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Wind-powered RO desalination

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ABSTRACT

Two pilot projects were dedicated to wind-powered RO desalination. *Project #1* had a wind turbine connected to a battery bank, while *Project #2* had a wind turbine connected directly to a crank mechanism, a compressor, and a water pump. The target of both projects was to produce potable water from sea water with satisfactory pressure and flow rate of RO permeate. Both projects showed that a combination of RO desalination and wind power is technological feasible when the RO system is operated with fluctuating and intermittent loads following the energy supply characteristic of the wind turbine. Depending on the technical design, the systems provide 1.4 and 7.5 m^3/24 h potable water, which satisfy basic needs for small populations in coastal regions.

Keywords: Wind power; Renewable energy; Wind turbine; Desalination; Reverse osmosis

1. Introduction

Water is a basic human need. There are about 332.5 million cubic miles (1,386 million cubic kilometers) of water on Earth. Less than 3% of this is fresh water, and two-thirds is locked up in ice caps and glaciers [1]. A constantly growing population requires increasing amount of fresh water. Even in developed countries, water is a limited resource. However, people at large take for granted free access to water to satisfy everyday needs. In developing nations, people suffer due to lack of water. Billions of people are affected by water shortage and no access to potable water.

Desalination of sea water has been available for some time by vapor compression, multi-stage flash, and reverse osmosis (RO). RO is the most appropriate desalination process relating to productivity, simplicity of operation, and energy consumption [2]. However, enough electrical energy for RO may not be available in poor coastal regions. Energy from wind is therefore an alternative local power source for RO.

2. Theoretical background

Wind is a flow of air masses caused by the uneven heating of the atmosphere, rotation of the earth, and irregularities of the earth's surfaces. Wind, with help of turbines, is used to generate electricity. Wind turbines convert the kinetic energy of the wind into mechanical power or, alternatively, a generator converts mechanical power into electricity [3].

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The forces of wind push the turbine blades, making them rotate and thereby creating mechanical energy. The spinning blades attached to a hub and a low-speed shaft turn along with the blades. The rotating low-speed shaft is connected to a gearbox that connects to a high-speed shaft on the opposite side of the gearbox. This high-speed shaft is further connected to an electrical generator that converts the mechanical energy from the rotation of the blades into electric energy. By rotations of 11–20 times per minute, each turbine can generate a maximum 1.5 megawatts of electricity [4].

3. Advantages and disadvantages of wind power

The most attractive features of wind-generated electricity are:

- *Renewability*: compared with alternative energy sources, wind is sustainable and continuously replenished. In coastal areas, wind has more or less non-intermittent flow all day round, while, for example, solar panels are productive during sun shining hours only [3]. Fig. 1 shows cost of different alternative sources of energy, where solar energy requires higher cost compare to wind.
- *Non-polluting resource*:

  In 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality [3].
- *Cost*: Fig. 2 shows a decrease in cost of wind energy of more than 90% since the early 1980's in USA [6]. Additionally, cost price of electricity produced by wind turbine depends on wind speed. Wind energy price at 7.16 m/s was 0.048 $/kWh, while at 8.08 m/s, it decreased to 0.036 $/kWh and at 9.32 m/s, as low as 0.026 $/kWh [7].

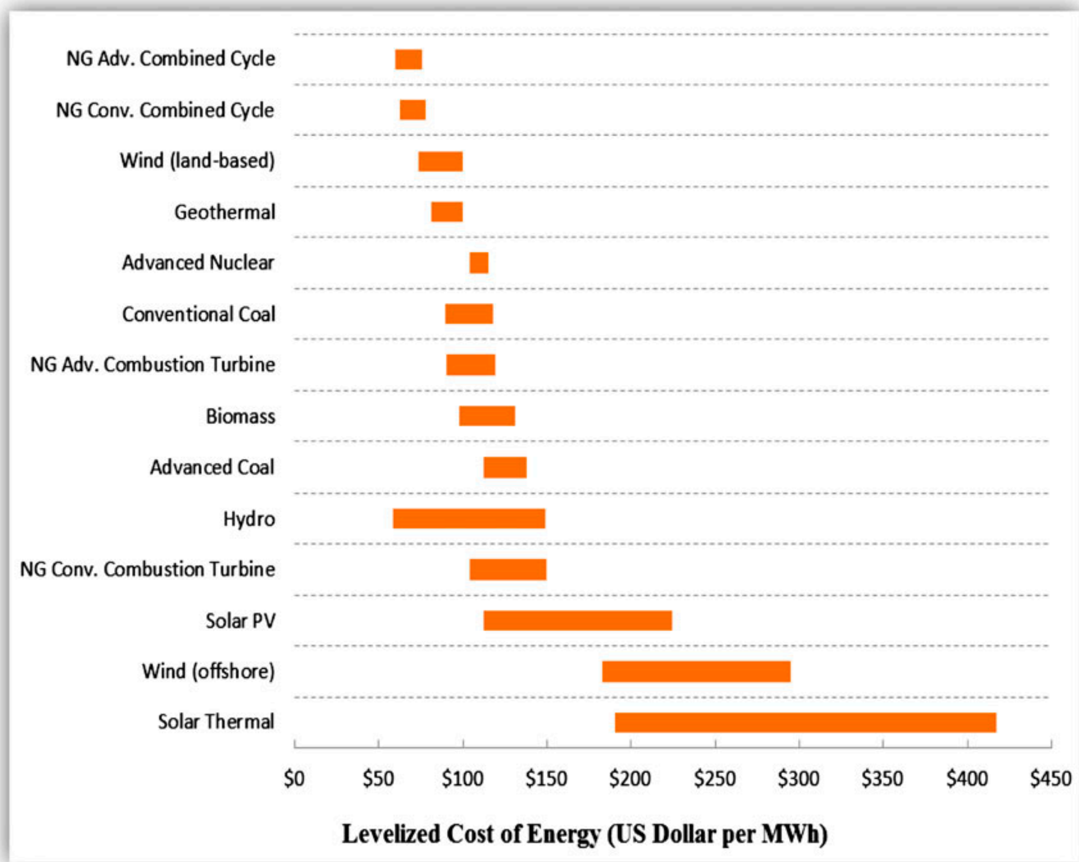

Fig. 1. Alternative energy cost [5].

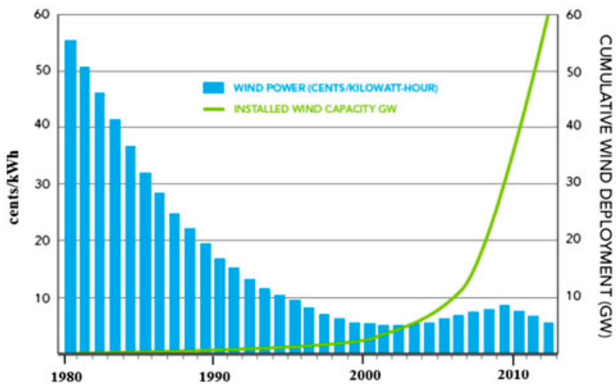

Fig. 2. Declining cost of wind energy over time in USA [6].

- *Total cost*: by comparing wind-generated energy systems with fossil-fueled systems on a "life-cycle" cost basis, counting fuel and operating expenses for the life of the generator, wind is competitive as there is no fuel to purchase and minimal operating expenses [3]. In addition, the equipment for wind power generating system is cheaper compared with other alternative energy system, for example, solar panels.

Disadvantages of wind-generated power according to [3]:

- *High initial investment*: roughly 80% of the cost is the machinery with the balance being site preparation and installation.
- *Environmental concerns*: in spite of insignificant negative impact of wind power plants, there are concerns over noise from the rotor blades, aesthetic (visual) impacts, constructions in virgin environment, and birds killed by rotors.
- *Supply*: the major challenge of wind as a source of power is the intermittent nature of wind flow, which cannot provide power always when electricity is needed. Mechanical power of wind cannot be stored. However, wind-generated electricity can be stored in batteries.
- *Location*: regions of proper wind are often located far from areas of electricity demand. Also, wind resource development competes with other land uses.

4. Experiments

4.1. Project #1

The pilot plan in Fig. 3 has a Coleman 600 W wind turbine connected to a battery bank of 10 rechargeable 110 amps sealed lead batteries, with total battery capacity of 1,100 amps realized when fully charged. All batteries are 12 V direct current (DC), and when connected in parallel supply 13.2 kW. A 12-V alternative current (AC) inverter converted 12 V DC from the battery bank to 220 V 50 Hz. The efficiency of inverter is 80%, yielding available power of 11.9 kW.

The pilot RO desalination unit has two pumps requiring electric power, a 400-W low-pressure feed pump, and a 750-W high-pressure pump. A solenoid valve of 25 W is added, requiring a total 1.2 kW. Premature fouling of membranes is negated by a flushing mechanism controlled by a timer.

A fully charged battery bank of 11.9 kW provides 10 h power reserve for RO desalination. The pilot plant has 3.3 m^3/d potable water production capacity. No wind provides zero charging of batteries. A fully charged battery bank, however, provided energy for productions of 1.4 m^3 permeate. The RO pilot plant fits a 20-foot container with the wind turbine on the container roof.

Knowledge gained through building and operating the pilot is used to design a full-scale green-field RO plant. The wind turbine will be 5 kW, leading to rapid charging of the battery bank. Also, the battery bank will have 24 h capacity to power RO desalination without wind. Chemical feed water additives shall be avoided as a UF membrane becomes pretreatment, providing silt density index of less than two (SDI < 2), thereby preventing premature fouling of the RO membranes [8].

4.2. Project #2

The project is based on energy provided from wind turbine that delivers energy for the whole desalination system (Fig. 4). The desalination unit (Fig. 4(A)) requires a water pressure of 55 bars to convert 60 m^3 of salt water into about 7.5 m^3/d potable water, using 8% recovery/membrane element. A water pump (Fig. 4(B)) driven by air pressure of about 3 bars from a compressor (Fig. 4(C)) delivers the RO desalination pressure. A direct-linked crank mechanism converts the rotational motion of the wind turbine (Fig. 4(F)) to a translation motion of the piston compressor. This system is designed to treat 35,000 mg/L TDS at 25˚C [2].

The membrane chosen for the project is Composite Polyamide Membrane (CPM), spiral wound: SW 30-2540 and SW 30-4040.

Water demand was calculated to estimate the amount of water from the RO installation. By assuming drinking water consumption at 10 L/24 h/pe, the

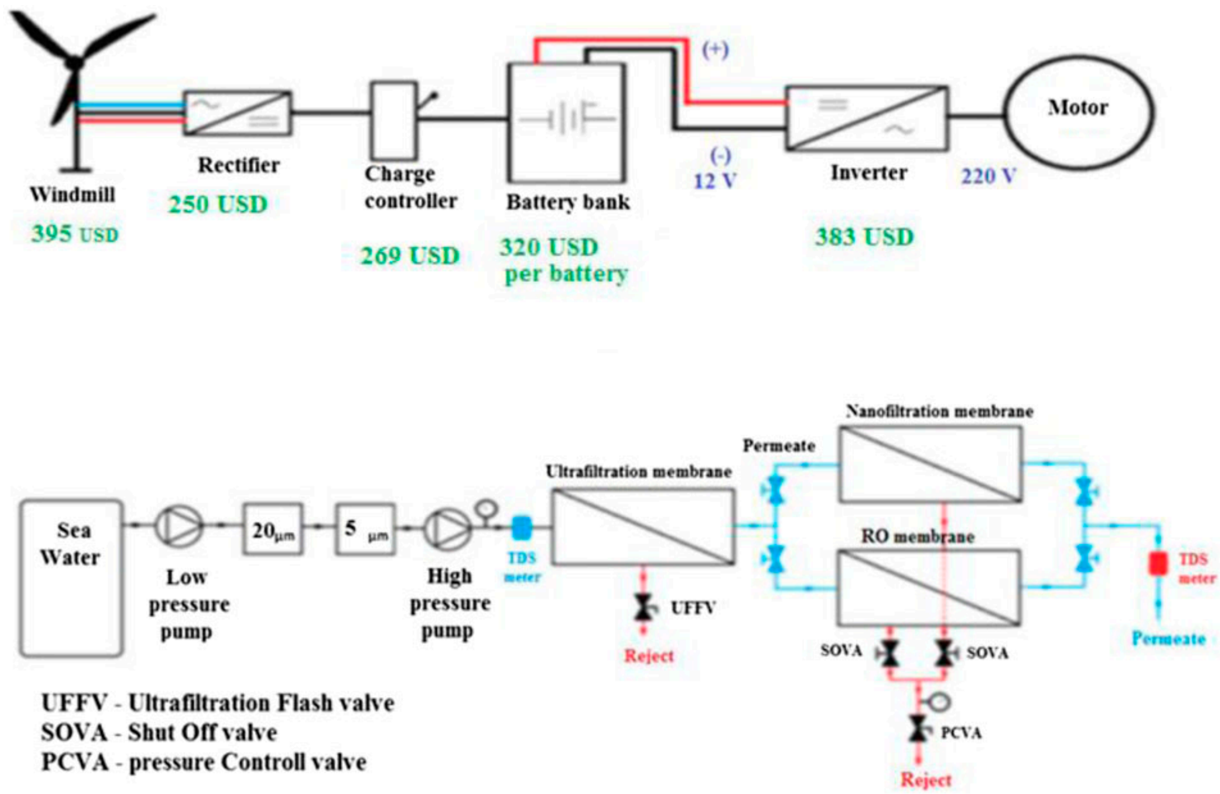

Fig. 3. Wind-generated power for RO desalination process [8].

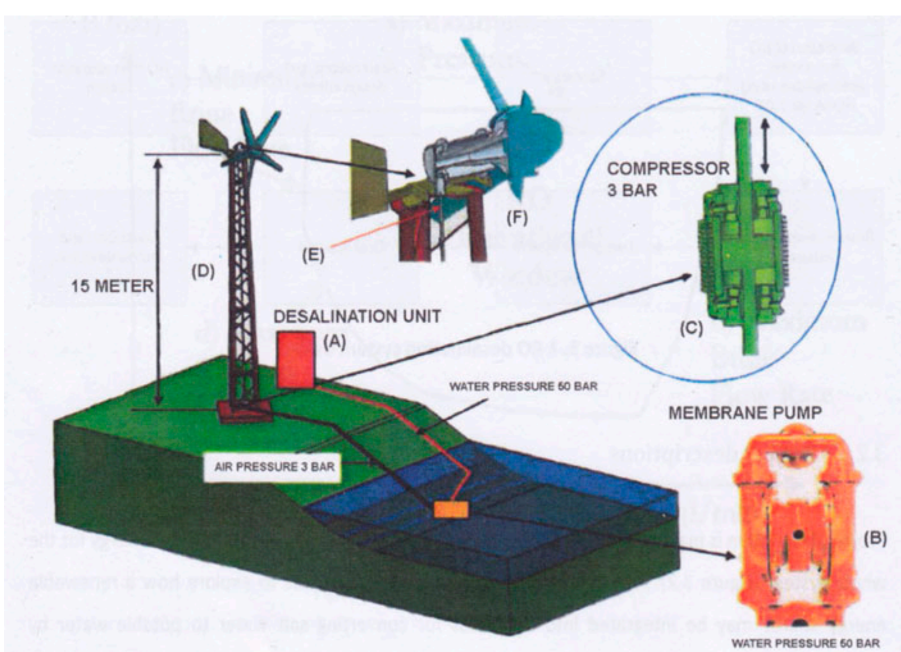

Fig. 4. Elements of wind-powered RO desalination unit [2].

estimated number of people to be supplied is $(7.5\,m^3/24\,h)/(0.01\,m^3/24\,h/pe = 750\ pe)$ [2].

The experiment showed that, under given conditions, the potable water supply is achieved with the following parameters:

- Permeate flow rate at $8.20\,m^3/24\,h$ yielding $7.5\,m^3/24\,h$ after loses in distribution system.
- Power consumption at minimum 1.45 kW for normal sea water and up to 2.39 kW for high salinity sea water.
- Specific energy consumption is $4.24\,kW/m^3$.
- Permeate TDS is 573 mg/L.
- Membrane elements: 8 [2].

5. Discussion and conclusions

The results of the experiment from Project #1show that a simple design of wind-powered RO system provides $1.4\,m^3/d$ of potable water, large enough to cover daily drinking water needs of a limited group of people. The important point of the experiment is that the wind turbine, the converter, and the pump for the RO unit do not have sufficient capacity for treatment of raw sea water with 35,000 ppm. That is why the experiment was run with brackish water as feed, providing treated water approaching 0 mg/L TDS.

Project #2 was carried out in five different scenarios, design based on RO module and different type of feed water (normal salinity and high salinity) using the same wind turbine installation. The most acceptable results of the experiments were in Scenario 1 with SW 30-2540 membrane and normal salinity of sea water. These results are satisfactory due to low power and specific energy consumption, which are the main factors for wind-powered RO unit. TDS of treated water in Scenario 1 is 577 mg/L. The flow rate of Scenario 1 is the lowest comparing to the other scenarios. However, there are no significant variations between any of them, and this flow rate is accepted as it shows the lowest power consumption.

Experiments show that small-scale RO desalination unit driven by wind-generated power is realistic and an acceptable solution for potable water supply. Design, power required for the desalination process, and amount of RO elements are calculated based on the estimation of desired quality and permeate flow rate.

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