Renewable and Sustainable Energy Reviews 82 (2018) 1261–1271

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Lifetime extension of onshore wind turbines: A review covering Germany, Spain, Denmark, and the UK

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ARTICLE INFO

Keywords:
Lifetime extension
Wind turbine
Remaining useful lifetime
Decision making
Operation and maintenance

ABSTRACT

A significant number of wind turbines will reach the end of their planned service life in the near future. A decision on lifetime extension is complex and experiences to date are limited. This review presents the current state-of-the-art for lifetime extension of onshore wind turbines in Germany, Spain, Denmark, and the UK. Information was gathered through a literature review and 24 guideline-based interviews with key market players. Technical, economic and legal aspects are discussed. Results indicate that end-of-life solutions will develop a significant market over the next five years. The application of updated load simulation and inspections for technical lifetime extension assessment differs between countries. A major concern is the uncertainty about future electricity spot market prices, which determine if lifetime extension is economically feasible.

1. Introduction

In 2016, 12% of the installed wind turbine capacity in Europe was older than 15 years. This share increases to 28% by 2020 [1]. These wind turbines will soon reach the end of their designed service life, which is typically 20 years. As a consequence, the wind industry needs to prepare for upcoming challenges, such as maintenance of aging assets, assessment of structural integrity, lifetime extension decision making, and decommissioning of turbines. Lifetime extension is appealing in that it can increase returns on investment of existing projects, but experiences to date are limited.

Operators must decide which option is best for their aging wind farms; options include: i) lifetime extension, ii) repowering, and iii) decommissioning of the site. Technical, economic and legal aspects drive the decision-making process. For lifetime extension, wind turbines must have sufficient structural life remaining that their safety level is not compromised. In addition, wear-out of components translates into higher operation and maintenance (O & M) costs and turbine downtime. Wind farm operators must sell the produced energy at the spot market or find bi-lateral agreements if no governmental subsidies exist. Changes in legislation prohibit repowering of some existing wind farm sites. Uncertainties make the decision process complex and only very limited literature is presently available.

On the technical side, recommendations for lifetime extension assessment were recently published by DNV GL [2], UL [3], Megavind [4], and the German Association of Wind Energy [5]. Holzmüller [6] applied generic aero-elastic models of onshore wind turbines to reassess fatigue loading in line with site-specific conditions. Ziegler and Muskulus [7] performed fatigue reassessment for offshore wind turbines. Loraux and Brühwiler [8] analysed two years of strain gauge measurements from a wind turbine tower and estimated the remaining fatigue life with this data set. The importance of load measurement campaigns to accurately depict the effect of wakes from neighboring turbines on the remaining fatigue lifetime was stressed by Karlina-Barber et al. [9]. On the economics side, drivers of lifetime extension were discussed by Rubert et al. [10]. Luengo and Kolios [11] review different end-of-life scenarios. A decision model on the optimal time to switch from lifetime extension to repowering was presented by Ziegler et al. [12]. To the knowledge of the authors, no study on the interaction of technical, economic, and legal aspects has so far been published.

The objective of this paper is to investigate the current trends, challenges, and research needs relating to lifetime extension of wind turbines. In order to achieve this goal, this paper reviews the current state-of-the-art for lifetime extension of onshore wind turbines based on

Abbreviations: O & M, Operation and maintenance; RUL, Remaining useful lifetime; SCADA, Supervisory control and data acquisition; IEC, International Electrotechnical Commission; NREL, National Renewable Energy Laboratory; DIBt, Deutsches Institut für Bautechnik

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http://dx.doi.org/10.1016/j.rser.2017.09.100
Received 4 January 2017; Received in revised form 2 September 2017; Accepted 26 September 2017

available scientific literature, standards and guidelines, together with qualitative interviews with key market players. A comprehensive overview of the market as well as technical, economic, and legal aspects of lifetime extension is presented for the selected countries of Germany, Spain, Denmark, and the UK. Furthermore, the practice of technical assessment and decision-making is compared between the countries. Five challenges and further needs for research are derived from the results.

The remainder of this paper is organised as follows. Section 2 describes the research methodology combining literature review and expert interviews with country-specific market players. Background information on the wind energy market is presented in Section 3 for each country. Section 4 presents results on lifetime extension as an outcome of the review of scientific literature and standards; technical, economic, and legal aspects are discussed. The design of the expert interviews and achieved results are presented in Section 5. Results are discussed in Section 6 and conclusions presented in Section 7.

2. Research methodology

Publicly accessible sources like standards, scientific articles, and reports contain limited information on the current lifetime extension practice within the wind industry. To overcome this shortcoming, further data is gathered through the consultation of experts in the field using a consistent interview template. Fig. 1 illustrates the research approach, which combines a thorough literature review with expert interviews in order to collect information on the state-of-the-art of lifetime extension.

Germany, Spain, Denmark, and the UK were selected for the study since lifetime extension is either important for them today due to the age of the fleet (Denmark, Germany, Spain) or will be in the near future (UK). In addition, these countries have rather different contexts in terms of their subsidy schemes, legislation, market structure and scarcity of sites, which is expected to influence the application of lifetime extension. Further information on the market characteristics of these countries is given in Sections 3 and 4.

3. Background on wind turbines at end-of-life

In 2015, Germany, Spain, and the UK had the largest cumulative installed wind capacity in Europe [1]. In Denmark, the installed wind capacity is comparatively less due to its smaller geographical area. Denmark, however, is leading in terms of the wind energy contribution to the national electricity consumption with 42.1% in 2015 [1]. Although the countries selected for this study are pioneers in wind energy, their industry developed differently over the past years. The annual installed capacity in Germany is still increasing, while in Denmark, Spain and the UK it is decreasing [1]. This reduction is driven by changes in political incentives, scarcity of sites for wind farm development in the case of Denmark, and problems with public acceptance as for example in the case of the UK [13]. In Spain, almost no new wind turbines have been installed since 2013 due to a drastic change of legislation, referred to as 'Energy Reform'. The new regulation entailed a complete removal of subsidies and incentives, such as the prior feed-in tariff and feed-in premium schemes [14,15]. In summary, despite Europe's 2030 renewable energy targets, new installations are dropping at a time when the fleet is aging.

Currently, Denmark, Germany and Spain have a significant capacity of old wind farms connected to the grid that are now facing the end of their planned service life. The situation is as follows:

- In 2016, roughly 3400 wind turbines had exceeded 20 years of operational life in Germany [16].
- The situation in Denmark is similar with 1250 turbines being older than 20 years in 2016 [17].
- More than 500 turbines had completed their 20-year lifetime in Spain in 2016, and this will increase to more than 4200 turbines in 2020 [18].
- In the UK only 19 onshore wind farms have exceeded 20 years of operation as of November 2016: of these eleven are still in operation (through lifetime extension), two were decommissioned, and five projects were repowered [19,20]. No public information was available for the one remaining wind farm. In total fourteen repowering projects have been completed or approved in the UK since 2010 [21].

The future age distribution of installed wind capacity almost looks dramatic. By 2020, 41% of the currently installed capacity in Germany will be over 15 years old, 44% in Spain, and 57% in Denmark. The UK has a comparatively younger fleet with a share of 10% of the current installed capacity that will be older than 15 years in 2020. These numbers refer to a scenario for 2020 projected from the installed capacity of the year 2016 without considering future installations.

Fig. 2 illustrates the annual number of wind turbines that will reach the end of their planned service life in Germany, Spain, Denmark, and the UK. It is clear that there is a significant market for end-of-life solutions for Germany, Denmark and Spain over the next decade, followed by the UK after 2024. For these countries, around 2000-4000 turbines per year will either need to be life extended, repowered or decommissioned.

In addition, Fig. 3 illustrates the rated power of turbines that reach their end of design lifetime at present and in near future. In 2016, turbines considered for lifetime extension were rated below 1 MW. From 2020 onwards, larger turbines will reach their 20th year of operation. In the future, it is expected that technology will progress less rapidly than over the past decades. Advances between existing and potentially repowered turbines diminish as time progresses and make lifetime extension more attractive.

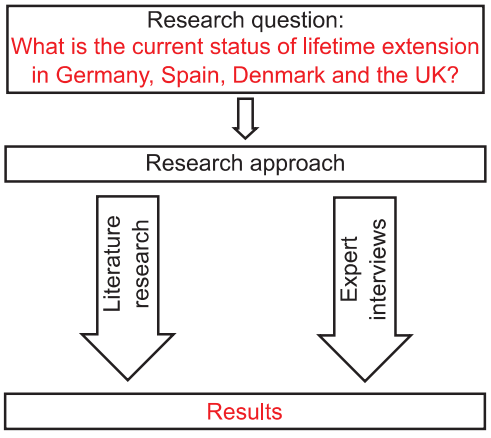

Fig. 1. Research methodology. Information of the current status of lifetime extension is gathered through a review of literature and qualitative expert interviews.

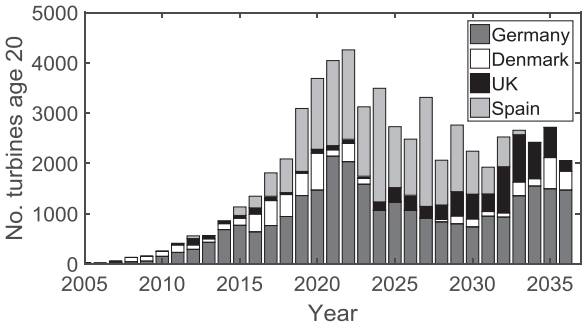

Fig. 2. Number of onshore wind turbines reaching 20-years of operation annually in Denmark, Germany, Spain and the UK. Data sources [16–18,22].