Offshore wind power: from xed to oating

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Wind power is expected to make the biggest contribution to renewable energy deployment targets for 2030 and beyond. Installed wind power capacity in the European Union is around 236 GW (end 2021); \NYM ,< TK TSXMTWJ \NSI FSI ,< TK TKKXMTWJ \NSI NY HT[JW (8% in France). The most promising scenarios aim to achieve a total capacity of 60 to 80 GW of installed offshore wind power by 2030, including 6 to 12 GW of floating offshore wind power.

This article provides some background on offshore wind energy. The advantages of floating wind power, the associated obstacles and innovative hybrid experimentation systems are briefly outlined.

The term "\Ðƒ/\| M®3R M encompasses two main types of wind turbine : "land-based" wind turbines, where the foundations are laid or buried in the seabed, and KÒ\è•3R(KM®3R M•“| 3R •“| 3R M 3ƒM 3Rƒ•èJJ M \Q platform connected to the seabed by anchor lines. These two technologies èJƒ\M 3Ð |M 3RM• |Qƒ ®/3J M•/ MÑ|ƒ•M \QQ farm with installed wind turbines was inaugurated in Denmark in 2002, •/ | Mè| M R\M \QQ | 3 wind farms to date.

France, for its part, is clearly lagging behind in the development of wind 'è|Qƒ#M Æ/3J M•/ MÑ|ƒ•M ÑÃ(# R Þ/5M\Qƒ M mercial wind farm was inaugurated in September 2022 and two others are expected to come on stream by •/ M R M\'MßÝßà$MQ\| M land-based wind power has been installed in Europe over the last twenty years. Other wind farms, each with an installed capacity of around àÝ|ÝNiÆM<M {“3-èJ R•M•\M•/ Mè- |è(M electricity consumption of around 750 000 people - are expected to follow in the near future.

While France may seem to be lagging behind its neighbours when it Q M ÒM\Ð•3R(M®3R M'è|Qƒ$M3•M3ƒM still at the forefront when it comes •\M Ò\è•3R(M®3R M'è|Qƒ#M MRM'è •$M'\J lowing the call for projects launched by ADEME in 2015, four pilot farms \Qy|3ƒ3R(M•/| MÒ\è•3R(M®3R M•“| bines of 8 to ÞÝNiÆM è /Mƒ/\“J M M commissioned in 2023 and 2024 on the Mediterranean coast. Since 2018, •/ MÒ\è•3R(M®3R M•“| 3R M'|\QM•/ M European FLOATGEN project [1] RM3RM•/ M• ƒ•My/èƒ Mè•M •/ M›-i<”-ÅM\Ðƒ/\| M• ƒ•Mƒ3• M\y- rated by the École Centrale de Nantes. The Multiannual Energy Programme (PPE) also provides for the installation \'M•/| MÒ\è•3R(M\Ðƒ/\| M®3R M'è|QƒM (two in the Mediterranean and one south of Brittany), each with a capa- 3•´M\'MßâÝNiÆ$M ´MßÝâÝ#M

1. Floatgen floating wind turbine from BW-Ideal, being tested at the SEM-REV sea trial site, 12 km from Le Croisic (Loire Atlantique).

Article available on website https://www.refletsdelaphysique.fr or https://doi.org/10.1051/refdp/2024s092

© Ole Jørgen Bratland. © Equinor. Hywind Tampen at Wergeland base in Gulen [5].

2. Photo of the Hywind Tampen floating wind farm in Norway.

> “ While France is particularly behind its neighbours in terms of offshore wind power, it is still at the forefront of floating wind power ”

The advantages of floating wind power

Floating wind turbine technology \Ð |ƒMèMR“Q |M\'Mè -èy3\R(ƒM 3R wind turbines installed on land. Firstly, it reduces the visual impact of •/ MQè /3R ƒMèR M \RÒ3 use of maritime space, by enabling installation in deeper areas further from the coast. Secondly, it reduces the impact of installation work, by replacing foundations with anchors. It also facilitates the installation of the wind turbines by enabling them to be assembled in port areas and towed to the site of operation. Finally, it increases the load factor of the machines, and therefore overall electricity production, by installing them in areas where the wind potential is particularly favourable.

J•/\“(/M Ò\è•3R(M ®3R have been the focus of attention for •/ MJèƒ•M• RM´ è|ƒ$M•/Þä Ñ|ƒ•Q®|M3Ý\3R#M this subject dates back to the early 1970s. Bill Heronemus, then Professor of Civil Engineering at the University of Massachusetts, was one of the R3•R(ƒM 3R M•/3ƒM Ñ J N 8 •® R•´M ´ è|ƒM•\Mƒ M•/ MÑ •|3èJƒM \'M èM Ò\è•3R(M ®3 concept, carried out in England as yè|•M\'M•/ MAat ¥My|\D •N8 took another twenty years for the Ñ|ƒ•Mƒ èM•|3èJƒM\'MèMßNi \ÐM•/ M \èƒ•M\'Mj\|®è´$Mè •/ MI´®3R M$ Q\My|\D •N8á9 3RMè“•“QRMßÝÞä$M•/ MÑ|ƒ• ®èƒM \QQ3ƒƒ3\R M\ÐM•/ M Scotland. This is the Hywind Scotland y|\D •$M \Qy|3ƒ3R(M Ñ- M® bines, each with a rated output of ãN iÆ#M ¥/3ƒM ®èƒM '\JJ\® Hywind Tampen project, comprising eleven wind turbines with a total èyè 3•´M\'MååNiÆM4Ñ(#Nß to supply oil and gas production facilities in the Norwegian North Sea, it went into production on

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Spar Barge Tension Leg Platform Semi-Submersible

3. Main float topologies used for floating wind turbines. From left to right: Spar, Barge, TLP, Semi-submersible. (Original figure taken from M. Scheu *et al* [6]).

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Some of the technological challenges of floating wind turbines

Despite the experience acquired [illegible] wind turbines of tomorrow still [illegible] combining the skills developed for onshore wind turbines with those of ocean engineering. On the other hand, some old wind turbine concepts, such as vertical axis wind turbines, are making a comeback in [illegible] turbines have inevitably converged towards the Danish three-bladed horizontal-axis model, new technical opportunities are opening up for [illegible] promises in terms of stability and durability.

Generally speaking, the various [illegible] types of platform. These are :

- SPAR, which are slender structures with a very deep draught (around [illegible] tonnes of ballast at the bottom to give the structure its stability;
- [illegible] that acquire their stability from their buoyant surface, which is intrinsically linked to the geome- [illegible] level of the free surface. These structures have the particularity of [illegible]
- TLP (Tension Leg Platform), which involves tensioning vertical anchor lines by adding buoyancy (non-ar- [illegible]
- [illegible] with three or four vertical columns connected by pontoons and metal braces. The diameter of the columns and their spacing ensure the stability of the system, particularly [illegible] forces. These structures generally [illegible]

One of the non-trivial aspects that [illegible] wind turbines is the influence of structural movements resulting from the combined action of wind and [illegible] tuations in the energy produced and fatigue stresses on the entire structure, from the blade to the anchoring lines, via the tower and the transition piece. One of the key issues in the [illegible] is therefore the introduction of robust, adaptive control systems

1• https://cutt.ly/floatgen_pris_la_mer

2• https://cutt.ly/umass_edu_windenergy

3• K.-C. Tong, "Technical and economic aspects of a floating offshore wind farm", *Journal of Wind Engineering and Industrial Aerodynamics* (1998) 399-410.

4• Trine Ingebjørg Ulla, "Expanding into Deeper Waters: Development of the Hywind floating wind Concept", BOEM Offshore Renewable Energy Workshop (2014).

5• www.equinor.com/energy/hywind-tampen

6• M. Scheu *et al.*, "Human exposure to motion during maintenance on floating offshore wind turbines", *Ocean Engineering,* 165 (2018) 293-306.

7• Retour en vidéo sur le projet SOFTWIND (2020) https://youtu.be/oppYPno1cww

8• https://cutt.ly/realtime_hybrid_model_test

9• www.weamec.fr/projets/softwind/

10• A. Otter *et al.*, "Emulating aerodynamic forces and moments for hybrid testing of floating wind turbine models", *J. Phys.: Conf. Ser.* 1618 (2020) 032022.

that minimise structural fatigue while maintaining optimum performance. Structural movements can also have an impact on the wake behaviour of wind turbines, modi fying their resorption process and possibly amplifying their 'meandering'. (The wake as a whole oscillates according to the large turbulent structures present in the atmosphere and, to a lesser extent, the instabilities intrinsic to the wake). With the organisa-
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ever-larger wind farms being the next step, production losses and increases in structural fatigue due to wake interactions are becoming a growing subject of investigation.

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4. Photos of experimental set-ups using different types of mechanical actuators to emulate rotor response during tank tests. From left to right: (a) servo cables [8], (b) air turbine [9], (c) set of thrusters for aerial drones (original figure by A. Otter *et al.* [10]).

c

The aim is also to continue the development of numerical models useful for dimensioning these structures, whether on the scale of a wind turbine or a wind farm.

In addition, the increase in technological maturity (Technological Readiness Level, TRL) must be accompanied by an increase in the complexity of the investigation tools used. The numerical tools used in the various design stages are tending towards multiphysics (coupling aerodynamics, hydrodynamics, automatic control and structural mechanics) and multiscale approaches, from a millimetre to several kilometres, if we are interes
• M3RM•/ 3|M\|(èR3ƒè
Demonstration conditions are also becoming increasingly complex, ranging from controlled laboratory conditions to real-life experiments.

Solutions for hybrid experimentation

The impossibility of reconciling the laws of similarity governing the main aerodynamic phenomena (similarity in Reynolds: for a given
Ò“3 $M•/ M| “ •3\RM 3
scale inherent in laboratory tests must be associated with an **increase** - inversely proportional - in the
ƒy M\'M•/ M|'|R M
hydrodynamics (similarity in Froude:
'\|MèM(3- RMÒ“3 $M•/
geometric scale inherent in laboratory tests must be associated with a **reduction** - proportional to the square root of the geometric scale - in
•/ M-J\ 3•´M\'M•/ M| '|R MÒ\®M

makes it impossible to simultaneously reproduce, on a reduced scale, the aerodynamic behaviour of
•/ MÒ“3 #Mƒ èJ $M•/ Mè |\´RèQ3 M
and hydrodynamic behaviour of
•/ MK®3R M•“| 3R M\MÒ\è•KMèƒƒ Q J´#M
The test infrastructure teams have had to develop technological jewels enabling them to reproduce the mechanical stress on the rotor using emulators controlled in real time and coupled with the wind turbine. These emulators are themselves excited by a swell generated experimentally in a hydrodynamic tank [7]. These emulators consist of a set of mechanical actuators, which in most cases are the thrusters of aerial drones or servo-controlled cables
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Software-in-the-loop, also exists in the
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movements are emulated with a hexapod, and the aerodynamic forces undergone by the wind turbine rotor are then measured precisely in the wind tunnel.
Æ/3J MÑ J M•|3èJƒMƒ\
of similarity and are a necessary step on the critical path of developing new concepts, they also generate other sources of complication linked to the use of sensors in uncontrolled and hostile environments, and to the variability of weather and ocean
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to obtain statistically convergent results and therefore reduces the representativeness of the results obtained.

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ity shows that it must take advantage of the triptych of investigation, i.e. numerical simulation, small-scale experimentation and full-scale experimentation, to meet the
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turbines economically viable and
/ Jy3R(M•/ QM•\MÑR M•/ 3|MyJè M3
the renewable energy mix by 2030. ■