Graphical Analysis of Wind Turbine Dynamics Through SCADA Data Mining

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1. Introduction

The widespread diffusion of SCADA control systems in modern wind turbine technology has revolutionized the management of machine portfolios. Potentially, every wind farm owner can develop its own tools for performance evaluation, fault diagnosis and prevention, optimization. Wind technology in the age of information therefore faces the challenge of elaborating vast amounts of data, processing them into knowledge, visualizing them intuitively. Due to the stochastic nature of the source, this ambition lies at the crossroad of engineering, physics, statistics and computer science and has therefore stimulated considerable debate in the scientific literature and fruitful collaborations between academia and industry. In the present work, a mathematical and graphical method is proposed for elaborating turbine state dynamics and SCADA measurements in a combined way. As shall be discussed later on, its strength lies in intuitiveness and versatility: it can be be used for a bird's eye view on a portfolio of machines, for inquiring whether maintenance programs have been planned judiciously, for a first investigation on the reasons of faults. Further, the graphical output does not depend at all on the input language of the single SCADA supplier. This method is tested on some wind farms owned by Renvico srl.

2. Approach

The source of information to be processed is twofold and possibly has different nature:

- Turbine States: they can be provided in the form of their continuous motion, with associated time stamp of incoming or phasing out, or in the form of progressive counters on 10-minute time basis. Whatever is their form, they provide the basic information about what the turbine is doing, i.e. producing output, awaiting enough wind strength, in error and so on.
- SCADA measurements: their standard form is provided on a 10-minute time basis and is made of average, minimum, maximum and standard deviation over a much finer sampling. They cover all the basic aspects of machine behaviour, including wind conditions and consequent response of the machine (nacelle position, pitch angle and so on), electric, mechanical and thermal aspects.

The philosophy of the method is associating two numbers to each 10-minute interval to each wind turbine: the former should codify what the turbine has done during the interval, the latter should be a meaningful SCADA measurement. The former is computed, whatever the transcription of state dynamics is (continuous or counter), associating to the interval a number representing the state that has been activated longer during the interval. The latter is of course customizable, in the sense that whatever SCADA measurement channel can be chosen. In the following Section 3 some intuitive choices are shown and discussed through examples.

Subsequently, the time evolution of these numbers is represented graphically: each turbine during a period is sketched with a bar, which is filled with a color and a moving black line. It is built as follows: the time evolution proceeds along the y-axis and basically is the juxtaposition of a black dot a horizontal color line. The dot represents the dominant state during a given 10-minute interval. The right-most one is the expected state, that is power production. Moving to the left, one finds start-up phases and brake programs, as shown in Table 1.

Stop7	Stop6	Stop5	Stop4	Stop3	Stop2	Stop1	Test3	Test2	Test1	Man. Op.	Br. Rel.	BLS	Conn.	Run-up	M. run-up	Start-up	Prod.

Table 1. The sequence of the states from left to right in our graphical codifying strategy.

The idea is that the left-most, the more severe. The horizontal line of background color is built as follows: the minimum and maximum of SCADA measurements during the period are recorded, and the interval between these two values is discretized and converted into a color palette. The lower limit is associated to the blue limit of the palette, the upper to the red limit. The scale of the y-axis, and therefore the time span of the analysis, is also customizable.

In Figure 1, the layout of a test case wind farm is sketched. Nine aerogenerators are installed, with 2 MW of rated power; the rotor diameter is 82 meters and the hub height is 80 meters.

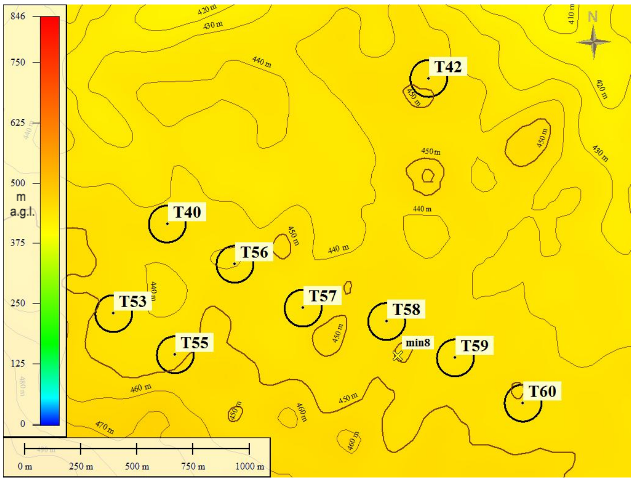

Figure 1. Layout of a test case wind farm

3. Main body of the abstract

Figures 2, 3, 4, 5 9, 10 summarize some sample results of the graphical approach depicted in Section 2. For each pair of plots, the leftmost displays nacelle wind speed as background color, the rightmost instead displays active power. In every figure there is a daily basis and the progressive numbers labeling downwards the y-axis represent the hour of the day.

Figures 2 and 3 show the wind farm during a day of normal power output production. The plots are useful for appreciating differences in how nacelle wind speed (and therefore active power) distributes along the farm. It can be valuable to integrate them with the plot having wind direction on the background for a graphic time history of the effect of wakes in flow distortion and therefore performances.

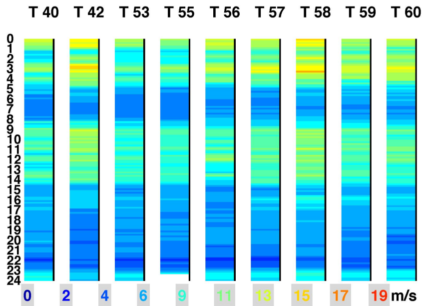

Figure 2. Graphical map: normal operation. Wind speed in background.

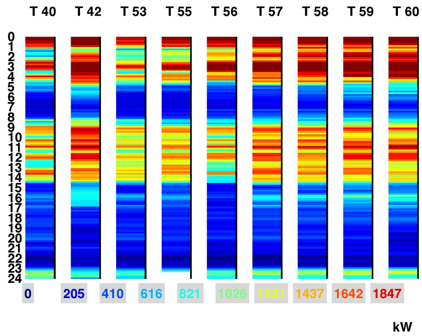

Figure 3. Graphical map: normal operation. Active power in background.

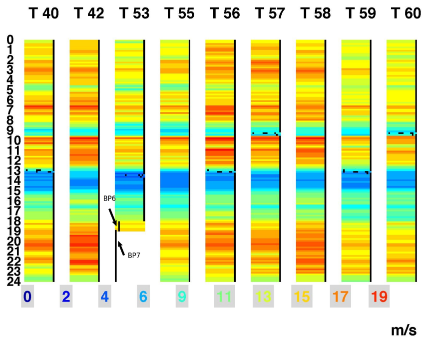

Figure 4. Graphical map: fault occurrence. Wind speed in background.

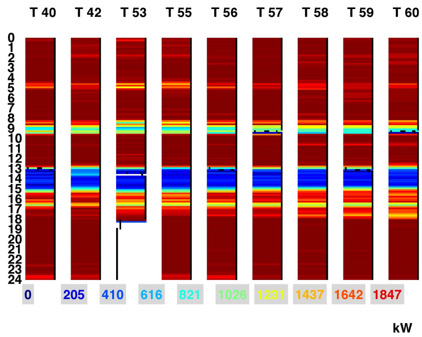

Figure 5. Graphical map: fault occurrence. Active power in background.

Figures 4 and 5 show a day during which an unexpected fault has occurred to turbine T55. Appreciate in particular the abrupt shift from the right-most state (power production) to the very left (corresponding to a brake program). Comparison against the background color map of the other turbines reveals that the fault occurred during a period with very strong wind, therefore implying a severe producible power loss. This approach can be applied for a bird's eye view on maintenance programs and for inquiring if they have been planned judiciously, in order to minimize power losses. Further, a longer time history can be used for gaining some information on the causes of fault occurrence: common and severe mechanical problems to the main shaft can be early detected through a check of possible bearings overheating, even in the operational phase. Figure 6 actually provides a sample of this approach, on the testing ground of a very windy day, and reveals very different thermal behaviours from the machines: T53 is the coolest because it is undergoing a stop and is not producing output, all the other machines are sensibly warmer and in particular three of them are so anomalously hot that it is likely they deserve deeper investigation.

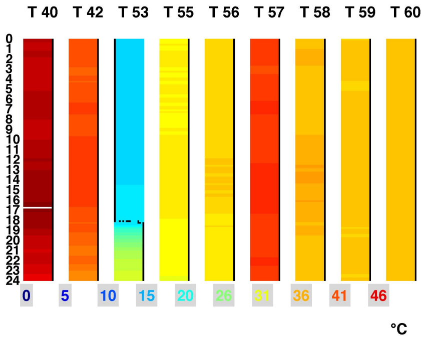

Figure 6. Graphical map: intense wind speed. Rotor bearing temperature in background.

Further insight on heating behaviour of the turbines is gained trough the auxiliary plots of Figures 7 and 8. The former displays the time evolution of rotor bearing temperature after turbine reboot, the latter displays the difference with respect to the reference value at turbine stopped. These plots highlight as anomalous exactly the same turbines as the graphical map of Figure 6.

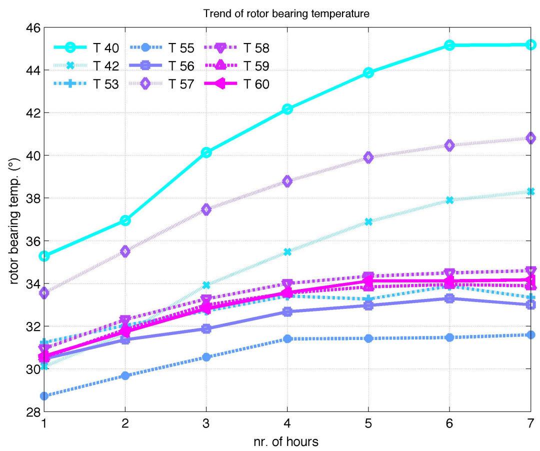

Figure 7. Time evolution of rotor bearing temperature after turbine reboot.

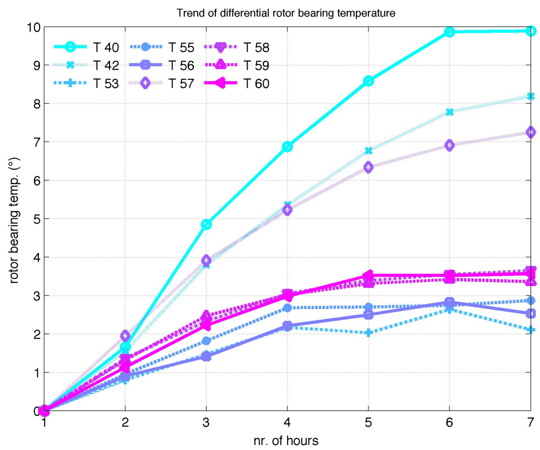

Figure 8. Time evolution of rotor bearing temperature after turbine reboot: difference against reference value at machine stopped.

Figures 9 and 10 show instead the recovery of the wind turbine from a fault. It is interesting to appreciate from these plots the time scale of the reboot.

4. Conclusions

In the present work, a method is proposed for jointly elaborating, into a graphical output, state dynamics and SCADA measurements of wind turbines. The approach is valuable both methodologically, because it combines in a unified framework two sources of information having

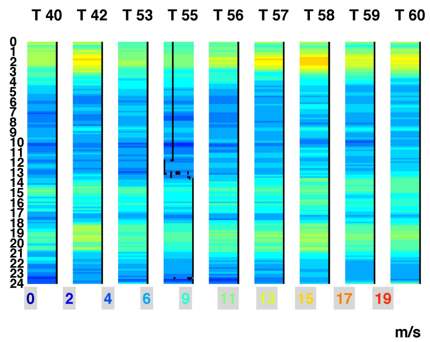

Figure 9. Graphical map: fault recovery. Wind speed in background.

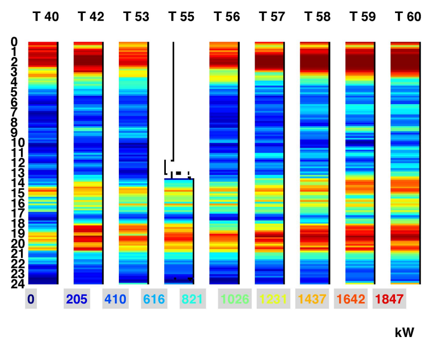

Figure 10. Graphical map: fault recovery. Active power in background.

intrinsically different time scales, and for the applicability and the features of the output, which we summarize here on:

- The method does not depend on the language of the single SCADA supplier. Even though the states can be codified differently for different SCADA systems, the output re-codifies them unambiguously.
- The output is intuitive: the history of a turbine on a customizable time scale is read downward along a bar, through the positioning of a moving line which indicates the state, on the background of a color which codifies the measurements of a SCADA channel, which can be customized.
- The plots are applicable for several uses: for example, for appreciating how parameters evolve during the productive phase and possibly inquiring overheating (as discussed in Section 3) or other common causes of fault onset, or for assessing how judicious are the planned maintenance programs.

The method has been applied on a wind turbine portfolio owned by Renvico srl. The present analysis is planned to be pushed forward by a mathematical point of view, in order to evolve from a graphical to a numerical output, made of non-dimensional, and thus universal, indexes for codifying goodness of wind turbines operational behaviour.

5. Learning Objectives

- Elaborating state dynamics and wind turbine SCADA measurements in a combined way.
- Graphical representation of the time evolution of a wind turbine portfolio.
- The use of simple graphical output for maintenance program evaluation and performance check.