Renewable and Sustainable Energy Reviews 53 (2016) 1212–1221

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Key challenges and prospects for large wind turbines

R. McKenna*, P. Ostman v.d. Leye, W. Fichtner

Chair for Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute for Technology (KIT), Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form
12 June 2015
Accepted 18 September 2015
Available online 10 November 2015

Keywords:
Onshore wind
Challenges
Prospects
Interviews

ABSTRACT

The so-called 20-20-20 targets for the European Union include a reduction in greenhouse gas emissions by 20% compared to 1990, 20% of primary energy from renewables, and a 20% reduction in primary energy demand through energy efficiency by 2020. Wind energy has played and will continue to play a significant role in progress towards meeting these goals; in 2012 it accounted for around 7% of total European electricity consumption. Against the background of the recent trend towards ever larger wind turbines at higher hub heights, this contribution explores the challenges to and prospects for a continued up-sizing of wind turbines in the future. Based on a literature review and interviews with experts in the European wind industry, the key challenges for large onshore wind turbines are identified and qualitatively analyzed in a European context. Further developments of large wind turbines depend on several components and related challenges rather than just one. The main challenges are thought to be related to social acceptance, the logistics of transport and erection, and the medium term sustainability of the political and economic support for wind energy. It seems likely that social acceptance will center around the issue of aerodynamic noise and the allowed distance from the turbine, although further research is required to fully understand the public perception of especially large wind power plants. In addition, the sheer size of larger wind turbines in the future presents significant challenges in terms of the materials and structures employed. There is little consensus on the likely development of drive train technologies, though a slight tendency towards direct drive systems with permanent magnet generators as well as multi-stage gearboxes was encountered, which could also serve to improve reliability. For the rotor blades, a trend towards fully carbon fiber blades is expected, and towers will continue to be constructed from steel and/or concrete, albeit both of these components increasingly in the form a modular construction.

Contents

1. Introduction, objectives and overview 1213
2. Methodology 1214
3. Challenges and potential solutions for large wind turbines 1215
   3.1. Wind measurement and forecasting 1215
   3.2. Rotor blades 1215
   3.3. Drive train 1217
   3.4. Tower 1218
   3.5. System integration and diagnostics 1218
   3.6. Socio-economic aspects 1220
4. Summary and conclusions 1220
References 1220

* Corresponding author. Postal address: IIP, Building 06.33, Hertzstrasse 16, 76187 Karlsruhe, Germany. Tel.: +49 721 6084 4582.
E-mail address: mckenna@kit.edu (R. McKenna).

http://dx.doi.org/10.1016/j.rser.2015.09.080
1364-0321/

1. Introduction, objectives and overview

The European Commission has set an ambitious target for 20% primary energy demand from renewable sources by 2020 [1], which is nationally implemented through the Member States' National Renewable Energy Action Plans (NREAPs). The NREAPs were submitted to the European Commission in 2010 and, after being approved following some modifications, are now being implemented. The NREAPs stipulate the planned expansion of renewable energies in each Member State until 2020, whereby the national target may be significantly different to the overall 20% goal, the reasoning being that the framework conditions in each country – that is, the renewable resources, political and economic conditions – differ greatly and the target-setting should reflect this. Beside the European goals, other countries like China and the USA have set themselves targets which combine to 1000 GW globally in 2030 [2].

Electricity generation from wind power in Europe has developed rapidly in recent years (cf. Fig. 1). The total installed capacity has roughly increased by a factor of 10 since the year 2000, from around 13 to 129 GW in 2014 [3,4]. About half of this total capacity is accounted for by Germany with 39 GW and Spain with 23 GW; together the UK, Italy and France account for about another quarter (with 12, 9 and 8 GW respectively) and the rest is distributed amongst many other member states [5]. At the time of writing the total electricity generation from wind in Europe accounts for about 7% of the total electricity demand. Some studies demonstrate that onshore wind is close to being competitive to fossil fuels regarding the generation costs [6]. So it is clear that wind, both on- and offshore, is playing and will continue to play a significant role in making progress towards European and national targets for 2020, as shown in Fig. 1.

While there are various possible turbine designs, the majority of turbines nowadays are built in an upwind horizontal-axis design with three blades, as shown schematically in Fig. 2. The turbine has a large central tower, on which sits a nacelle, which holds the generator, gearbox (if present) and converter. Attached to the nacelle is the rotor hub to which the rotor blades are mounted. Since all alternative designs for wind turbines play a relatively minor role at present, this paper focuses on the standard design: an upwind horizontal-axis three-bladed design.

One trend that has been encountered alongside the rapid capacity expansions is the one towards larger turbines. Indeed, turbine sizes, especially rotor diameters and hub heights, and therefore also the nameplate capacities, have increased dramatically in the last few decades. The average new onshore turbine capacity, for example, was below 1 MW in the 1990s but is now of the order of 3 MW (cf. Fig. 3), and is expected to increase further in the future. The key driver behind this increase in size is and will probably continue to be the levelized costs of electricity generation, perhaps also alongside multi-objective optimization criteria including annual energy production (AEP) and total mass [7]. The optimization of wind turbines should maximize their aerodynamic performance below the rated speed and withstand fatigue and extreme loads above it [8]. Towards this objective, small aerodynamic and structural improvements in wind turbines can achieve small increases in the AEP, and thus also lower costs. The latter modifications have a relatively small potential in comparison to those relating to higher hub heights and rotor diameters. This is because despite the higher associated investment, O&M (operation and maintenance) costs, structural and other related challenges, larger turbines exhibit ceteris paribus lower electricity generation costs, due to the higher wind speeds (and the cubic relationship with the wind power) and the much larger swept areas (which is proportional to the square of the diameter).

These historical and current trends present several research questions relating to the (possible) future developments of wind energy in

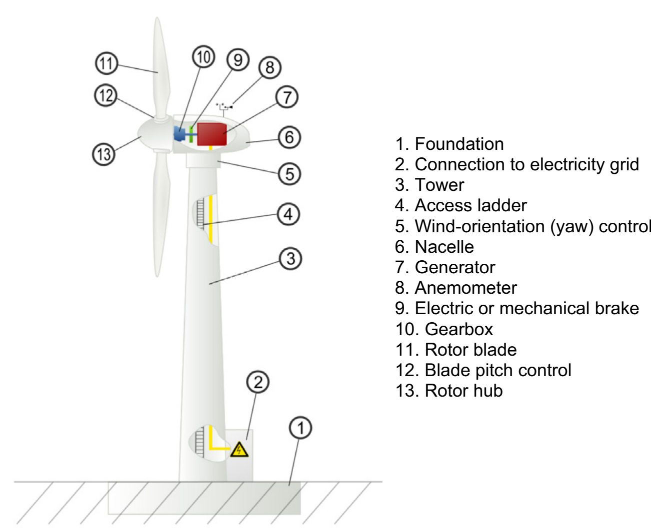

Fig. 2. Standard turbine with upwind horizontal-axis three-bladed design and a description of the components. Source: [9].

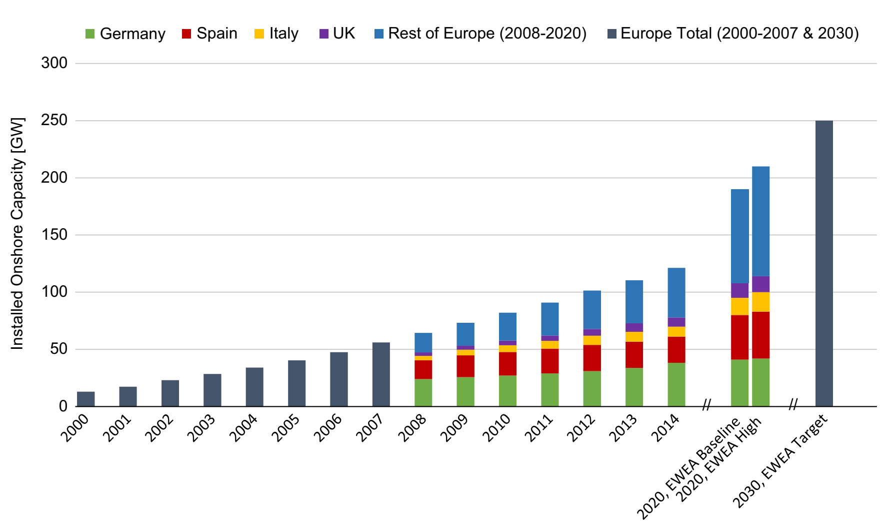

Fig. 1. Installed onshore wind capacity in the EU from 2000 to 2014 and EWEA targets for 2020 and 2030. Source: [3,4].