SIMULATION OF GESMEY GENERATOR MANOEUVERS

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ABSTRACT
GESMEY generator is a Tidal Energy Converter -TEC- device designed to operate in medium and high depth locations with an original design based on a moored system and a main structure of star aspect. After a brief introduction where the interest of this type of generators for the marine currents energy harnessing is presented, the objectives of the GESMEY Project, the design procedure and some results and the automation process scheduled for moving it from the submerged operation state to the floating maintenance situation are presented too. The needs of new models and tools for the study of the dynamical response of these kind of devices under these operation states together with the design solutions that have been taken in this original design are described. Finally, simulation results of some of the GESMEY manoeuvres obtained with a tool we have developed and with some commercial simulation tools are presented. The comparative study of both simulation responses validates the simplest dynamical model used for controlling the generator.

Keywords: marine current converter, moored device, manoeuvres modelling and simulation.

1. INTRODUCTION

Marine currents are one of the most promising marine renewable energy -MRE- sources that mainly is derived from tides movement. The main advantages for harnessing tidal energy are:

- Specific locations in the oceans with high energy density, mainly near shore.
- 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 other devices like wave converters.

The energy that could be extracted from ocean currents is estimated around 800 TWh/year -about 4% of global electricity consumption- (IEC 2011), but currently it is not possible to exploit the most important part of this huge energy potential since most of this energy -about 80%- is concentrated inside areas with depths over 40 meters. Then, it is necessary a second generation of converters capable of extracting this energy from these high depth sites.

At this moment the development of TEC devices for the stream exploitation, is focusing on the first generation devices (King 2009; Myers 2011) that work supported on the sea bottom, and then suitable only for sites with depths below 40 m. Figure 1 shows some prototypes of this kind of devices from hundreds of kW to 1 MW in testing period -Atlantis, Open-Hydro- and one -the Sea-Gen device, of 1.2 MW- working under commercial test stage from July 2009.

Figure 1: Sea-Gen, Atlantis, Morild & Open-Hydro TECs

2. THE GESMEY PROJECT

2.1. Generator Design

The initial goal of GESMEY Project -Spanish acronym from Submarine Electrical Generator with Y shape Framework- was to develop a device specially designed to harnessing the currents of the Strait of Gibraltar. This strait has a very irregular bathymetric profile, with zones between 90 m and 960 m depth in the channel axis (figure 2). 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 goes at a lower level and reverse direction.

There are several places with a “mean spring tide” speed up 2 m/s in the Strait, but normally they are in deep sites, usually over 80 to 100 meters depth locations (Gª-Lafuente 2010).

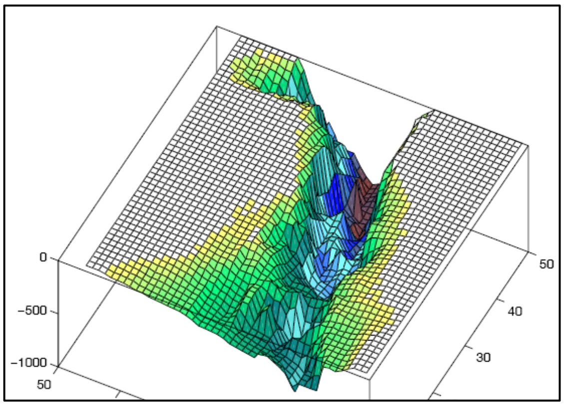

Figure 2. Bathymetric Profile of the Gibraltar Strait

Thus, the main objective of the GESMEY Project was to develop a second generation device with a low life cycle cost, designed for the Strait of Gibraltar and others world sites with water depths over 40 m where the present devices cannot operate. The main goals that the GESMEY design (López 2009) 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 commercial off-the-shelf (COTS) technologies.

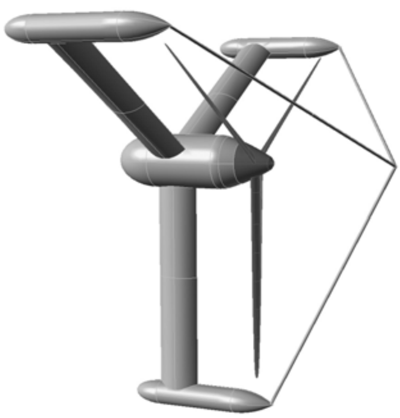

Figure 3. GESMEY Device in Operation State

As a result of the study of alternatives, we choose the design drawn in figure 3. 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,.
- Columns: Main structural parts and ancillary ballast tanks.
- End Torpedoes: Main ballast tanks.

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 (2010).

2.2. Main States of Operation

Under operation, as is shown in figure 3, the device is maintained on position by a mooring systems adapted to the site environmental conditions. By 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 and force produced by the rotor.

For maintenance -when it is necessary to extract the device form water- the procedure is very simple (figure 4). First, removing some water ballast, 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 device floats on sea surface with the rotor outside water (figure 5). The device is self supported for transport.

For the device commissioning or recovering the operation state after a maintenance procedure, it can be used the reverse sequence. The whole procedure will be fully automatized with only a remote supervisory control from the tidal farm control station.

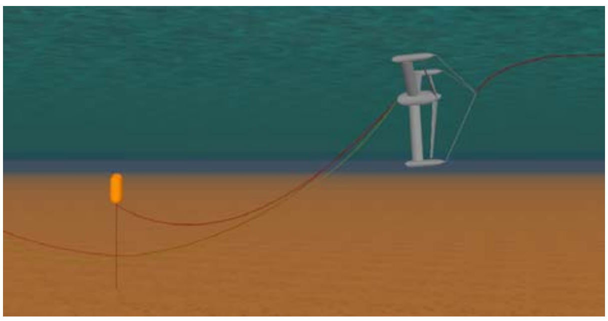

Figure 4. Image of the Emerging Manoeuvre

2.3. Project Development

The “five stages protocol” showed on table 1 (Southampton 2008) for MER converters development has been adopted during the GESMEY Project, and the executed stages are summarized below.

The starting point of the Project was the Universidad Politécnica de Madrid -UPM- patent (López 2007). The Project Stage 1 -named Functional

Definition Phase- was developed between 2008 and 2009 by the UPM GIT-ERM R&D Group on Marine Renewable Energy and the Fundación SOERMAR that is the R&D centre of the private Spanish Shipyards.

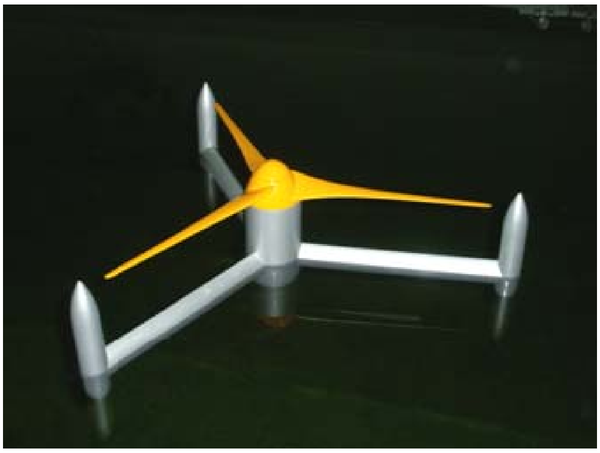

Figure 5. Scale Model of GESMEY Device in Maintenance State.

Table 1: MER Devices Development Stages

Stage	Development Level	Main Tasks
1	Conceptual Design	Explain main concepts and components. Identify R&D needs.
2	Construction Design	Detailed machinery and structure design. Physical tests at middle scale and/or CFD simulation
3	Operation Design	Physical tests at large scale, with integration between subsystems
4	Technical Demonstration Prototype	Full-scale prototype testing at sea
5	Commercial Demonstration Prototype	Full-scale commercial demonstrator testing

As results of this stage various designs adapted to various power and current speed profiles where carried out. The chosen design for 1 MW unidirectional currents -named GSY-U1M- is showed on figure 2. Their main values are summarized on table 2.

During 2010 and 2011 we are developing Stages 2 and 3 of the MRE protocol by a consortium of the UPM GIT-ERM Group, SOERMAR and Balenciaga Shipyard. The main delivery from these Stages will be a 10 kW prototype that will be intensively tested on sea at the end of 2011.

Next prototypes of 100 kW and 1 MW (Stages 4 and 5) are under technical design in order to start their test at 2013. The geographical testing areas have already been selected around the Spanish Coast, where marine currents offer good values and there are high depths where first-generation devices cannot operate nowadays.

Table 2: GESMEY U1M Main Specifications

Nominal power	1.0 MW
Nominal current speed	1.8 m/s
Rotor blades diameter	32 m
Site depth	80 m
Device maximum diameter	38 m
Force over mooring	1.0 MN
Structure weight	80 t
Device weight	140 t
Buoy volume (x3)	200 m^3

3. GESMEY MODELLING

3.1. GESMEY General Modelling

During the GESMEY Project Stage 1, different possibilities for making a computerized tool which facilitates the calculations on operation state 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, weights...- 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.

A special analysis study for the complete mooring system is required and it becomes a specific topic for a 2nd generation TEC design.

Because the effort to make a static analysis tool is similar to the required to develop a dynamical one, both analysis have been integrated together. By this way, the manoeuvres analysis have been carried out in a coupled mode with it, and diverse models and tools have been used for comparing and validating simulation results.

3.2. GESMEY Dynamic Models

A moored TEC is considered a device working in movement with some degrees of freedom, in opposition to the devices rested in the sea bottom in which the main dynamical problem is the fluctuation of the forces in the blades due to the effect of the current's turbulence -fluctuation of the inlet velocity in a blade section- caused by the waves in its upper part and the depth variation (shear effect) in its lower part (Bard 2009). This is why in a moored TEC it is necessary to complement the static analysis with the dynamic effects, at early design stages, which could include:

- The study of the turbulence of the current over the rotor and its transmission through the PTO. This field requires more intensive analysis by hydrodynamics specialists.

- The analysis of the kinematic and mechanical behaviours of the mooring system in static and dynamic regime. This is the more specific case for the moored TECs so it will be analyzed in more detail in the next sections.
- The analysis of the dynamic loads generated in all the structural elements, which can be done with the usual FEM methods and S-N curves (DNV 2008).
- The study of the seakeeping when the TEC is over the sea surface. Tests and tools usually used for the study of offshore structures can be directly applied.
- And last but not least the PTO control. This can be analyzed with usual simulation tools like Matlab and Simulink (Somolinos 2010).

3.3. GESMEY Hydrodynamic Model

There are specific commercial tools for the study of the moored systems, as OrcaFlex (Orcina 2011), developed for the offshore industry, extensively used and validated, and homologated by certification entities, as the Ship Classification Societies.

But, for the usage of these commercial tools the following additional operations are required:

- The modelling of the hydrodynamic aspects of the TEC (drag, lift, added mass).
- The development of procedures for the integration of the simulation and control tools.

A valid method to solve the first of the former tasks is the decomposition of the TEC in a series of elements, which usually have a well defined geometry - cylinders, ellipsoidal prisms, spheres, flat plates, ellipsoids, etc.-, then study the behaviour of each of these geometries separately and finally add their effects.

The same type of tools and models can be used for the study of the manoeuvres of the TEC, including the change from the operation situation to the floating situation and vice-versa but adding a module representing the actuator's effect, usually a change in the volume of some ballast tanks.

Therefore, two mathematical sub-models are necessary: the mechanic and the hydrodynamic ones. Both of them can be developed based on similar ones used in naval architecture design.

For the GESMEY TEC the hydrodynamic model developed is based on the segregation of the device structure into different elements and then the computation of their drags as function of their respective speeds, according with equation (1).

$$Fd = 0.5 \cdot Cd \cdot \rho \cdot A \cdot V^2 \qquad (1)$$

Where Fd denotes the drag of each element, A is its significant surface, V and ρ represents the water speed and density and Cd is the form coefficient.

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 orient along 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 with the definition of the mooring points and the torque from the rotor.

The dynamic equations of the generator with one mooring point (like in the emersion manoeuvre) are obtained from a model with only a point mass concentrated in device c.o.g. The acting forces over the device (figure 6) put the rope in tension, keeping it straight, and producing a torque about its attachment point at sea ground (G), so the basic equation becomes (2).

$$\Sigma Q = I \cdot d^2\alpha/dt^2 + dI/dt \cdot d\alpha/dt \qquad (2)$$

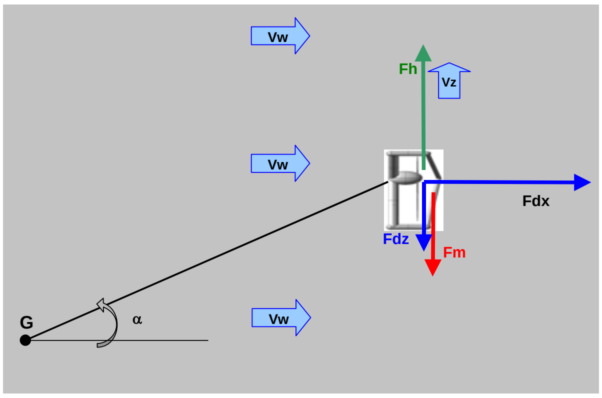

Figure 6. Main Hydrodynamic Forces

Usually dI/dt is very low and then the second term can be neglected, I denotes the device inertia -around G turning point-, α the rope's angle and ΣQ the sum of the turning torques caused by the input forces on the devices If vertical forces (Fz) an horizontal ones (Fx) are grouped and L denotes the length of the rope. ΣQ can be written as (3).

$$\Sigma Q = - L \cdot Fz(t) \cdot \cos\alpha(t) - L \cdot Fx(t) \cdot \sin\alpha(t) \qquad (3)$$

The horizontal force is related with the structure and rotor drag of the device and it can be calculated from equation (4). Vertical forces are equal to the net buoyancy -volume mass minus weight- plus the drag due to the vertical motion as is expressed in (5).

$$Fx = Kdx \cdot |Vw - Vx(t)| \cdot (Vw - Vx(t)) \qquad (4)$$

$$Fz = Mg \cdot g - Vg \cdot \rho \cdot g - Kdz \cdot |Vz(t)| \cdot Vz(t)) \qquad (5)$$

Where Kdx and Kdz denotes the hydrodynamic drag coefficients, Vw the water current speed, Vx and Vz the device horizontal and vertical speeds, Mg and

Vg are the generator mass and volume, ρ is the water density and g the Earth gravity.

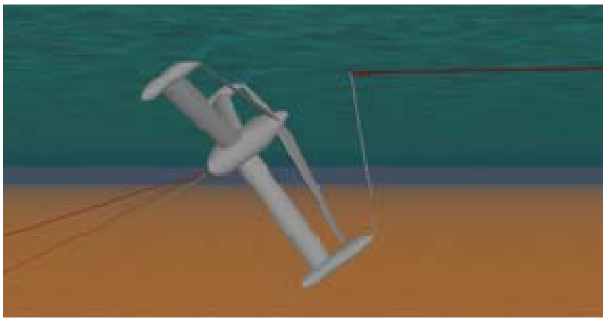

Figure 7. GESMEY Self-rotation State

4. GESMEY SIMULATIONS

4.1. Manoeuvres Aims

As it was said in section 2, one of the keys to the success of the GESMEY generator is the simplicity of their manoeuvres for installation, maintenance and decommissioning. As an example, the emersion process to bring up the generator to the sea surface for the periodical maintenance includes the following steps:

- On operation, the device is maintained on position by the mooring system and by controlling the ballast level.
- When the “stern rope” is detached and some ballast removed, the device goes up to surface smoothly (figure 4).
- When it reaches the sea surface a new change on ballast tanks produce a self-rotation (figure 7).
- Finally the device floats on sea surface with the rotor outside, ready for first level maintenance or transport (figure 5).

4.2. Model Validations

Based on the results of the HACERIC tool, the two-dimensional model resumed in section 3.3 was tested using Simulink (Somolinos 2009), by supposing a virtual rigid fitting cable with negligible hydrodynamic properties, modelling the global mass and the drag forces in the two main directions and neglecting the device turn (minimum in the step 2).

By comparing the results of this first simulation with the obtained with OrcaFlex, the main differences were observed when the TEC was reaching the surface, appearing also differences in the oscillation periods.

That is why it was decided to do a more detailed study of the hydrodynamic behaviour -drag and added mass- (White 2006; Korotkin 2007), of the generator structure and make some tests in a towing tank, with the model showed of figure 5.

Finally, by applying the results of this study to the simulations done for a basic case with Simulink and OrcaFlex, and with some parameter fitting the simplest model was adjusted with a precision of 1% in the submerged phase and 5% on the surface, so the model can be validated considered, waiting for the final calibration based on experimental tests.

4.3. Simulation Results

A brief comparison between the obtained results from Simulink and OrcaFlex for the emersion process of a simple body, with the refined hydrodynamic model, is shown in figure 8. The added masses for this model are different from those on a ship and their calculation required an important and novelty effort.

It can clearly observed from this figure, that both simulation results begin from the same 50 meters depth at the initial time of t = 0 seconds. Both time responses offer a similar rise time of about 72 seconds, been the obtained results from OrcaFlex -when added masses and hydrodynamic effects of the structure are better modelled and considered- a little faster than the obtained results from Simulink (simplest model). The same effect of this slightly faster response can be appreciated if the frequencies of the oscillations part of the whole responses are analyzed.

The reasons of these small discrepancies can be justified in base of the difficulties for modelling partially submerged bodies. The method can be improved by using RAOs methods, but the obtained results are considered of enough precision, because in practice the waves’ effects, even for the lower waves, will be more important than the natural oscillations passed the first two or three cycles.

The good agreement between both simulation responses obtained with different tools as Simulink and OrcaFlex justifies the goodness of the dynamic models that have been used, and confirms the feasibility previous to experimental testing with a real prototype. Both responses exhibit non linear oscillations with similar amplitudes and small damping factors which correspond with the water-air interaction of the generator in the final stage of the emersion manoeuvre.

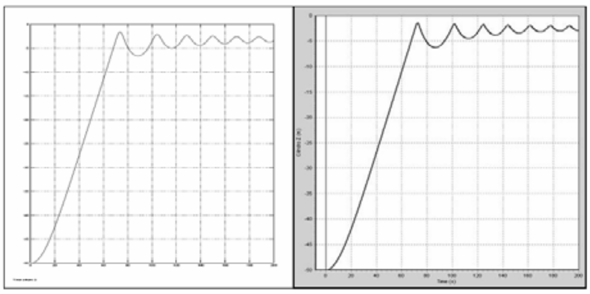

Figure 8. Simulated Dynamic Response from Simulink and from OrcaFlex

Finally in the figure 9 the trim angle -red- and the depth of the centre of gravity -green-, obtained from the simulation of the turning phase, are shown. These curves correspond to the initial tests of the ballast control system, and they show that the self-rotation is very fast when passed a critical angle with some post-critical point's oscillations.

As result of these simulations, it is necessary to design a robust ballast control system based on the obtained dynamic model that allows performs smooth manoeuvres without any kind of human intervention. Currently a 1/10 scale model for testing at sea -inside the project stage 3- is being built in order to perform validation procedures based on extended experimental tests, and a good match between simulation models of diverse complexity level and real measured responses is expected..

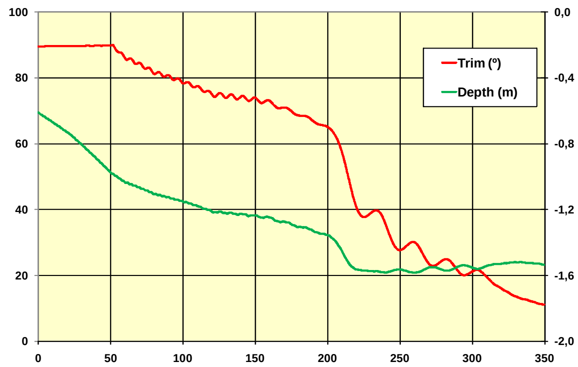

Figure 9. Surface Turn Simulation Results

5. CONCLUSIONS

This work has shown the state of development of the TECs, the tools used for their design and analysis, and how these problems have been solved in the particular case of the GESMEY generator.

Also has showed that it is necessary a new generation of converters capable of extracting energy of currents from sites with a depth over 40 m.

The design of the GESMEY generator properly achieves their proposed objectives, being one of the more promising generators of the second generation.

The study of the dynamic problems is an especially important challenge. More detailed studies are needed, especially in the fields of the hydrodynamic and manoeuvring control.

The preliminary results from GESMEY simulations with different models and tools show a good agreement of manoeuvring results.

It is convenient to complete these studies of the turning movements with higher scale models, in order to check the interaction between the ballast control system and the movements on the surface.

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