EVOLVEMENT OF AUTONOMOUS OFFSHORE ECOLOGICAL SEA WATER REVERSE OSMOSIS SYSTEM

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ABSTRACT

Many small islands face water shortage problems and although willing to adopt ecological solutions, local expertise is not always available to work on sustainable development and support sophisticated solutions. An innovative solution for arid, but windy and sunny Aegean islands has been developed; a floating platform that uses wind and solar energy to desalinate seawater to potable water. The developed prototype system called ‘Ydriada’ is 100% renewable energy efficient and operates autonomously based on intelligent control, suitable power electronics and safety mechanisms. The solution is environmental friendly as it uses only wind and sun as energy sources and brine does not include any chemicals and is disposed on surface of deep water. Further improvements and evolvement of the prototype system focused on operational parameters adjustment, control algorithms improvement and component enhancement. A Photovoltaic system has been added and utilized to increase production hours creating a hybrid main power system. Significant effort was devoted in component adjustment, integration and intelligent control in order to reduce energy requirements and increase reliability. The operation of reverse osmosis was modified in order to increase efficiency, while powered from variable power sources. Also the automatic control system has been enhanced in order to increase safety in unmanned operation.

Keywords: renewable energy desalination, offshore autonomous desalination, offshore floating windturbine, environmental friendly reverse osmosis.

1. Introduction

Many small islands face water shortage problems. Societies are continuously working on ways to cope with water shortage problems by treating saltwater and brackish water [8]. Sea water reverse osmosis desalination units are efficient [9], but still energy demanding installations that require on average 5 Kwh for producing 1000 litres of potable water. Providing electrical energy in isolated islands from fuel oil makes the production of potable water inconvenient since its cost rises according to fuel cost [2]. The use of renewable sources such as wind and sun for supplying energy to desalination installations can be an efficient and prominent solution [5].

2. Technical requirements

Studying previous desalination applications in small islands and also pilot projects where reverse osmosis is powered by renewable energy, it was evident that several discouraging factors prohibit development of such applications. The main drawbacks are the following: (a) difficulty to find suitable areas where all environmental considerations are met for desalination installation together with renewable energy system installation, (b) infrastructure limitations in case of grid connection, because in most cases the renewable power source is far from desalination system, (c) disturbance caused to inhabitants, (c) lack of technical expertise of local people in order to operate such systems. Taking into account all the above the design of a suitable desalination system should have the following characteristics: (a) operates automatically, (b) is self powered from renewable energy sources, (c) does not disturb people, (d) does not cause any negative environmental impact [7].

It has to be noted though that desalination plants have two categories of potential environmental impacts: impacts of energy use and consequences of the refusal of the brine. The use of Renewable Energy Sources (RES), which gives the possibility of providing free energy from renewable sources, shows that the result on the part of energy consumption does not pollute the environment. However, the study for the operation of large units and wider implementation needs further investigation, before desalination becomes a good techno-economic choice. Hence, the problem for the generalized use of desalination methods is not economical, since the cost of produced water is not necessarily prohibitive, but the potential impact from desalination units should be more investigated.

These impacts are related to the density of the concentrated brine which returns to the sea. This results to an increased salinity of the water, at some distance from the exit of the system, and affects the marine ecosystem. Therefore a further and very careful investigation of the excact position of the system's installation would result to a reduction of the burden on the marine environments, if the system would be installed at an area where sea currents would take away and dissolve the concentration of the brine.

3. System development

In order to meet all requirements a new design was developed which is an offshore floating system that uses wind and solar energy to desalinate seawater to potable water. This concept has several advantages which include: (a) local renewable energy production and elimination of long power grid, (b) desalination operation in deep clear water, (c) offshore wind conditions, (d) placement of the unit far from populated areas, so that it does not disturb, (e) easy towing if required. On the other hand this concept creates significant operational issues, which require several component modifications in order to provide technical solutions in system integration for safe unmanned operation. 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 cost and problems, mainly for batteries and desalination unit components such as pumps, filters, membranes.

The floating structure hosts all components and supports the windturbine and photovoltaic panels. Internally, it includes (a) a control room, which holds electrical power components and control equipment, (b) a machine room, which hold reverse osmosis equipment and pumps and (c) a fresh water storage tank. The electrical design enables adjustments of all components though control systems with small battery energy storage [10], [11], considering that water production is similar to energy storage. Windturbine is the main power component with 32Kw and operates at varying rotational speed. The photovoltaic system has 10Kw capacity. The output voltage is 3-phase 380V AC with 60KVA capacity. An additional photovoltaic string of 1Kw together with a dedicated battery bank is used as additional reserve power source for critical control and safety equipment. The desalination unit has been adjusted regarding cost effective issues [1], [6]. 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 sea water [3]. 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.

4. System operation and control strategies

Important issue for its unmanned operation in the Aegean Sea is the control and communication devices. Redundant and intelligent systems have been introduced to create fail safe devices. Each subsystem has its local control unit and these units accept commands from a higher level, where master control coordinates all operations. The main components are wind generator active rectifier and inverter, wind turbine control, reverse osmosis control, master control and SCADA system. Master control provides the following operation modes: Normal autonomous operation, Manual mode, Tele-operation and Remote fault diagnosis. During autonomous normal operation the main control algorithms deal with Power management, Energy storage management, Back up and Stand by systems handling. Control optimization focuses on production, safety and minimum maintenance. Additional safety issues like monitoring of critical parameters, alarms and notification mechanisms have been developed. Extensive data logging is performed in order to analyze performance and to prevent future failures. These data are used to improve control algorithms and system operation management.

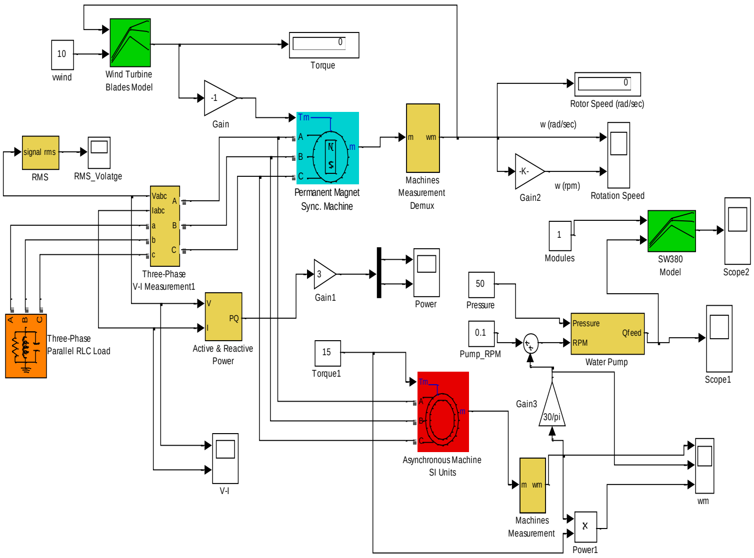

Figure 1: Block simulation of components

Simulation has been used both in operation improvement, in order to examine control strategies and system performance. The following issues like: when to start and stop desalination unit, how much energy to retrieve from the batteries, when to shutdown auxiliary equipment, how much energy to get from the windturbine in order to maximize production, have been examined through simulation of several alternative strategies. Simulation has been particularly useful for (a) the examination of system behavior under different conditions, (b) examination of transient phenomena, (c) reducing time required to examine situations that rarely happen, (d) reducing risk for faults and system failures, (e) studying different management strategies.

The multivariable possibilities of utilizing available power from wind and sun to water production, storage and auxiliary consumption can be seen in the following operation diagrams. Exergy analysis can be a useful evaluation for a desalination system [4]. We compute the hydraulic energy of plant pumps per cubic meter of fresh water produced (KWh/m3) at several time intervals taking into account the reverse osmosis desalination pumps.

$$SpecificEnergy = \frac{HydraulicEnergy}{PotableWater\,Produced} = \frac{HydraulicPower}{PermeateFlow} =$$

$$= \frac{FeedWaterPumpPower_1 + HighPressurePumpPower_2 + HighPressureBoosterPumpPower_3}{PermeateFlow_4} =$$

$$= \frac{P_1 * Q_1 + P_2 * Q_2 + \Delta P_3 * Q_3}{Q_4}$$

Figure 2 shows the relationship between hydraulic power and water production. In figure 3 the corresponding histogram of hydraulic power per potable water produced at different renewable available power levels is shown.

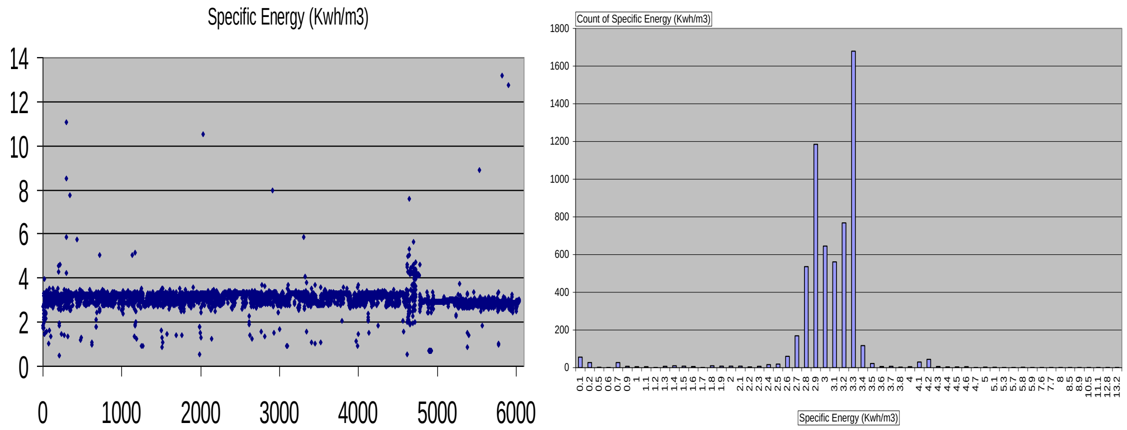

Figure 2, 3: Specific hydraulic energy per m3 of produced water and histogram

Additional simulation studies were performed regarding component dimensioning through homer software. For example in case the photovoltaic power is increased to 15kw water production is increased by 27% compared to wind only system. More important is the design of higher production units. Therefore an interesting case is a system with a 100Kw wind turbine together with a 30 KW photovoltaic system. This system can be incorporated on a similar floating structure with minor changes. In this case there is a three fold increase in water production. The system is situated at Heraklia Island Aegean Sea southeast of Naxos Island in geographical position 36°52'04.8"N 25°28'22.7"E fig 5.

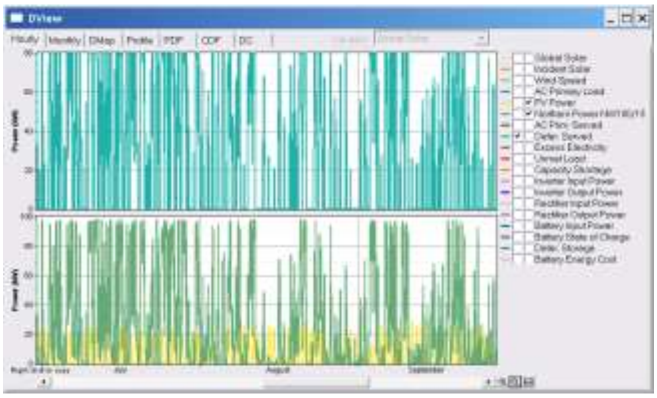

Figure 4: Renewable power output and reverse osmosis simulation

Figure 5: Autonomous ecological potable water production system at Heraklia Island (google map).

5. Conclusions

Utilization of what abounds in island areas such as wind, sun and sea water can be very helpful for producing potable water. Based on this concept, the floating, autonomous reverse osmosis desalination system has been designed and developed. The pilot unit implemented uses sea as feed water, wind and sun as energy sources emulating a natural spring. The proposed solution encourages the use of renewable resources [11] and avoids environmental impacts even in cases where land based solutions are prohibitive, because they require significant infrastructure construction for wind parks, grid connection and desalination plant. Further problems of brine disposal in sensitive environmental areas have been addressed and resolved in the developed floating system. Development of control strategy and safety interlocks was very important for safe unmanned operation.

The system utilizes sea in a sustainable way using environmental friendly methods for addressing a critical issue, which is the scarcity of water resources. The pilot unit is anchored in Iraklia, a small island in the insular region of the Aegean Sea. Tens of other small islands in this region experience water shortages during the dry period, which coincides with the high tourist season of the Greek Archipelago. Further improvements and production increase is possible following this design at a larger scale in order to achieve suitable solutions for different regions.

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