance scheduling at wind farms

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Abstract

The paper introduces a system for supporting the diagnostics and maintenance of wind farms. The work flow in the system covers the detection of failures based on data registered by the SCADA supervisory system of the turbines, the assignment of maintenance tasks to each failure, the scheduling of maintenance tasks on the short-term horizon, and the reporting of maintenance task execution. Finally, various reports are generated from the data collected throughout the above process about the reliability and maintainability of the turbines. In this paper, the primary focus is on maintenance scheduling, using a fine-grained representation of all requirements of the tasks, including resources, spare parts, weather, as well as turbine conditions.

Introduction

Efficient maintenance is crucial for the economic operation of wind energy systems. Wind farm operators must continuously monitor the condition of their turbines, detect if a turbine needs maintenance, and determine the appropriate maintenance action to be performed. Furthermore, the optimal timing and assignment of maintenance tasks to resources must be computed. Maintenance scheduling is not only an important, but also a complex problem. The scheduler must consider the availability of various resources, spare parts, and appropriate skilled personnel, while minimizing the disruptions caused in production.

The paper introduces an integrated system for the diagnosis and maintenance of wind farms. The system, called WindMT, has been developed recently in an EU-funded research project aimed at the improvement of the reliability of wind energy systems, involving wind turbine manufacturers, component suppliers, and research institutes[1]. Below we present the key functionalities of the system, briefly describe the models and algorithms for maintenance scheduling, give some technical details about the developed system, and summarize the screenplay of the planned live demonstration at ICAPS 2011.

Integrated System for Diagnosis and Maintenance

The system performs failure detection and prognosis on quasi-online data from the SCADA supervisory system. In case a failure is detected or prognosed, it assists human experts in initiating the corresponding corrective or predictive maintenance tasks–the available digitized knowledge on mapping failures to tasks is not reliable enough to completely automate this step. Other planned tasks, such as preventive maintenance or retrofitting originate from the ERP system. The developed system schedules the maintenance tasks on a short term horizon so as to minimize production loss due to failures and maintenance. The execution of maintenance tasks is tracked, during which technicians provide valuable detailed information on the nature of the failure, the failed component, and the actual execution of the task, such as its duration and the usage of spare parts. The work flow is summarized in Figure 1.

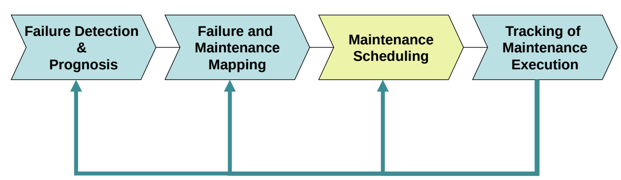

Figure 1: Key functionalities and the work flow in the system.

The integrated handling of failures, maintenance, and execution makes it possible to feed back the acquired knowledge in order to improve failure detection and prognosis models, the mapping of failures to maintenance tasks, the definition of the maintenance tasks, and through component reliability statistics, even the turbine design. Therefore, the system not only supports the daily operation of the turbines, but it is also a key element for achieving the long-term digitization objectives of the wind farm owner and maintenance service provider companies. Hence, this system represents a significant step towards the practical implementation of the vision stated in (Takata *et al.* 2004) that maintenance should

[1]For further details, check `www.reliawind.eu`.

be a key element of the life cycle management of the products.

Maintenance Scheduling

Modeling the Scheduling Problem

The WindMT system is responsible for the diagnosis and maintenance of multiple wind farms in an area, supervised by the same regional office of the wind farm operator company. There are typically up to 20 farms with at most 300 turbines belonging to a regional office. Since different offices share their resources only in exceptional cases, the scheduling problems of different offices can be modeled as independent.

A detailed maintenance schedule is prepared for a short-term horizon of 3-7 days, on a rolling horizon basis. The schedule is updated every morning, which implies that usually only the tasks of the first day are executed as planned. A key reason for not updating the schedule within the day is that technicians have limited connectivity to the office, therefore notifying them about the modified schedule and acquiring feedback about the execution status in real-time is impossible. Potential changes in the schedule will be managed manually by the experts in the regional office. Furthermore, despite the obvious uncertainties in the scheduling problem, all parameters–including weather conditions and spare part availability–are assumed to be deterministic within the day.

The developed model covers all types of maintenance, including corrective (repairing a failure), preventive (performing periodical maintenance to safeguard from failures) and predictive (condition-based preventive) maintenance, as well as retrofits (upgrading the turbine). From the scheduling perspective, the only difference between these types of maintenance is that corrective maintenance is timely immediately when the task is generated, whereas other, planned maintenance tasks have a target date and an opportunity window, i.e., a time window around the target date in which the task should be executed.

Tasks require different kinds of resources, such as skilled personnel, spare parts, and special equipment. Tasks are executed by technicians, working in fixed teams of two people. A team can execute only one task at a time, and it must finish the task before moving to the location of the next task. However, there are a few extremely long tasks that can be broken into smaller segments or even preempted, i.e., the team may execute another task if circumstances are unsuitable for working on the large task. Traveling from one farm to another one takes a given amount of travel time, whereas the time of travel within the farm can be neglected.

Spare parts are assigned to tasks before scheduling would take place, hence, they imply a release time for the tasks. The availability interval of some special equipment, such as external cranes, may also be limited, hence, the equipment also entails time windows and capacity constraints for the tasks.

An interesting and highly domain specific feature of the scheduling problem is the dependence of maintenance tasks on weather conditions, such as wind speed or temperature. For instance, tasks requiring an outer crane can be executed in calm winds only. Hence, the forecasted weather defines the time periods when certain tasks can be executed. Furthermore, wind speed determines the energy produced by a turbine, and hence, the production loss in periods when the turbine is affected by a failure or stopped for maintenance. More precisely, the production loss incurred by a failure in any period of time can be estimated from the forecasted wind speed, the turbine characteristics, and a loss percent assigned to the failure. Note that multiple tasks/failures can affect the turbine at the same time.

Finally, sets of tasks may interfere beyond competition for common resources as well. Namely, some tasks are executable only when the turbine is (or even multiple turbines are) in a special condition, e.g., with no pressure in the hydraulic system. Pairs of tasks can be executable in parallel only if the turbine conditions are compatible.

Scheduling consists in determining the set of tasks that should be executed within the scheduling horizon and assigning a team and a start time to them, so as to minimize the total production loss, including the due to failures and due to stopping the turbine for maintenance.

Solution Approach

The scheduler uses a combination of mixed-integer programming (MIP) and custom heuristics for solving the above scheduling problem. The core problem is encoded as a MIP using a time-indexed formulation, and it is solved by the default branch and bound algorithm of a commercial MIP solver package. The MIP model is presented in detail in (Kovács *et al.* 2011).

The heuristics perform the pre-processing of the input problem and the post-processing of the schedule computed by the MIP as follows:

- In practice technicians move within a small set of nearby farms only. Often, the bipartite graph of allowed technician-farm assignments contains multiple independent components, which means that the scheduling problem can be decomposed to sub-problems corresponding to zones within the region. In case of very large components, the algorithm forms independent zones by heuristically removing edges from the bipartite graph.
- In case of massively oversubscribed scheduling problems, a heuristic omits the least important tasks. This way, the total volume of tasks in the MIP will exceed the available capacity by at most a given percent, 25% in the experimental settings (travel times and other periods of forced inactivity are ignored here). These heuristics ensure that the size of the core problem faced by the MIP solver will always be tractable.
- Since preemption is allowed for some extremely long tasks, these tasks are partitioned to smaller segments and precedence constraints are posted between the segments.
- In the post-processing step, a heuristic looks for potential improvements of the schedule by re-partitioning and re-assigning the above long tasks.

In computational experiments with the core MIP, the solver constructed exact optimal solutions for problem instances with up to 50 tasks, as well as quality schedules with relative gaps compared to the lower bounds well below 1% for up to 100 tasks. In experiments with the complete solver (including the MIP and the heuristic) the system could handle problems with more than 1000 tasks, which is more than what we expect in a real application.

The WindMT System

WindMT is a Java-based multi-tier application whose presentation layer runs in web browsers on PCs and PDAs (with limited functionality in the latter). The application interfaces with various IT systems of the wind turbine operator and the maintenance service provider companies, including SCADA supervisory system, the enterprise resource planning (ERP) system, the maintenance management system, and a weather forecast service, as shown in the system architecture diagram in Figure 2. The scheduling algorithm is built on the top of the ILOG Cplex 11.2 commercial MIP solver package. Figure 3 shows a screen shot of the system presenting the template for the wind turbine breakdown structure, while Figure 4 displays a screen shot of a Gantt chart representation of a maintenance schedule.

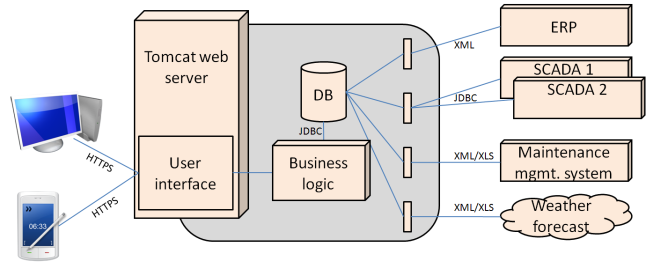

Figure 2: System architecture.

Demonstration

The demonstration planned for ICAPS 2011 covers the complete work flow in the system, starting with the detection of failures, manual and automatic assignment of maintenance tasks to failures, scheduling the maintenance tasks, and finally, execution reporting. In addition, some reports based on the data collected throughout the process will be shown. The demo will be conducted on a small set of manually forged sample data, which is representative but not identical to real-life data of wind turbine manufacturers. Currently,

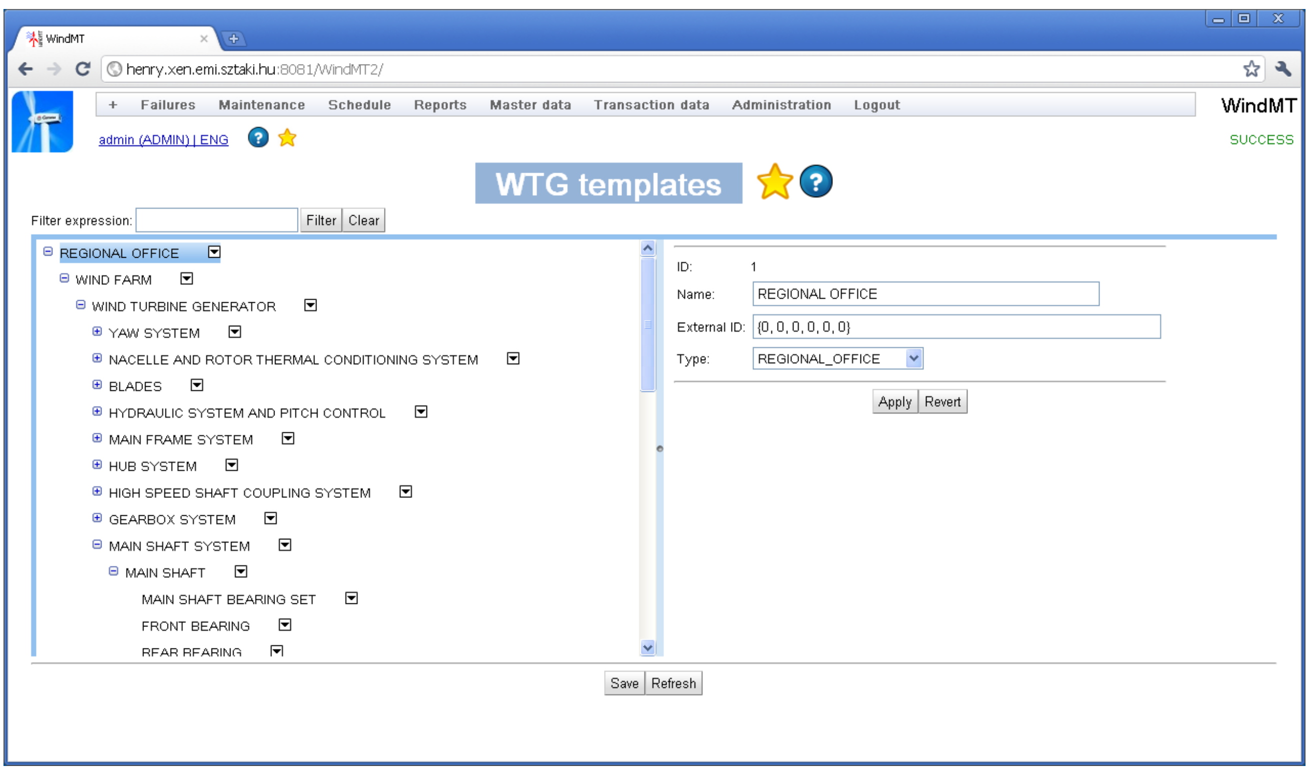

Figure 3: Screenshot of WindMT: tree-structured template of the wind energy system. The tree is rooted in a regional office, responsible for the maintenance of multiple wind farms in an area. Each farm consists of multiple wind turbines. The architecture of a turbine is elaborated in the level of detail that is relevant for statistics about failure occurrences. Individual wind turbines may differ arbitrarily from this template.

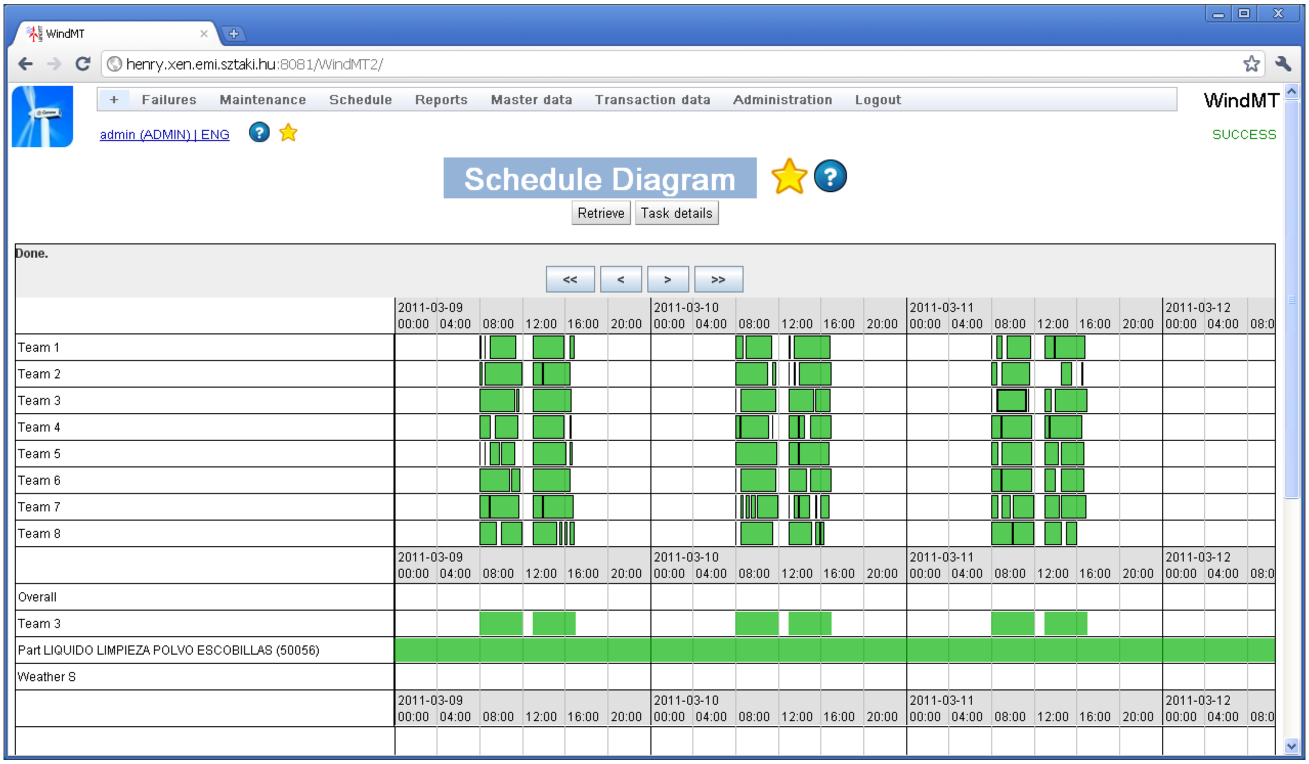

Figure 4: Screenshot of WindMT: maintenance schedule displayed in a Gantt chart. Each of the upper rows contains the tasks to be executed by a specific team in the next three days. The rows in the bottom display the availability of the resources required by the selected task. It is also possible to manually edit the schedule on this screen.

the database of the system contains 100 wind turbines located in 3 farms, ca. 50 failure modes, and master data about 25 different maintenance tasks.

Acknowledgments

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