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Concept study of offshore wind and tidal hybrid conversion based on real time simulation

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Abstract.

This paper deals with a conversion system concept based on the real time simulation of a hybrid offshore wind and tidal current system. In order to provide reliable, environmental, and cost-effective electrical energy we present a simulation research device composed by two real time emulators:, one for each type of energy: a wind turbine emulator and a tidal turbine emulator. The wind turbine emulator based on a permanent magnet synchronous machine, is used to simulate the characteristics of a working turbine and an electrical generator. The tidal turbine emulator has in its composition 3 electrical drives: an asynchronous drive with vector control used to simulate the behaviour of a tidal turbine, a double feed asynchronous generator and an active break. Both of them are using the "hardware-in the-loop" techniques.

Key words

Offshore wind turbine, tidal turbine, real time simulation, hardware-in the-loop simulation, hybrid connection

1. Introduction

The seas and the oceans cover two thirds of the Earth's surface and contain different amount of energy, and its possible resources are far beyond the energy needed by the humanity. The energy resources came from two types of phenomenon: solar energy and gravity variations due to changes in positions of Earth, Moon and Sun [1].
The planetary ocean contains numerous forms of renewable energies, who, in absolute, deliver enough energy to meet the needs of the entire planet. The recovery of a very small part of this energy is now possible thanks to the recent growth of complementary techniques to exploit the various forms of marine energy, including: wave energy, offshore wind energy, tidal energy and thermal energy [2].
Many researches are conducted in the studies of this renewable energies cause of the threat of climate change, diminishing fossil fuels resources and the existent risks over the global energetic security are all engines that dives the states, communities and industry to diversify their sources of supply.
In this study we intend to show how to maximize the electrical energy conversion from the resources that the nature (sea) gives in a certain point. In this case it is taken into consideration the possibilities to obtain electrical energy using a hybrid connection between the offshore wind turbine and the tidal marine turbine [3].
The harmonic development of this new way of exploiting the sea must be done in close consultation with other users of the maritime space. The necessary knowledge of all environmental impacts and societal impacts can be gained by experiments in pilot plants [4].
The wind energy is not really a marine energy, but the exploitation in the sea conditions presents particular characteristics:

- the wind is much powerful and much constant in the sea then on the land, giving a better energy production;
- the sea offers large open spaces and there for bigger machines can be installed.

It is desirable that the total power of the plant shall be as big as possible:

- During construction, the relative costs of development and mobilization of resources for the means of intervention are more rentable.
- A cable for connection to the grid is more reliable and much cheaper if it is used to transport the maximum energy that it can carry. [5]

Tidal energy is generated by the relative motion of the water which interacts via gravitational forces. Periodic changes of water levels, and associated tidal currents, are due to the gravitational attraction by the Sun and Moon[6]. The magnitude of the tide at a location is the result of the changing positions of the Moon and Sun relative to the Earth, the effects of Earth rotation, and the local shape of the sea floor and coastlines.

A tidal generator uses this phenomenon to generate electricity. The stronger the tide, either in water level height or tidal current velocities, the greater the potential for tidal electricity generation [7,8].

Wind and tidal simulation plays an important task in hybrid connection research, particularly for interaction analysis between tidal and offshore wind power system. The hybrid models describe the fluctuations in the tidal and offshore wind speed, which causes the fluctuation in the power production of the hybrid turbine.

The hybrid connection between the two simulators is designed to simulate the realistic situation of the power fluctuation during continuous operation of tidal and offshore wind turbine.

2. Introduction into the Hybrid System: offshore wind turbine-tidal wind turbine

There are wind offshore power plant working in different corners of the world, but the tidal energy conversion is a field that is still in development, exist advanced projects [9], but certified technology does not exist at this moment.

The idea of combining these types of energies is also a new one, and it needs advanced researches involving the electrical energy production that can be made using the two resources in the same time [10].

This type of hybrid power plant can be used to produce energy in many situations, for example like in the case of small islands, where the high cost of extending the electricity grid requires institutions to consider other alternatives. Among them are the uses of groups generators diesel often regarded as an economical and reliably, but in this moment giving his impact to the environment there is the need to be thinking at other resources.

The wind turbines and the tidal turbines supply electricity without interruption, without noise or environmental pollution (excepting the presence of electromechanical batteries difficult to recycle). They are also building to require little maintenance and show reliability. Their problems lie in the high investment costs required for their installation and limited electrical charge to satisfy.

The hybrid systems, like the one presented in this paper, have many advantages because all their pluses are combined to form a better systems and to compensate for the non-continuous electricity production. Yet, there are also some issues like:

- chose the correct size of each component of the energy system;
- optimize energy management within the system;
- find the optimal configuration in order to obtain the minimum cost of production.

From the general point of view, one can find that is important to have the same foundation for the two turbines, in order to have a more economic system. This does not concern the present paper, but this is still a field where many researches can be conducted, because it needs to have multiple characteristics: esthetical (no one wants to damage the landscape), environmental friendly, but also has to be resistant enough to be able to take the waters galling and the wear that comes from the two turbines.

In fig. 1 is shown the general the structure of the hybrid connection. It is composed, in a simplify view, from two turbines the offshore wind turbine, the tidal turbine and the power electronics device (PE) used to obtain a good quality of the energy and to solve the grid connection problems, and storage problems. Also, an effective maintenance system has to be studied, because do to the harsh environmental condition many problems have to be taken into consideration.

The main goal, at the end, is to obtain a system who offers the combined powers of the two turbines:

$$P_{hybrid} = P_t + P_w , \tag{1}$$

where P_{hybrid} is the power of the entire system, P_t is the power of the tidal turbine and P_w is the power of the wind turbine.

In the hybrid connection the two energy sources has to compensate one another in order to produce energy in continuous regime. It is a well-known fact that the biggest problem with the renewable energies is that they do not produce energy continuously.

In this study the diesel generator, used mainly in all hybrid connections as a backup for energy production. It is the tidal turbine the one who will fulfil this place and be considered as a continuous source, because the resource is most of the time constant and predictable. There are rare cases when the marine current surpasses the nominal speed or underpass it. As for the wind turbine, working in offshore gives it an almost continuous working regime, due to the much important wind presence, comparing with land condition. But, if there are problems with any off the resources they can be helped with the power stoked into batteries.

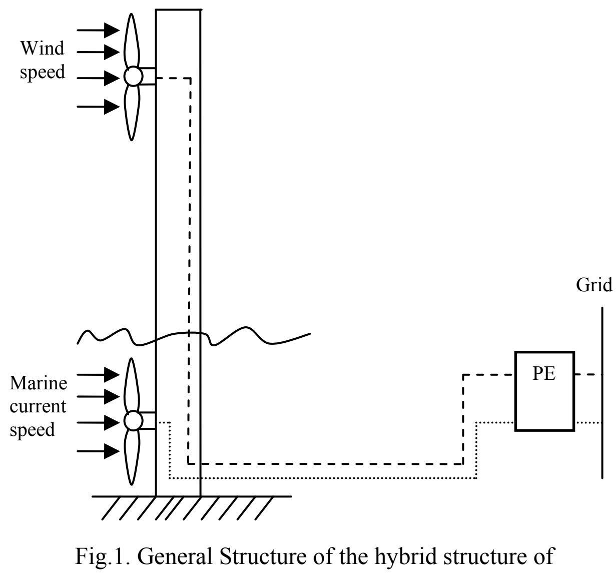

Fig.1. General Structure of the hybrid structure of energy conversion

Connecting this to types of energies offers many problems to be studied, mostly because of the fluctuation of the energy.

We develop two emulators that could reproduce the behaviour of these turbines:

- the wind turbine emulator is functional for a long time and is build using the "hardware-in the-loop" technique[16].
- the tidal turbine emulator, who uses the same technique as the wind turbine simulator, and at this time is still in development.

The experience gained from studying hybrid system, concerning the field of wind turbine-diesel generator-photovoltaic hybrid system, is used for a better understanding of the phenomena developed by the hybrid connections [10].

The simulators develop a power of 2 kW, are the beginning of the research and thru extrapolation one can obtain the characteristics for a power plant, with a lot bigger powers.

3. Principal of "hardware-in the-loop" simulation

In order to simulate the static characteristics and some dynamics of a real offshore wind turbine, or tidal turbine, real time emulators are used [11].

There are different categories of real time simulators, depending on their conception approach. Here, it is conceived following the "hardware in the loop simulation" principals, meaning that a natural phenomenon can be studied in laboratory condition by dividing the process in to sub-systems interconnected in a loop, a software subs-system and mechanical subsystem.

In figure 2 is shown the general schema simulator, conceived with the "hardware-in the-loop simulation" (HILS) approach and the structure is:

- ***the Informatics subsystem*** provides, with a small possible error, numerical models of the marine current system; it supplies references signals for the second system and it is composed by:
  - a computation device in which there is implemented the programs to control and observe the electromechanical sub-system;
  - the interface unit that ensures the communication between the computation device and the electro-mechanics components.
- ***The Electromechanical subsystem*** that receives the references from the informatics system and reproduces at its shaft the characteristics of the marine current turbine, then it send's back the information to the control system.

The informatics subsystem (IS) is a supervising and control unit, which executes several functions in real time:

- it simulates

  a) the wind turbine characteristics,

  b) the wind,

- it computes the references for the electromechanical subsystem,
- it executes digital algorithms for the control structures,
- it ensures real time supervision of the simulation process.

It is considered that the turbine is simulated by knowing its static $\Gamma = f(\Omega)$ given by the manufacturer or experimentally measured.

The outline of this emulator is shown in figure 2.

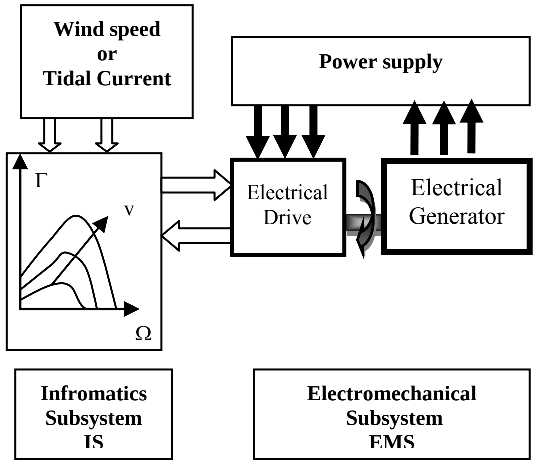

Fig.2. Hardware in the loop Simulator Synopsis

The electromechanical subsystem (EMS) is a multivariable servo system, formed by a mechanically-coupled electric-drive with an electric generator. It is able to realise very good dynamics for fast variations of variables and of electrical charge. The servo-motor operates on its rotor shaft as a real turbine: it develops the same torque (Γ) at the same angular speed (Ω) as if the turbine is placed under real environment characterized determined by a specified speed.

The emulator realizes static characteristic given in the form:

$$\Gamma_m(\Omega, u_2, ..., u_2) = \Gamma_l(\Omega, u_{p+1}, ..., u_m) \qquad (2)$$

where Γ_m and Γ_l are the active and resistant torque respectively, $u_1, ..., u_p$ are the input variables that influence the active torque in steady-state operating conditions and $u_{p+1}, ..., u_m$ are the input variables that influence the static characteristics of the resistant torque.

The wind turbine dynamic model is assumed to be:

$$\begin{cases} \underline{\dot{x}} = \underline{F}(\underline{x}, \underline{u}) \\ \underline{y} = G(\underline{x}, \underline{u}) \end{cases} \qquad (3)$$

where the state vector $\underline{x}$ and the input vector $\underline{u}$ are:

$$\underline{x} = (\Omega, x_2, ..., x_n) \qquad (4)$$

$$\underline{u} = \begin{bmatrix} \underline{u}_1 \\ \underline{u}_2 \end{bmatrix}, \qquad (5)$$

with $\underline{u}_1 = (\underline{u}_1, \underline{u}_2, ..., \underline{u}_p)^T$; $\underline{u}_1 = (\underline{u}_{p+1} \cdots, \underline{u}_m)^T$ (6)

In steady state condition, the algebraic equation:

$$\underline{F}(\underline{x}, \underline{u}) = 0 \qquad (7)$$

also includes state condition (3) of the static characteristics.

4. Offshore Wind Turbine Real Time Emulator

The development of high-efficiency wind energy conversion systems involves the use of real time simulators. The simulators equipment contains an electromechanical part that provides, on its shaft, the static and dynamic characteristics of a given turbine.
The offshore wind turbine real time emulator (OWTRTE is developed by using HILS, therefore it has an informatics subsystem and an electromechanical subsystem. The IS has fulfil the duties described in the previous chapter, and is composed from a computer, where specific control and supervision programs are running [12].
The electromechanical subsystem is composed from two electrical drives: a synchronous drive used to simulate the wind turbine and a generator drive. The synchronous drive used is a brushless machine. This choice was dictated by the advantages of this type of engine:

- High power density;
- Excellent performance >90%;
- Low noise;
- High thermal dissipation;
- Low inertia- short acceleration time;
- Important speed range variability;
- Torque in stand still working.

The model installed consists of a ferrite magnet synchronous drive, with a resolver on the rear of the motor that provides position and velocity measurements.
The generator used is synchronous machine do to the concerns to increase the systems reliability by eliminating the speed gear, used to multiply the speed on the shaft. Its advantages are seen if operating in isolated sites connected with other alternative sources, because is produces electrical with good quality.

5. Tidal Turbine Real Time Emulator

The real time tidal turbine emulator (RTTTE) is conceived to generate the “tidal power characteristics” on its shaft. The characteristics used to control the induction machine are obtained with the help of the Ocean Engineering Laboratory, from the Inha University [13].
The purpose of the emulator is to study and optimize the energy produced from the tides kinetic energy.
The IS has the same charges as the one from the wind turbine simulator, and with specific software programs it controls the EMS.

The EMS of the tidal turbine emulator has three parts (fig.3.): [14]

- *the turbine emulation is realized with* an asynchronous machine vector controlled (rated power: 2200W);
- *the electrical generator is a* double-feed asynchronous generator, as the one used in the real system (rated power: 1000 W);
- *the active break* is based on asynchronous machine vector controlled, used to create an extra charge and a variable inertia momentum (rated power: 2600 W).

The simplest dynamic model of the turbine is taken into consideration first, and it is given by of the motion equation:

$$J\frac{d\Omega}{dt} = T_{mc}\left(\Omega, v\right) - T_g\left(\Omega\right) - \Gamma_l \qquad (8)$$

where: Ω - the shaft rotation speed, v- marine current speed, J- the total moment of inertia, $T_{mc}\left(\Omega, v\right)$- the marine current turbine (MCT) torque characteristic, $T_g\left(\Omega\right)$- the static characteristics of the electrical generator. The MCT torque is calculated using the relation:

$$T_{mc} = \frac{1}{2}\rho\pi C_T\left(\lambda\right)v^2R^3 \qquad (9)$$

where: R- the blade radius, λ is the speed ratio[13].

$$\lambda = \frac{R\Omega}{v} \qquad (10)$$

and $C_T\left(\lambda\right)$ is the torque coefficient characteristic, which is obtained by simulating the turbine on the informatics environment using the blade characteristics.

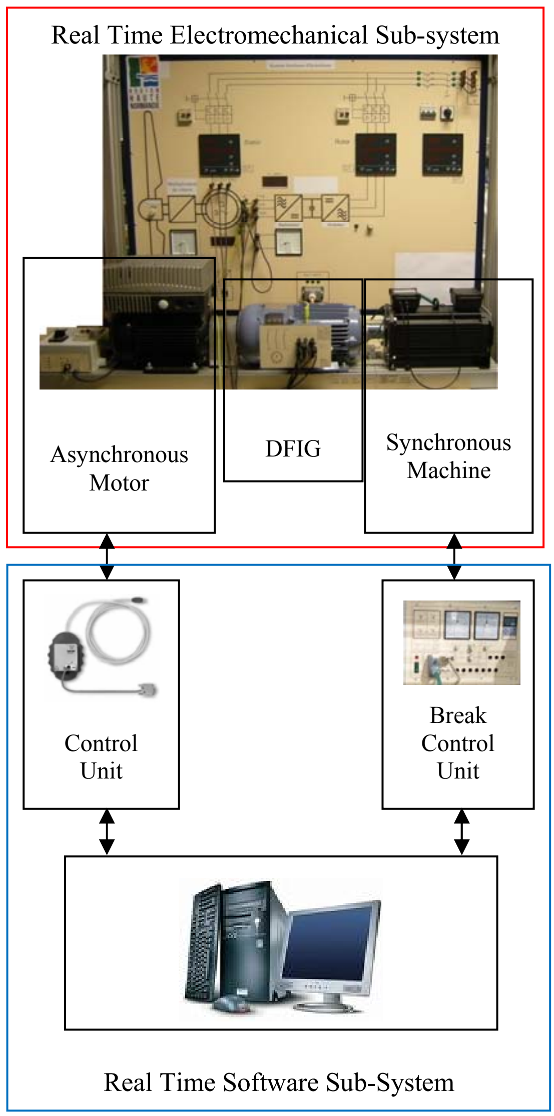

Fig.3: Synopsis of the Real Time Tidal Turbine Emulator

The ***asynchronous machine*** with wound rotor is used to emulate the *marine current turbine* and is able to realize very good dynamics for the variation of the resource and for the electrical charge.

After the turbine emulator(fig.3), on the shaft of the emulator is connected ***the generator***, which is a double feed induction generator (DFIG).It is used for the study of the energy conversion, from mechanical energy, obtained on the shaft from the turbine emulator, into electrical energy

The *active break* is a permanent magnets synchronous machine with vector control and can work in all four quadrants. It is used to create an extra charge (variation of $T_{mc}(\Omega, v)$) and to simulate an adjustable moment of inertia (*J*), different interactions between the turbine and the environment can modify mechanical characteristics of the conversion system.

6. Hybrid System connection: offshore wind turbine emulator-tidal turbine emulator

The hybrid energy system is based on the connexion of two sources of renewable energy, and for this research there will be used real time emulators. The wind turbine emulator is a controlled synchronous motor, which reproduces at its shaft the same characteristics as the real turbine and the electrical generator produces electrical power.

In the other part, the tidal turbine emulator reproduces the behaviour of the real turbine, using an asynchronous motor driving a double feed induction generator.

This connection involves many problems, because perturbations appear from each side, making it hard to control.

In figure 4 is the presented the schematic hybrid connection of this two types of turbines. The *Control and Supervision Device* (CSD) has the task to ensure the possibility to connect into a single AC Bus line the power lines. This is the major target of our researches. This is a new development into the hybrid connection filed of research, because mainly it is simpler to use AC/DC converters and to have at the point of connection the same type of electrical energy.

The main objective of using the real time emulators is to interconnect two energy resources in AS environment, offering a lower price for the electrical energy and help develop a new direction of research.

Another characteristic of the CSD is to decide where and how to use the produced energy. It has multiple choices and taking into consideration the demand and the priority criteria's it decides where to send the produced energy. So, in this way this system will have the possibility to be implemented into local grid network.

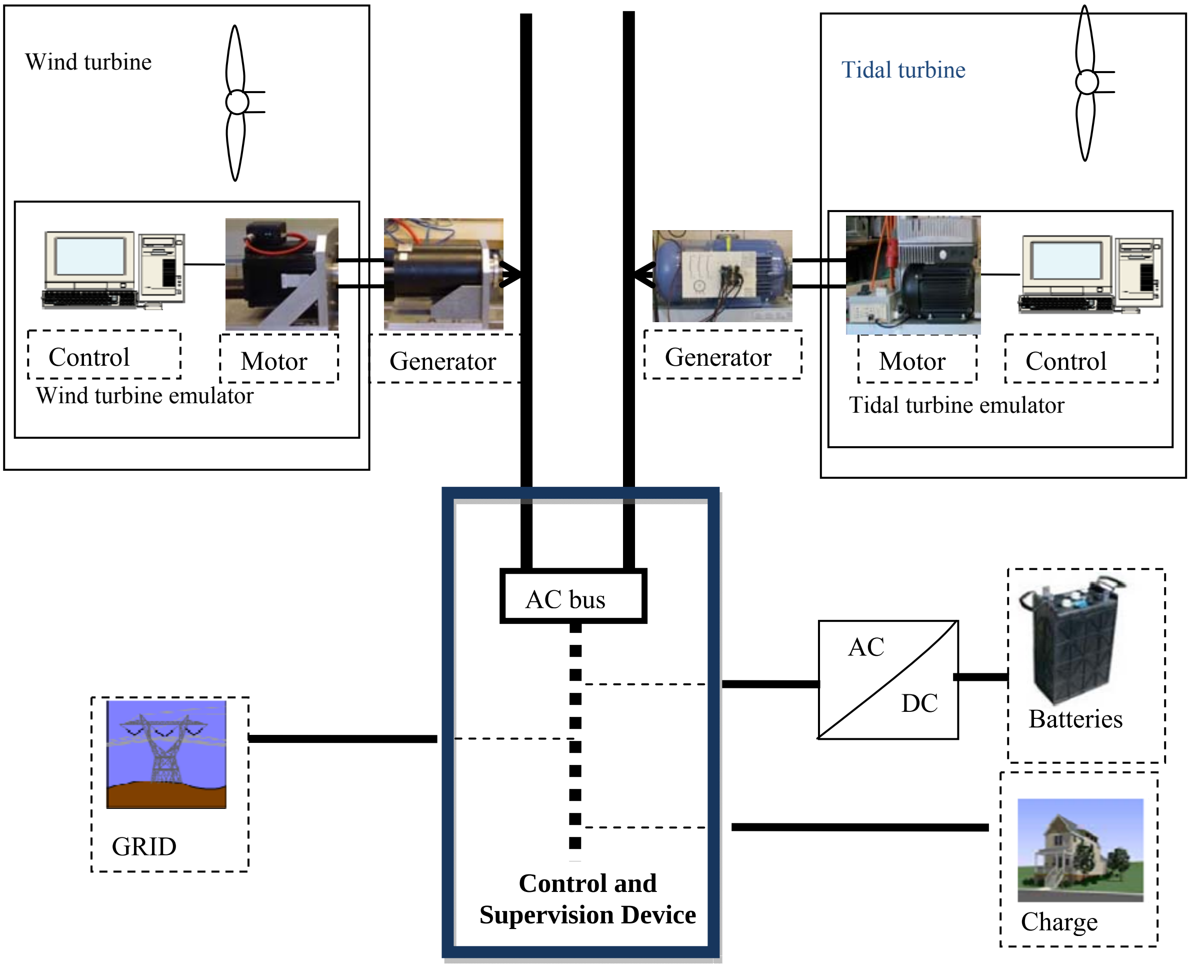

Fig.4. Hybrid connection wind turbine emulator – tidal turbine emulator

7. Conclusion

This paper presents a concept research for tidal turbine-offshore wind turbine hybrid connection system based on real time simulation. The paper puts forward the reasons why such a study is welcomed at this moment.

It is developed the general structure of a hybrid structure concerning the using of two real time emulators: a wind turbine emulator and a tidal turbine emulator. Both of the emulators are conceived with the hardware-in the-loop simulation principles.

The structures of the two emulators are presented, in the succeeding of the paper. The wind turbine emulator has in composition an informatics system and an electromechanical system, based on a permanent magnet synchronous simulator and a synchronous generator. The tidal turbine emulator is formed from a software system and an electromechanical system, which contains an asynchronous drive: a doubly feed induction generator and an active break.

The final part of the paper proposes the structure connection between the emulators and research directions that are to be studied from now on.

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