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Optimisation of Data Acquisition in Wind Turbines with Data-Driven Conversion Functions for Sensor Measurements

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Abstract

Operation and Maintenance (O&M) is an important cost driver of modern wind turbines. Condition monitoring (CM) allows the implementation of predictive O&M strategies helping to reduce costs. In this work a novel approach for wind turbine condition monitoring is proposed focusing on synergistic effects of coexisting sensing technologies. The main objective is to understand the predictability of signals using information from other measurements recorded at different locations of the turbine. The approach is based on a multi-step procedure to pre-process data, train a set of conversion functions and evaluate their performance. A subsequent sensitivity analysis measuring the impact of the input variables on the predicted response reveals hidden relationships between signals. The concept feasibility is tested in a case study using Supervisory Control And Data Acquisition (SCADA) data from an offshore turbine.

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1. Introduction

The costs associated with Operation and Maintenance (O&M) of wind turbines account for about 10-15% of the overall energy generation cost for onshore [1] and 25-30% for offshore wind turbines [2]. For wind farms approaching the end of life the O&M costs may rise up to 35% [3]. Currently, the wind industry is incurring significant numbers of main component failures, causing large downtimes and consequently loss of power production [4], [5], [6]. Throughout many years of experience in other industrial sectors, condition based maintenance (CBM) has become an established and cost-effective maintenance strategy [7], [8]. The need for cost-effective maintenance is further intensified

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by the increasing installation of wind turbines offshore, where logistics are more difficult. This implies an increased reliance on remote sensing systems for health assessment in the transition from corrective to predictive maintenance.

Early condition monitoring of wind turbines was based on the high frequency signals provided by a dedicated Condition Monitoring System (CMS), in particular acceleration measurements (cf. [7]). The advantages and economic benefits of CMS in the wind energy sector were analysed for instance in [9]-[10]. Current trends also provide clear evidence of an increasing exploitation of Supervisory Control And Data Acquisition (SCADA) data for monitoring purposes, thanks to its economic advantages and well established online data management. Following the latest development in the field with regards to wind energy applications, artificial intelligence systems are receiving greater consideration. An example of application is presented by Kusiak and Verma where genetic programming is employed to predict blade pitch faults as early as an hour before occurrence [11]. Bangalore and Tjernberg detected gearbox bearing damage with artificial neural networks (ANNs) one week earlier than the CMS [12]. A comprehensive review of the main advances in this area is provided in [13].

There is a potential to widen the monitoring concept by taking advantage from combined information of operational and condition monitoring data. However, wind farm operators and manufacturers claim to gather extensive data from wind farms while lacking the capability to translate data into useful information for decision making. This motivates further research for optimisation and standardisation of monitoring systems [14]. In this context, less effort has been made to investigate synergistic effects of coexisting sensing technologies, e.g. SCADA and CMS. Hence, modern approaches should focus on analysing the correlation between signals, in the attempt to enable better understanding of the measurement data and eventually exclude irrelevant input variables.

The initial idea of the concept presented in this paper was developed during the 1^{st} *Joint Industrial Workshop* (JIW) within the European Union's H2020 project AWESOME, as documented in [15]. This work is a continuation and extension of the main idea presented in the workshop. A case study is carried out testing different techniques on field data. The primary objective is the optimisation of the data acquisition by taking advantage of correlated signals and mining algorithms. The base of the methodology is the prediction of certain variables using a set of conversion functions between measurements. The approach is fully data driven, which implies that it is not relying on physical models. The next section of this paper includes an outline of the proposed approach, followed by details of a case study and results. The last section provides an outlook of ongoing and recommended future research in this field.

2. Methodology

A framework is proposed to investigate relationships between coexisting measurements to reveal potentially helpful correlations and synergistic effects. This hidden information will be identified by the evaluation of data-driven conversion functions. To allow all possible interactions, selecting the input-output relations is not limited to a physical understanding of the system. On the contrary, each available signal $x_1, x_2, x_3 ... x_{n-1}$ has to be used as an input for modelling one of the other signals (x_i). Only the target signal itself is excluded from the input set, in order to discard trivial conversion functions. Each signal acts once as the target, resulting in n multiple input and single output conversion functions predicting with an error ϵ.

$$x_i = f_i(x \in X \setminus x_i) + \epsilon_i \qquad \text{with } X = \{x_1, x_2, x_3, ..., x_n\} \text{ and } i = 1, 2, 3, ..., n \tag{1}$$

Figure 1 illustrates a single exemplary conversion function in a wind turbine drive train. The investigation of synergistic effects is based on three main steps:

1. Pre-process and extract features of training data,
2. Build n conversion functions,
3. Evaluate conversion functions.

In the first step, measurement data are prepared to be used to set up and feed the conversion functions. Pre-processing has to include checking for missing signals and invalid values. Duplicated or non-working sensors are excluded. As SCADA signals, which are commonly provided in 10 minute resolution, will be combined with dedicated CMS measurements at high sampling rate, a common working frequency has to be determined. It might be

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