SIMULATION OF THE EMERSION PROCEDURE FOR A NEW UNDERWATER GENERATOR

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ABSTRACT

During the last years, a great amount of electrical underwater generator designs have been proposed for exploiting the sea energy resources. Multidisciplinary engineering is needed to conceive, to design and to construct any of these devices and a large amount of concepts have to be taken into account when an underwater generator is designed. SOERMAR and the Technical University of Madrid are developing a new concept for marine current energy use: The GESMEY project, whose main goals and conceptual design are briefly described. It is based on a Y structure with additional elements which can handle its own floatability by controlling the amount of water ballast inside these elements.

This paper analyses one of the methods proposed to move the generator from the operation depth to the sea surface in order to prepare it for the maintenance position in a controlled way. The obtained simulated results of the emersion procedure are presented in this paper.

Keywords: Underwater generators, Simulation, Non-linear systems

1. INTRODUCTION

The growing energy demand of the world, the variable cost of oil and the Kyoto agreement to decrease the CO2 emissions, have made that several technicians and scientific to study alternative ways of obtaining energy. By considering the ocean as one of the most important renewable energy resource, different technologies have appeared for extracting energy from it, some of these ones stand out for its importance: wind offshore, waves energy and tidal and current energy. (Bedard, Roger, 2008), (Savage, Anne et al. 2007)

The last one has a lot of locations with high energy density, better mean/max power ratio that wind and waves systems, lower environmental impact, higher expected reliability and, long term predictable velocity and energy due that thermal, salinity and these seasonal currents are well known and nearly constant, on the other side, tidal currents can be predicted a lot of years in advance with a high accuracy. (Delgado Cabello, Javier et al. 2006)

There are a lot of concepts proposed for sea wind, tidal and wave energy extraction. Same decades ago, tidal energy was obtained by means of artificial barriers (like La Rance facility), but at present most of the prototypes that have been proposed use techniques, that are following similar principles of those for extracting energy from the wind. If the layout of underwater generators is generally based on a marine current turbine, the main differences between some prototypes are related to the rotor size and orientation, the location of the generators and the devices of anchoring to the sea bottom. (Eddine Ben Elghali, Seif et al. 2007), (Fraenkel, P.L. 2007).

The Ocean Current Turbines (OCT) for extracting electrical energy from the marine currents have the advantage (in comparison with the wind energy generators) of the greater density of the water, which implies smaller size of the propeller.

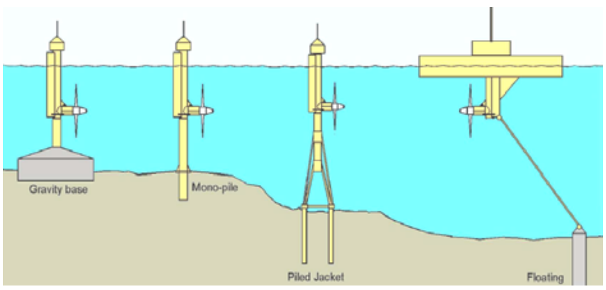

Figure 1: Conventional anchoring systems

The main limitations of these prototypes can be considered as follow: Important civil work on bottom and special equipment for deploying with big elevation mechanism to maintenance (See figures 1 and 2). In order to minimize these disadvantages, UPM and SOERMAR are developing an underwater system, with an improved technology, capable to produce energy from the ocean currents: the GESMEY generator.

Figure 2: Existing devices

Grouping all the generators of different technologies, as function of their field of application; the evolution of the OCTs can be classified attending to this technologies integration in the following way: (See figure 2)

- 1st generation: Designed for the utilization of the tides, closing estuaries with preys and using similar turbines than in the fluvial flows of water.
- 2nd generation: Systems placed over the bottom of the sea. There exists a great set of devices. The main limitation is the civil work for installing the generator and the cost of the maintenance tasks, which requires special machinery, or extracting the generator to the surface of the sea with external machines… Another limitation is the relative small depth of the bottom of the sea for this generation of devices
- 3rd generation: Designs for high depth bottoms (more than 40 m), or floating devices, and the GESMEY design which is briefly described below.

From a strategically point of view of the Spanish coasts where marine currents can be exploited, the zone with the biggest currents in Spain is the Strait of Gibraltar (GS). This strait is the natural zone of communication between the Mediterranean Sea and the Atlantic Ocean. It has a variable width from 44 km in the west input until the minimum of 14 km in the narrowest zone between *Tarifa* and *Punta Cires*.

There a great exchange of water exists between both seas. In general, the currents can be considered as bi-directional ones. In this particular area, the main causes of this exchange can be summarized attending to the following natural considerations:

- Different density of water of both seas. Because of their not equal salinity and temperature.
- Difference of levels between both seas due to the tides and due to the evaporation of water in the Mediterranean Sea side of the strait.
- Difference between the atmospheric pressure from the Alboran Sea (east zone) and the Gulf of Cadiz (west zone).

More precise values and studies of the properties of the marine currents in the zone of the Strait of Gibraltar can be seen at (Vargas, J.M. et al. 2006),(López Piñeiro, A. et al. 2008), (Juanes González J.M,2007).

2. SYSTEM DESCRIPTION

The GESMEY system (Figure 3) has a propeller with three blades that there moves an electrical generator, which is located in the central dome or pod. Three arms joins the dome with each of its tip float. The ensemble is joined by a device with ropes that anchor to the sea bed.

The main function of the central dome is to locate the elements for converting the mechanical energy of the propeller into the electric power that can be extracted to an electric power station of the land using a submarine cable that includes the electrical line of power and the link of communication with the control remote station.

Inside the central dome, the auxiliary devices needed for cooling, protection, measurement and control are located. An important part of the inner volume of the floats is used as water ballast stores. The control of the quantity of water ballast allows handling the position and/or the orientation of the generator. Different control schemes can be used for this purpose, because one, or several, or all the water ballast stores can be managed individually.

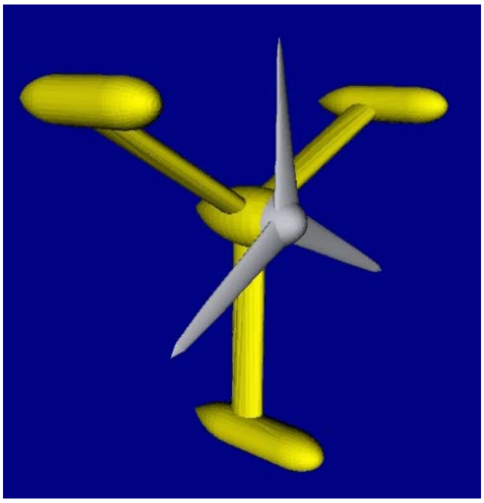

Figure 3: Basic GESMEY design

The weights and forces distribution lets the system, compensate the torques applied to the generator in the sense that it can line up with the own direction of the marine currents. The applied torque to the propeller makes the generator be orientated as it is shown in figure 4.

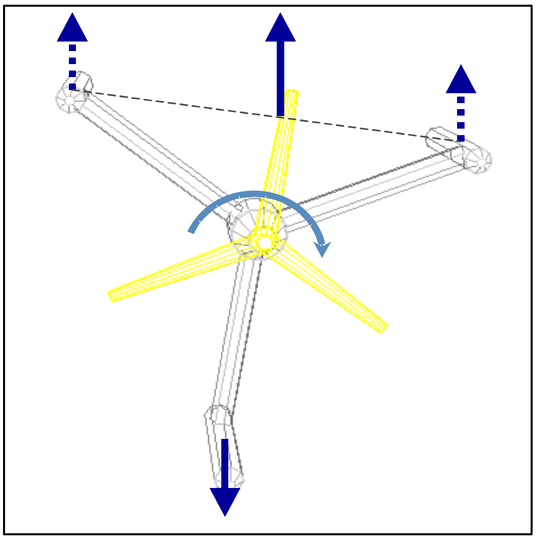

Figure 4: Main Forces and torque acting over the GESMEY

The proposed system will have a few economic costs lower than those of other existing generators due to its major stability, flexibility and because the operations of maintenance have been highly simplified.

The modes of operation of GESMEY can be summarized in two ones: the normal operation mode -submerged-, and the state of operation for maintenance -floating in the sea surface-. One of the principal aims in the design of the generator was to facilitate the maintenance work from a point of view of the access to the elements of the system with a self-operated system to move from one operation mode to the other.

Another of the most evident improvements of the proposed design is that the use of external elements or external machinery for the emersion or sunk of the generator is avoided.

It is possible to control the depth of the generator handling the quantity of water ballast inside it and/or controlling the tension of the ropes that anchor the generator to the sea bed. Both procedures of immersion and emersion seem to be symmetrical. Nevertheless, the emersion procedure turns out to be critical and is for it that needs a special control to move from the depth of operation to the surface, with uncontrolled buoyancy lost, without sudden changes, and in a smooth way.

3. MODES OF OPERATION

The modes of operation of GESMEY can be summarized in two ones:

- The normal operation mode -submerged-, (as Figure 3) with a vertical orientation. In this mode of operation, the generator can be of any of these states: in a blocked state (ordered from the control unit), with the propeller in a stopped state, because of the small current velocity and in normal operation state, that is to say, generating electrical energy.
- The state of operation for maintenance -floating in the sea surface- with an horizontal orientation. One of the principal aims in the design of the generator was to facilitate the maintenance work from a point of view of the access to the elements of the system with a self-operated system to move from one operation mode to the other.

Using an automated procedure of emersion, another one of the evident improvements of the proposed design is that the use of external elements or external machinery for the emersion or sunk of the generator, can be avoided, since it is the own generator which is capable of generating the control signals to go to the surface of the sea without any kind of external intervention.

The change from a mode operation to another has to be ordered by a human operator from the SCADA system, and has to be executed by the own generator in an completely automated way. Two basic procedures represent the changes of modes of operation of the generator:

- The immersion procedure lets the generator go from the surface of the sea to the normal position of producing energy (vertical and submerged).
- The emersion procedure makes the generator become to an horizontal posture over the sea, starting from the position of normal operation. Figure 5 shows the different initial-intermediate-final stages during the emersion procedure.

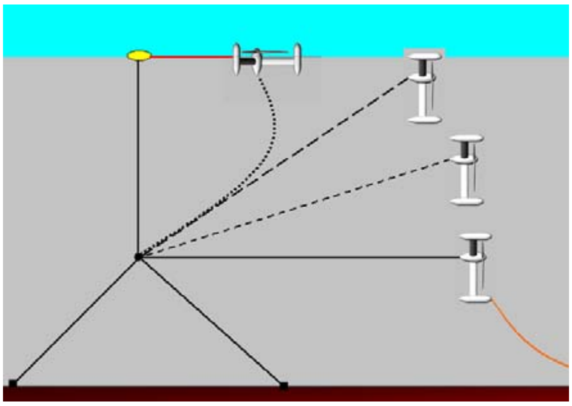

Figure 5: Schematics view of the emersion procedure of the generator.

4. CUALITATIVE DYNAMIC MODEL OF THE SYSTEM

The dynamic equations that govern the movements of the generator are obtained from a model of only one point mass located in the central dome. The applied forces (it is a strongly non linear system) that act over the generator are of different nature, and can be grouped as:

- The vertical forces: Composed by the own (proper) weight, the floating force (which is controllable), the vertical hydrodynamic friction force and the vertical components of the reaction forces over the ropes
- The horizontal forces: The hydro-dynamical forces due to the marine currents and the horizontal components of the reaction forces over the ropes.

Simulation of the quasi-static position and orientation of the generator under the normal mode of operation requires the use of distributed masses along the structure and a more precise forces and torques computation. For the dynamical response of the system during transient motions, (immersion and emersion procedures), the dynamical equations are obtained from the mentioned forces applied to the main mass. All forces are obtained as function of the values of the estimated current speed in the Gibraltar Strait environment.

Taking into account all the equations implied in the system, a dynamical model with next properties is obtained:

- It is an strongly non linear system
- The coefficients of the equations are time dependant
- There exists a great coupling among many of the equations.

These are the main causes because it is necessary the simulation of the system into a computer in order to obtain the solution (temporal response of the system) during the emersion procedure. These equations have been programmed in the SIMULINK-MATLAB environment using double integration and variable step discretization.

Because of the simplicity of the design, the only control signal which lets handle GESMEY is the amount of water ballast inside the generator. Based on this limitation, controllability of the system, time response signals, levels of saturation of the actuators, and some others results have to be analyzed.

5. SIMULATION RESULTS

Figure 6 shows the blocks diagram implemented in the SIMULINK environment. It clearly can be seen the non linearity of the system and the strong coupling among equations mentioned in the previous section.

The values and coefficients used in this simulation are corresponding estimations from some of the Gibraltar Strait zones. The dimensions of the generator and lengths of the ropes have been optimized for each of the concrete areas.

The obtained results confirm that it is necessary the generation of reference signals for controlling the management of the ballasts of the generator, so that they allow us to obtain a smooth response, with no strong oscillations.

Without an adequate reference of the water ballast of the underwater generator, or without any closed-loop control system in the emersion procedure, it is possible to put in risk the own generator, as well as the devices,

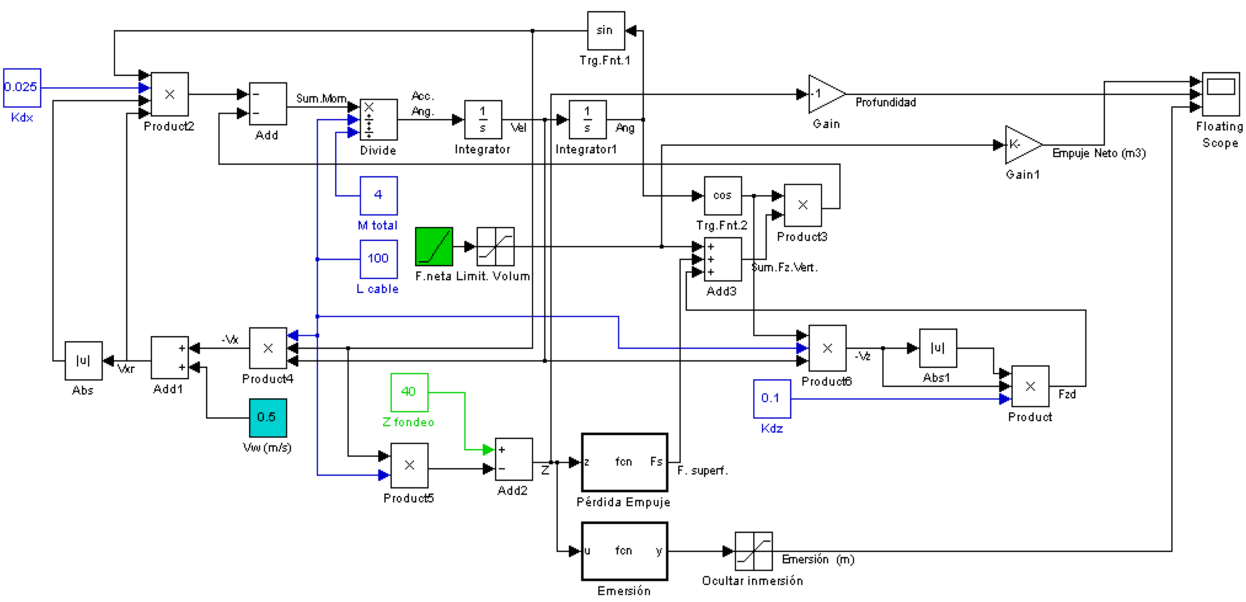

Figure 6. Blocks diagram in the SIMULINK environment

components and even personnel of the team of maintenance, when it emerges from depth.

With an adequate reference of control of water ballast, it is possible to obtain a good response of the system during the emersion procedure.

The used reference signal can be seen from figure 7. It represents the evolution of the input signal in m^3 of removed water ballast. At the beginning of the operation, the water tanks are practically full, and a very small resulting (floating) force is applied to the generator. The procedure beginning instant occurs when the ropes that hold the generator are given up (t = 0 seconds). If a bigger floating force is used as reference signal, the response of the system can become an inadmissible overshooting response.

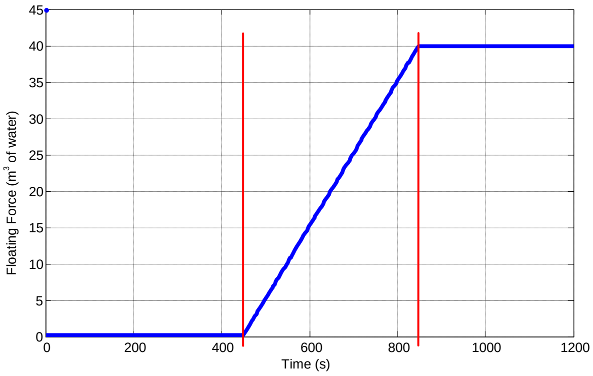

Figure 7. Signal of reference.

Then, when the generator has reached the surface of the sea, a ramp input signal is used as reference to empty the tanks of water in order to the generator emerges so much as it could. The desired depth position of the generator is defined by its own weight with the tanks of water ballast fully empty (minimum).

One of the main ropes is joined with the generator in a permanent mode. This link prevents the generator takes an undesirable path far from the nominal position. This main rope and the interface between water and the air let the generator turn from a vertical to an horizontal orientation without any controlled external effort.

The simulated response of the depth of the generator (see figure 8) shows that the emersion will be carried out in approximately 500 seconds. It shows a temporary response without any overshoot and with an oscillating superposed signal of very small amplitude and small damping. The vertical solid lines denote the time interval when the water ballast stores are being emptied completely.

In order to characterize the mentioned small oscillating signal in the steady state, this one exhibit an amplitude of over 0.6 m (when a 100 m length cable and a generator of about 30 m diameter is used), a natural frequency of oscillation of approximately 2.4 cycles per minute and a small damping ratio. From a practical point of view, this signal will be able not to be taken into account if a simple comparison between this signal and the amplitude of sea waves during the maintenance period (calmness) is made.

A few seconds after the transient emersion of the generator, the steady state error of the response can be considered cero if small oscillating signal is neglected.

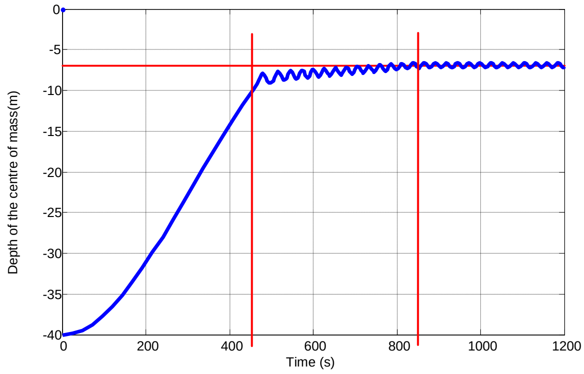

Figure 8. Depth of the generator during the emersion procedure

The difference between the depth of the center of mass of the generator from the beginning instant of the ramp until the end of the ramp time can be easily appreciate in the same figure 8. For this simulation, the obtained value of this distance is about 1.58 m. This is considered of a great importance to let a human worker be able to access to the interior of the dome with major comfort, without the need of a diver not of special facilities, as soon as the generator has reached the final position.

6. CONCLUSIONS

A new submarine generator for the exploitation of the energy of the marine currents has been briefly described in this study. Its special configuration allows these generators to be installed in deeper waters than some of the existing generators up to now.

The costs of the necessary civil work for its installation, as well as the economic costs of the maintenance tasks are minimized due to the fact that the generator is able to emerge and it can also be immersed simply controlling the water ballasts inside the own generator and the ropes of anchorage to the sea bottom.

These operations of immersion and emersion can be done in a completely automatic way, either from the order given by a human operator or a remote control system. It can be easily observed that the emersion procedure results the most critical one in the sense of the risk of the execution, the risks of persons, devices, and the own generator. In other words, the immersion results a simpler and less complex procedure than the emersion one.

The equations that govern the dynamic behaviour of the generator in these transitions, turn out to be not linear, but they are strongly connected and with coefficients dependent on time. These circumstances increase the big risks that exist in case the procedure of emersion is not carried out in a controlled way.

The simulation of the obtained equations in a computer is necessary in order to study the dynamic behaviour of the system and to design the appropriate input signal of reference.

Results show that it is possible to execute the emersion procedure in a completely automated way, by simply controlling the ballast water of the generator.

In order to improve the system response during the same emersion procedure, a sensor of depth and an inclinometer are currently being used to control the depth and the orientation of the generator respectively, with a closed-loop control scheme.

ACKNOWLEDGMENTS

This work was partially supported by the Spanish "Ministerio de Ciencia e Investigación" under grant IAP-590000-2008-6 in collaboration with the SOERMAR Foundation and the Universidad Politécnica de Madrid for the development of the patent number P200700987.

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