

MODELLING AND SIMULATION OF MOORED DEVICES FOR OCEAN CURRENTS ENERGY HARNESSING

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ABSTRACT

The main objective of this paper is the presentation of modelling solutions of floating devices that can be used for harnessing energy from ocean currents. It has been structured into three main parts.

First, the growing current interest in marine renewable energy in general, and in extracting energy from currents in particular, is presented, showing the large number of solutions that are emerging and some of the most significant types.

GESMEY generator is presented in second section. It is based on a new concept that has been patented by the Universidad Politécnica de Madrid and which is currently being developed through a collaborative agreement with the SOERMAR Foundation. The main feature of this generator is that on operation is fully submerged, and no other facilities are required to move to floating state for maintenance, which greatly increases its performance.

Third part of the article is devoted to present the modelling and simulation challenges that arise in the development of devices for harnessing the energy of marine currents, along with some solutions which have been adopted within the frame of the GESMEY Project, making particular emphasis on the dynamics of the generator and its control.

Key words: Marine renewable energy, ocean current turbines, modelling and simulation

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INTRODUCTION. INTEREST OF MARINE RENEWABLE ENERGY USE

The growing energy demand of the world, the variable cost of oil and the Kyoto and followings agreements to decrease the CO₂ emissions, have made the engineers and scientifics to study alternative ways of obtaining energy. By considering the ocean as one of the most important renewable energy resource (Bedard, 2008), different technologies have appeared for extracting energy from it.

Energy from the sun and the moon is captured and stored by the ocean water in different ways. That is the main reason because different marine renewable energies (MRE) are being developed (Huckerby et al., 2008) which can be classified as:

- Wind offshore: currently, has a large increase on installed power with larger units (80 m diameter rotors) than land ones by the lesser value of surges but with bigger costs of installation, maintenance and line transmission.
- Wave power: there exist a large number of projects at different stages. They offer a great variety of possible operating locations near the coast all over the World, but the proposed devices must be improved to withstand the storms of the sea (Perera et al., 2010).
- Tidal height (potential energy), a more experienced ERM with a limited future due to the negative environmental impacts of the necessary dams.
- Tidal flow and current (kinetic energy), with a similar number of designs to those of the waves. (King et al, 2009).
- Thermal gradient (OTEC) and salinity gradient, with few and high cost research projects.
- Submarine geothermal energy and marine biomass, currently limited expectations.

Marine currents are the one of the most promising MRE –with wind and waves energy– and are originated by several causes. The mains are: tides, winds, different density between waters and the Coriolis forces of the Earth. They key current source are the tides and only in those areas where the average velocity of the streams can be high is possible to obtain enough kinetic energy to be considered as an important source of renewable energy. The main advantages for harnessing the tidal energy are:

- There are many locations in the oceans with high energy density.
- It is possible to obtain a reliable long-term prediction of speed and power.
- Better relationship between mean and nominal power than other MREs.
- Very low environmental impact.
- High reliability compared to wave devices.

The quantification of the energy that could be extracted from sea and ocean currents is estimated at more than 800 TWh/year -about 4% of global electricity consumption- (Soerensen, 2008), but currently it is not possible to exploit the most important part of this huge energy potential since most of this energy is concentrated inside areas with depths over 40 meters. Then, it is necessary a new generation of converters capable of extracting this energy from these high depth sites.

STATE OF THE ART AND MOST SIGNIFICANT TYPES OF DEVICES

Nowadays the tidal stream development technology is still in the beginning of its life and there are only some devices used more as a test to learn and improve the technology, than to generate and sell electricity. Currently, there are over seventy devices into the tidal stream generation technology, and most of these concepts use an horizontal axis rotor as first converter, without any sign that the industry is going to converge towards a single configuration now. There is only one machine connected to the electrical network and this is the Marine Current Turbine's Sea Gen with 1,2 Mw generation power, which is located into the sea at the Strangford Narrows. (Fraenkel, 2010).

The other technological concepts are in different stages of development but not on industrial exploitation, and none of them, Sea Gen included, are capable to exploit currents that are at more of 40 meters depth sites.

While the development of devices for the stream exploitation, usually called Tidal Energy Converters (TEC), is focusing on the so-called "first-generation" (fixed to the bottom of the sea, and suitable for sites with depths below 40 m), there are a small

number of "second generation" developments (anchored with cables and suitable for depths over 40m). The four most common kinds of TECs are displayed in figure 1:

- Devices with open rotors: a good example is the Gen Sea, above mentioned.
- Turbine type devices with closed conduit: like the Open Centre Turbine.
- Devices with blades rotating about an axis perpendicular to the current: like Enermar.
- Devices with oscillating or linear displacement blades: the Pulse Stream is shown.



Figure 1. Sea Gen, OCT, Enermar & Pulse Stream TECs.

GESMEY PROJECT DESCRIPTION

Objectives

The initial goal of GESMEY Project (Spanish acronym from Submarine Electrical Generator with Y shape Framework) was to develop a specially designed device to harnessing the currents of the Strait of Gibraltar. This Strait is the natural way of connection between the Mediterranean Sea and the Atlantic Ocean. It has a very irregular

bathymetric profile, with an average depth of 550 m in the main channel, and with zones between 90 m and 960 m depth. The energetic resource that the Strait offers is made up by a double current, a superficial one from the Atlantic to the Mediterranean and the other one that go by the bottom from the Mediterranean to the Atlantic.

The principal part of the energy associated to these tides is into the upper Atlantic water currents and they are going along an hypothetical channel surrounded by the sea surface and the low level that is situated over 100 meters depth. On the Strait there are several places with a “mean spring tide” speed up 2 m/s but normally they are in deep waters, usually on 80 to 100 meters depth locations.

By this, the GESMEY project main objective was to develop a device with a low cost of life cycle, designed for the Strait of Gibraltar and others World sites with water depths over 40 m where the current devices (first generation devices) cannot operate. It should be noted that second-generation devices (Black & Veatch, 2004) allow access to 80% of the oceans currents energy. The goals that the GESMEY design can be resumed as:

- Simplified deployment
- Minimum environmental impact
- No surface elements on operation
- Robust and simple construction
- Easily scalable (depth, stream, speed, nominal power)
- Use of mature commercial off-the-shelf (COTS) technologies

Project methodology and stages

During the development of a MRE device, a five stages protocol (U. Southampton, 2008) can be used as guideline to reduce costs and ensure development quality. The use of this protocol on the GESMEY project is summarized below.

The starting point of GESMEY Project was a Universidad Politécnica de Madrid (UPM) patent (Lopez, 2007) which has received an award from the Madrid Regional Administration. The Project is been developed in collaboration between a research team from the E.T.S. Ingenieros Navales (ETSIN) of the UPM and other one from the SOERMAR Foundation Technological Centre.

The Project Stage 1 has been supported by funds from The Spanish National Research Program 2008/2011 (Subprogram of Industrial Applied Research, Call 2008, Ministry of Science and Innovation) and was developed between 2008 and 2009. During 2010, new funds have been obtained from the Spanish Ministry of Industry, Tourism and Commerce to develop Stages 2 and 3 of the MRE protocol.

Over the basic concept of GESMEY generator (Lopez, 2007), there were a lot of design options and it was necessary to make a feasibility study to choose the best option as a starting point to perform the device functional design. This proposed specific methodology to carry out this task is shown in figure 2.

Device description

As a result of the study of alternatives, we choose the GESMEY design drawn in figure 3 (left). It can be seen that the GESMEY TEC comprises the following elements:

- Rotor: With fixed pitch blades to improve efficiency and reliability.
- Central POD: Power Take-Off (PTO) components and ancillary systems, based on COTS elements.
- Columns: Main structural parts and ancillary ballast tanks.
- End Torpedoes: Main ballast tanks. They provide stability during operation (asymmetric load) and on flotation (like a semi-submersible platform).

An important portion of the inner volume of the columns and torpedoes is used as water ballast tanks. The changes on their ballast volume lets handle its floatability and then the position and/or the orientation of the device are controlled. More details of the design, distribution of elements, location of components, and dimensions are described in (Núñez et al., 2010).

Operational states

On operation, as is showed on figure 3 (right), the device is maintained on position by mooring systems adapted to location environmental condition and controlling the ballast water level on torpedoes (the uppers with net buoyancy and the lowers with net weight) an adequate stability is achieved to keep the device vertical with reduced heel and trim angles on despite the torque produced by the rotor.

For maintenance, decommissioning or when it is necessary to extract the device from water, the procedure is very simple (see figure 4). First, when a rope is detached and some ballast removed, the device goes up to surface smoothly. When it reaches the sea surface, a new change on ballast tanks produces a self rotation. And finally the de-

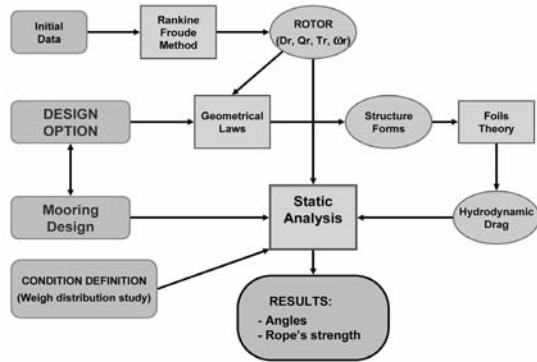


Figure 2: Flow diagram of the used methodology.

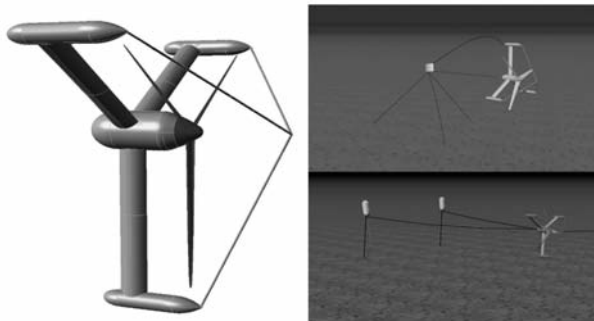


Figure 3: GESMEY device and two mooring alternatives.

vice floats on sea surface with the rotor outside water, ready for first level maintenance or transport. The device is self supported for transport.

For installation of the device or going back to operation state after a maintenance procedure, it can be used the reverse sequence. The whole procedure can be fully automatized with a supervisory control from the tidal farm operators.

MODELING AND SIMULATION OF MOORED TECs

At the first phase of the GESMEY Project, it was found that there was no turnkey design and calculation tools that can solve the design, calculation, analysis and simulation needs for a device like the proposed one, which should work submerged like a submarine and stand with a different orientation when it is on the sea surface.

Therefore in the definition stage a set of tasks for the analysis and adaptation of existing tools –for models development, calculation and simulation, etc.– were carried out. These methods and tools can be applied to other submerged and moored MER devices. Next subsections are devoted to present some of the most significant aspects of the carried out analysis for modelling and simulation.

Hydrodynamic behaviour

The key element of a TEC is the rotor. It is the component that converts the water kinetic energy into mechanical energy. As it was described above, in most cases the rotor is similar to the one from a wind generator or from a hydro turbine, but in the case of the TECs, as an additional feature normally it should work in both directions.

The models and tools used for the design of ships propellers are not suitable for the analysis of TECs rotors because of their different shape and because they work in the reverse sense, that is, by absorbing energy instead of transfer it to the water. Therefore the typical propeller curves ($K_t(J)$ and $K_q(J)$), where K_t , K_q and J are the thrust, torque and advance coefficients cannot be used.

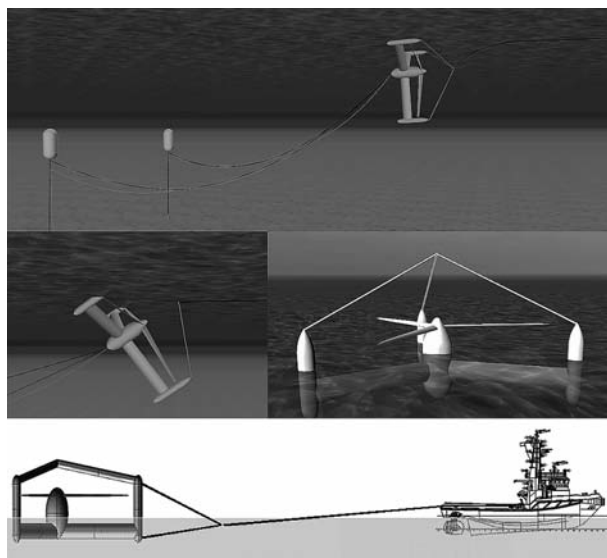


Figure 4: GESMEY procedures for maintenance and transport.

Instead of these curves, C_p (Power Coefficient), C_t (Thrust Coefficient) and C_q (Torque Coefficient) defined all of them as function of λ = TSR (Tip Speed Ratio) are used. They are defined as:

$$TSR = \frac{\omega \cdot R}{V} \quad (1)$$

$$C_p = \frac{P}{0,5 \cdot \rho \cdot A \cdot V^3} \quad (2)$$

$$C_t = \frac{T}{0,5 \cdot \rho \cdot A \cdot V^2} \quad (3)$$

$$C_q = \frac{Q}{0,5 \cdot \rho \cdot A \cdot R \cdot V^2} \quad (4)$$

Being:

- ρ Water density (1025 kg/m³ for salad water)
- ω Angular speed of the rotor
- A Useful area of the rotor
- R Rotor ratio (to blade tip)
- V Water current velocity (free waters measured)
- P, T, Q Power, Thrust and Torque on the rotor shaft.

For rotor modelling, $C_p(\lambda)$ and $C_t(\lambda)$ are needed - C_q can be obtained from C_p - and they can be obtained from hydrodynamic test canal experiments (Bahaj et al., 2007) or from numerical computerized models. The general aspect of both curves can be seen from figure 5.

When a propeller works at its optimum point, the energy extraction coefficient (C_p) which measures the ratio between shaft power and the mass of water flowing through the device is between 0.4 and 0.5, being the theoretical maximum achievable known as the “Betz limit” $C_p < 0.59$.

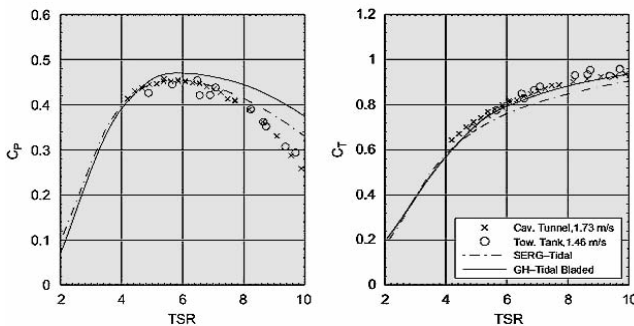


Figure 5. Typical C_p C_t curves for a TEC rotor.

Within the GESMEY Stage 1, the propeller has been tested in a towing tank and computational fluid dynamics (CFD) simulations have been carried out in order to optimize its structure design with constructible shapes (figure 6).

Device in operation

In operation (producing energy) a moored submerged TEC works practically in steady state due the slow variation of current velocity. Disturbances came from the turbulence in the current profile if the device is very close to the bottom and that can be wave-induced if it is near the surface. Under these limit conditions, such efforts will produce large fluctuations in the blade's root, but the torque and thrust oscillations transmitted to the PTO is reduced if the rotor has three or more blades.

This greatly simplifies the analysis of the behaviour of TEC in operation, and it can be done using simple static models. The objectives of this analysis are to know the device forces, torques and orientation angles, allowing to adjust the ballast tanks level.

Therefore, two mathematical sub models are necessary: the mechanical and the hydrodynamic ones. Both of them have been developed in basis the similar ones used in naval architecture design. The "hydrodynamic model" developed is based on first, segregating the device structure into different elements and, second, computing their drag as function of their respective speed, according with the formulae:

$$Fd = 0,5 \cdot Cd \cdot \rho \cdot A \cdot V^2 \quad (5)$$

Where F_d denotes the drag of each element, A is its significant surface, V represents the water speed and C_d is the form coefficient -Reynolds Number dependent- that has a small change with velocity because of the huge dimensions of the elements.

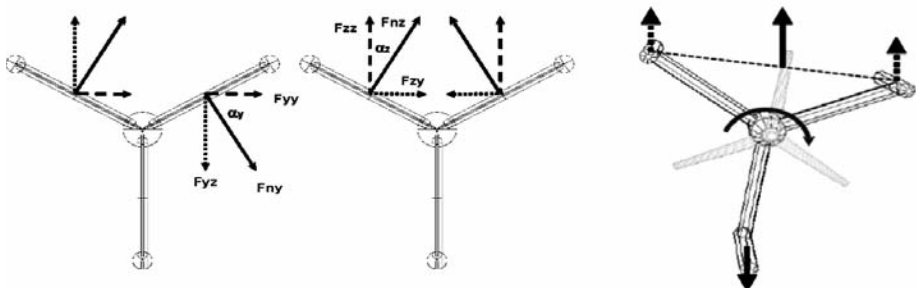


Figure 7. Basic elements forces. Hydrostatic equilibrium.



Figure 6. Preliminary physical and CFD models of the GESMEY rotor and structure.

The values of the forces along the three principal axes are calculated and applied in the centre of each element (see figure 7 left & centre). The model neglect the lift forces because all the elements are disposed in a symmetric way with respect to the direction of the flow, and the mooring system let the device automatically oriented in the flow direction.

All the volumes are computed, and then, buoyancy forces are applied over each of these elements. On the other hand, all the weights are computed too, and gravitational forces are obtained. The “hydrostatic forces” are obtained by composing both forces.

Once all the hydrodynamic, hydrostatic and rotor forces have been computed, they are integrated into the “mechanical model” together, in order to get essentially the heel and trim angles values obtained from the device “metacentric height” (GB), the definition of the mooring points and the torque from the rotor.

During the Project Stage 1, different possibilities for making a computerized tool which facilitates the calculations seen above were considered. The final developed tool HACERIC (Spanish acronym from: tool for the analysis of radial bodies inside currents flow) let the user enter data (sizes, weight...) corresponding to the device under analysis and adjust different ballast tanks levels, obtaining as results the most significant forces, torques, and orientation angles of the device.

When GESMEY is operating at 2 m/s, HACERIC show these results: 14 degrees of heel angle; negligible trim and yaw angles (see figure 7, right) and a total force of 1.0 MN over the mooring ropes. Also we checked -with the Orcaflex tool, showed below- that the effects of 4 m height waves into the device movements are minimal.

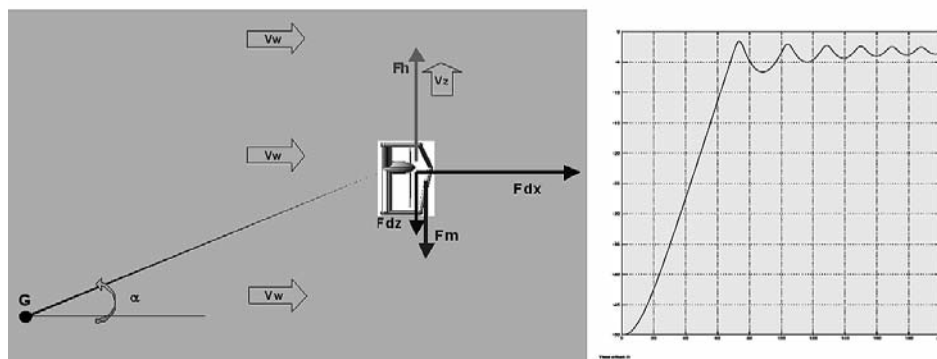


Figure 8. Basic modelling and simulation results of GESMEY emersion.

Emersion and immersion manoeuvres

All TEC that works underwater, must to be designed so that they can perform the manoeuvres of immersion and emersion in a controlled way. These manoeuvres are necessary during the device installation and decommissioning operations, and every time it is necessary do maintenance tasks.

These processes are clearly dynamics, being necessary to develop behaviour models and adapt existing simulation tools. Within these processes, there are two very different phases: first when the TEC is totally submerged (for example, during the emersion of GESMEY device, the objective is to maintain the vertical orientation) and the second when the TEC goes out of water (partly) appearing a free surface (in the case of GESMEY corresponds to the rotation showed in figure 4).

For modelling the first phase (figure 8) the model must represent the main forces and moments: restorative (buoyancy and weight), dissipative (resistance and lift) and inertial (actual and added masses). The problem is that many of these forces are not linear, being particularly complex the modelling of the added mass (Korotkin, 2009).

A simplified 2D model has been implemented under the Simulink-Matlab environment. Details of the used model can be seen from (López et al., 2009) and depth of the device as function of time when an emersion procedure is ordered can be seen from figure 8. It can be clearly appreciated the non linear and with small damped behaviour response when the device reaches the water surface.

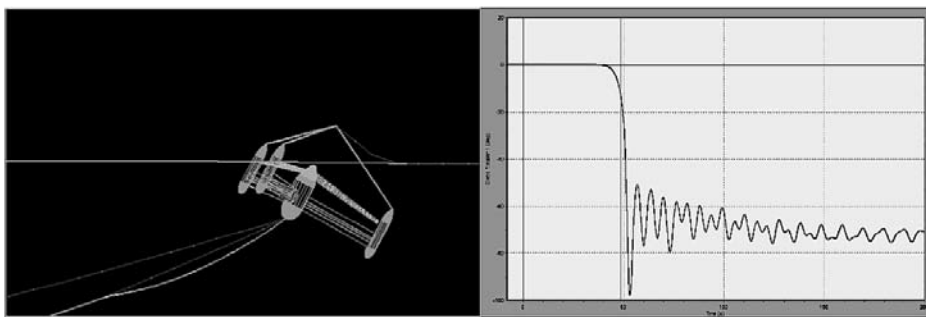


Figure 9. GESMEY surface turn modelling and simulation with Orcaflex.

An additional problem that arises when modelling the behaviour of moored bodies is to characterize the behaviour of ropes. This is a widely studied and complex hydro-elastic problem, and however, very difficult to implement in tools such as Simulink-Matlab. In order to solve this handicap, the use of the simulation tool (3D) Orcaflex was decided. Orcaflex is considered as the main reference mooring design tool in the field of offshore marine systems. Working with this tool presents two problems:

- To model complex bodies, as they are the TECs, it is necessary to define the body like a set of elements (8 in the case of GESMEY) and for each to put in a set of parameters like volume, weight and hydrodynamic drag, added mass etc. To solve this problem, we have generated a parametric calculus procedure.
- It is difficult to implement in the model the control systems necessary to simulate the automatic operation of the TEC. So far we have solved this problem by simulating processes (Figure 9) with model predictive control, being planned in the future to develop an interface between Simulink and Orcaflex.

Power electromechanical system (PTO)

Because the speed of ocean currents cannot be considered constant, GESMEY has been designed and configured as a variable-speed turbine in order to capture the maximum amount of power over a wide range of water speeds. By this, is necessary the use of active control systems that meet different objectives depending upon the water speed.

The PTO consists on a set of components from the propeller to the electronic converter. The main elements of the PTO are: the rotor, the mechanical gearbox, the synchronous generator, the breaking system and the electronics converter.

The proposed dynamic model can be see at (Somolinos, 2010) and a voltage controller has been implemented for simulation of this turbine in the Matlab-Simulink software. Some simulated results are obtained under different changing conditions of the water currents and under a step increment of the voltage reference input.

Figure 10.a shows the speed of the current input. It has been obtained in a synthetic way, adding an step increment of (-1.3 m/s at instant $t = 20$ s), and a limited bandwidth white noise. The reference signal for the controlled system is the desired voltage of the load. Its starting value is 1900 V and after 10 seconds, the desired voltage is changed to 2100 V with a step signal increment of +200 V.

Figure 10.b shows the electrical torque. Figure 10.c shows the angular speed of the PTO (high speed shaft). It can be observed the generator speed evolution when the input reference changes. Finally, figure 10.d shows the real voltage response of the system and the voltage reference input signal.

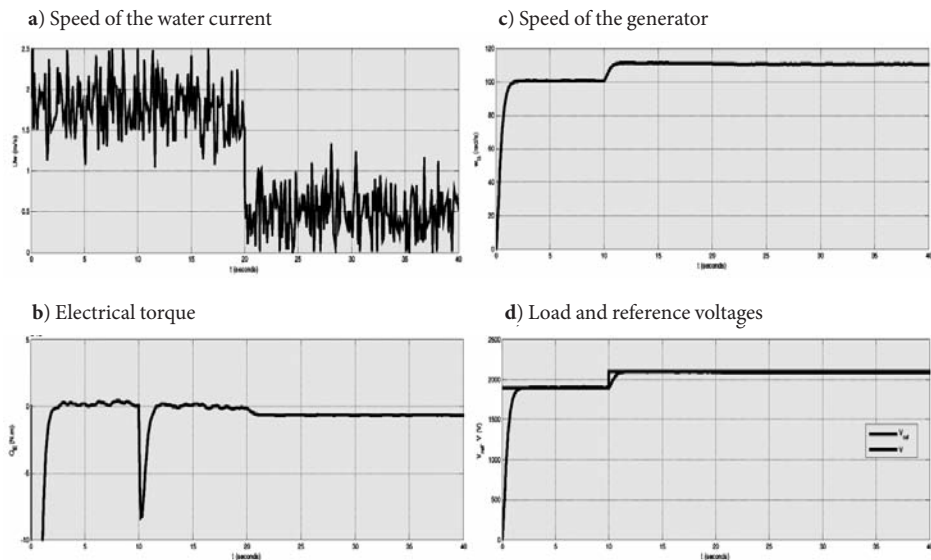


Figure 10. PTO response curves for a simulated operation.

CONCLUSIONS

From the analysis of the state of the art of the Marine Renewable Energies and from the GESMEY Project experience, it is found that the extensive development that will take in the coming years in this area is an opportunity for industry and for R&D. In order to reach the success, projects must follow an established development stages protocols and must be supported by consolidated groups that are able to solve the financial, technological and scientific challenges that will take place.

Among the scientific challenges to the case of moored TECs it is needed to develop new models and calculation and simulation tools. Within GESMEY project these problems are been addressing. Solutions with a right balance between scientific rigor, the precision of the results and cost (acquisition, development and use) of the models and tools have been found.

The taken steps thus far, would have shown the feasibility, performance and ease of operation and maintenance of GESMEY device, and they have proven to be possible to develop the basic tools at a reasonable cost.

Next steps will focus, from the technological point of view, on the development of an experimental prototype of 10 kW and a detailed project of a 1 MW generator. From the scientific viewpoint, the validation and calibration of the tools developed, through a testing program in test channel is needed, and a detailed study of the control of the procedures of immersion and emersion have to be improved and tested.

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MODELADO Y SIMULACIÓN DE DISPOSITIVOS FONDEADOS PARA EL APROVECHAMIENTO DE LA ENERGÍA DE LAS CORRIENTES MARINAS

RESUMEN

En este artículo, tras presentar el estado actual del aprovechamiento de las energías renovables marinas (MRE), y en especial los dispositivos para el aprovechamiento de la de las corrientes (TECs), se describe el generador GESMEY en desarrollo entre la UPM y SOERMAR y los modelos y simulaciones desarrollados para él y que son utilizables en otros TECs fondeados.

INTRODUCCIÓN. INTERÉS DEL USO DE LAS MRE

Entre las fuentes de MRE: viento, olas, corrientes, altura de mareas, gradientes térmico y salino, etc., las tres primeras son las que tienen un mayor potencial. La energía de las corrientes (mayoritariamente de las mareas) se estima en 800 TWh/año, existiendo bastantes lugares en el mundo, donde se concentra. Sus principales ventajas son su predictibilidad, alto factor de utilización, fiabilidad y bajo impacto ambiental.

ESTADO DEL ARTE Y TIPOS DE TECs REPRESENTATIVOS

En la actualidad existen más de 70 conceptos de TECs en diversas fases de desarrollo y de distintas tipologías. En la figura 1 se muestran cuatro ejemplos significativos, que corresponden a turbinas de rotor abierto y cerrado con eje horizontal, a una turbina de eje vertical y a un dispositivo de palas oscilantes. Entre todos los proyectos, puede considerarse que el de referencia es el Sea Gen, cuyo prototipo comercial de 1,2 MW, lleva más de un año entregando energía a la red.

DESCRIPCIÓN DEL PROYECTO GESMEY

Aunque el objetivo inicial del proyecto GESMEY (Generador Eléctrico SubMARino con Estructura en Y), es el aprovechamiento de la energía de las corrientes en el Estrecho de Gibraltar, al ser un dispositivo de 2ª generación (apto para trabajar en lugares con más de 40 m de lámina de agua), es utilizable en otros lugares con esas profundidades, con lo que tiene acceso al 80% de la energía de las corrientes, frente al 20% disponible para los de 1ª generación. Su diseño se ha basado en unos objetivos

ambiciosos (instalación simple, mínimo impacto ambiental, sin elementos en superficie, simple de construcción, basado en elementos estándar y escalable) con objeto de optimizar su ciclo de vida y maximizar su rentabilidad.

En el proyecto GESMEY durante 2008 y 2009 se realizó la fase 1 (diseño funcional) y en la actualidad se están abordando las 2 y 3 (diseños constructivo y operativo con pruebas de un primer prototipo en el mar). En la figura 2 se muestra el proceso seguido para la elección de diseño final entre distintas alternativas.

En la figura 3 se muestra el diseño del TEC GESMEY. Consta de un domo (POD) central en el que va el tren de potencia (PTO) y los equipos auxiliares en cuyo extremo se sitúa un rotor de tres palas de paso fijo (para simplificar la construcción y aumentar la fiabilidad). Del centro del domo salen tres brazos (en cuyo interior van tanques de lastre). En el extremo de cada brazo se dispone un cuerpo en forma de torpedo, en cuyo interior van los tanques de lastre principales.

En operación produciendo energía (figura 3, derecha), el dispositivo está unido a una serie de cables de fondeo, que lo sujetan al fondo, a través de una serie de boyas sumergidas, permitiendo que se oriente automáticamente en la dirección de la corriente. La diferencia de llenado entre los tanques de lastre superiores e inferiores, produce una altura metacéntrica suficiente para estabilizar el generador en vertical, frente al par producido por el rotor.

Cuando se desea sacarlo a la superficie (figura 4), basta con liberar alguno de los cables y vaciar de forma controlada uno de los tanques, lográndose que el dispositivo suba en vertical de forma suave. Cuando emerge una parte, se vacían, de forma secuencial, el resto de los tanques de lastre, girando y quedando flotando en horizontal y dispuesto para las tareas de mantenimiento de primer nivel o el transporte.

MODELADO Y SIMULACIÓN DE TECs FONDEADOS

El elemento fundamental de un TEC es el rotor, que se modela a través de las curvas de potencia y empuje (C_p y C_t en función del TSR), tal como se ve en la figura 5. Dentro de GESMEY se ha ensayado un modelo a escala y se han realizado simulaciones con CFDs.

Al no existir herramientas adecuadas para el análisis de TECs sumergidos, se ha desarrollado la aplicación HACERIC que integra modelos hidrostáticos, hidrodinámicos y mecánicos originales, permitiendo calcular las fuerzas de fondeo y los ángulos de operación. Los modelos se basan (figura 7) en la descomposición del TEC en una serie de cuerpos simples, que son estudiados por separado, integrándose sus fuerzas y momentos para analizar el comportamiento del conjunto.

Para el estudio y simulación de las maniobras de emersión e inmersión se han utilizado las herramientas Simulink y ORCAFLEX que es la de referencia dentro del campo offshore para sistemas fondeados. Con ambas (figura 8) se han logrado unos buenos resultados en la fase sumergida, pero Simulink presenta problemas en cuanto

hay parte del dispositivo fuera del agua. Por ello, para las fases de giro el trabajo se ha centrado en ORCAFLEX (figura 9), habiéndose desarrollado métodos originales para el cálculo de los parámetros hidrodinámicos que hay que incorporar al modelo.

Dado que GESMEY utiliza un sistema de paso fijo en el rotor, el generador tiene que trabajar a velocidad variable, en función de la velocidad del agua. En la referencia (Somolinos, 2010) se describe el sistema de control desarrollado.

CONCLUSIONES

El desarrollo de las MRE en los próximos años supone un reto tecnológico y financiero y una oportunidad para el desarrollo de nuevos proyectos de I+D. Los modelos y herramientas desarrollados dentro del proyecto GESMEY han demostrado su utilidad para su uso por otros TECs de segunda generación, siendo necesario trabajos complementarios de desarrollo, validación y calibración que se van a abordar próximamente.