DESIGN TOOLS FOR OFFSHORE RENEWABLE ENERGY

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1.- INTRODUCTION

Offshore wind is growing very fast with 22 GW of cumulative power and more than 5,000 turbines installed in Europe by the end of 2019 [1] while other offshore renewable technologies such as tidal stream or wave power are still in their infancy with a number of projects in the range of MW [2]. Offshore wind deployment is mainly concentrated in areas with continental shelf, such as the North Sea in Europe, where shallow waters can be found hundreds of km far offshore. However new solutions for deeper waters are emerging (mainly based on floating platforms) allowing offshore wind deployment in many places around the world [3].

Renewable Energy sources play a fundamental role in the fight against climate change. The crisis caused by covid-19 can make the world forget this fight by adopting economic measures that are harmful to the health of our planet. And this is what thirteen EU Environment and Climate ministers requested to Brussels. Along the same lines, the European Alliance for a Green Recovery arises, supported by a continuously growing number of representatives from the political, economic and social world. In their manifesto they demand that the European Green Deal [4] approved in January 2020 with the ambitious plan to make Europe the first climate-neutral continent by 2050, should be the way out of the crisis.

In fact, offshore renewable energy sources might play a crucial role in meeting low-carbon energy scenarios, which is one of the six key principles of the Green Recovery, contributing at the same time to economic growth and job creation. However, continuous cost reduction is needed to achieve more efficient and cost competitive technologies. Design tools can help to accelerate cost reduction in early stages of technology development or project planning. The objective of this article is to introduce some examples of design tools developed within four R&D European projects in order to present their main functionalities and provide references for further documentation and use. These include multi-physics numerical modelling; decision-making tools during the planning phase and structured innovation and stage gate tools. Section 2 describes a multi-physics approach methodology for numerical modelling from the initial design, to model experimental validation and Hardware In the Loop (HIL) testing, including downloadable documentation and public models. Section 3 describes open-source decision-making design tools to asses different alternatives for deployment of offshore renewable farms for wave and tidal energy arrays. Finally, section 4 extends new design tools focused on fostering the innovative thinking and asses the development and deployment of device concepts through the evaluation of different metrics.

2. MULTI-PHYSICS NUMERICAL MODELLING

Numerical models are used in the wind sector for the simulation of the behaviour of systems, subsystems and components, for their design validation. In onshore wind, numerical modelling characterizes the aerodynamics, in order to simulate the loads and effects on different components. The objective is to verify the structural design of those components or subsystems. In offshore wind, hydrodynamic effects must also be considered, and the models become more complex. A multi-physics approach, with aero-hydro-servo-elastic models, allows to include all the coupled effects to which a wind turbine is subjected. Coupling effects are even more complex when floating wind turbines are modelled, since the turbine is subjected to hydrodynamic effects that affect the aerodynamic loads over it: the mooring system introduces an additional degree of freedom in comparison to fixed offshore wind turbines. TECNALIA follows this multi-physics approach in its projects with the following steps:

- Definition of the **Design Basis**: site conditions, wind turbine, design standards and substructure features
- Definition of the **Design Load Cases:** Driving Design Load Cases and full set of Design Load Cases (DLCs).

- Development of **full coupled aero-hydro-servo-elastic numerical models**, for the DLCs simulation –design validation-
- **Reduced scale wave tank campaigns** for the **numerical model calibration and validation**: selection of the load cases, scaled model design, experiments follow-up and results post-processing.

Different Software (SW) packages are used to develop coupled codes for offshore wind including commercial SW like ANSYS Structural -structural calculation- ANSYS AQWA, WAMIT and OrcaFlex -hydrodynamic calculation- and free SW like FAST for the aerodynamic calculations -developed by the NREL, National Renewable Energy Laboratory of the USA.

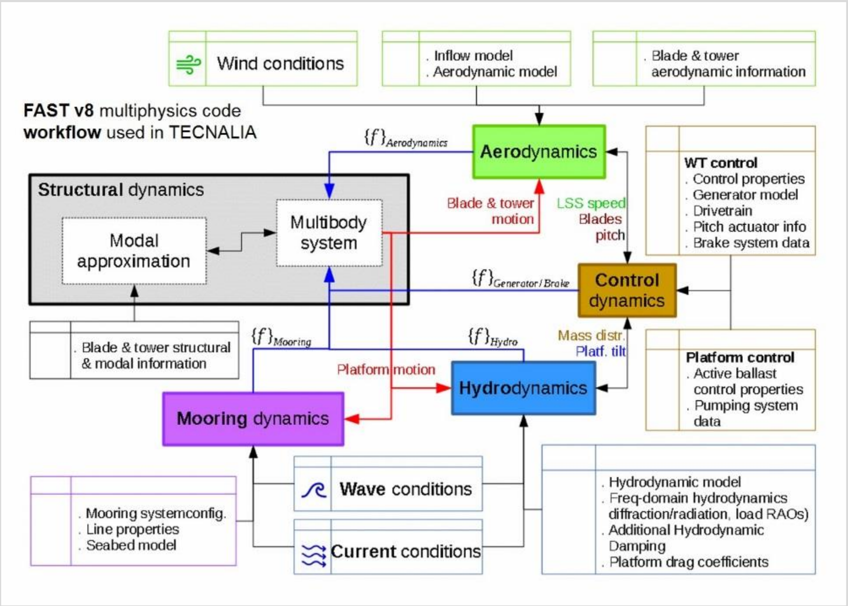

Fig. 1. FAST v8 multi-physics code workflow used in TECNALIA

This approach has been used in the H2020 LIFES50+ [5] project which includes the design of four floating concepts for a 10 MW reference wind turbine. TECNALIA carried out the design of one of the concepts: NAUTILUS steel semisubmersible structure [6]. In the first stage, the Design Basis and Design Load Cases were defined for three different sites, representative of different metoceanic conditions and potential markets. Full coupled aero-hydro-servo-elastic numerical models were developed for the validation of the conceptual design [7].

The four floating wind turbine technologies developed, were evaluated based on four criteria: costs (LCOE – Levelized Cost of Energy), environmental aspects (LCA -Life Cycle Analysis), risk analysis, and floating wind turbine performance (KPI – Key Performance Indicators). With further detail, the LCOE can be obtained using (1):

$$LCOE = \frac{CAPEX + \sum_{t=1}^{n} \frac{OPEX}{(1+k)^t}}{\sum_{t=1}^{n} \frac{AEP}{(1+k)^t}} \qquad (1)$$

In which CAPEX represents the capital expenditure, OPEX the Operational expenditure, discounted to present day value, with *k* being the discount rate, divided by the discounted energy produced (AEP, Annual Energy Production) throughout the technology's operational life, and *n* being the number of years of the project [8].

The information provided by the concept developers was analysed using hydrodynamic tools like ANSYS AQWA, OrcaFlex, SIMO RIFLEX and WAMIT, coupled with aerodynamic tools like FAST, HWAC2 and BLADED, in order to assess the dynamic behaviour of the technologies for different conditions. The work included a benchmark on bottom fixed vs floating offshore wind industrial design methodologies, taking into consideration all the industrialization stages for a wind farm development: engineering, procurement, manufacturing, transport, installation, commissioning, operation and maintenance, and decommissioning. Methodology can be found in [9].

After the evaluation, two of the concepts were selected for further development during the second stage of the project, being NAUTILUS one of them. TECNALIA worked in the development of advanced numerical modelling for a more detailed design of the floating wind turbine. Those models were calibrated and validated with the results of reduced-scale wave tank and wind tunnel campaigns. Both experimental studies took advantage of the numerical models to design a new testing procedure, called Hardware In the Loop (HIL) which allows combining the real test of the prototype under physical phenomena (in this case wave or wind) and real equipment, with, mathematical models and simulations of a phenomena (wind or wave) and components that are not physically reproducible at the laboratory environment. Therefore, in the wave tank, the waves are physically generated, and the wind thrust is simulated with a numerical model developed with FAST, which reacts to the wave's excitation. The wind thrust on the floating wind turbine is applied using 6 actuators -physical lines connected to the tower top- in two parallel horizontal planes to simulate all loads generated by the numerical model. The methodology and the implementation was carried out by SINTEF Ocean. In the wind tunnel, physical wind is complemented with numerical model hydrodynamics developed using the wave tank testing results, to control a hexapod which provides the floating wind turbine motions [10]. In this case, the experimental testing and the hexapod to simulate the hydrodynamics was developed by Politecnico di Milano university. These new testing procedures give an important role to the development of accurate and feasible numerical models [11].

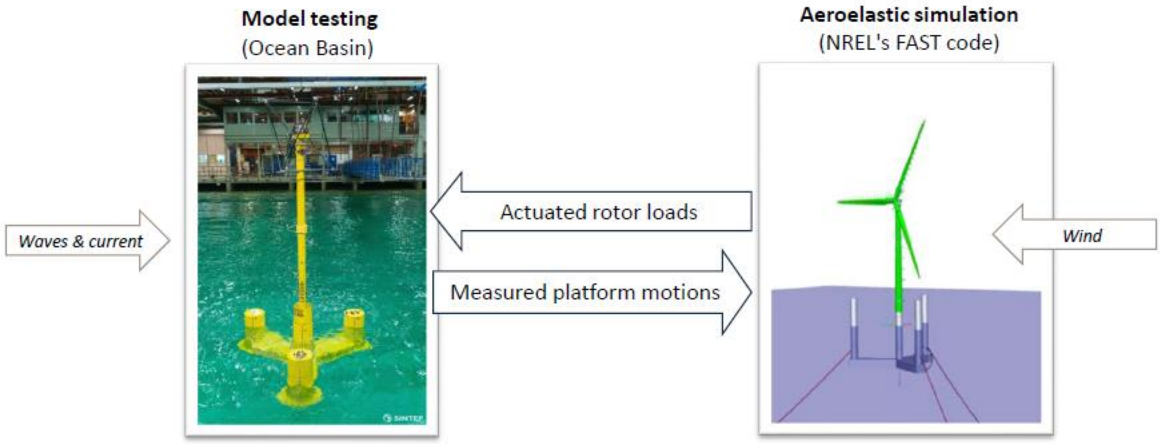

Fig. 2 .Hardware in the loop configuration used for the wave tank testing in LIFES50+ project [11]

As part of LIFES50+ public results, several deliverables related to numerical models can be downloaded from the results section of the project web site [5]. Deliverables D4.2 to D4.8 are public reports dealing with different topics of floating offshore wind numerical modelling. It can be highlighted *D4.2 Public definition of the two LIFES50+ 10MW floater concepts*, which provides the description of the public numerical models available for the two concepts used in the experimental campaign: NAUTILUS steel semisubmersible and Olav Olsen's concrete semisubmersible. Numerical models were developed using FAST free software. Both models and the reports can be downloaded at [12].

3. DECISION-MAKING TOOLS DURING THE PLANNING PHASE

One of the most critical factors that determines the viability of an offshore renewable project is making the appropriate technical decisions during the design stage of the farm. In offshore wind, experience has proved that decisions taken at early design stages can lead to important savings on the total investment of the park. To achieve these savings, promoters need to have the right decision tools to assess the impact of the different technical alternatives through global indicators, such as energy yield, lifetime costs, reliability, maintainability or environmental/social acceptance.

Over the years TECNALIA has developed a wide range of tools to support the analysis of costs, technical risks and financial risks associated with different design alternatives for deployment of offshore renewable farms:

- Results are presented in a language **easy to understand** by the main stakeholders involved in the final investment decision (either public or private promoters).
- An **intuitive design** provides control to the user.
- **Modular** architecture facilitates the **integration** with other bespoke and proprietary engineering tools.
- Use of databases of the **balance of plant components and logistics** (ships, ports, equipment, ...).
- **Sensitivity analysis** and design optimisation.

The FP7-funded DTOcean project [13] produced a first generation of freely available, open-source design tools for wave and tidal energy arrays.

These tools have been used on leading tidal and wave energy projects, including the recently installed four-turbine 6MW MeyGen tidal array in the UK, and a wave energy application by Sandia National Laboratories in the USA (see for example [14]). The software tools enable the user to carry out an optimal design of the subsystems (i.e. array layouts, electrical infrastructure, moorings and foundations, installation procedures and operations and maintenance plans) required to put an array of ocean energy converters into operation (deployment tools), accounting for the economic viability of the project, but also assessing its environmental impact and its reliability (assessment tools).

The main economic Key Performance Indicator (KPI) assessed in the DTOcean toolset is the Levelised Cost of Energy LCOE, as defined in (1). Such metric offers a holistic view of the performance of the systems and can be optimised for taking a decision about the final array layout. Nevertheless, the modularity of the software and the capability of carrying out sensitivity analyses, enables the user to achieve a better understanding of the relevance of one subsystem in the balance of plant. For example, in terms of the hydrodynamic modelling of array interactions for ocean energy converters (OEC), this has been solved through an exact algebraic method (for wave) and parametric modelling (for tidal), while the optimal farm layout in terms of captured energy is obtained using different evolutionary optimisation algorithms (see [15]). As a general conclusion of such sensitivity study, based on the hydrodynamics of the devices, it turns out that devices placed at distances greater than 8-10 times the device diameter (in case of circular point absorbers) have not shown significant hydrodynamic interactions.

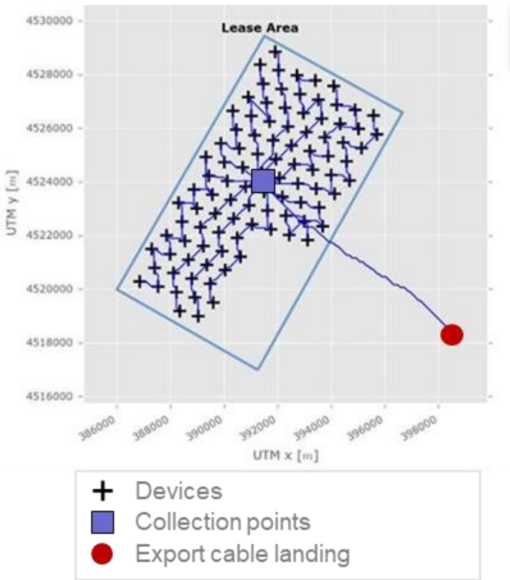

Fig. 3: Optimised farm Layout obtained with DTOcean v2.0 tools (reproduced from Data Only Greater – https://www.dataonlygreater.com with permission from M. B. R. Topper)

As afore said, within the framework of the DTOcean toolset, a set of tools for the evaluation of the environmental impact and the reliability of the system were provided.

A more integrated and global approach was, however, developed during the OPERA project [16]. The model developed in this project is a *Global Economic Model*, providing an economic assessment based on LCOE, performs a Life-Cycle Assessment (LCA) and calculates the Socio-economic Cost of Energy (SCOE) [17].

Whilst for the LCOE the definition in Eq. (1) still applies, the LCA and the SCOE are metrics related respectively to the potential environmental impacts of project activities in terms of Global Warming Potential (GWP) and other socio-economic impacts of the energy sector. The *Global Economic Model* has been developed to build on the strengths of the pre-existing models. The *Global Economic Model* integrates the three models above described and a bespoke Operation and Maintenance (O&M) model, based on preventive and corrective maintenance.

The H2020 DTOceanPlus project [18] is extending the functionality of the DTOcean integrated suite of design tools for ocean energy technologies, including sub-systems, energy capture devices and arrays. The software tools will improve system design and evaluation process taking into account the energy yield, lifetime cost, reliability and socioeconomic impacts.

4.- STRUCTURED INNOVATION AND STAGE GATE TOOLS

Offshore renewable technologies, in particular wave and tidal, require innovations aiming at increasing efficiency, reliability and survivability and leading to achieve cost-competitive solutions. These innovations need to be evaluated at early stages of development since the process to validate them at real offshore conditions is very expensive.

The second generation of design DTOceanPlus [18] tools will support the entire technology innovation process from concept through to development and deployment. Technology concept selection is enabled by the Structured Innovation design tool, technology development is supported by the Stage-gate design tool, while technology deployment is guided by the Deployment design tools. These tools will be combined with Assessment Design tools to measure improvement to reliability, performance and survivability of ocean energy systems and analysing the impact of design on energy yield, O&M costs, and the environment. Whilst the Structured Innovation design tool and the Stage-gate design tool represent a novelty, the scope of the Deployment design tools and Assessment design tools will be extended with respect to the DTOcean platform toolset in order to provide tools, such as the Site Characterization tool, or the Energy transformation tool, that are able to cover areas in which DTOcean was particularly weak.

- **Structured Innovation design tool for technology concept selection.** In order to achieve true commercialization, ocean energy sector must first reach a much greater level of design consensus. A great number of technology concepts are competing to enter and move through the development process, particularly in the wave energy sector. Given the limited resources available to the sector, this lack of design consensus presents a significant challenge to technology developers (who need to select a single or small number of concepts to develop further) and funders (who need to select a single or small number of concepts to support). By way of comparison, the more mature and significantly commercialized wind energy sector has largely come to focus on the horizontal axis turbine concept, allowing the focusing of development resources on increasing efficiency of the overall innovation process. Structured Innovation has a strong track record in mature, commercialized sectors such as aerospace and automotive. The Structured innovation methodology represents therefore a technique to stimulate rigour, organized and consistent innovative thinking, technology selection and impact assessment. This technique combines functions such as understanding the mission, the future vision, the market (including the potential for commercial exploitation, competition, differentiation, social value etc.) and the development of potential solutions. This is broadly described in British Standard BS7000-1, "Design Management Systems, Part 1 – Guide to Managing Innovation" amongst others [19]. The methodology is being developed in DTOceanPlus in accordance with the concept shown in *Fig.*4:

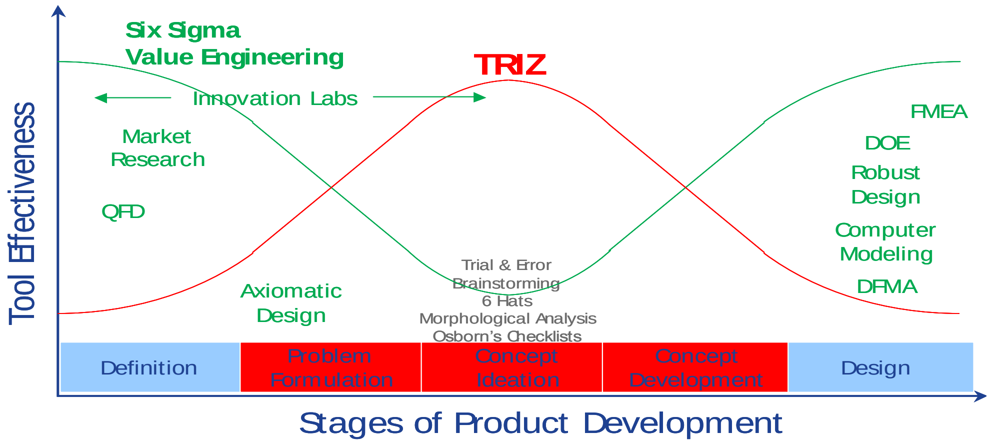

Fig.4: Tool Effect vs. Product Development Stage [20]

- **Stage-gate design tool for technology development.** Within the technology development process, it is necessary to adopt a structured method of assessing and measuring the concept development process. This ensures that the technology development process provides an evidence based structured method of re-assessing the continued suitability of a concept to be supported. A stage-gate development process defines suitable design assessment metrics that should be monitored throughout technology development, and thresholds for these metrics that must be met to demonstrate successful progress. DTOceanPlus is developing and advancing Stage-gate processes with current international efforts (led by WES, OCEANERA-NET and the US Department of Energy) to define suitable metrics for ocean energy technologies.

  The Stage Gate Framework being developed in DTOceanPlus, is a structure which defines the set-up of the stage gate assessment including what Evaluation Areas to assess, in what level of detail and against which benchmarks for success. The Stage Gate frameworks hinges upon the Deployment and Assessment design tools for the evaluation of metrics, intended as the measures of success which define the performance of a technology. Deployment tools provide detailed design information of all the components of an array, including a variety of alternatives for each of the subsystems (i.e. wave/tidal converter, different PTO, mechanical, electrical options) for a better assessment.

  By guiding the user towards the evaluation of these metrics, the stage-gate design tools will assess the development of ocean energy technologies from concept through to deployment. Technology developers will be able to use these tools to ensure that they are on the path to successful deployment and re-assess design decisions as they progress. Technology funders will be able to use these tools to identify the most suitable technologies, for both initial and continued support.

Central to the integration of these sets of tools will be a set of digital models for ocean energy systems. These models will provide a standard framework for the description of sub-systems, devices and arrays. Not only will these models provide the communication method between the various tools in the DTOceanPlus suite, they will also provide a common language for the entire ocean energy sector. This common language will significantly enhance the ability of sector stakeholders to work collaboratively, thus accelerating development of the sector, whilst also further supporting stakeholders who wish to make objective comparisons between various technologies.

5.- CONCLUSIONS

Offshore renewable energy will play a crucial role in a future decarbonized energy mix, while contributing towards sustainable economic growth and stable job creation, provided that cost competitive technologies are available. Research, development and innovation are without a doubt part of the solution for a continuous cost reduction of offshore renewable technologies. Design tools can be used in different stages of technology development or deployment planning to facilitate decision making and to accelerate market uptake.

This article has presented public results (open source tools and documents) describing a methodology for multi-physics approach when facing a new project, including downloadable documents and models, and a set of different design tools produced by four European funded projects on offshore wind, wave and tidal energy as shown in Table 1.

- Multi-physics numerical modelling allows to include all the coupled effects to which an offshore wind turbine is subjected to, during different design stages: conceptual, basic, detailed.
- Dynamic simulations complemented and calibrated with reduced scale experiments, are used for the design validation at the different stages of the technology development.

Tool	User- TRL	Description	Project References
Structured Innovation design tool	Technology developers Low TRLs (1-3)	Technology concept selection. Techniques to stimulate rigour, organized and consistent innovative thinking, technology concept selection and impact assessment	DTOceanPlus project [18]
Stage Gate design tool	Public funders & technology developers All TRLs (1-9)	Technology development process. Evaluation of the metrics to assess the development of ocean energy technologies from concept through to deployment	DTOceanPlus project [18]
Deployment and assessment design tools	Project developers and investors Medium-High TRLs (5-9)	Design tools to support the analysis of costs, technical risks and financial risks associated with different design alternatives for deployment of offshore renewable farms at the design stage of the farm	LIFE50+ [5] DTOcean project [13] OPERA project [16], [17] DTOceanPlus project [18]

Table 1. Design tools for Offshore Renewable Energy at different stages of development

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