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## Through-life engineering services of wind turbines<sup>☆</sup>

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### ABSTRACT

The past decade has seen exponential yearly growth in installed capacity wind energy power generation. As a result, wind farm (WF) projects have evolved from small scale isolated installations into complex utility scale power generation systems comprising of arrays of large wind turbines (WTs), which are designed to operate in harsh environments. However, this has increased the need for through-life engineering service (TES) for WTs especially in offshore applications, where the operations and maintenance (O&M) becomes more complicated as a result of the harsh marine weather and environmental conditions. In this paper, a generic methodology to benchmark TES in industries is presented and used to assess TES in the wind industry. This was done by identifying the current state-of-the-art in methods and applications, requirements and needs, challenges, and opportunities of TES in the wind sector. Furthermore an illustrative case study on WT gearbox through-life support is presented demonstrating how some of the core aspects, such as remote condition monitoring, can be used to aid the in-service support of wind turbine gearboxes.

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### Introduction

Renewable and alternative energy technologies have developed from very small scale R&D projects to commercial technologies, contributing to the global energy and power generation mix [1]. Of significance is the power generation from wind energy which is now a very popular source of clean energy, having had an exponential growth in the last two decades (see Fig. 1) and currently generating about 2.5% of global electricity supply [2]. This growth has been forecasted to continue, as the amount of global electricity that could be supplied by wind in 2020 is estimated to be between 8 and 12% [2].

As the typical WT is designed for at least a 20 year life time, there is an essential need for through-life support in order to sustain the continuous operation of the WTs at a minimum life-cycle cost. However, designing, delivering and most especially, supporting WTs are not without challenges, one of which is as a result of the nature of their operating environments (offshore

locations in particular). Also, as governments reduce or pull out from subsidies and tax credits, the industry is faced with a challenge of cost reduction (both on the product design and manufacture, and the O&M costs) so as to be as competitive as the conventional and nuclear power sectors with relatively low cost of energy.

This paper is in two parts: the first half explores the original topic of TES in the wind industry, presented by the authors in an earlier publication [1], by identifying the state-of-the-art and current challenges of TES in the wind industry. Also, a forward looking perspective is taken by identifying possible opportunities which could address the challenges and meet future TES needs and requirements in the industry. The second half presents a case study on WT gearbox through-life support, which takes further previous work by the authors (see [1]) by going through the key steps of identifying the TES requirements and needs and its implementation. A focus will be placed on how TES can be applied to offshore WFs since the impacts of poorly understood and executed in-service phase on O&M costs are far greater in offshore applications, and furthermore offshore wind is still in its nascent stages [4].

The main contributions of this paper is as follows:

- This paper closes the gaps in literature in the topic of TES in the wind industry. As at the time of writing this paper, there was little literature in the research domain that dealt with the topic which is of importance for the wind industry.

<sup>☆</sup> An earlier version of this paper was presented at the Third International Conference on Through-Life Engineering Services in 2014 held on 4–5 November 2014 at Cranfield University in UK.

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### Nomenclature

CBM	condition based maintenance
CM	condition monitoring
CMS	condition monitoring systems
KPIs	key performance indicators
MRO	maintenance repair and overhaul
OEM	original equipment manufacturer
O&M	operations & maintenance
PD	product development
PSS	product service systems
SCADA	supervisory control and data acquisition
TES	through-life engineering services
WF	wind farm
WT	wind turbine

- This paper also proposes an approach for benchmarking TES presented as a methodology (identifying the current state – defining the requirements and needs – identifying challenges – designing implementation) which can be easily applied to other industries that looking to explore the adoption of TES.
- A case study on WT gearbox TES which identifies and addresses salient issues being faced in the offshore wind industry was also presented. One particular issue dealt with in this paper is the use of remote monitoring as a key enabler for the continuous learning and optimisation of WTs in a TES context.

### Theoretical background

#### Related works

For many long-lived complex engineering artefacts, such as aircrafts, ships, naval vessels, conventional and nuclear power systems, to name a few, there is a great emphasis on TES, right from the early PD stages through utilisation and until retirement. This is partly because of their complex design, but also because they are expensive to manufacture and maintain. Furthermore, these kinds of artefacts need continuous support since they are typically in operation for decades. This means that the majority of the life cycle costs are attributed to the in-service phase of these systems, with maintenance costs often exceeding the initial capital cost over the life time of the artefact [5]. Modern WTs used in most WF projects have close similarities to these kinds of artefacts in many of these aspects. First, WTs are designed to be in service 20 years or more,

during which the WTs are expected to keep operating as long as the wind blows. Second, due to the complexity in design and the nature of their operations, WTs require adequate support during in-service especially for the offshore types. Hence a similar emphasis on TES is also required by companies who make, operate and maintain WTs in order to deliver the necessary through-life support for WFs.

According to literature [1,6–8], TES involves the managing products and services which are needed in order to deliver a fully integrated capability (product, its functionality and required support) to the customer. This process of integrating of products and services implies that OEMs now have more responsibility for the entire life cycle of a product and are not just responsible for making a product and selling service and support offerings to customers as add-ons [7,9]. As a result, there is now a reduction in the ownership costs of a product for the customer [6], i.e. customers do not necessarily own the product but pay for the capabilities it provides [10]. Another dimension of TES is that it presents OEMs with the opportunity of learning about product usage by customers [7], since they have access to product in-service data. Hence, this gives them a broader scope and motivation to learn from their involvement in in-service activities and use this knowledge for product improvements via redesign and upgrades [1,10]. Perhaps the most important aspect of TES is that it provides OEMS with a means to ensure that the required product value is realised by the customer over all stages of the life-cycle. Value may be a combination of services or promised function, capability or availability.

Relevant to the scope of this research article, antecedent literature have researched into identifying and understanding the challenges and opportunities of TES in different sectors such as Nuclear [11], Maritime [12] and Automotive [13]. For example, Norden et al. [12] proposed a new service contract business model for through-life asset management in the maritime industry. This model provides a holistic service package which is customisable and offered for a fixed time based fee. Knowles [13] discussed the through-life management of electric vehicles, identifying the role which TES has played in addressing the issues with electric vehicles' technologies, and recommending directions for future research. More closely related to the support WTs are the works by Tracht et al. in [14,15], where they deal with an aspect of TES of offshore WTs by developing models for accurate spare parts demand forecasts.

#### On a methodology for benchmarking TES

When the authors of this paper ventured on the quest of exploring the potential applying TES in the wind industry two

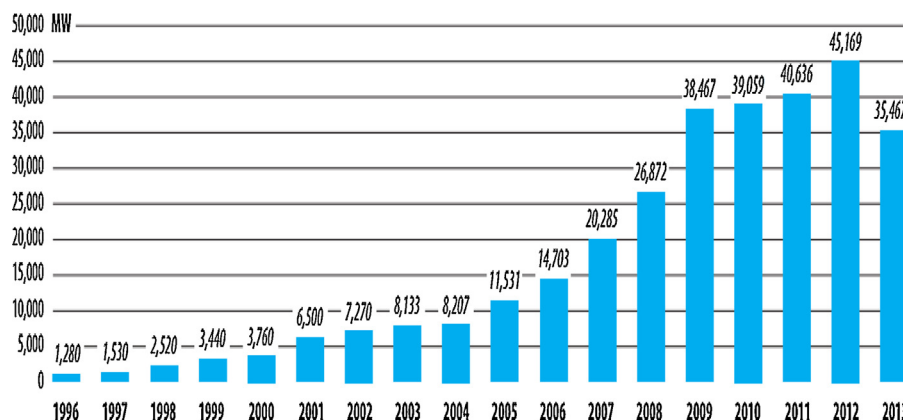


Fig. 1. Global annual installed wind capacity [3].

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