PREPRINT

EVALUATION OF WAVE ENERGY FOR A NEAR-THE-COAST OFFSHORE DESALINATION PLANT

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Abstract

This paper presents the design of a renewable energy offshore desalination plant currently under preliminary development. The purpose of the installation is to test the feasibility of producing drinkable water using renewable energies in offshore installations. This is proposed, as an alternative for those locations where the land use, the civil engineering works and the environmental impact make a land-based solution inadequate. The proposed system is composed of a primary energy source (wave energy), which provides electricity to a marine reverse osmosis plant, that adapts its production to the available energy, balancing production and demand using an external grid.

I. INTRODUCTION

Offshore desalination plants powered by renewable energies are currently under study in several parts of the world as an alternative for a coastal desalination facility, for those locations where the lack of suitable land makes a land-based desalination plant inadequate. This paper studies a proposal to use an offshore wave platform currently under development as the sole energy source of a reverse osmosis (RO) plant to produce drinkable water that is then transported through pipes.

Renewable energy is the main source of energy, so a central problem would be balancing the energy consumption with the energy production: as energy production is variable, the RO plant has to be designed with variable production in mind [1,2]. The proposal presented here is based on dividing the RO plant in a few sections, that would be switched on or shutdown, depending on the available energy following the ideas for hydrogen production presented in [3]. The discrepancies between production and consumptions would be balanced using a external grid (the objective is to minimize the use of this external grid). In a parallel paper [10] an off-grid approach is being tested.

The process diagram shown in Figure 1 incorporates the main blocks of our proposal: the renewable energy source, the seawater pumps, the desalination units and the transfer pumps. Managing these components requires a specific control system, which is discussed later.

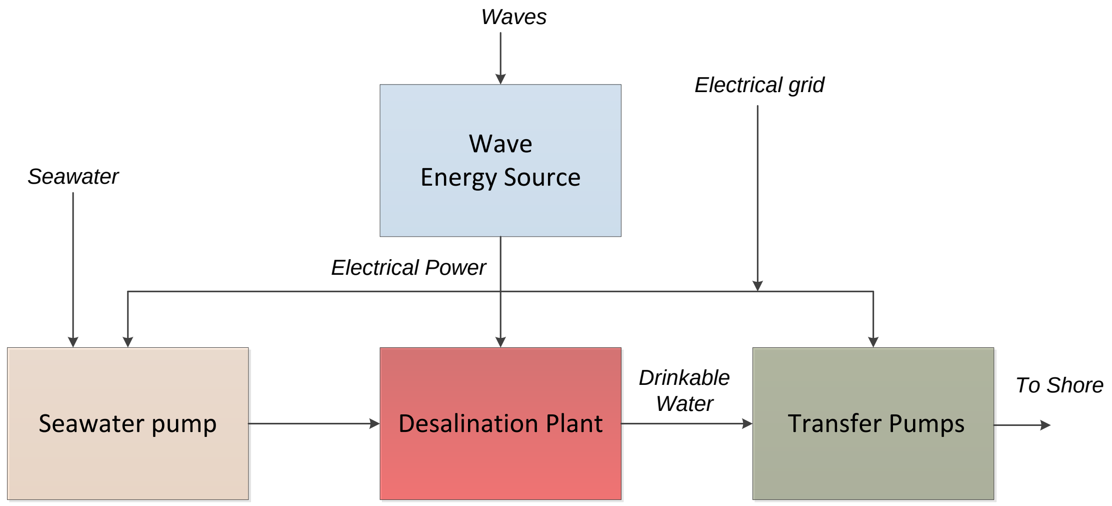

Figure 1: Process diagram of the near-the-coast offshore desalination system

II. DESALINATION PLANT OPERATION

As it has already been mentioned, renewable energy production changes with time, which requires adapting the production of water (and thus the power consumption) to the available power. This is challenging for desalination plants, as they are normally designed to operate at an optimal working point, without using frequency variators [4].

Changing the working point of the plant (thus, changing the flow/pressure combination from the nominal one) makes possible to adapt the RO electrical load to the demand, but this gives a reduction in efficiency. Moreover any shutdown of sections of the plant requires specific cleanings, which reduces the overall production. To overcome this difficulty in this project it was decided to partition the high pressure part of the RO plant in three sections (A, B and C): All the sections operate as a standard RO plant (producing water with maximum efficiency, at a fixed working point). A specific control system, discussed later would be responsible of adapting power consumption to demand, trying to operate always the overall plant at the best possible efficiency.

As an example, the proposed structure of a desalination plant designed to operate consuming between 95kW and 575kW of electricity is shown in Figure 2: section A is designed to produce 150m3/h, whereas section B produces 0m3/h, and C around 40m3/h.

In addition, there is one seawater pump (SWP) that provides water from the seawater intake to the seawater tank. The pump works with a power of 160kW and a flow rate of 250m3/h. This pump is an on-off pump that works or not while the tank level is between certain values: if the tank level is higher than a security value, the pump immediately switches off. Thus, the tank level can be controlled as will be detailed in section 3.

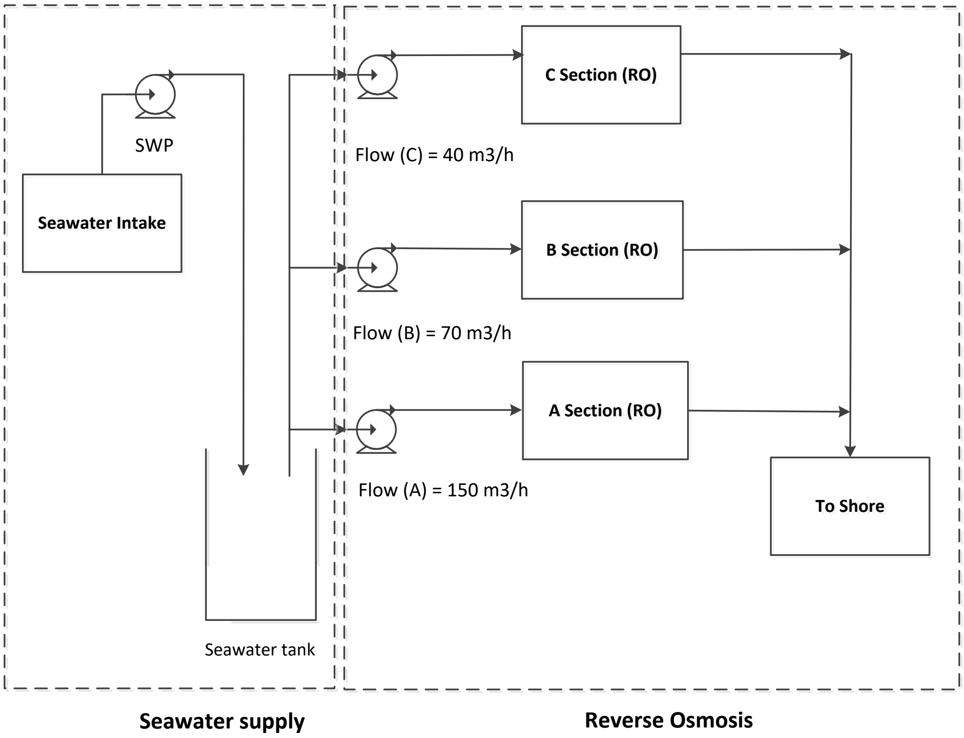

Figure 2: Structure of proposed desalination plant

III. CONTROL SYSTEM

A central component to ensure smooth operation of the facility is the control system that should balance electricity production and consumption, by adapting the consumed loads: power of the seawater pump (SWP) and the pumps working in the different sections of the RO. It is assumed that the control system is based on the two following ideas:

i. One control variable is the connection/disconnection of the different sections A, B and C in the RO (See Figure 3).
ii. Different sections of the RO are switched on/off depending on the amount of energy produced. Each section operates in a certain range of energy available (see Figure 4).
iii. Another control variable is the connection/disconnection of the SWP: this pump operates independently of the RO plant:
    a. When the level of the seawater tank is higher than a certain safety value, the SWP switches off.
    b. When the level of the seawater tank is lower than a certain safety value, the SWP switches on.

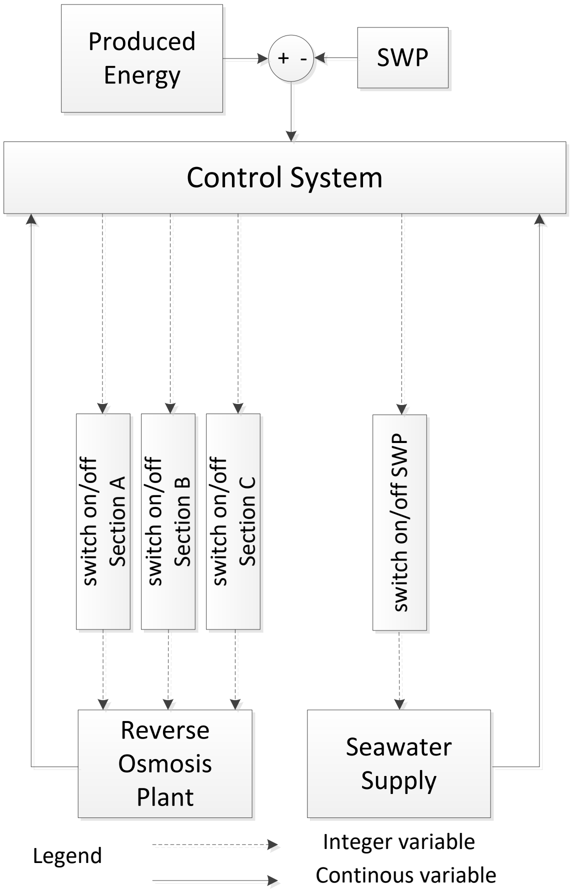

Figure 3: Proposed control

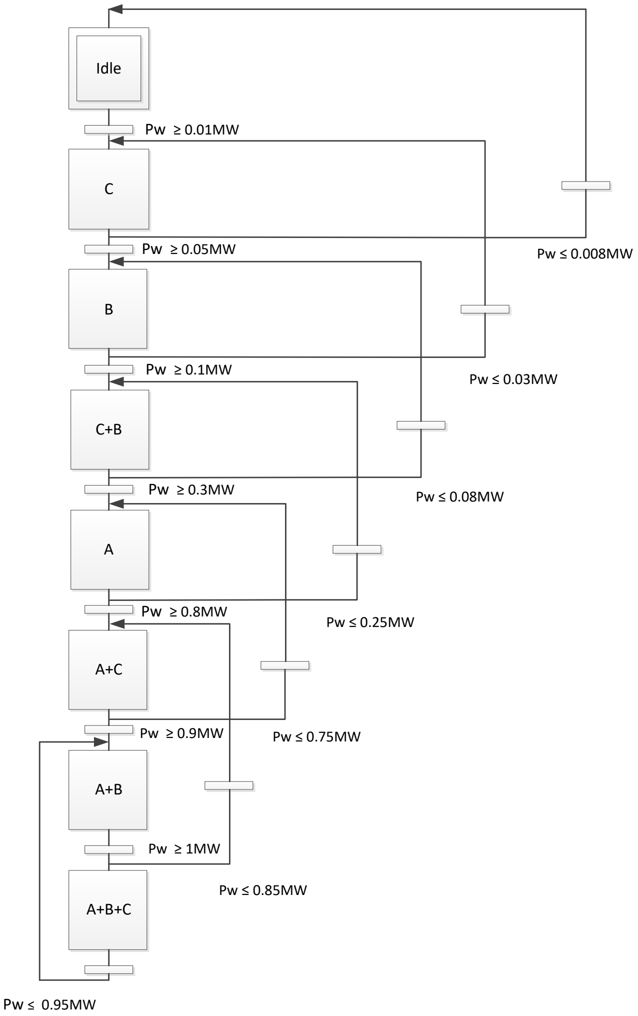

Figure 4: Sequential Function Chart of the Control Logic of the RO

IV. WAVE CONVERTERS

The number of companies that design a device capable of exploiting wave energy is increasing every day. The electrical power generated by a wave energy converter (WEC) is determined by its characteristics and the wave weather in the location [5]. We assume here the use of a multibody floating WEC; the energy is extracted by the relative motion of different parts of the structure. These devices are adequate for in deep water (>40m) [3]. More precisely, the device used is a floating heave-buoy array (F-HBA), which is represented in Figure 5. It is a multibody floating WEC, composed of many heaving buoys connected to a common reference structure. This structure is composed of an arrangement of a single support structure and a series of ballast baskets, connected through tension wires. The total buoyancy force from the buoys is balanced by net gravity forces of the bridge and the ballast baskets. The buoys are connected to the submerged structure via a hydraulic Power Take-Off (PTO) system, which converts the mechanical energy of the device into electricity. In the case of wave activated body WECs, they can be based on hydraulic components (hydraulic rams and motors) combined with an electrical generator [6], or they can be fully electric [7,8]. The second proposal was assumed in this work due to the special conditions in offshore plants. The microgrid designed in this paper has shedable loads (RO sections and SWP), so the consumed power adapts to the varying input power. The battery controllers ensure the needed grid regulation. One of the key points in the structural design and energy extraction capacity of the device is the response to different periods and wave heights (Figure 6). To evaluate the energy produced by the WEC, water waves are considered to travel along the surface of the sea with an approximate sinusoidal profile, characterized in terms of the time between successive crests and the size of these crests [9]. Wave height and period are represented by statistical measurements, the most common being the significant wave height, Hs(t) (around four time the root-mean square of the surface elevation during a given window), and the wave period Tp(t). The devices have a maximum range of operation: The energy that can be used by a device is limited to a maximum wave height and a minimum wave period. Multiplying the WEC power matrix (Figure 6) by the buoy-measured data of the sea location, the mean absorbed power during a specific time period of the device can be derived.

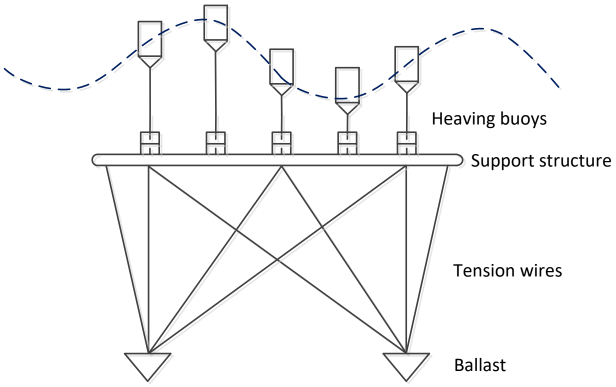

Figure 5: Scheme of the WEC

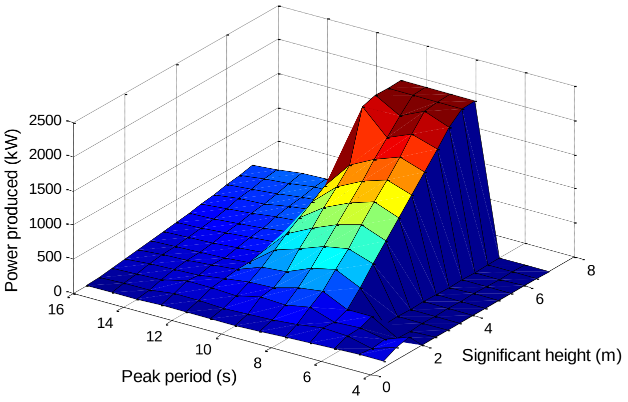

Figure 6: Wave converter transfer function.

V. NUMERICAL RESULTS

To validate the proposed offshore platform and the sizing methodology, a case-study was carried out for a specific location, selected by its good wave regime. For this location, buoy data was measured for days (wave heights, periods, water salinity and temperature, etc.). Based on this data a platform was designed using the proposed sizing methodology. This design was then tested assuming different platform parameter. Some preliminary results for 165 days are shown in Figures 7 to 12, with the detail results for 20 days presented in Figures 13 to 18.

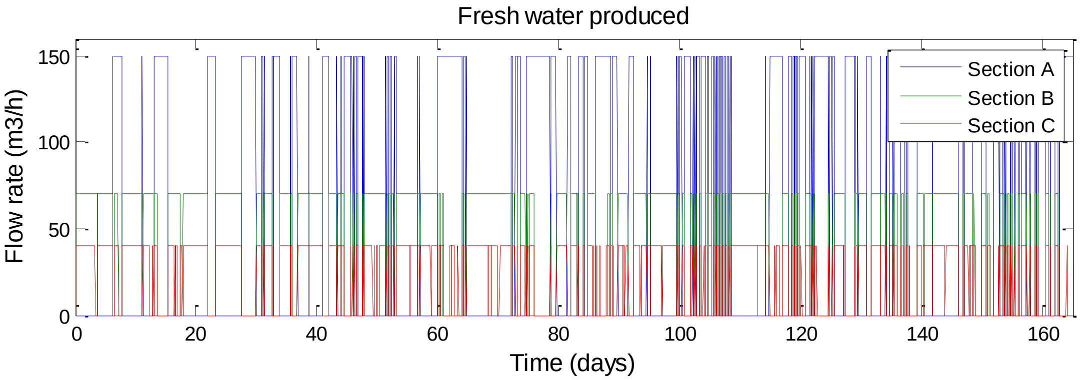

Figure 7: Fresh water produced

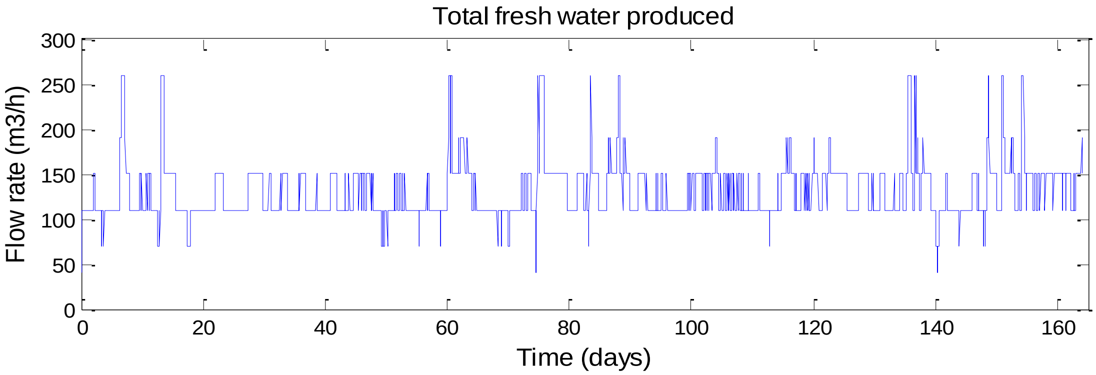

Figure 8: Total fresh water produced

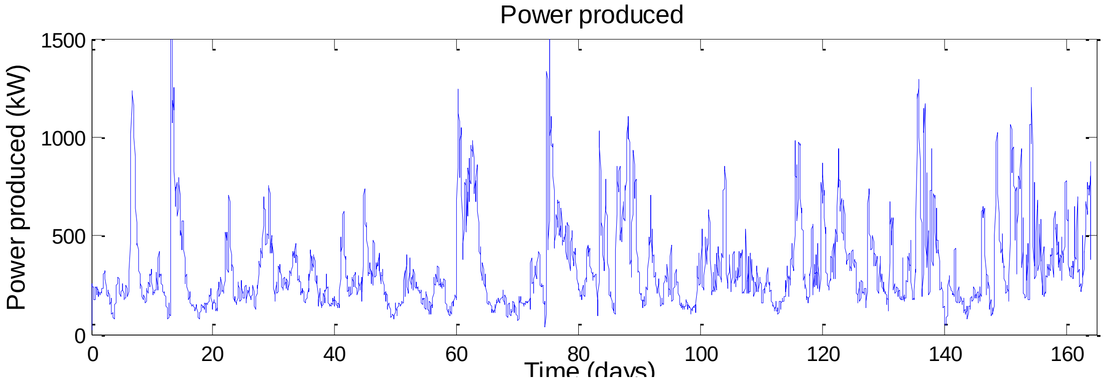

Figure 9: Power produced

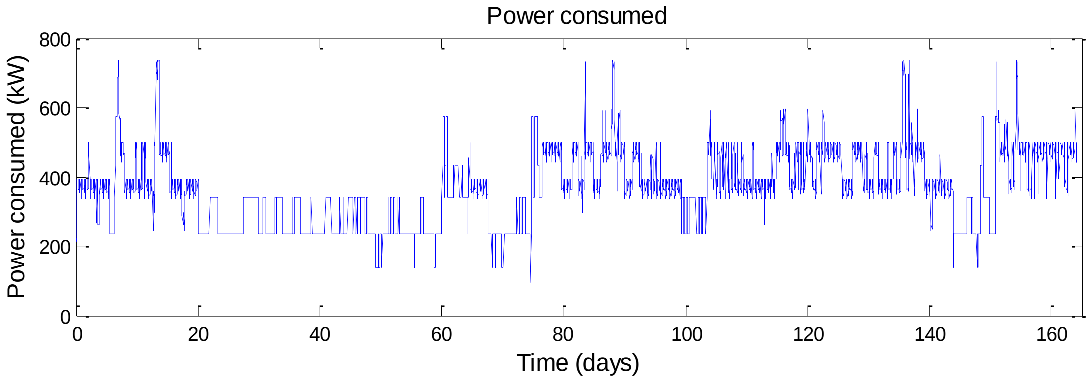

Figure 10: Total power consumed

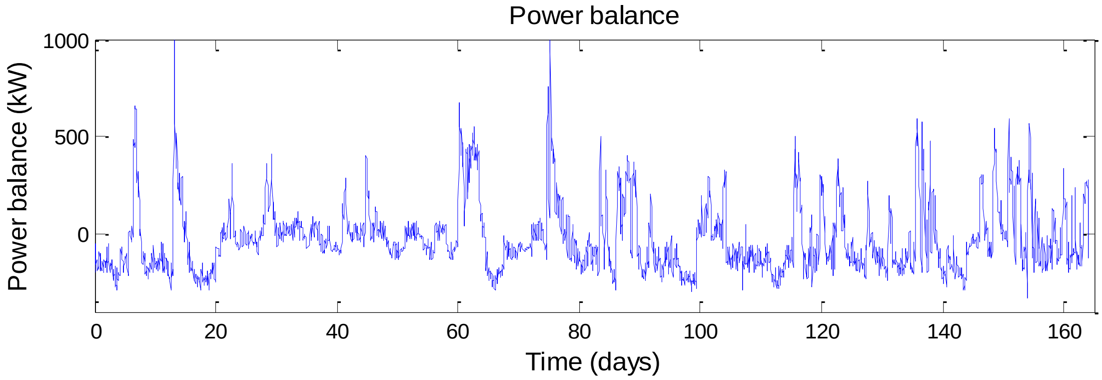

Figure 11: Power balance

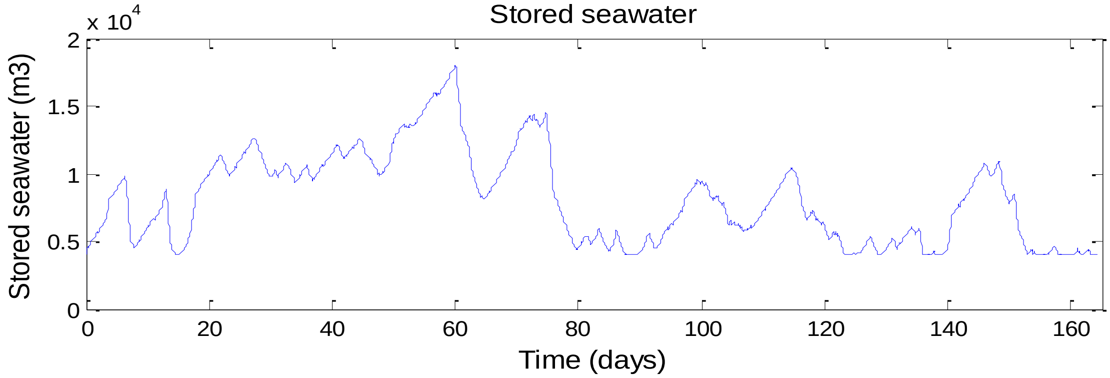

Figure 12: Stored seawater

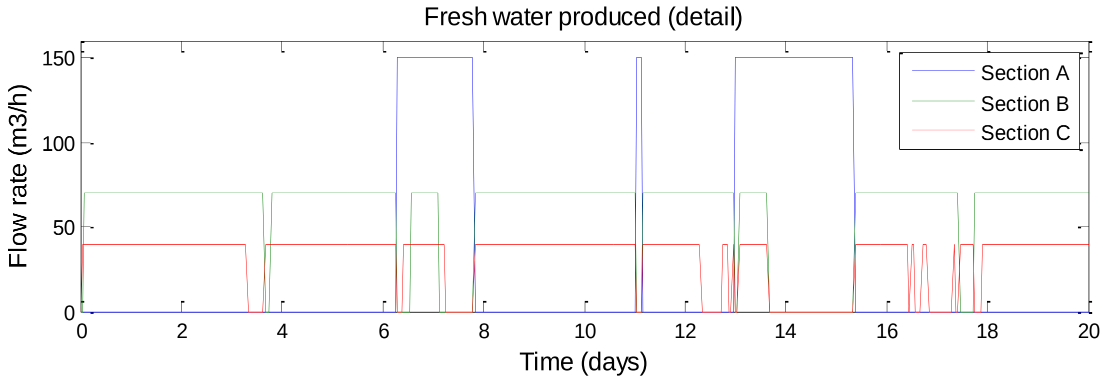

Figure 13: Fresh water produced (detail)

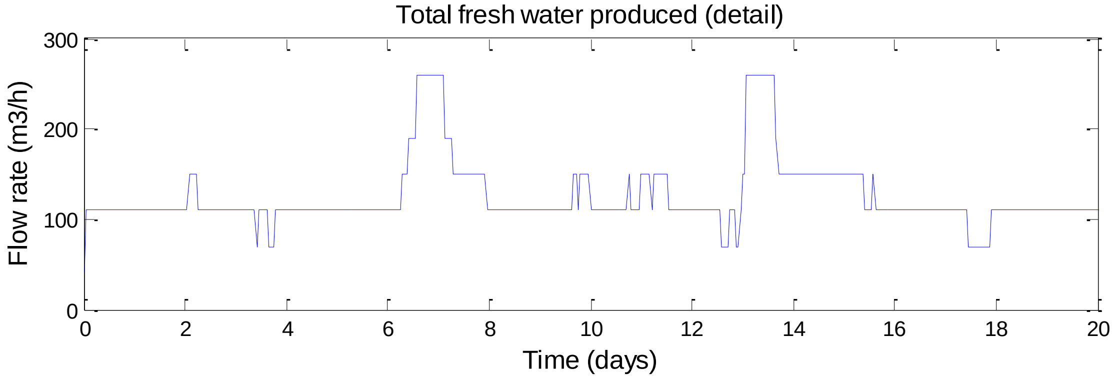

Figure 14: Total fresh water produced (detail)

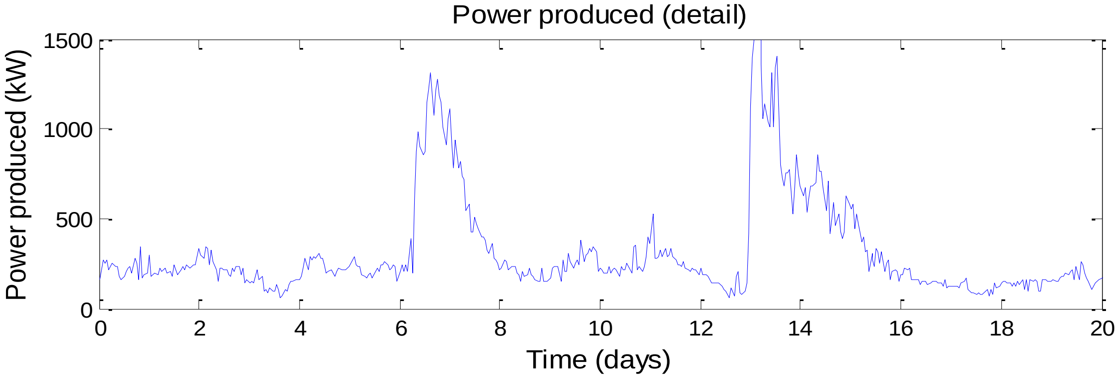

Figure 15: Power produced (detail)

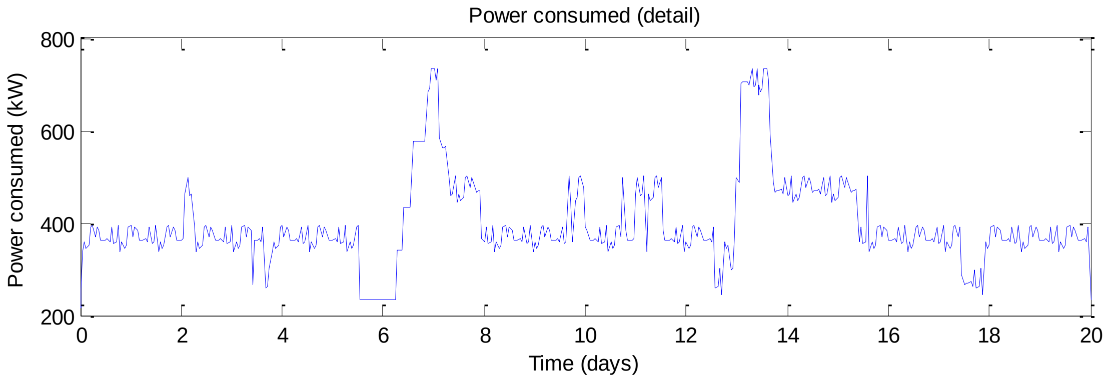

Figure 16: Total power consumed (detail)

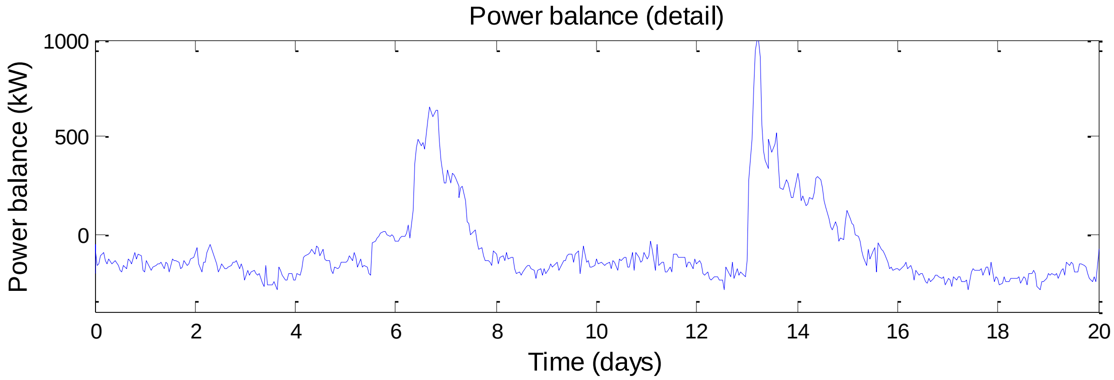

Figure 17: Power balance (detail)

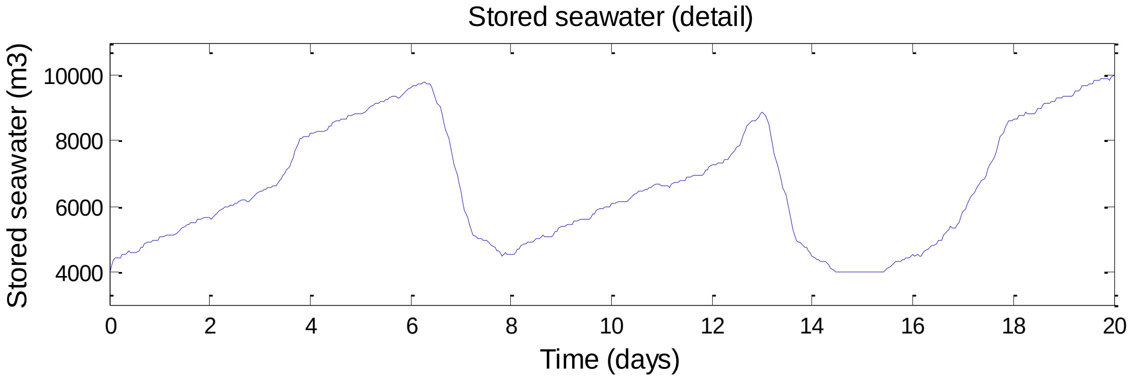

Figure 18: Stored seawater (detail)

The evaluation during 165 days using the buoy measured data confirms a mean production of 122m^3/h (2.4 Kwh/m^3 of freshwater): 94.5% of the power is used by the RO pumps and 5.5% by the SWP. Table 1 presents a summary of the monthly average of water and energy produced and consumed.

Table 1: Monthly averages of water and power

Fresh water (m^3/month)	Power produced by the WEC (MWh/month)	Power consumed by the RO pumps (MWh/month)	Power consumed by the SWP (MWh/month)
87980	246.2	201.8	11.70

VI. DISCUSSION

A proposal for a renewable energy offshore desalination plant has been presented, that will be used to test the feasibility of producing drinkable water in offshore installations. The presented system is composed of a wave converter which provides electrical energy to an independent marine reverse osmosis plant, which adapts its consumptions to the energy produced. In this paper a connection to the grid is assumed, in order to balance production with consumption.

To demonstrate the feasibility of the proposed platform, this proposal has been evaluated for one specific location, using buoy-measured data for sizing the proposed platform at this location. The selected design was then evaluated in terms of water production and evolution of the platform parameters, showing how the proposed design methodology makes possible to desalinate water in a sustainable way. Further work must be done to optimize the sizing of components based on an advanced control system and to design an evaluation of costs and risks validating in different locations.

VII. ACKNOWLEDGEMENTS

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Keywords: Reverse Osmosis, Sustainable Desalination, Marine Desalination.

VIII. REFERENCES

1. Tadeo, F., del Val, R., Palacin L., de Prada, D., Salazar J. Control of reverse osmosis plants using renewable energies, control and application. Proc. UKACC’09, Cambridge, UK, 2009.
2. Seibert, U., Vogt, G., Brenning, C., Gebhard, R., Holz, F. Autonomous, desalination system concepts for seawater and brackish water in rural areas with renewable energies. Desalination, vol. 168, pp. 29-37, 2004.
3. Serna, A., Tadeo, F. Offshore hydrogen production from wave energy. International Journal of Hydrogen Energy, in press: dx.doi.org/10.1016/j.ijhydene.2013.04.113, 2013.

4. Palacin, L., Tadeo, F., de Prada, C., Elfil, H., Salazar J. Operation of desalination plants using hybrid control. Desalination and Water Treatment. Vol. 25, pp. 119-126, 2011.

5. Babarit, A., Hals, J., Muliawan, M.J., Kurniawan, A., Moan, T., Krokstad, J. Numerical benchmarking study of a selection of wave energy converters, Renewable Energy, vol. 45, pp. 44-63, 2012.

6. Henderson, R. Design, simulation and testing of a novel hydraulic power take-off system for the Pelamis wave energy converter, Renewable Energy, vol. 31, no.2, pp. 271-83, 2006.

7. Eriksson, M. Modelling and experimental verification of direct drive wave energy conversion –Buoy-generator dynamics, PhD thesis, Uppsala Universitet, Sweden, 2007.

8. Ruellan, M., Ben Ahmed, H., Multon, B., Josset C., A. Babarit, A., Clément, A.H. Design methodology for a SEAREV wave energy converter, IEEE Transactions on Energy Conversion, vol. 25, no. 3, pp. 760-7, 2010.

9. Thorpe, T.W. A Brief Review of Wave Energy. A report produced for the UK Department of Trade and Industry, ETSU-R120:24-25. Harwell, UK. 1999.

10. Serna, A., Tadeo, F., Offshore desalination using wave energy, Advances in Mechanical Engineering vol. 2013, Article ID 539857, 8 pages, 2013.