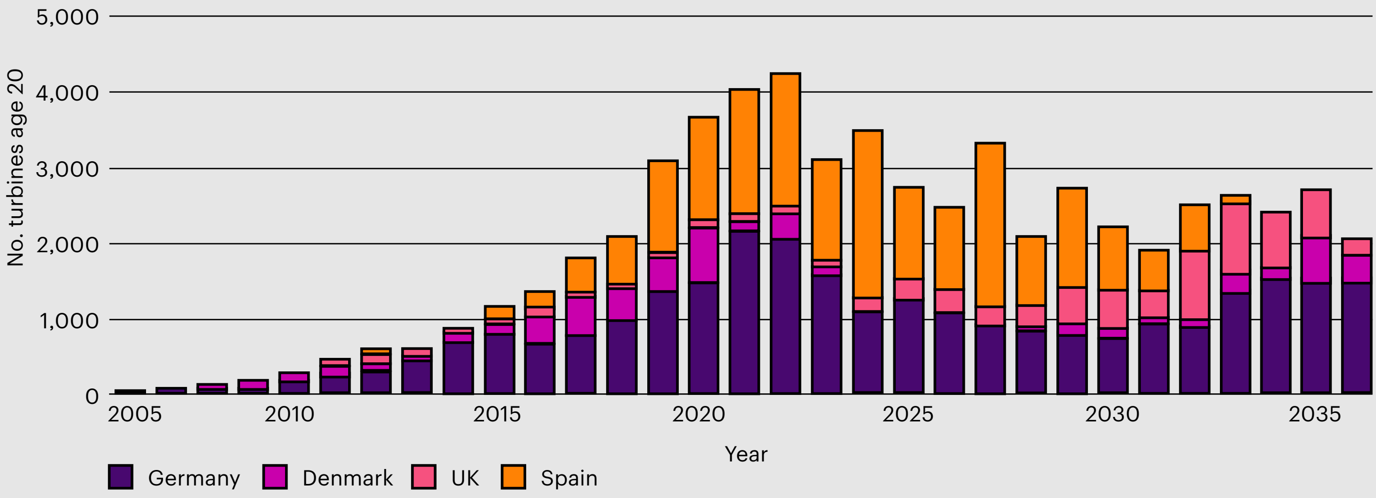
Wind power: extending beyond the design life

Introduction

As wind farms age, owners need to make decisions regarding either the extension of the operational life of its plants or their complete decommissioning and repowering. In addition to the commercial factors affecting these decisions, technical aspects must also be considered to ascertain the risk associated with the prolonged operation of an aging fleet.

Assuming a typical design life of 20 years, it is expected that 86 GW of wind generation capacity will be decommissioned across Europe by 2030 if operational lives are not extended[1].

Figure 1: **Number of onshore wind turbines reaching 20-years of operation annually in Denmark, Germany, Spain and the UK**



Source: L. Ziegler, E. Gonzalez, T. Rubert, U. Smolka and J. J. Melero,"Lifetime extension of onshore wind turbines: A review covering Germany, Spain, Denmark, and the UK," Renewable and Sustainable Energy Reviews,vol. 82, no. 1, pp. 1261-1271, 2018. https://www.sciencedirect.com/science/article/pii/S1364032117313503

[1] By Paul Dvorak, September 29, 2017, "An Owner's guide to wind turbine life extension", 10th Annual Wind O&M Europe 2018 Conference https://www.windpowerengineering.com/owners-guide-wind-turbine-lifetime-extensions/

Commercial considerations

While repowering wind farms using novel technologies offers higher energy yields and financial revenues, the increasing cost of capital, difficulties in securing a land lease, planning permissions, grid licenses and a drop in the level of subsidy available to Onshore/Offshore projects all encourage owners to consider extending the operational life of their existing fleet.

One immediate benefit of extending the operational life is the reduction in levelized cost of energy (LCOE) and an increase in revenue over the plant's lifetime; however, the life cycle cost remains approximately unchanged, with some variation in the operational expenditure (OPEX). This assumes that no major part of the plant requires replacement, and only minor refurbishments and maintenance are necessary.

The average cost of extending the operational life of an Onshore Wind farm is approximately 100 KEUR/MW, whereas the cost of repowering is approximately 1 MEUR/MW.

Technical considerations

Conventional commercial wind turbines are typically designed and certified for 20 years of operation; these specifications include those for major structural components of the turbine such as blades, towers, foundations, yaw rings, pitch bearings and drive train components.

Typically, the structural components of turbines are subjected to cyclic fatigue loads; the reliability and failure probability of such components therefore increases as the turbine approaches the end of its design life. For instance, rotating bearings in turbines are designed based on 90% reliability, implying that the probability of bearing failure before the end of the designated 20-year design life is 10%[2]. Moreover, the blade exterior (including leading edges) requires ongoing and thorough life maintenance. However, the structural elements are designed to last for the intended design life (i.e. 20 years).

Towers are designed based on class loads on Onshore Wind turbines. However, Offshore Wind towers are designed based on the design of the offshore foundation and site-specific metocean loads, as well as according to an iterative process executed by the foundation designer and turbine original equipment manufacturer (OEM).

Onshore turbines can have gravity or pile-based foundations. Furthermore, they are normally designed based on the interpretation of the climatic class loads on the tower bottom and according to the EUROCODE design standard.

Offshore foundations are often monopile or jacket types, designed in conjunction with the turbine tower using site specific metocean loads. It is expected that a lesser degree of conservatism is considered in the design of the offshore foundation in compared to older onshore foundations, due to accounting for site-specific loading in the design process.

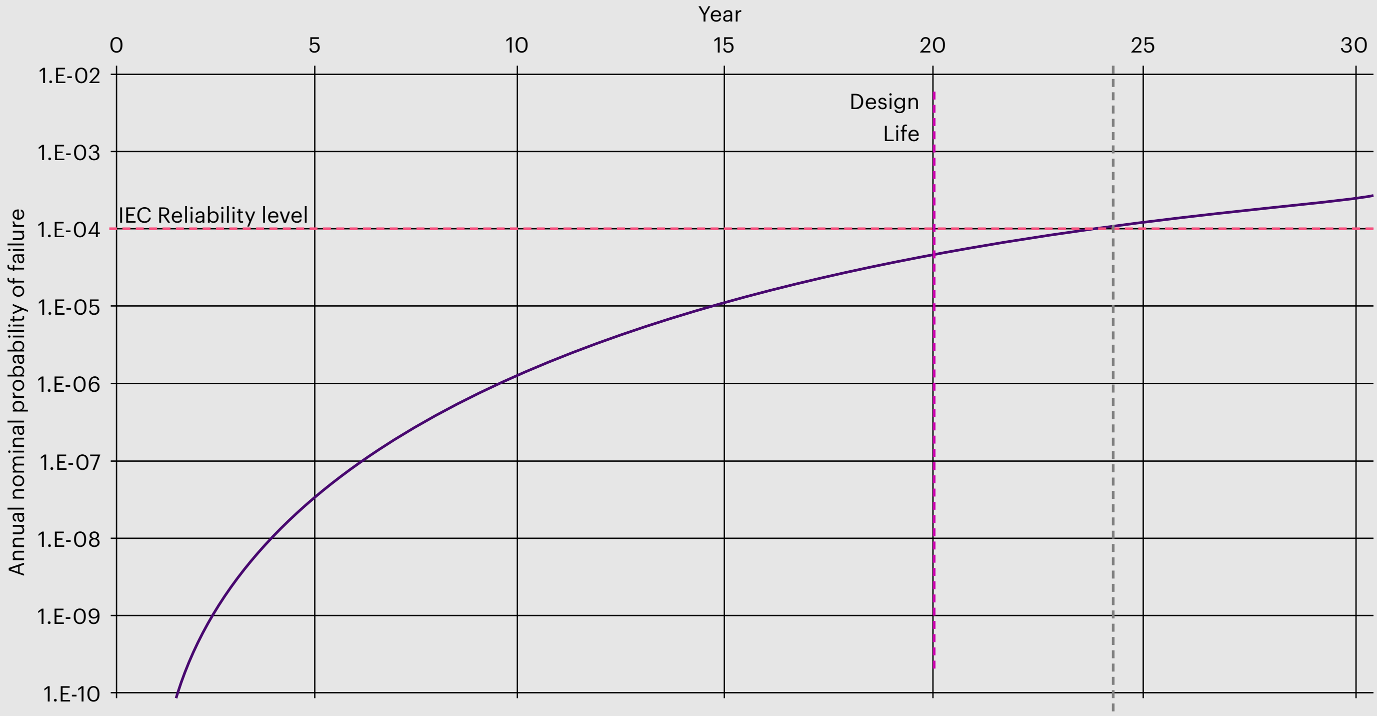
Potential to extend Operational life

The reliability target for operation of the wind turbine is nominal annual probability of fatigue failure of one in ten thousand (10^{-4}) according to IEC 61400-1 standard, based on which the turbines are certified, and partial safety factors are applied to both class loads and material strengths in the design of turbine components. This often introduces an element of conservatism in designing the structural components and rotor nacelle assemblies (RNAs).

> **"It is expected that a lesser degree of conservatism is considered in the design of the offshore foundation in compared to older onshore foundations."**

[2] John Coultate, Mike Hornemann, December 2017, "Why wind -Turbine gearboxes fail to hit the 20 – year mark", WindPower Engineering & Development https://www.windpowerengineering.com/wind-turbine-gearboxes-fail-hit-20-year-mark/

Figure 2: **Failure rate curve of a typical wind turbine**



Source: Wind Energy Ireland, " Wind Energy Ireland Guide to Wind Turbine Lifetime Extension", October 2021 https://windenergyireland.com/all-documents?s_files_title=Wind%20Energy%20Ireland%20Guide%20to%20Wind%20Turbine%20Lifetime%20Extension

Typically, uncertainties in wind conditions can be relatively large, particularly owing to seasonal variations, storms and changing terrain conditions over the life of a turbine. Furthermore, the instability of power grids in locations such as Ireland can introduce variability in power production and reduce the load factor of the operating fleet.

The combined effects of conservatism in the original design of turbines, uncertainty in site-specific weather conditions, and variability in the power grid can facilitate wind turbines to operate beyond their certified design life. In other words, the design life of the turbine may not be fully consumed within 20 years of operation.

The design life of a turbine can be reassessed using the actual operational data obtained from the turbine supervisory control and data acquisition (SCADA) system. Correspondingly, fatigue analysis can be performed using 10 min average SCADA data to determine the remaining useful life (RUL) of the turbine.

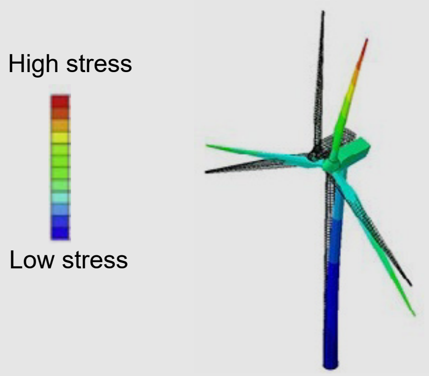
Notably, methods used to conduct life assessments of wind turbine design have been well documented. However, only limited codes and standards are available for assessing the life extension potential of operational wind farms. The two primary documented guidelines are the DNVGL-SE-0263 "Certification of lifetime extension of wind turbines" and the UL4143 "Standard for Safety Wind Turbine Generator–Lifetime Extension (LTE)."

DNV GL-SE-0263 considers the following four primary methods for extending the life of wind turbines: in-service inspections, together with simplified, detailed, and probabilistic analytical assessments. Notably, the choice of the assessment method often depends on the availability of original design information. A simplified approach is normally selected when wind farm design documentation and calculations are unavailable, which is often the case for old wind farms, for which copies of as-built documentation are not digitally stored or are missing owing to repeated changes in ownership.

As displayed in Figure 3 overleaf, the simplified approach uses a generic aero-elastic model of a wind turbine to estimate the RUL, using IEC 61400 generic class loads. However, detailed methods require access to the original design documentation to perform the corresponding assessment. Unlike simplified and detailed methods that use load calculations to assess the structural integrity of a turbine, the probabilistic method uses stochastic models that determine the failure probabilities of different components[3].

[3] Chandran, Aneesh & Dettmer, Ronald & Gilmour, Nicholas & Harper, Daniel. (2021). Wind farm life extension: A review of economic, social, technical and safety factors. https://www.researchgate.net/publication/355164408_Wind_farm_life_extension_A_review_of_economic_social_technical_and_safety_factors/link/6161bfc9ae47db4e57b3a440/download

Figure 3: **Wind turbine Aero-Elastic model**



Source: WindForS, Windenergie Forschungscluster

After the foregoing assessment, certification is issued to projects for an extended operation period. However, the validity of this certificate is limited to the extended lifetime during which the turbines may require regular inspection, and the corresponding report is sent to the certification body.

The IEC 61400-28 "Wind Energy generation system – through life management and life extension of wind power assets" is currently being developed by the International Electrotechnical Commission. IEC 61400-28 is expected to introduce more relaxed reliability requirements for operation beyond the design life.

Regulatory requirements

Apart from the general safety regulation and machinery directive for extending wind turbine operations beyond their design life, no specific regulations exist in Spain or the UK. This is because the concept of life extension is relatively new, and this subject is yet to mature and develop in these countries.

The UK is expected to introduce its legislation in the future, owing to an increasing number of turbines approaching the end of their design life. However, this is not the case for Denmark and Germany, wherein the average age of the turbine fleets is older than in the UK and Spain. In Germany, DNVGL-SE-0263 is followed for operational life extension and is regulated by the German Institute for Construction Technology (DIBt). The standard entails analytical and practical assessments of all components at the end of the design life.

The regulation for the extension of life in Denmark is mandated under Executive Order 73, which includes requirements for inspecting both blades and structural components at the end of the design life, which are repeated annually.

Interface considerations

Other factors that require consideration before making decisions regarding the operation of wind turbines beyond their certified design life include the park control system and SCADA infrastructure.

Notably, wind turbines are connected machines, requiring reliable communication with local and remote external servers for safe operation. Moreover, the turbine controller and SCADA infrastructure require constant updating or upgrading to avoid the risk of cyber-attacks. Older turbines and wind farms are often not designed to withstand cyber-attacks, and they may not comply with the IEC/ISO 62443 standard for the security and safety of industrial automation. For that reason, upgrading SCADA systems on older wind farms is paramount in minimizing cyber risk exposure and vulnerability to new attacks.

Notably, the balance of plant electrical systems, such as main transformers for transmission network connected projects, array cables, HV substation and protection, are considered critical parts of any wind farm, being crucial in ensuring that power can be exported to the grid. The power industry has extensive experience in extending the life of electrical assets and power transformers in thermal and other conventional power plants which can be applicable to the windfarms. Asset aging plans therefore need to be developed, which consider a series of integrity tests and inspections to ascertain the operational life while ensuring compliance with new grid regulations imposed on power generators.

The covenants and conditions set out in the lease of land agreements, together with planning documents from local authorities, are other important aspects to be considered. Typically, access or emergency roads to the plant may not remain viable during the extended operational period, resulting in operational difficulties in the upcoming years. Additionally, development on neighbouring lands may require plants to comply with unforeseen safety, operational and environmental requirements.

Risk considerations

Whilst the revenue through the subsidy scheme is expected to be curtailed or terminated during the extended operation, it may not necessarily result in lower Business Interruption values because the lead time for replacing the main components (such as rotor and blade bearings) can be longer, owing to obsolescence, lack of spares or smaller supply chains.

The turbine-type certificate no longer remains valid for operations beyond turbines' design life. The requirements from regulatory bodies, lender or insurers may include conditions for the turbines to be type certified. The certification of extended operation based on a recognized industry guideline (for example, IEC 61400-28) is crucial in assuring the reliable operation of the turbine until the type certificate expires.

Likewise, the third-party requirements may involve an obligation for thorough and frequent inspection of the key structural components. This may not be in line with the ambitions of the owner to reduce the OPEX and the cost of maintenance during the extended operational period and the final years before decommissioning.

Conclusion: strengthening standardization and regulation

The current Net Zero targets in many European countries and increases in spot market prices are having a positive effect on the economic viability of the extension of windfarm lifetimes. On a global scale, it is expected that around 180 GW of installed wind energy will reach the end of design life within the next decades[4]. While a strong regularity regime for extending the operational life does not exist, the industry is expected to strengthen the standardization and regulation for the operation of aging assets, in line with the formal release of IEC 61400-24.

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[4] https://iopscience.iop.org/article/10.1088/1742-6596/1222/1/012033