DEVELOPMENT OF A FLOATING WIND-DESALINATION MULTI-USE PLATFORM (MUP) IN THE CONTEXT OF OPTIMAL USE OF MARITIME SPACE

A. Stefanakou*, I. Dagkinis*, T. Lilas*, A. Maglara† and A. Vatistas†

*Dept. of Shipping Trade & Transport, University of the Aegean, Greece
† Ecowindwater ltd., Greece
sttm10028@stt.aegean.gr

Keywords: Offshore autonomous desalination, offshore floating wind turbine, multi-use platform, environmental friendly reverse osmosis, compressed air energy storage.

Abstract

Water scarcity is a major problem in many islands. The aim of this paper is to further enhance a pilot technology, which utilizes wind and solar energy to desalinate sea water in order to develop a proof-of-concept design for a fully integrated multi-component and multi-use platform in order to exploit ocean resources in a sustainable way for the production of drinking water and/or electricity under various configurations. The ability of the system to adopt multiple configurations means that it can be tailor made to the specific requirements in different areas. The main idea of the project was to find an economic and ecological solution for the producing drinking water and/or electricity with energy provided by a wind generator and a photovoltaic system, for the water stressed islands of the Aegean by integrating a desalination unit with wind power and photovoltaic panel in the same floating structure. Also, as well as the floating structure is made of steel pipes, it can safely be used as compressed air storage tanks for pressures up to 80 bar. Alternative design combinations of offshore wind turbine together with photovoltaics, desalination unit, compressed air storage and grid connection are presented in order to meet different requirements.

1 Introduction

Fresh water and energy are two inseparable and essential commodities and their scarcity is a major problem that needs to be efficiently solved. Unfortunately, many countries in the world that lack freshwater sources are also deficient in energy sources. Desalination is an alternative technology for water production based on salt separation from water. However, the energy requirements for that process are high and can be a problem, mainly in isolated areas. Renewable energy sources are the best way to supply energy needs [1]. Although, as desalination technologies are energy intensive, they would be appropriate in areas where: there is no alternative (islands), cost of other resources are high (transportation costs), low-cost energy is readily available (Middle East oil-reach countries), and high living standards override the cost factor (the case of tourism) [2].

An innovative solution for arid but windy and sunny areas is described in this paper. The main idea for the development of the prototype floating platform was to find an economic viable and ecological solution for producing drinking water and/or electricity under various configurations. The ability of the system to adopt multiple configurations means that it can be tailor made to the specific requirements in different areas. The energy is provided by a wind generator and a photovoltaic system, suitable for water stressed islands of the Aegean Sea by integrating a desalination unit with wind power and photovoltaics on the same floating structure. Energy storage in batteries is kept to a minimum as water production is variable and follows available renewable energy. Also potable water production can be seen as a form of renewable energy storage. Also, as well as the floating structure is made of steel pipes, it can safely be used as compressed air storage tanks for pressures up to 80 bar. This pressure is compatible with desalination unit operating pressure and simulation shows that it is possible to significantly increase water production by utilizing compressed air energy.

The system incorporates a number of innovative characteristics regarding the integration of the different components. Innovation lies in the engineering of the floating platform harmonized with the operation of the wind turbine, as well as the improved energy management in the desalination process. The reverse osmosis chemical-free desalination system ensures compliance with EU's water directives and contributes to cost reduction due to low maintenance and in the absence of chemical waste disposal.

The system has good survivability, cost-effective and stable floating design with low cost benefits realised at assembly, transport & installation, O&M and decommissioning stages. Also, it demonstrates a multiple use of space and infrastructure, as both potable water production and electricity production with storage are collocated sharing the same marine space, operating with fully integrated technologies on the same platform, which complies with the EU's Maritime Spatial Planning targets [3]. The ability to supply energy and fresh water sustainably the floating offshore platform system is also possible to optimize design in order to engage and support other sectors such as tourism, leisure, offshore aquaculture in the future.

2 Description of the concept

From an operational point of view potable water is produced from seawater desalination unit, which requires energy. This is provided by the wind generator and the photovoltaic systems. Management system controls the operations and also handles safety issues. The main energy is a wind generator. The reason is that Aegean islands are windy in general and second PV energy is more expensive per kilowatt. Therefore, PV modules provide smaller power contribution and mainly operate as an auxiliary source. Energy management is crucial and has three main targets: (a) System survival in case where there is prolonged period without significant energy input. This means that the system will always be able to perform crucial operations and never leave critical systems without energy. (b) Extract as much energy as possible from wind and maximize water production. (c) Reduce maintenance costs and problems, mainly for batteries and desalination unit components such as pumps, filters, membranes. Research has focused on: (a) optimizing energy efficiency of desalination unit over a wide range of water output according to available power from renewable sources, (b) environmental friendly operation without any chemical additives, (c) design of the floating structure so that it is stable, not affected by wind and waves in all weather conditions, so that it provides safe operation of all components, (d) suitable modifications of wind turbine components for standalone operation, (e) design of the electrical interconnection, (f) design of control and teleoperation system. In the next paragraphs each subsystem development is presented.

2.1 Floating structure

The development of the floating structure in order to fulfil controversial requirements went over the following phases: (a) Survey studies worldwide for floating wind turbines and state of the art. [4, 5, 6] (b) Design of feasible solution that can fulfill the requirements. (c) Optimization of design characteristics to improve performance and reduce cost. (d) Final stability study and load analysis of optimized design. The optimization goals were to minimize movements and loads from waves, improve the operation conditions for the wind turbine and withstand extreme weather conditions. Simulations programs like Sesam, Wamit, Ansys, and Abaqus have been examined. First optimization step was to examine the shape of the structure and then modify critical dimensions. Then we examined the influence of several characteristic dimensions of the floating structure to the natural periods of the structure. Optimization results and final design study concluded to the following dimensions of the platform: platform radius 14.5 m, central floater diameter 4 m, peripheral floater diameter 2m, height 8m.

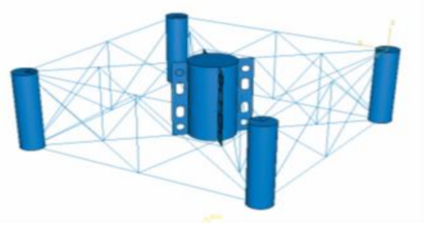

Figure 1: Floating structure

The connections of all floaters takes place with a tubular mesh with pipe diameter of 273 mm and wall thick-ness of 8.8 mm. There are peripheral and central mesh connections as shown in figures 2 and 3.

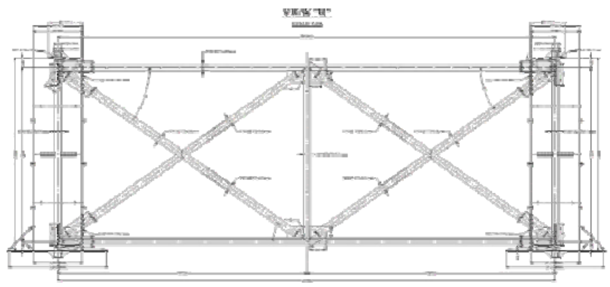

Figure 2: The side tubular mesh

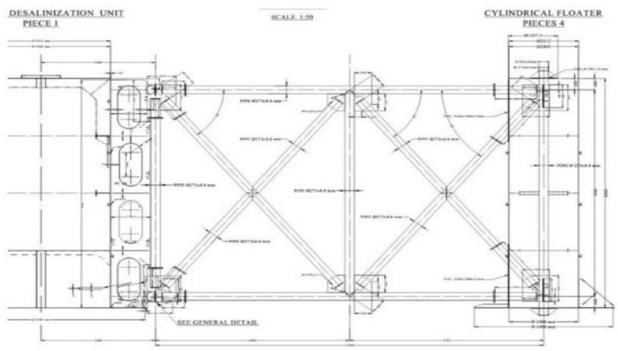

Figure 3: The inner connection between the peripheral and central floaters.

The floating structure hosts all components and supports the wind turbine and photovoltaic panel. Internally, it includes: (a) a control room, which holds electrical power components and control equipment, (b) a machine room, which holds reverse osmosis equipment and pumps and (c) a fresh water storage tank.

2.2 Wind turbine

Wind turbine, which is placed in the central floater, is the main power component with 32 Kw and operates at varying rotational speed. The generator is multipole with permanent magnets and therefore it does not have a gearbox between the hub and the generator. The power curve is kept constant above 13 m/sec. This configuration enables start up with requires only minimal power for the control electronics and pitch adjustments.

2.3 Photovoltaic system

The photovoltaic system has 10 Kw capacity. The output voltage is DC and becomes 3-phase 380V AC through an inverter.

2.4 Desalination unit

The desalination unit has been adjusted regarding cost effective uses [7, 8]. Reverse osmosis has been adapted to operate with varying power, adjusting flow and pressure, using in this way almost all available wind power. Therefore, depending on wind speed when more power is available more potable water is produced. There is a significant variation in production from 1 cubic meter per hour to 3.5 cubic meter depending on available power and salinity. Studies were carried out in order to adjust operational parameters in order to minimize fouling and scaling effects on membranes without chemical treatment of incoming seawater [9]. All motor pumps are driven by inverters in order to adjust gradually all operating parameters. In this way it is possible to experiment on different operating parameters and adjust them.

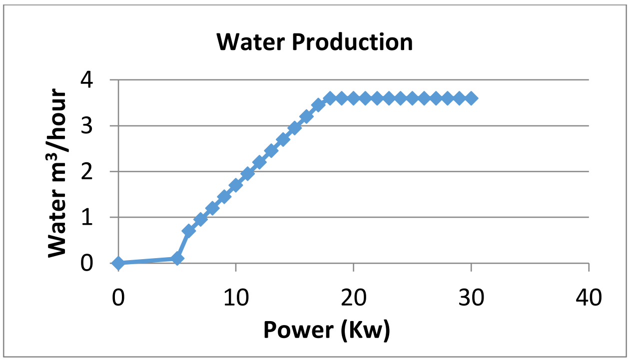

Figure 4: Water production energy requirements

2.5 Energy storage

Energy storage in batteries is kept to a minimum as water production is variable and follows available renewable energy. Also potable water production can be seen as a form of renewable energy storage. Nevertheless, the floating structure is made of steel pipes, which can safely be used as compressed air storage tanks [10] for pressures up to 80 bar. This pressure is compatible with desalination unit operating pressure and simulation shows that it is possible to increase water production by utilizing compressed air energy. The compressed air inside a storage tank, can serve as an energy source to drive the RO system and also dampen the fluctuations caused by the stochastic nature of the wind.
In the first stage, feed water is pumped inside the pre-charged pressure vessel of 40 bar, so that the gas inside the pressure vessel is compressed, which increases the pressure inside the vessel. In the second stage, when the pressure reaches 60 bar then pressurized feed water is discharged into the RO membrane unit. If pressure reaches 75 bar, then water pumping is reduced and matches water production. In case pressure increases further water pumping stops at 80 bar. The advantages of the compressed air system are that the desalination process is less affected from fluctuating wind energy and start-stops are reduced. The pressurized feed water is discharged in a controlled manner and stops when the pressure drops to the lower limit of 40bar.
For the basis of comparison, the system with compressed air energy storage mechanism was modeled in order to estimate the improvements. The water production increased in periods with high variation in wind speed. These irregularities included extreme fluctuations in wind patterns and periods of very low wind speeds. The available volume is 50m3 and the compression of air slow so the process is considered isothermal. Heat is dissipated in environment during compression and heat is absorbed from sea during expansion.

It may be assumed that the compressed air obeys the ideal gas law,
p V = n R T = constant
From a process from an initial state A to a final state B, with absolute temperature T = T A = T B constant, the work required for compression (negative) or done by the expansion (positive), is

$$W_{A\to B} = \int_{V_A}^{V_B} p dV = \int_{V_A}^{V_B} \frac{nRT}{V} dV = p_A V_A ln \frac{p_A}{p_B}$$

where $p_A V_A = p_B V_B$
Here, p is the absolute pressure, V is the volume of the vessel, n s the amount of substance of gas (mol) and R is the ideal gas constant. Therefore, the energy that can be stored is:

State A: $p_A = 40\ bar$
V_A=50 m³
State B: $p_B = 80\ bar$

$$W_{A\to B} = p_A V_A \ln \frac{p_A}{p_B} = 138.63 \text{ MJ}$$

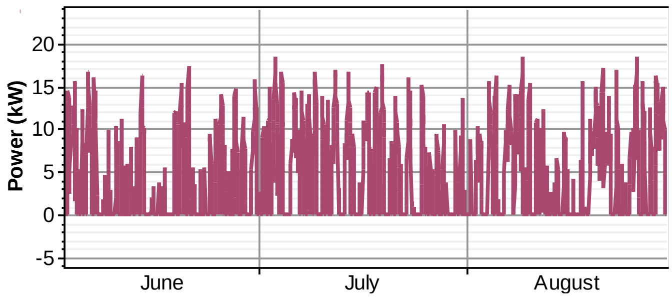

Figure 5: Excess electricity that is not utilized without compressed air energy storage system

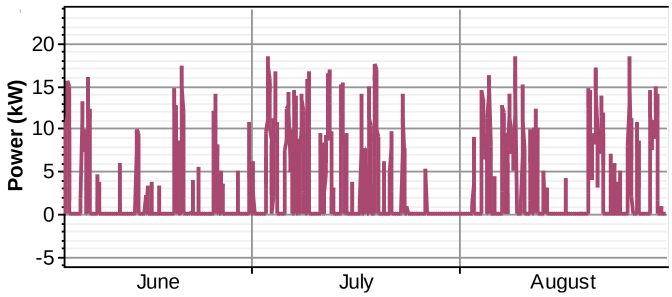

Figure 6: Excess electricity that is not utilized with compressed air energy storage system

Also, a model was developed with an *energy storage tank*. The results from this model suggested that such a system is a feasible option to account for variability in the wind patterns and less electricity is not utilized for water production. The main conclusion was that with an *energy storage tank* the system was able to provide 9% more water.

Figure 7: The Multi-use platform

3 Alternative design combinations of MUP

As has already been mentioned, the ability of the system to adopt multiple configurations means that it can be tailor made to the specific requirements in different areas. The flexibility of the MUP means that it can operate both on and off the water and/or the electricity grid as a single or an array of multiple units. The power generated by the wind generator offers a complete independence to the unit. Buffer systems are used to optimize operational efficiency in the form of compressed air and water storage an advantage during the intermittent and variable wind energy resource. The proposed MUP two product offering, is available under the following configurations:

Configuration A: Grid connected (water) dedicated to water production. This offering is intended for remote locations such as touristic islands to serve the needs during periods where there is high influx of people during high tourism season. The MUP under this configuration will be connected to a water storage facility such as reservoirs or water tanks via a water pipe network. The power needs for the desalinations will be covered by a wind generator.

Configuration B: Grid connected (electrical) dedicated to electricity production. This offering is intended for remote locations such as touristic islands to serve the needs during low tourism season i.e. where there is no high influx of people and hence the existing water resources are adequate to meet the needs of the local population. The electricity produced will be cheaper than a fossil fuel operated power plant and will be exported by connection to the local grid.

Configuration C: Grid connected (water, electrical) simultaneous water production and electricity export. This offering is intended for remote locations such as touristic islands to serve the needs on demand in a dynamic configuration. Water and electricity grid connection will allow both products offered simultaneously, ideally during periods where the water demand is not in highest but still required. Another scenario would be a deliberately reduced water production regime where a percentage of energy is exported to the grid which can be re-deployed during periods of low wind resource or to assist by providing starting torque to the turbine following downtime. This would reduce the risk for water production downtime due to lack of adequate wind resource.

Configuration D: Off-grid continuous water and/or electricity production. This offering is intended for remote offshore locations such to serve the needs on demand in a dynamic configuration. The operation will be off grid under two main scenarios:

Firstly, the supply of water to a small remote island where the near-shore presence of the MUP would cause serious conflicts with other sea activities (e.g. busy marinas, leisure, fishing etc.) and where its presence would be intolerable. For this scenario the MUP could be moored further offshore to avoid conflict and use a water transport vessel to transport the water to the shore.

A second scenario would be the supply of fresh water and/or electricity to another offshore activity such as an oil & gas platform, offshore aquaculture farm (e.g. for automatic feeding, monitoring, fish stock processing) or autonomous marina.

Configuration E: Micro-grid continuous water and/or electricity production. This offering is intended to supply water and/or electricity to a primary fixed island location with electrical and/or water grid connection. At the same time, it will be serving other islands' needs off-grid i.e. by supplying water using water transport barge/vessel. Electricity offering would be available if grid interconnection exists to these islands.

4 Site conditions

The optimum wind-desalination floating MUP site selection will take into consideration a number of factor outlined below:

One of the most important factors is to avoid conflict with others sectors. Site selection will aim at the same time to minimize conflicts with other sea users such as fishing, aquaculture, tourism, leisure (marinas), port /shipping sector activities.

Equally important factor is the low visibility from settlements and population centres. Especially in the case of touristic islands and coastal areas, siting of wind turbines could be perceived negatively and often referred to as visual pollution [11]. Therefore, the positioning of the MUP will have to take into account the optimal distance from the shore as well as the alignment, which should exclude increased population centers and touristic development spots where possible.

Within proximity to coastal logistics and infrastructure facilities. Easy access from/to major coast facility (e.g. port, shipyard) will assist installation, repair/maintenance works and decommissioning [12].

The most important factor regarding site selection is based on good wind resource [13]. A detailed assessment of the candidate sites with high resolution data will accurately estimate the energy production and subsequent water production volume by desalination. Existing data suggests that high average wind velocity>8 m/sec is observed at 100 m height in the Aegean Sea.

Alignment with coastal locations so that can access water grid connection points. The site selection will take into consideration the local water storage, treatment and supply distribution infrastructure to minimizing the onshore transmission assets required for connection.

Alignment with coastal locations so that can access electrical grid connection points. The site selection will take into consideration the local electricity supply distribution infrastructure to minimizing the onshore transmission assets required for connection [14].

Unsuitable areas for installation will be excluded such as those that cause conflicts due to factors such as environmental, technical, social, economic, cultural, etc., and they are subject to standing legislation and on the characteristic of the study area (for example: NATURA 2000, distance from settlements, ship routes, etc.)

Conclusions

Two of the most pressing environmental challenges of today, energy production and water supply, are met with the innovative and practical solution to meet the water and energy needs of remote locations.

The combination of technologies is based on a semi-submersible steel platform, accommodating an offshore wind turbine, photovoltaics and desalination unit using Reverse Osmosis (RO). The combined technologies can deliver both fresh water and electricity in a dynamic configuration meeting customer needs including catering for seasonal fluctuations.
The power generated by the wind turbine offers a complete independence to the unit. Buffer systems are used to optimise operational efficiency in the form of compressed air and water storage an advantage during the intermittent and variable wind energy resource. The floating platform is made of steel pipes, it can safely be used as a compressed air storage tanks for pressures up to 80 bar. The results from simulation show that the adjustment of such a system of compressed air in the platform can significantly increase the water production.

Also, the proposed solution demonstrates the multiple use of space, as both potable water production and electricity production with storage are collocated sharing the same marine space, operating with fully integrated technologies on the same platform. It is characteristic that the development of multi-use offshore platform concept has clearly become one of the EU's most interesting and ambitious projects in order to ensure the integrated, sustainable and ecological exploitation of oceanic resources.

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