Wind Energy Based Desalination Processes and Plants

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1 Introduction

Water is a valuable natural resource and its shortage is a serious problem being faced by many areas of the planet. Decision making on the water supply method includes technical and economic evaluation of various alternatives, taking into account the urgent character of the problem and the need for its sustainable solution.

Desalination of brackish [1] and sea water [2] has become one of the most widely applicable methods to meet water demand and it is today widely applied in areas with limited water resources. One of the most promising desalination methods is based on reverse osmosis (RO) phenomenon. A critical issue in water desalination is the high energy demand and, more specifically, electricity for RO desalination units. RO is the desalination process with quite low energy requirements. Therefore, it was expectable that significant efforts would be taken to implement widely available and environmentally compatible energy sources for the desalination process.

The objective of the present work is to analyze the current status and the prospects of the wind based desalination plants and to highlight the main design and operation features of these units, as well as the difficulties and critical factors in their implementation.

2 RES based Desalination Processes

The use of renewable energy sources for the operation of desalination plants is a feasible and environmentally compatible solution in areas with significant RES potential.

The main driving forces for applying RES in desalination plants are the seasonal variability in water (and energy) demand, usually occuring when renewable energy availability is high, the limited availability of conventional energy supply in remote areas, the sufficiency of RES in islands, the technological advancements being achieved in desalination systems, the limitation of environmental impacts of conventional desalination systems and the relative easiness of the plant's operation and maintenance compared to conventional energy ones.

Especially for the Greek islands, where there is water and energy shortage and, at the same time a high RES potential, the RES based desalination plants comprise a promising technically feasible and financially attractive solution.

To that end, a lot of research and development work has been carried out and the problem of the optimal configuration / combination of a RES energy source with a desalination plant attracts the interest of many researchers and construction and engineering companies.

The best coupling of RES to desalination systems is determined from various criteria, such as the system's efficiency, the investment and operational cost, availability of operational personnel, the suitability of the system to the characteristics of the location, the possibility for future increase of the system capacity, etc.[3]).

The selection of the appropriate RES desalination technology depends on a number of factors, including:

- required quantity of potable water (plant capacity),
- feed water salinity,
- remoteness,
- availability of grid electricity,
- technical infrastructure,
- type and potential of the local renewable energy resource.

Various combinations of RES and desalination systems have been proposed and implemented, each one with its own characteristics and suitability under certain criteria [3, 4, 5]. Desalination systems driven by wind power are the most frequent renewable energy desalination plants (Figure 1).

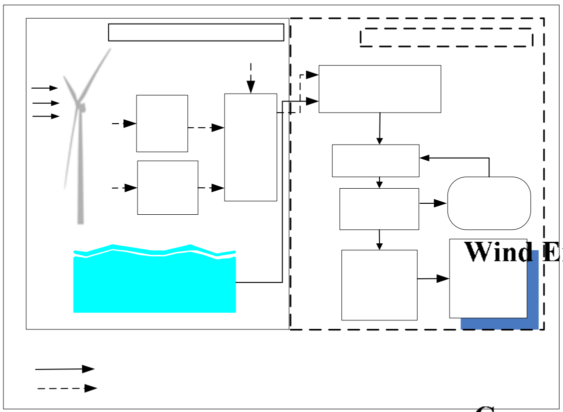

Figure 1: Structure of a wind based RO desalination plant

Coastal areas have a high availability of wind power resources, and wind power is the most competitive renewable energy technology in power generation. Therefore, wind powered desalination is a promising alternative. The idea to use wind power as an energy source for desalination is not new. Wind conditions, for example, in coastal areas are often in favor of this desalination system.

More specifically, wind energy can be used efficiently on condition that the average wind velocity is above 5 m/s. This makes wind-powered desalination a particularly interesting option for windy islands, both for the solution of their energy supply problem and for the operation of sea water desalination plants.

The new generation of small and medium-sized wind turbines that has been developed in the past years offers a high amount of reliability in service combined with low investment costs.

Two types of applications are usually referred as wind energy and desalination couplings. The first type concerns the coupling of the wind generator and the desalination plant on a small size autonomous electricity grid. The second concerns the direct coupling of these two for the sole purpose of production of water.

Desalination plants using membrane technologies are available in a wide range of capacities. As far as the recommended RES – desalination combinations are concerned, it is considered that wind desalination is most suitable for small (1-50 m^3/day) and medium (50-250 m^3/day) scale plants [6].

3. Energy Issues in Desalination Plants

All desalination systems use energy and, in fact, the energy consumption is one of the most important elements in determining water costs. About 0.7 kWh/m^3 is theoretically the minimum energy required to obtain fresh water from seawater. [5]. For RO systems the energy consumption is in the range of 5-10 kWh/m^3 without energy recovery (large production plants), and 3-4 kWh/m^3 with energy recovery. [6].

Recent developments in wind turbine technology mean that wind power can now be regarded as a reliable and cost-effective power source for many areas of the world [7].

Wind turbines may be classified depending on their nominal power "N_o" as very small (N_o<10 kW), small (N_o<100 kW), medium sized (N_o<0.5 MW) and large (N_o>0.5 MW) ones. All are based on mature technologies and they are commercially available except for the very large power systems, which still require several adjustments.

The basic assumptions for the required calculations concerning the energy efficiency of the wind turbines with or without an energy storage system may be considered as following:

For a wind turbine with a nominal power of N_o kW, we expect an energy production "E" in the order of magnitude of "E=CF.N_o.8760" kWh/year. Note that the installation capacity factor "CF" usually varies between 20% and 30%. Depending on the type of desalination plant, the required amount of energy per m^3 of potable water will also be given. Therefore, we may have a series of alternatives concerning the installed power of the wind turbine and the combined capacity of the desalination plant. Many other parameters should be taken into account in this design issues, such as the possible losses of an energy storage system or the availability of a water storage system. [8, 9].

The variable nature of wind power is not a problem as afar as water availability is concerned, because water can be stored inexpensively even for long periods of time without deterioration. With a plant that is dimensioned according to the local wind conditions, water becomes available any time. However, variable wind power may cause operational problems in the system's operation and this is one of the most serious issues to be resolved in the design and implementation of this type of projects.

4. Environmental Impacts of RES based desalination plants

Desalination plants cover the needs of remote areas in water. Usually they are implemented as a result of an analysis and alternative solutions evaluation amongst various possible solutions for water supply. For example, on several Greek islands, fresh water requirements are covered by the construction of large dams or ground reservoirs of desalination plants. In smaller islands, the only available solution is the transport of fresh water by ship, with high costs and improper hygienic conditions [10]. All these water supply methods cause a spectrum of environmental impacts, more or less serious depending on the type of the project, its location and scale.

The main environmental impacts of an RO desalination plant are the following:

- Noise disturbance
- Optical disturbance
- Land use
- Interference with public access in the coast
- Abstraction of brackish groundwater
- Discharge of brine - a concentrated salt solution that may be hot and may contain various chemicals on coastal or marine eco-systems or, in the case of inland brackish water desalination, on rivers and aquifers.
- The emission of greenhouse gases in the production of electricity and steam needed to power the desalination plants in case the energy provided is from the grid and fossil fuels are used to generate it.

The main positive environmental impact from desalination is that it reduces the pressure on conventional water resources. In particular, seawater desalination can help to relieve the pressure on overexploited coastal aquifers. [7].

In case that it is decided also to built a RES unit, either to cover only desalination unit's needs or to cover also energy demand of the area [9], then a strategic environmental assessment is needed that will evaluate in a integrated manner the impacts of all major projects being included.

5. Wind based desalination – Operational issues

One of the problems of utilising wind power in process applications is the variable nature of the resource. While the wind is relatively predictable it is seldom constant and there will be periods when there will be none at all. The storage of wind energy in the form of electrical power is really only practical when small amounts are involved [11]. Storage batteries increase the total investment cost therefore, to run a process of any magnitude on stored electrical energy is not a practical proposition.

However if the product of the process can be stored inexpensively then it may be practical to oversize the process equipment to allow for downtime. Water can be stored for long periods of time without deterioration and the storage vessels are relatively cheap.

Variable power input force the desalination plant to operate in non-optimal conditions and may cause operational problems. To avoid the fluctuations inherent in renewable energies, different energy storage systems may be used. [12].

The only matters that would require some careful design would be the relative sizes of the wind turbine and the RO plant and the cut-in and cut-out criteria for the RO plant to avoid excessive startup and shutdown cycles.

The intermediate energy storage system would be necessary, but it would reduce the available energy and would increase the cost of the plant.

The main drawback of RO in remote areas is the complex pre-treatment, the requirement of skilled workers, chemicals and membrane replacement.

For the operation of a wind-powered desalination plant, it is most important to have a plant that is insensitive to repeated start-up and shutdown cycles caused by sometimes rapidly changing wind conditions. Reverse osmosis is, with regard to pretreatment, membrane fouling, after-treatment and efficiency of the high pressure pumps, a process that is rather sensitive to a stop and start operation. In order to stand the discontinuous mode of operation, a new reverse osmosis membrane was developed, incorporating advantages of both spiral wound and plate and frame designs.

6. Wind based desalination – Design issues

The main design variables that affect the design of an wind - RO system are:

- The water demand and, therefore, the RO plant's capacity
- The location that the wind turbine and the desalination plant will be installed (required sitting, altitude etc.)
- the feed water salinity
- the wind speed distribution
- the configuration of the energy system
- the water storage capacity
- the available power distribution
- desalination unit energy consumption
- the salt rejection,
- the operating pressure,
- the permeate flux, both in terms of overall product rate and specific rate (per unit membrane area).

The various alternative Wind-RO configuration possibilities are the following [13]:

Systems with back up (diesel/grid)

In these systems, an additional energy source is provided (a diesel-powered generator or even the local grid) so that the power supplied to the RO is constant. The back-up generation complements the power generated from the wind turbine to match the RO unit power consumption. The main benefit of these systems, as in any hybrid wind-diesel configuration is the achievement of fuel savings, which may increase the generator availability and reduce overall energy costs.

Systems without back up

Systems without an external energy source can be divided into two categories, with emphasis on the RO unit operation: systems which run under approximately constant operating conditions; and those that experience variable operational conditions.

Near constant operating conditions

In this case an attempt is made to operate the RO unit with approximately constant operating conditions

Use of an energy storage device

Energy storage devices are employed to accumulate energy surplus during periods when the power generated by the wind turbine is greater than the load demand from the desalination unit. This surplus would then be used later when the generated power is insufficient to meet the load demand.

One common way of storing the surplus energy is by using batteries [9] or water pumping systems [14]. Storage sizing should be considered in the design stage. In addition, capital and maintenance costs should carefully be assessed.

7. Cost Analysis of Wind Based Desalination

The most promising potential market for wind powered RO is in present or potential
future island tourist developments in places such as the Mediterranean islands, the Pacific Islands etc. Generally, if wind powered electricity generation is an economic proposition in any of these places and water is scarce (which it usually is), then wind powered reverse osmosis should also be economic. It is unlikely that energy storage would prove economical in these larger systems, although energy recovery for seawater plants would almost certainly be so.

In general, the cost reduction of renewable energy systems has been significant during the last decades. Therefore, future reductions as well as the rise of fossil fuel prices could make possible the competitiveness of seawater desalination driven by renewable energies.

For a given wind farm installed capacity (with a particular type of wind-turbine) and a given wind regime, there exists, from an economics point of view, an optimum nominal production capacity for each plant, that needs to be specified in each case under consideration. In this context, a wind farm with a nominal power of 460 kW and a wind regime (in the area of Pozo Izquierdo, proposed for its installation in Gran Canaria) with an annual average speed of 7.9 m/sec 10 m above ground level, would give rise to an optimum number of RO plants of 11, each with a capacity of 100 m^3/d. However, for technical and economical reasons the decision was made to use eight RO plants, each with a capacity of 25 m^3/d [15].

The average installed costs of seawater RO plants are in the range of $1,000 to $1,500 per cubic meter per day capacity.

The economics [16] of a combination of a wind turbine with an RO plant is helped by the fact that water is a storable commodity.

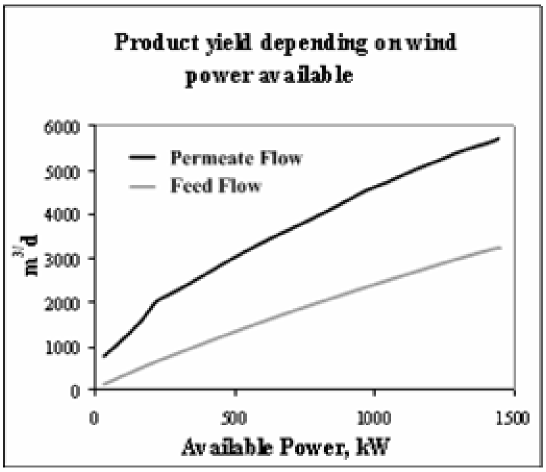

Figure 2. Product yield depending on wind power available [9]

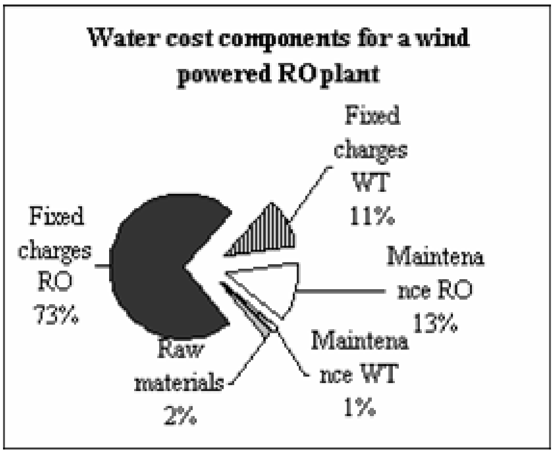

Figure 3. Water cost components for a wind powered RO plant. [9]

Factors affecting water production cost in wind based desalination plants are shown in the following Table 1.

Direct Capital Cost	
	Cost of land Cost of Wind turbine Cost of energy storage systems Cost of the RO plant components
Annual Operating Cost	
	Electricity cost Manpower cost Maintenance and spares cost Chemicals cost Membranes replacement

Table 1: Cost items of a wind based desalination plant

The water cost of a wind brackish water reverse osmosis unit (large system, about 250 m^3/day) is of the order of 2 Euro/m^3. The implemented in Tenerife, Spain included for a 200 kW wind turbine, which would operate on average wind velocity 7,5 m/s, with an expected yearly energy yield around 600 MWh. This amount of energy is capable of producing over 200 m^3/d water [15].

8. Wind based desalination – Implementation issues

The practical experience on wind powered RO systems has been with relatively small capacity systems. There have been a number of attempts to combine wind energy with RO. A number of plants have actually been operated. However, most of them were of small size, mainly for research purposes. Therefore not many conclusions have been reached in terms of expertise and know how. It is still difficult to control the usage of wind in a cost effective way. Coupling of a variable energy supply system, as mentioned earlier, to a desalination unit requires either power or demand management, and there is not much experience on it. However, the prospects of this combination are high mainly due to the low cost of wind energy.

The operational experience from early demonstration units is expected to contribute to improved designs and a large number commercial systems are expected to be implemented.

In this section we will describe two examples of wind based desalination units installed and operating in the Greek islands.

i) Milos Desalination Plant

In a Greek island called Milos and belonging in the Cyclades complex, a wind based desalination unit has recently been installed and operates since summer 2007. The unit has a capacity of 3000m^3/day. At the moment it operates in a daily production of 2000m^3 of potable water. This is a private investment that has been subsidized by the state. The water is sold to the municipality of Milos, in a continuous effort to solve the urgent water shortage problem, especially during the summer months. The contract that has been signed between the private company and Milos

Municipality refers to a selling price of the water almost 1,8 euros/m^3.

The entire plant includes:

- The desalination plant
- A wind turbine of 600 kW
- The storage tanks (capacity 3000m^3)
- The remote control system

Before the installation of the unit, water was transported from Athens at a very high cost and very poor quality [10]. The implementation of this novel project has improved the quality of life of the island in many respects.

The sitting of the unit in a very touristic island as Milos could be a major problem, mainly because of the optical and noise disturbance. Therefore, the unit has been located on a hill that is not apparent from the most island villages.

ii) A Floating Wind Turbine/ Desalination Plant [14]

The first floating wind turbine/desalination plant in the world has been developed by a number of scientists / engineers with an academic and professional origin and lead by the University of the Aegean. Two of the most pressing environmental chal-lenges of today—energy production and water supply—have been met with an innovative and practical solution to meet the water needs of Greek islands.

The Floating Autonomous Environmental Friendly and Efficient Desalination Unit (FAEFEDU) is designed to produce potable water from sea water and do so by generating its own power through wind turbines on board.

The unit sits on a special floating 20 X 20 meter platform with a height of 8 meters for a cylinder and a 22-meter tower and can adapt to any weather conditions. Water production is more than 70 cubic meters per day—enough for the needs of about 300 people.

In order to achieve the largest possible energy and desalination production, scientists focused on minimizing the scale and polluting effects on the central unit, increasing the energy efficiency of the cycle.

In addition, because the unit is autonomous, it is not required to be connected to the national electrical grid. Since the unit is portable, it can be stationed away from populated centres and be placed wherever needed, on a seasonal basis for instance, to service the needs of islands that have an enlarged population during summer months. In addition, the unit can be repositioned to take advantage of changing weather conditions.

FAEFEDU is fully autonomous, has an advanced automatic control system, operates unmanned and can be tele-operated and monitored remotely. The innovative system also eliminates any destructive land-based environmental interventions, since no roads or land construction are needed and no waste is produced.

The Greek research community was heavily involved in the project, coordinating various disciplines to fulfil the diverse needs of the unit. In addition, the Greek shipbuilding sector contributed with its vast know-how to produce the project at an attractive cost. Equipment providers from Germany, Sweden, and other European countries also participated.

The unit, the first of its kind in the world, was included in the “Natural Environment and Sustainable Development” section of the Operational Competitiveness Programme of the Greek state and was co-financed by the European Fund for Regional Development and domestic Hellenic sources.

9. Conclusions and significance

The reverse osmosis technique is the most suitable for use in stand-alone wind- powered desalination systems. These systems are very valuable for regions like the Mediterranean islands, usually facing scarcity of potable water and lack of conventional energy sources, but do have at their disposal exploitable wind energy resources.

The financial performance of wind-powered desalination are also favourable. The costs are similar with what is expected for a conventional desalination system, proving to be particularly cost-competitive in areas with good wind resources that have high costs of energy. It can be concluded that wind-powered desalination can be competitive with other desalination systems, providing safe and clean drinking water efficiently in an environmentally responsible manner. Now that significantly larger and more reliable wind turbines have become available, wind powered desalination is poised to make the breakthrough into commercial applications.

The actual ratio of wind turbine size to RO plant sire that might be used in any instance should result from an optimisation making use of data that will be site specific for both the wind turbine and for the RO plant.

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