Potential improvements in the life-cycle performance of support structures for onshore wind turbines – an interview study in Sweden

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ABSTRACT

Wind energy is one of the fastest growing renewable energy sources thanks to its cost-effectivity and sustainability. This paper investigates how construction and maintenance of support structures for onshore wind turbines can be improved. Interviews were performed to identify potential areas for improvement in design, construction, operation, maintenance, and end-of-life. Defects due to poor detailing in design and construction have been recurring and may have important consequences. More structured data collection during the construction stages and more robust inspection protocols can help to ensure adequate life-cycle performance of the support structures. Possibilities to reuse and recycle foundations by the end of the turbine's operational lifetime, which remain unexploited and unresearched, are also discussed.

Key words: Wind Power, Reinforced concrete foundations, Durability, Construction, Structural Design, Repowering, Sustainability.

1. INTRODUCTION

Over the last decades wind energy has developed at a growing pace in order to meet the rising demand for renewable energy. According to IEA's scenario for net zero CO_2 emissions by 2050 in line with IPCC's pathways to limit global warming to 1.5°C, wind energy would need to become the first energy source by 2030, with a power generation of more than 8000 TWh. This corresponds to a huge increase from today's 1600 TWh [1], which requires the construction of hundreds of thousands of turbines. In Sweden too, a rapid expansion of wind energy is taking place, with 357 new turbines installed in 2020 to reach a yearly electricity production of 27.5 TWh corresponding to 16 % of the electricity produced in the country [2].

The construction of a single foundation for a modern onshore wind turbine typically requires 1000 m^3 of concrete and 200 tonnes of steel for the reinforcement of concrete and the bolts anchored in the foundation to connect the tower [3]. The concrete and reinforcing steel used in the foundation account for about 75 % in weight of the materials used in wind farm projects and for about 15 % of the life cycle greenhouse gas emissions [4]. The construction of such massive concrete structures implies many challenges in design, production, and quality control. Defects in the different construction stages can lead to the non-fulfilment of serviceability or structural stability requirements [5, 6]. Poor structural design and detailing, due to scaling up solutions used for smaller turbines, and lack of practice-based learning and continuous improvement have been pointed as the reasons for defects [5, 6]. Wind turbines have a design life of 20 to 25 years, and so have their foundations, which is significantly less than other types of concrete structures that are commonly designed for more than 100 years. While recycling metals at the end-of-life contribute to reducing the environmental impact, this is not the case for the materials used in the foundations. These are typically left in place when wind farms are decommissioned. Following the exponential development of wind energy in the last two decades, a growing number of turbines will reach the end of their design service life in the coming years. The development of wind energy, the evolution of the applied technology (e.g., turbines, materials, sensors), the need to reduce the environmental impacts, the construction challenges, and economic and supply chain considerations (e.g., high fluctuations of steel prices and the recent possibility of a cement shortage in Sweden) call for investigating possible bottlenecks in the construction, service life, and end-of-life of wind turbine foundations.

In this study, interviews were performed to gather current knowledge and practice about wind turbine support structures, with a focus on structural, material, and construction aspects, in order to identify potential improvements of their life-cycle performance.

2. METHOD

The study is based on interviews with professionals of the wind power industry in Sweden. The semi-structured interviews, encompassing about fifteen open-ended questions, related to planning, design, construction, quality control, maintenance, and end-of-life of wind turbine foundations. The aim was to collect experience from current practice and observations, and to obtain views on future developments. The five interviewees had many years of experience in the field, having been involved in several onshore wind farm projects in different roles (e.g., project development, tender management, project management, permit assessment and inspection), at different stages (e.g., planning and preparation of documents, production, operation and maintenance), for different stakeholders (client, operator, consultant, and construction company), and both in research and development. The interviews were conducted online, recorded and later transcribed. The authors then used this material to compile the results in this document. Follow-up questions were adjusted according to the interviewees, depending on their roles and experience.

3. RESULTS

The interviews highlighted that errors and/or defects arising during the construction of foundations usually happen due to poor detailed design or execution. The quality of the concrete surface seems to be a recurring problem, observed on several foundations in different projects (e.g., thermal and plastic cracks, ASR, gap or cracked grout at the tower-foundation interface) that can cause further problematic degradations during the service life of the foundations. However, improvements have been introduced in recent years to avoid problems that were prevalent in the past (e.g., detailed design of tower-foundation connection, choice of concrete material). Good planning (using backup solutions to ensure a continuous concrete flow) appears as an important factor to achieve a smooth process for concrete and reinforcement works. Remaining difficulties are related to the bolts used to connect the tower to the foundation and the control of their prestressing force during service life, which is essential to guarantee a reliable connection. The interviews indicated that inspection of the foundations is often exclusively based on visual assessment of the concrete surface to detect eventual cracks immediately after construction. Specific inspection and maintenance measures are undertaken in case a problem is detected or suspected. At present, some data is registered during the construction stage (e.g., concrete material properties and temperature during curing) but nothing during operation regarding the foundations. This data is usually kept within the project; hence it is seldom used and hard to access afterwards.

The interviews confirmed that the concrete foundations are almost always left in place and buried below a layer of soil (typically 50 cm in Sweden) when the turbine is dismounted at the end of its operational lifetime of 20 to 25 years. Foundations (as well as access roads and cables) could undeniably reach longer lifetimes with slight adaptations. However, reusing existing foundations for new turbines seems difficult at present due to the rapid development of turbine technology. Extending the service life of existing turbines and their foundations seems to be a more relevant and good alternative, but it raises the challenge of assessing the remaining fatigue life of the structural components. Today, the design of the foundation commonly comes last, after the choice of turbine type and placement, and load calculations. Reusing the foundations for new turbines would require a reversed way of thinking, starting from an existing foundation and assessing its resistance to design loads differing from the ones it was originally designed for. Although it would lead to a reduction in the use of material and CO_2 emissions, the economic benefits are difficult to assess. Several interviewees believed that there is a lack of studies on how much can be saved by reusing the foundations and other infrastructures in repowering projects.

4. DISCUSSION

Cracks in the concrete seems to be a recurring problem. Although some improvements have been introduced lately to address the common causes in design and execution, the interviews showed that some issues are still encountered, which corroborates observations from other studies [5].The occurrence of defects in foundations, together with the fact that foundations sustain larger loads from bigger and more powerful turbines poses the question of whether additional inspection and monitoring measures are required during construction and service life to ensure the safe operation of the greater asset supported by each foundation.

Wind turbines are optimized for the given operational lifetime of the wind farm, usually governed by permitting and financial considerations. This leads to a remarkably short design life for wind turbine foundations and other infrastructures used in wind farms (e.g., access roads, crane pads, and cables), which could be increased with minor adjustments. Nevertheless, lifetime extension, reuse or recycling of foundations is still not taken into account in the planning and design phase of wind farm projects. Today, these possibilities are mostly seen as being economically unviable considering the current decommissioning of turbines that were built 20 to 25 years ago, when wind energy technology was largely immature and much smaller foundations were used. Although technological developments are still on-going, the size of onshore wind turbines is not increasing like the one of offshore turbines anymore and it may be expected to reach a plateau in the coming years, mostly due to height limits for approval and social acceptance, transportation and installation constraints. From a structural design point of view, both lifetime extension and reuse of foundations require confidence in the remaining fatigue life of the structures, which requires data that is not monitored today. Cost-benefit analyses at the overall project level are needed to investigate the potential of reusing existing foundations and other infrastructures in various cases (e.g., size and number of turbines, location) and to take it into account in future wind farm projects.

5. CONCLUSIONS

To avoid defects and errors in the construction of wind turbine foundations, care must be taken to achieve good design and production planning and follow-up. The development of inspection protocols based not only on visual check but on a more comprehensive monitoring system, enabling data collection and analysis during construction and operation, can improve quality and reliability of the structures. Alternative options for the end-of-life of foundations (i.e., lifetime extension, reuse or recycling) and their potential environmental and economic implications need to be further studied in view of the increasing number of turbines that will reach the end of their operational lifetime and the growing need for repowering. This calls for the development of technical solutions and the integration of structural health monitoring systems in new foundations.

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