

Preliminary study of a concept of wind-tidal turbine coupling using functional similarities of real time emulation

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Abstract. Horizontal tidal turbine presents important similarities to the wind turbine power systems. Therefore, it would be useful to exploit this similarity to study this important source of energy. In this paper, a new concept of a hybrid offshore wind-tidal power generation systems coupled electromechanically is studied. Furthermore, a 'time virtual' approach is also presented in order to investigate and compare the energy potentials for given tidal and wind sites. Both the new concept of coupling and virtual time method are simulated in Matlab/Simulink and applied on Real Time Emulator. Obtained results are presented and discussed.

Key words

Wind turbine, tidal turbine, hybrid system, real time emulator.

1. Introduction

The competitive cost and its purity of toxic emission are the main motivations to develop and research to exploit tidal currents and wind energy. Hybridization of these resources it became an important issue, for reliable electrical networks. Thus, developed methodologies are highly needed to optimize the functionality of decentralized networks. The concept of the tidal turbine is quite similar to a wind turbine. In GREAH Laboratory, multi-function emulator is developed to study the hybridization of wind-tidal power conversion chain systems [1]. However, the coupling of wind - tidal turbines leads to a complex system which has an unpredictable reflection that may effect on the stability and the performance of the energy system in general.

This work addresses approaches of specific energy management methodologies that firstly established and simulated in Matlab/Simulink environment, for wind and tidal turbines separately, consequently a new concept of

The project is co-financed by European Union with European Regional Development Funds (ERDF) and by the Regional Council of Normandy.

hybrid wind - tidal turbine system is develop and simulated [2] [3].

This work focus also, on the technology of power conversion related to the already existed offshore installations, these developments are related to the integration of wind-tidal turbines into the decentralized electrical generation networks (mini and island-networks) designed for the Green Island electrical supply concept.

2. Similarities Wind-Tidal Turbine

The functional concepts of horizontal tidal turbine are close to those of a wind turbine. So, fast development could be expected for tidal power generation system, depending on the already developed technologies of wind power systems [4] [5].

Both wind and tidal horizontal turbines operate based on the same principle of energy conversion. In other words, convert the kinetic energy of a fluid into mechanical energy then transforms this later into electrical energy. Despite some differences in the properties of both resources (water and air), but the tidal energy conversion system is very similar to the wind energy conversion system i.e. (have the same structure). Due to the intermittency of the natural resources, these resources can be modeled as nonlinear input with different statistical properties [6].

As the power coefficient C_p represents the efficiency of the turbine, to convert fluid energy into mechanical energy. In this work, the estimation of this coefficient is based on the theory of Rankine ó Froude. Considering incompressible fluids, thus simplify modeling resources to be implemented as input in real time emulator and in control system [7]. Based on these approaches [8], we have developed simulation software that makes it possible to obtain mechanical power as function of rotation speed and some

other static characteristics of a hybrid system consisting of a wind turbine of 3kW at average wind speed $v = 13\text{m/s}$, and a tidal turbine of 3.5kW, at average tidal current speed of 4m/s .

It is supposed that static characteristics of the turbine to be simulated are unknown, turbine static characteristics are obtained using the simulation approach that developed at GREAH lab and are tested at the Inha University (South Korea). These results are validated with real ocean turbine installed in Circulating Water Channel of Inha University Ocean Engineering Laboratory [9]

The qualitative analyses takes into account the wind speed vector in respect to the turbine blades in horizontal axe, for a section of blade at a distance r from the axes of rotated propeller. Figure 1 represents lift and drag forces on a specific section of rotating blade.

The used adopted approach is based on specific methods and modelling algorithms of wind turbine, through which the pitch angle can be changed, starting from its constructive characteristics. These algorithms allow generating the main characteristics of the turbine:

- Power coefficient $C_p = C_p(\lambda, \beta)$ (1)

- Torque coefficient $C_T = C_T(\Omega, v, \beta)$ (2)

The torque coefficient C is calculated as a function of wind or tidal currents speed v , as well as the rotation speed of the turbine rotor Ω , and angle of incidence [10] [11]. By integrating the length of the turbine blade lift and drag forces are obtained:

$$D = \frac{1}{2} C_x \rho v^2 A ; L = \frac{1}{2} C_z \rho v^2 A \quad (3)$$

Where;

C_x and C_z are, respectively, the dimensionless coefficients, of drag and lift forces; A : is the surface of the blade (the chord multiplied by the blade length); ρ : Air density; L : lift force and D drag force.

Both suggested turbines have three blades and the pitch angle is considered constant.

Figures 2 and 3 present power characteristics of simulated wind turbine and tidal turbine used in the study.

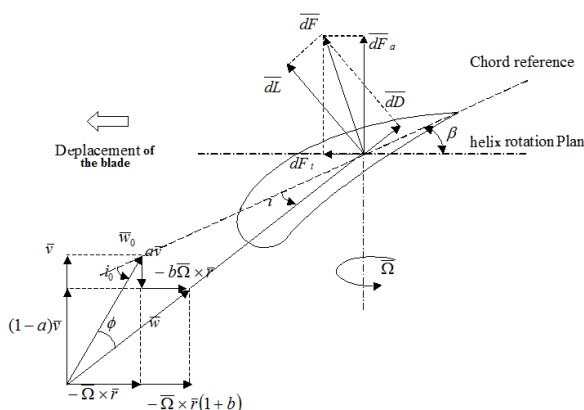


Fig. 1. Representation of speed wind and forces for a section at a distance R from the axis of the propeller

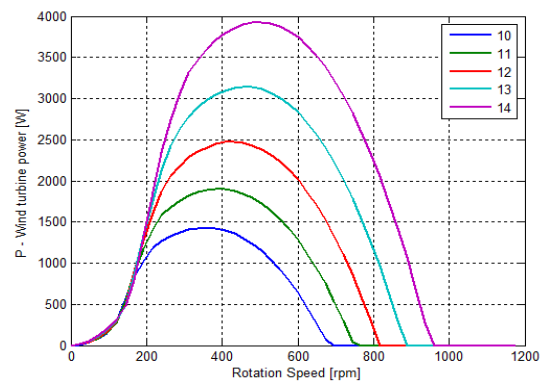


Fig. 2. Characteristics Power - speed of the wind turbine

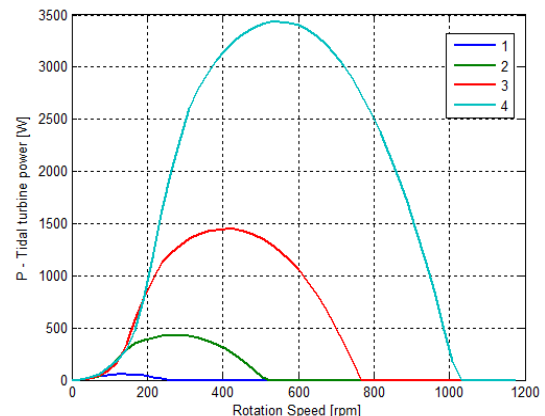


Fig. 3. Characteristic Power of speed of tidal turbine

3. Principles of Real-Time Emulation of Actuators

Emulator components are chosen with very small time constant comparing with the simulated actuators. Speed and torque variation on the actuator's shaft vary slower than the corresponding variables of the servo-motor which follows with the smallest possible errors the references (set point) given by the software subsystem. Therefore, errors in the servo loops must be negligible.

Most servo-motors have small time constant and that is why many actuator types can be simulated and extended. This remark is illustrated in figure 5.

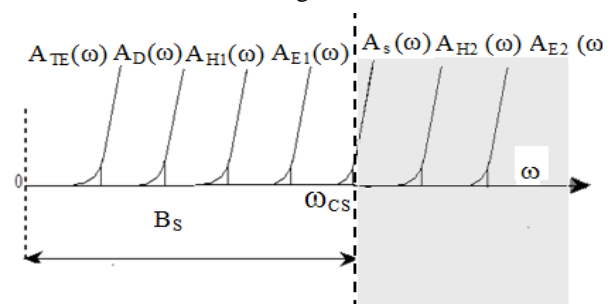


Fig. 4. Bandwidth of the emulator

with the bandwidth B_s corresponding to the several simulated actuators under investigation and emulation control. The emulator bandwidth is defined as the frequency range $(0, \omega_{cs})$, in which the attenuation does not exceed a given limit, for example 3 dB (where ω_{cs} ; the cut-off frequency of the subsystem). Consequently, it can be

consider that the hardware system to be investigated is a wind turbine $A_{TE}()$, a diesel motor $A_D()$, some hydraulic motors $A_{H1}()$; $A_{H2}()$ or some electrical motors $A_{E1}()$; $A_{E2}()$.

Figure 5 illustrates the complete structure of the hardware hybrid wind-tidal emulator system [14]:

Electro-mechanical system consisting of:

- 1) A vector controlled asynchronous motor is used to drive a Doubly-Fed Induction Generator [13]. It is powered by a built-in frequency converter, to allow the adjustment of its speed. This electrical drive emulates

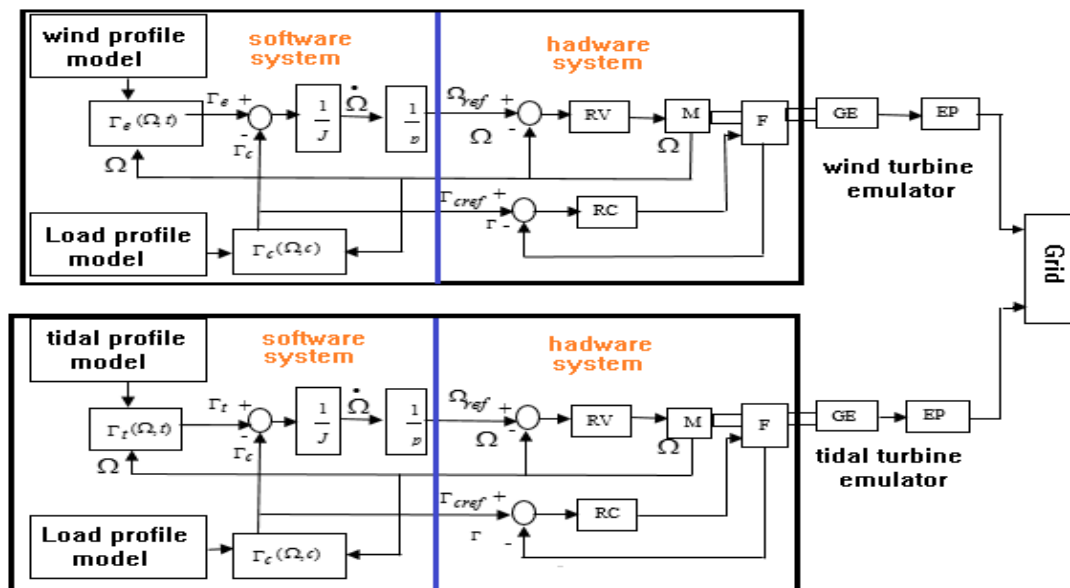


Fig.5. Structure of a hybrid wind-tidal system emulator

With:

$\Gamma_e(\Omega, t)$, $\Gamma_t(\Omega, t)$, wind and tidal turbine torque respectively; $\Gamma_c(\Omega, c)$, torque of the load depending on the variations of the load; RV and RC, are speed and torque regulator blocks respectively; M and F, are electrical motor and mechanical breaks respectively; GE and EP, are the electrical generator and static power converter respectively [12]. The emulator is composed of two subsystems:

- 1) A software simulator, which must be numerically realized, is describing the system to be investigated with the smallest possible errors. It generates signals that serve as references (set-points) to the hardware subsystem.
- 2) The multi-function hardware servo system, which receives signals generated by the software simulator, the electromechanical system consisting of two electric drives coupled mechanically.

In the emulator structure of the wind-turbine hybrid system presented above, we can notice that the emulator of the wind system is similar to that of the emulator of the tidal system, which shows and reinforces our considerations on the similarities between these two systems in their operating principles.

4. Emulator of Wind-Tidal Hybrid System

The experimental platform shown in figure 6 is structured based on two systems, electromechanical system and software system.

the wind turbine by reproducing on its shaft the turbine static characteristics.

- 2) Synchronous motor emulates tidal turbine if it is needed. This electrical drive is used also as a load when single turbine is simulated. Also it is possible to generate different values of torque and as result different operating points can be obtained.
- 3) Doubly-Fed Induction Generator (DFIG) 2-poles is used to generate electrical power ≈ 1.2 kW.
- 4) Compacted power converter AC / DC and DC / AC is connected into the rotor side of the DFIG.

Software system consists of:

- 1) A computer unit on where the wind and tidal turbines models are implmented;
- 2) dSPACE unit: it is a set of hardware and software components used as communication intermediate between software and hardware systems. The hardware components consist of a DS1103 main board for fast prototyping and 2 interface boards with the PC [12] [13].

The software system is consist of programming unit, and code generation tools to simulate mathematical models [14]. The emulator also equipped with an input/output connection system for communication between computer and electromechanical system.

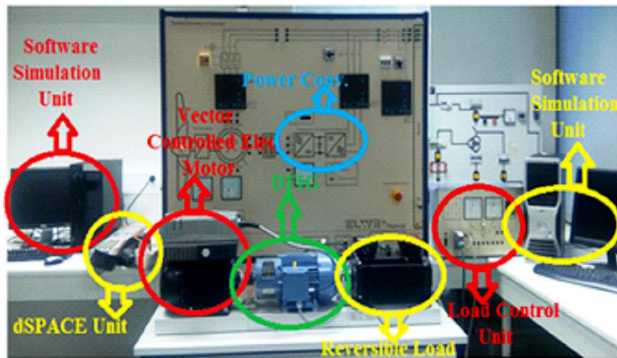


Fig. 6 Emulator of wind/tidal system in GREAH

5. Simulation Methodology

A. Simulation in « virtual time »

Based on the virtual time method, it is possible to extract a multi-wind profile from the original wind profile for example in this work, 300 samples of wind profile is extracted from the original wind profile 18000 samples. Hardware emulator of wind and tidal systems are used in this virtual time approach in order to reduce computational time for energy analysis of the wind and tidal power systems. Also, the operational time is reduced, experiment emulations it could be used for real time advanced control. The effect of simulation time acceleration on the energy potential for a given site is also investigated, using Software In the Loop (SIL) and experimentally using Hardware In the Loop (HIL) for the same given data. Figures 7 and 8 illustrate a comparison between simulation/emulator results with 18000 samples for wind profile.

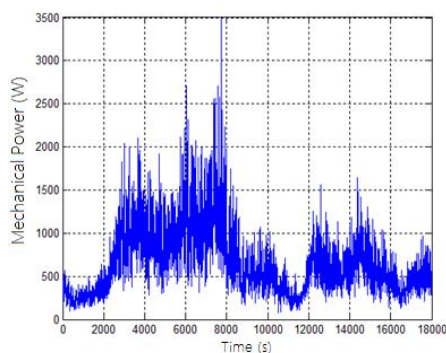


Fig.7. Generated Mechanical Power Software Simulation

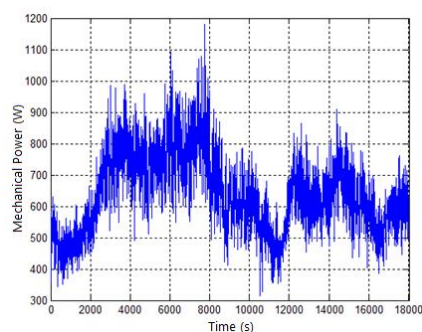


Fig.8. Generated Mechanical Power Experimentally

The average mechanical power generated by the software simulation is 654 W, while it is 641 W generated by the emulator.

This difference is generated because we use a sample every second in the software simulation, while in the emulator samples are taken every 1.2 second.

Although there is about 2% difference between hardware emulator and software simulation but it is still acceptable results.

Figures 9 and 10 show the results obtained with time acceleration method.

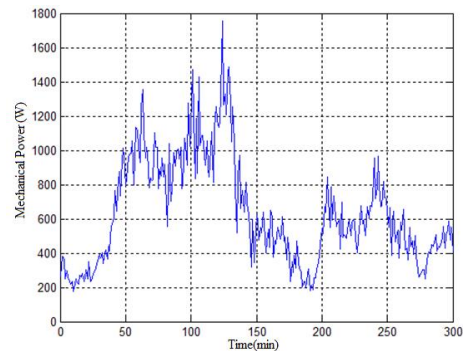


Fig. 9. Mechanical Power Generated by Software Simulation

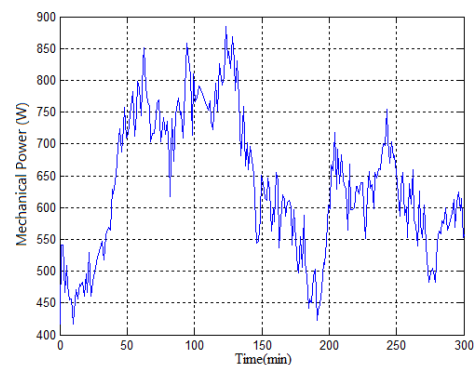


Fig. 10. Wind turbine power generated experimentally

A wind profile of 300 samples extracted from the original wind profile, figure 9 shows the average mechanical power generated by software simulation is about $P_{\text{average}} = 638\text{W}$. Figure 10 presents the average mechanical power generated by emulator is about 619W, i.e. 1sample/minute. So, the difference is about 3%.

On the other hand, experimentally when the profile of 300 samples which generates about 641W, compared to the profile of 18000 samples which generates about 619W, the average difference is found 3.4%, it is still reasonable result when comparing with time difference between the period of simulation and the number of samples.

Two major remarks emerge from these experiments:

- 1) Accelerated time simulation, either software or experimental, give a good approximation for variable sampling periods, in addition the system modeling is well defined;

- 2) In experimental simulation, compromise is essential between the choice of sampling time and results precision.

B. Simulation of electromechanical coupling wind-tidal turbines

A new concept of a hybrid wind-tidal turbines emulator, is addressed an electro-mechanical coupling of wind turbine with hydraulic turbine on the same axis of rotation of a Doubly-Fed Induction Generator (DFIG) [13] [16].

In electromechanical coupling, it is possible to have several modes of operation:

- 1) Simultaneous mode operation, which makes it possible to operate two turbines at the same time (wind and tidal).
- 2) Single mode operation, only one turbine connected to the generator, while the other turbine is disconnected, according to certain conditions.

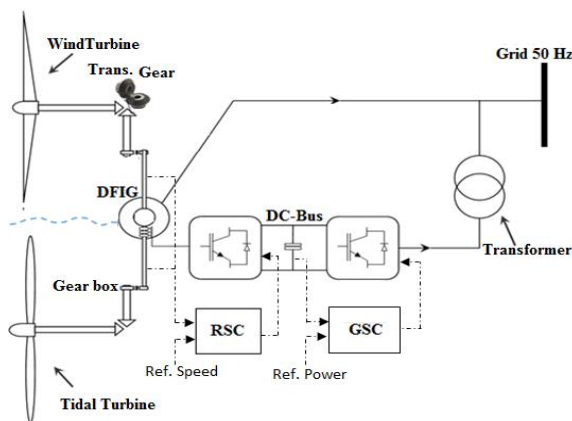


Fig. 11. Electromechanical coupling of wind/tidal turbines.

The tidal turbine can mitigate downward wind production and vice versa; the energy flow is well reinforced [17].

The wind turbine is emulated by the vector control servomotor using the HILS concept (Hardware In the Loop Simulation), and the tidal turbine is emulated by the permanent magnet synchronous machine which emulated the mechanical load in the system.

Emulation is presented further more in the following paragraph.

Based on the functional similarities between wind and tidal turbines, a small scale wind and tidal turbines are coupled on the same shaft implemented experimentally in GREAH laboratory, where a wind turbine is represented by a vector controlled asynchronous motor, while the tidal turbine is represented by synchronous permanent magnets machine, this later played the role of brake (mechanical load) in the emulator.

However, simultaneous coupling of wind and tidal turbines are simulated. For instant, supposed that the tidal speed is low and as result the turbine will be as mechanical load and

will drive the electric machine under synchronous speed, then it would be inefficient for to be coupled at the same time with the wind turbine on the generator's shaft. This can be the same case, by inverting whole the situation.

Figures 12 and 13 present experimental results of wind and tidal turbines coupled to the shaft of the electric generator separately [11].

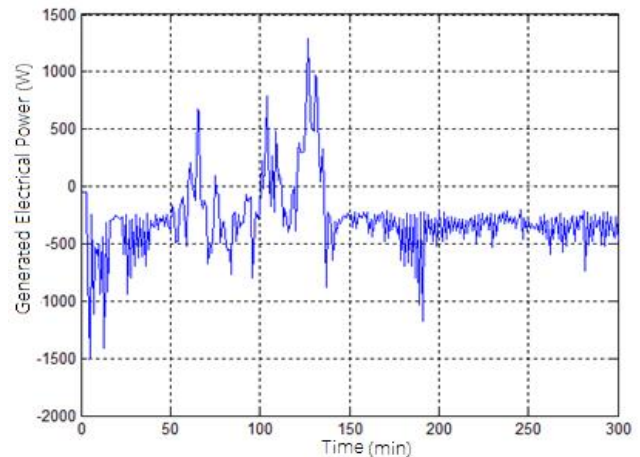


Fig. 12. Electrical Power Generated Experimentally by Wind Turbine Only

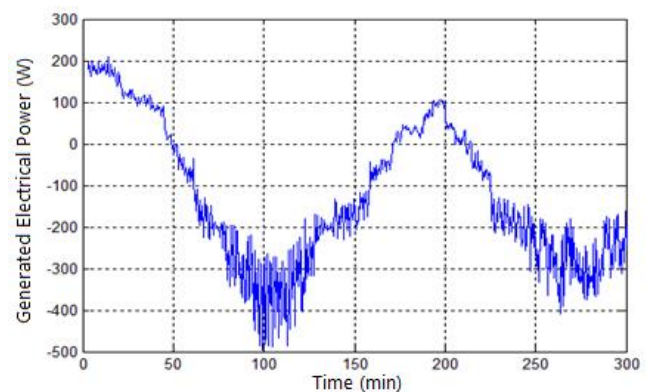


Fig. 13. electrical power generated experimentally by tidal turbine only

Figure 14 illustrates the electrical power generated experimentally by electro-mechanical coupling wind tidal turbine system.

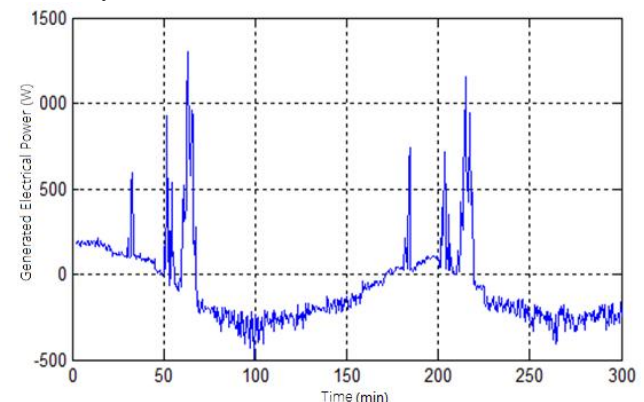


Fig. 14. Electrical power generated by hybrid system

Figure 14 shows intervals where the reference speed of rotation is lower than the speed of synchronism of i.e. 1500 revolutions / min the machine operates in motor mode; and

in the intervals where the reference rotational speed is greater than the synchronism speed, the electric machine operates in generator mod.

We can also note that there are several intervals where the energy supply provided by each of the turbines, is insufficient for the operation in the generating regime of the electric machine; in this case it is necessary whether to disconnect the electric machine from the network to avoid risks operation or to add a storage and boost energy units to overcome voltage drop problems.

In this stage of the concept development, of electromechanical coupling between wind and tidal, the unit controlled electric drives are used to emulate wind and tidal turbines. These structures control were chosen during the design and the choice of the equipment and components of the emulator. In both mode of operation (hybrid system or separated systems), vector control ensures a preliminary validation and reliability of the electromechanical coupling of two renewable energy sources of different dynamics. Future development will focus on a complex control structure that must allow the fault-ride capability operations of the system and its connection to smart grids [11] [12].

6. Conclusions

The aim of this work is to present, on one hand, a methodology called "accelerated simulation time" and its experimental validation, and on the other hand, to present the flexibility of a multi-function emulator, that allows various emulation architectures: wind turbines, tidal turbines, hybrid wind - tidal turbines systems.

It is shown by software simulation and experimental simulation that, the number of samples or time of sampling can be reduced. And as result, the simulation time is reduced with good estimation result obtained.

We obtained practically the same average values of power and rotation speed, with differences not exceeding 5%. This allowed us to save time in simulation and calculation. This methodology could be implemented for advanced control using previsional data of wind and tidal sources.

In the second part of this work, we presented various variants of experimental turbine emulation, based on the HILS concept (Hardware In the Loop Simulation) used in the GREAH laboratory. Furthermore, hybrid wind-tidal turbines emulator system is experimentally performed, where two turbines are coupled on the same shaft along with Doubly-Fed Induction Generator (DFIG).

The main objective is to study this concept of electromechanical and its impact on the output power of the system; the obtained results are correlated with wind and tidal speed profiles, in which statistical properties impacting global power chain could be complementary and in particular in function of the given sites.

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