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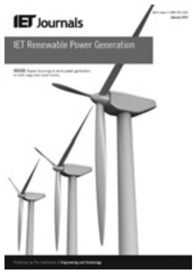
Published in IET Renewable Power Generation
Received on 14th August 2012
Revised on 6th December 2012
Accepted on 9th January 2013
doi: 10.1049/iet-rpg.2012.0228



ISSN 1752-1416

Feasibility study of photovoltaic powered reverse osmosis and pumping plant configurations

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Abstract: The present study has as main goal to make a technical and financial feasibility study of a photovoltaic powered reverse osmosis (PV–RO) and pumping system developed at the Renewable Energies Laboratory, Federal University of Ceará, in Fortaleza, Brazil, with the aim to supply drinking water for human consumption at low cost from brackish water in semi-arid areas. The research intends to determine parameters like drinking water production, specific energy consumption and specific costs, as well as the optimal system size regarding financial viability. The used configurations allow comparing two strategies: with and without batteries. The research was conducted with different levels of brackish water salinity, to identify a viability limit. The technical and financial analysis show that the unit produces satisfactory and competitive results, comparing with different plants in the world, concluding that, assuming a 2748 mg/l brackish water well, the configuration that brings the best cost/benefit is the no battery plant using 3 PV panels, which provides a daily production of 175 l of drinking water at 324.60 mg/l, with a specific consumption of 3.12 kWh/m^3 and presenting a competitive specific cost of 10.32 US$/m^3.

1 Introduction

Drinking water supply remains an unresolved issue for many populations around the world in the present century, mainly in arid and semi-arid areas. According to the United Nations Educational, Scientific and Cultural Organisation (UNESCO), until 2025 more than 3 billion of people will not have access to drinking water [1]. Parallel to that, the mentioned areas are characterised for having a precarious conventional electricity supply, thus reducing the available options to develop a reliable drinking water supply.

Desalination of brackish and seawater is one of the alternatives for ensuring a dependable supply of drinking water. To achieve this goal, the process of reverse osmosis (RO) has become a significant technical option. Osmosis is a diffusion process by which the solvent spontaneously passes through a semi-permeable membrane separating two solutions having different salt concentrations. It is common in its most natural form in living organisms. Animals and plants use osmosis for transporting substances. The process of osmosis can be reversed and is then called RO. This process is used chiefly for separating the solvent (water) from aqueous salt solutions. When a pressure greater than its osmotic pressure is applied to the more concentrated solution, the osmotic process reverses. This means that when the applied pressure exceeds a certain value depending on the solution concentration, the natural tendency for solvent to flow through the membrane in the direction diluting the more concentrated solution can be cancelled and even reversed.

This reversal of the flow direction causes solvent to flow from the raw water through the membrane, having as consequence that part of the raw water becomes more concentrated brine. The solvent (water) which has diffused through the membrane to the drinking water side has only a very small residual salt content called the salt slip. For the present project, the used RO membrane (FILMTEC TW30-1812-100) has a permeate flow of 16 l/h and a salt rejection of 90% based on the conditions: 250 ppm softened tapwater, 25°C, 15% recovery and applied pressure of 50 psi. A sufficiently large working pressure is necessary for utilising the RO effect. The magnitude of the pressure affects the flow rate of drinking water through the membrane. The solvent flow rate increases with the working pressure but the residual salt content of the drinking water remains nearly constant. Therefore salt concentration of the obtained drinking water becomes smaller as pressure is increased.

The membrane processes involved in RO are particularly suitable for water processing because here substance separation is only a physical process, involving no chemical changes of the separated substances. Furthermore, separation runs at normal room temperature so that neither the separated substances nor the membrane modules are subjected to thermal stress. RO is a method for substance separation involving relatively small energy and investment costs because, apart from the concentrate, no other subsidiary products arise which could pollute the environment, and the amount of energy needed to separate the substances is relatively small. To compare the electrical-equivalent energy consumption of desalination alternatives, multi-stage flash has a value of 15.5 kWh/m^3, multi-effect distillation a value of 6.5 kWh/m^3, mechanical vapour compression shows a range of 8–14 kWh/m^3 and RO a range of 4–7 kWh/m^3 [2].

Looking at the state of the art of renewable energy (RE) powered desalination plants worldwide, according to [2–5], it can be seen that photovoltaic (PV) and wind energy converters-powered RO plants are the most attractive combinations for desalination. The combination of different RE sources and desalination methods is shown in Fig. 1.

The world's first PV (8 kWp) powered seawater (feed water salinity of 42 800 ppm) RO system was installed in Jeddah, Saudi Arabia, on the eastern shore of the Red Sea [6]. The standalone system produced a quantity of water sufficient to meet the drinking water needs of a community of 250 people and also provided the power requirement of a complete digital logging system. The battery bank was made from a series connection of 40 lead acid units. According to the author, 'this demonstration system is just the start to more and larger solar-powered RO desalination systems'.

An overview of PV–RO systems is given in [7]: 29 plants for the desalination of brackish water and 16 plants for seawater. About 64% of the PV plants has an installed power up to 10 kWp, about 60% of the PV–RO plants use energy storage, about 71% of the PV–RO plants has a daily drinking water production up to 10 m^3 and about 75% of the plants has a specific cost up to 10 US$/m^3. For seawater desalination, the specific energy consumption (SEC) varies from 2.4 to 17.9 kWh/m^3; for brackish water desalination, SEC varies from 0.9 to 29.1 kWh/m^3.

A batteryless PV–RO plant for seawater desalination equipped with an energy recovery device (Clark pump type) is installed, tested and compared with a battery-based system in [8]. The DC power is produced from a PV array (850 Wp) that is connected to the DC motor either directly or via charge controller and a 315 Ah battery bank. The main conclusions are no big difference in the SEC (battery-based system: 4.3 kWh/m^3; direct coupled system: 4.6 kWh/m^3); for a specific available solar energy the battery-based system produces only 6.5% more product water; a small battery bank in such a plant is not economically justified because of the high capital, maintenance and replacement cost. The water production cost (7.8 €/m^3) for the direct coupled system compares well with the available water cost in the Agean Greek Islands.

An experimental study is conducted to investigate the potential of the development of water desalination using a PV powered system in Jordan [9]. The system is mechanically powered, directly coupling the PV power system to a DC motor. Two strategies are compared for the PV modules: fixed flat plate and one-axis tracking system. As conclusion, a gain of 25 and 15% of electrical power and output water flow, respectively, could be achieved using the east–west one-axis tracking system compared with fixed flat plate.

An economic feasibility study of a 20 m^3/day RO plant for seawater desalination with three alternative powering systems is described in [10]: a diesel-assisted PV–RO plant with a diesel generator used to drive the RO plant by night or during blackout hours, a RO plant fully driven by a diesel generator and a RO plant powered only by solar panels (22.49 kWp). The solar-driven plant is characterised by a specific water cost of 7.34 $/m^3 and the lowest SEC of 7.33 kWh/m^3, compared with the other two scenarios.

A pioneer project for drinking water supply to a rural community in semi-arid Brazil is described in [11]. Two strategies are investigated: first the PV–RO plant is equipped with a DC motor; and second, a three-phase induction motor is used. Through the analysis of the stored data the second option is chosen as the best alternative. This strategy has a SEC of 3.03 kWh/m^3, a pressure of 8.27 bar applied to the membranes, a recovery ratio of 27% and a drinking water cost of US$ 12.76/m^3.

A RO (spiral-wound membrane) plant for seawater desalination with an average daily drinking water production of 0.8–3 m^3 installed on the island of Gran Canaria is described in [12]. The plant is supplied by a standalone 4.8 kWp PV system with a battery bank (1240 Ah nominal capacity). At a feed pressure of 48 bar, a SEC of 16.3 kWh/m^3 and a permeate production of 124 l/h with a conductivity of 730 µS/cm (about 450 ppm) are found. At a feed pressure of 63 bar, a SEC of 15 kWh/m^3 and a permeate production of 155 l/h with a conductivity of 540 µS/cm (about 330 ppm) are found.

Small RO systems running on PV systems for rural sites are described in [13]. The raw water was prepared in laboratory with conductivity between 2000 and 5000 µS/cm (at 20°C). The spiral wound membrane material was cellulosic

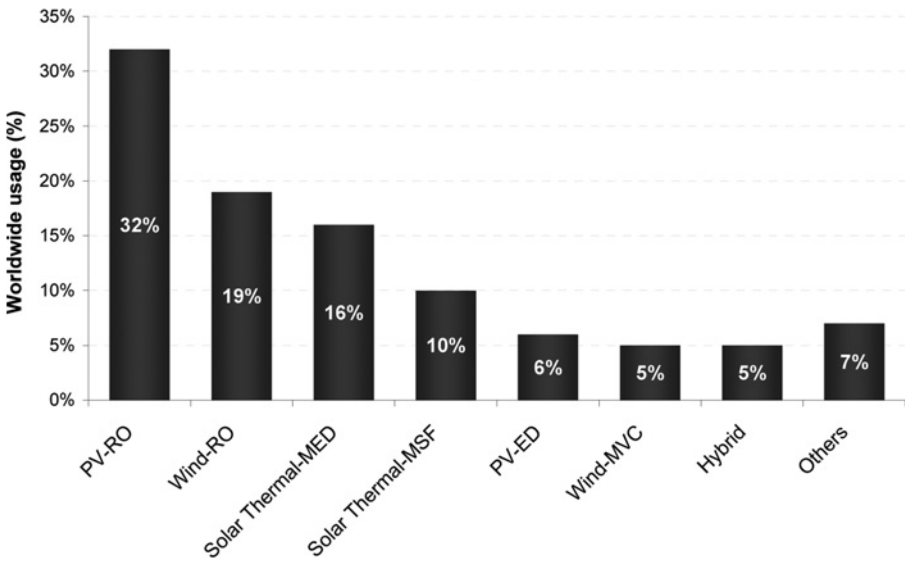

Fig. 1 *Combination of RE sources and desalination methods [4]*

compound, with a maximal feed flow of 7.6 l/m, maximal temperature of 45°C and maximal pressure of 17.2 bar. The desalination pilot system was coupled to a standalone PV system of 100 and 150 Wp, directly connected to the pump with no batteries. During the tests with 2×50 Wp PV modules, the permeate flow varied between 1.0 and 1.9 l/h with a feed pressure between 2.5 and 3.3 bar and a SEC between 144.5 and 103.8 kJ/kg, respectively. With a nominal power of 3×50 Wp, a minimal SEC of 92.0 kJ/kg was found with a permeate flow of 3.2 l/h and a feed pressure of 4.0 bar.

A PV–RO plant for use in remote areas of the Australian outback is described in [14]. Clean drinking water was able to be produced from a variety of feed waters, including high salinity (3500 mg/l) bore water and high turbidity (200 NTU) dam water. The SEC ranged from 2 to 8 kWh/m^3 of disinfected and desalinated drinking water, depending on the salinity of the feed water and the system operating conditions. The optimum operating pressure when filtering bore water was in the range 6–7 bar.

PV–RO plants are a feasible option for semi-arid areas, like the Brazilian Northeast region, where the average temperature is around 27°C and a solar potential of about 2000 kWh/m^2 per year is available. This region has an irregular rainfall distribution; most of the rainfall (~85% of the precipitation) occurs within the short rainy season (January–May) and mainly in the coastal area, leading to the characterisation of part of the region as the 'Drought Polygon'. Furthermore, ~75% of the groundwater has total dissolved solids concentration higher than 500 mg/l, which means that this water is inadequate for human consumption. An additional motivation for the use of this combined technologies (PV + RO) is the natural occurrence of solar/rainfall seasonal complementarity in this region, as can be observed from the meteorological data collected at Ceará state.

According to the literature, most of the PV–RO plants use energy storage aiming to guarantee the produced water quality and the membranes operational life, as well as to reduce the plant dependence on meteorological conditions. However, batteries make a plant more complex, increase costs, require regular maintenance and have a shorter operational life than the rest of the system. The non-existence of batteries decreases the maintenance needs, a fundamental aspect in projects for remote areas. However, because of the intermittent PV power supply, variable pressure and flow conditions are expected, influencing the RO membrane performance.

The advantages and disadvantages of using batteries are analysed in the present paper, since the developed plant allows the study of the operational parameters with or without energy storage. Additional to that analysis, the PV–RO plant allows for controlled variation of the number of PV modules and input water salinity, which will be used to determine the plant performance under different configurations.

2 Description of the developed plant

The developed plant, installed at the Laboratory of Renewable Energies Laboratory, Federal University of Ceará (UFC), in Fortaleza, Brazil, aims to provide drinking water for about 60 people from a brackish water well. The plant uses up to five PV panels, a motor-pump for pumping water from the well to an intermediate reservoir, a second motor-pump for pressurising water towards the RO membranes, a set of filters used for water pre-treatment, two parallel RO membranes, a bank of batteries with charge controller and a data acquisition system with various sensors connected to a supervisory system. The PV modules are directly coupled to the DC motors, with no power electronics interface, aiming to reduce the plant cost.

According to Fig. 2, the operation of the developed plant can be described as follows: brackish water is pumped from the well by a motor-pump to an intermediate reservoir (water storage tank). Then, a second motor-pump sends water with high pressure from the storage tank to the pre-treatment filter set. After that, the brackish water reaches the RO membranes and is divided into two streams:

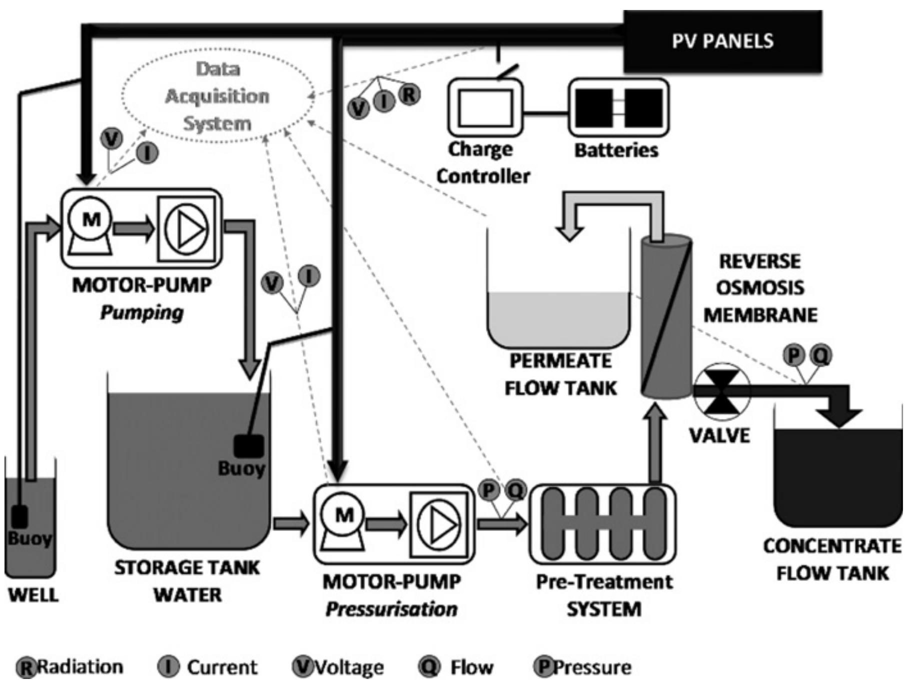

Fig. 2 *General schematic of the developed plant*

doi: 10.1049/iet-rpg.2012.0228

Fig. 3 *RO unit and water tanks*

one with higher salt content (concentrate) and the other with drinking water (permeate). A valve installed in the concentrate pipe controls the input pressure on the membranes, preventing a pressure higher than the nominal as well as an overcurrent in the motor. Power comes from the PV panels, with the option of connecting a battery bank using a charger controller. Several sensors are placed throughout the plant, supervised by a supervisory system and with data being stored in a computer.

The main components used in the developed plant are described below (Figs. 3 and 4):

- A total of five PV polycrystalline panels are used in the present project; each panel has the following specifications: KC85T, maximal power = 87 Wp, $V_{MPP} = 17.4$ V, $I_{MPP} = 5.02$ A, $V_{OC} = 21.7$ V, $I_{SC} = 5.34$ A, under standard test conditions.
- The battery bank consists of lead-acid batteries 12MC150 (12 V_{DC}, 150 A at 25°C).
- Charge controller C30A +, with a maximal loading current = 30 A.
- Motor-pump for sending water from the intermediate reservoir to the RO membranes (SHURFLO 8000 Series Diaphragm Pump, with a nominal maximal pressure of 60 psi, for a water flow at ambient temperature of 4.6 l/m, a current of 7.2 A and a voltage of 12 V_{DC}).
- Motor-pump for pumping water from the well to the intermediate reservoir (SHURFLO 2088 Series Diaphragm Pump, with a nominal maximal pressure of 50 psi, for a water flow at ambient temperature of 6.6 l/m, a current of 9.9 A and a voltage of 12 V_{DC}).
- Pre-treatment filters: water pre-treatment is important for the RO membranes, avoiding problems such as blocking of pores and growth of microorganisms. A total of four filters in series are used (two sediment filters, a carbon filter and an ion filter).
- Two RO membranes are arranged in parallel to obtain a higher water production. The used polyamide thin-film composite RO membrane (FILMTEC TW30-1812-100) has a permeate flow of 16 l/h and a salt rejection of 90% based on the conditions: 250 ppm softened tapwater, 25°C, 15% recovery and applied pressure of 50 psi. These membranes are capable of filtering particles of 0.1 ηm and can avoid bacteria, viruses, ions and dissolved salts. Water salinity was analysed using a portable conductivimeter Phtek CD203, calibrated with standard solutions.

Fig. 4 *Used PV array*

• Data acquisition system: a pyranometer (CMP3), pressure (two PN2024 sensors, range of −14.5 to 145 psi) and flow sensors (range of 0–50 l/m for the SU7000 sensor and 0–25 l/m for the SM6000 sensor), voltage dividers and amplifiers (voltages and currents of the motors). All sensors are connected to a supervisory system with programmable logic controllers and all data are stored in a personal computer using a tool developed by the authors using the software ELIPSE.

3 Results and discussions

As mentioned, the developed plant has features that enable analysis under various configurations, either by connecting or not connecting the battery bank and increasing or decreasing the number of PV panels or by varying the level of salinity of the input water. The financial aspects of these different configurations are also considered, helping to choose the configuration that represents the optimal cost.

For the plant without batteries, the number of PV modules should be sized to guarantee a minimal number of operation hours of the loads (motor-pumps), according to the available solar radiation (energy input). The motor-pump for desalination should be sized taking into account the pressure and flow to be applied to the RO membrane, operational parameters specific for each membrane. The type and number of membranes depend on the feed water salt concentration and the daily drinking water production, which is a function of the number of people to be supplied. For the plant with energy storage, the battery capacity should be sized taking into account the daily load demand, the number of days of operation without energy input, the battery deep of discharge and energy efficiency and the available solar radiation.

Fig. 5 shows the minimum radiation required for the nominal maximal pressure (60 psi, for a water flow at ambient temperature of 4.6 l/m, a current of 7.2 A and a voltage of 12 V_{DC}) of the motor-pump responsible for sending water to the RO membranes (SHURFLO 8000 Series Diaphragm Pump), according to the number of PV panels (horizontal lines), together with radiation curves for both a sunny and a cloudy day. Fig. 6 shows the average plant operation time at this nominal maximal pressure, according to radiation data of November 2010, varying the number of PV panels. The minimum solar radiation necessary to the RO process depends on the quantity of PV panels. According to that, if the system has more PV panels, it will work longer. For local solar radiation values, the plant operates, on monthly average, during 4.6, 6.0 and 6.9 h, with 2, 3 and 4 panels, respectively.

The main steps of the present feasibility study are:

• Feed water was tested for different levels of salinity, aiming to reproduce the groundwater conditions found in the Brazilian semi-arid: 1347, 2748 and 5247 mg/l (additionally, a 288 mg/l level was used only to check the RO-plant behaviour).
• For an input water salinity of ~288 and 5247 mg/l, two types of configurations were used: four PV panels and no batteries, five PV panels with batteries.
• For a salinity of ~1347 and 2748 mg/l, four different configurations are used: three of them without batteries (4, 3 and 2 PV panels) and the last one with batteries (5 PV panels). More attention was given to these levels of brackish water salinity because of the fact that these concentrations are very representative for the Brazilian semi-arid wells.

Table 1 summarises the operational results of the 12 investigated configurations of the developed PV–RO plant.

The analysis of the results indicates the relationships between the different variables. Considering, for instance, the different input water salt concentration values: if there is no variation in the number of PV panels and there is an increase in salt concentration, a decrease in salt rejection can be seen. That means, the higher the input water salt concentration, the lower the membrane capacity to reduce salt flow. This effect can be seen in Fig. 7, where salt rejection is shown as a function of input water salt concentration for the used PV configurations.

Fig. 8 shows the relationship between daily drinking water production and input water salt concentration for the used PV configurations. The following aspects can be observed:

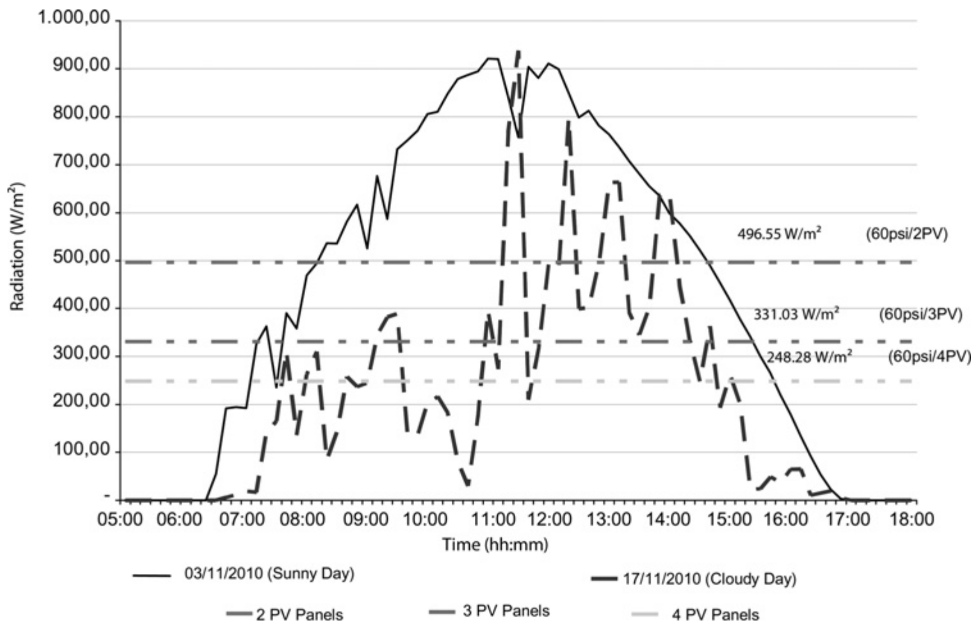

Fig. 5 *Radiation curves for Fortaleza, Brazil (3rd and 17th November 2010)*

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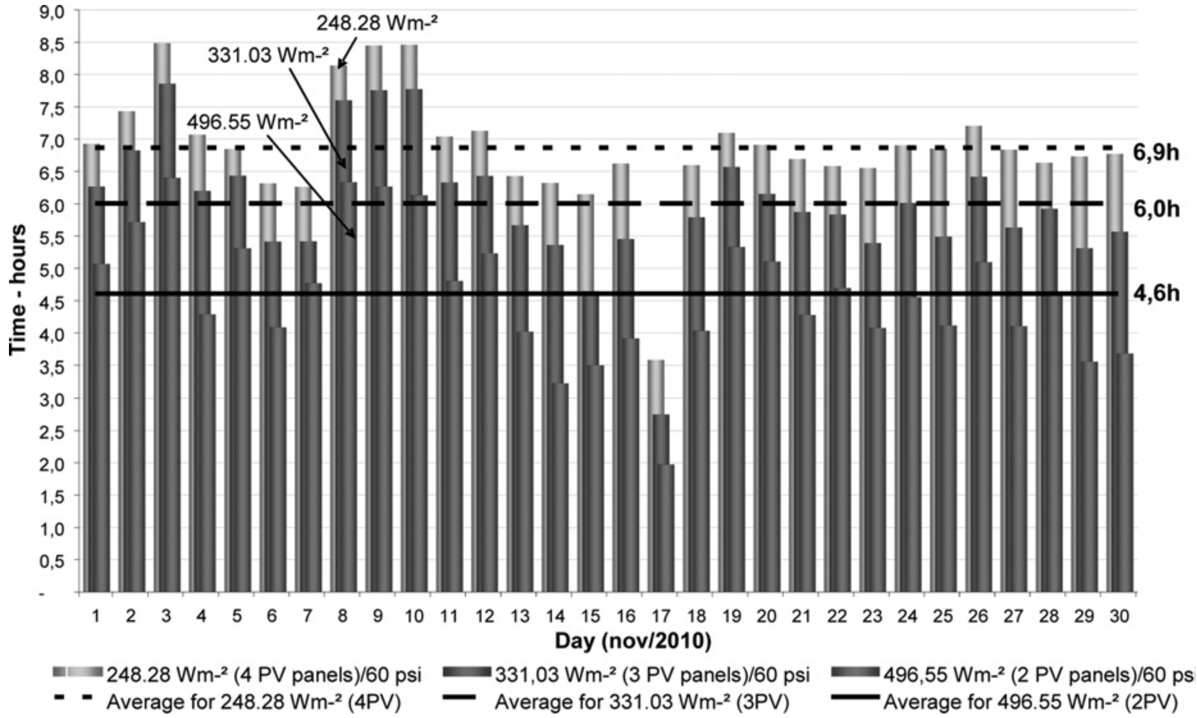

Fig. 6 *Average plant operation time at nominal conditions (November 2010 in Fortaleza)*

Table 1 Operational results of the PV–RO plant

Number of PV panels/ batteries	Input water salt concentration, mg/l	Drinking water salt concentration, mg/l	Salt rejection, %	Drinking water production, l/day	Recovery ratio, %	Specific energy consumption, kWh/m³	Input pressure, psi	Average working time, h/day
4/no	288.98	11.43	96.04	234	20.59	2.56	53.09	8.83
5/yes	288.98	8.73	96.98	726	21.51	1.47	55.37	24.00
4/no	1347.03	80.47	94.03	203	17.98	2.89	56.33	8.00
3/no	1347.03	92.54	93.13	195	17.10	2.82	55.59	8.33
2/no	1347.03	111.05	91.76	175	16.63	2.78	55.53	7.83
5/yes	1347.03	70.90	94.74	637	18.00	1.65	63.00	24.00
4/no	2748.00	275.09	89.99	183	16.26	3.18	56.91	8.67
3/no	2748.00	324.60	88.19	175	16.09	3.12	60.91	8.22
2/no	2748.00	399.26	85.47	157	15.28	3.08	53.33	7.40
5/yes	2748.00	233.82	91.49	580	16.35	1.82	54.45	24.00
4/no	5247.03	1091.38	79.20	128	10.55	4.29	63.87	8.17
5/yes	5247.03	949.50	81.90	397	10.69	3.31	61.55	24.00

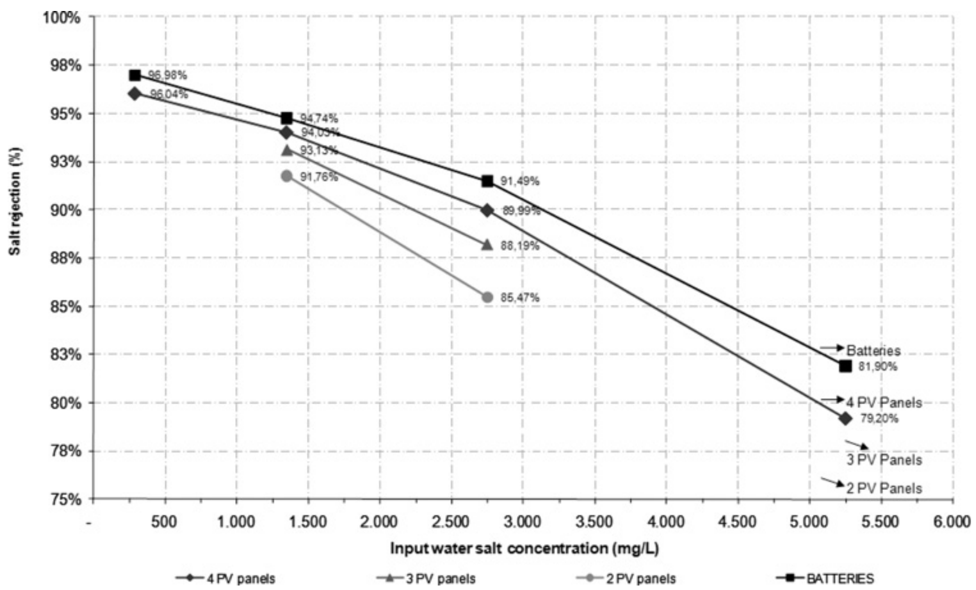

Fig. 7 *Salt rejection against input water salt concentration*

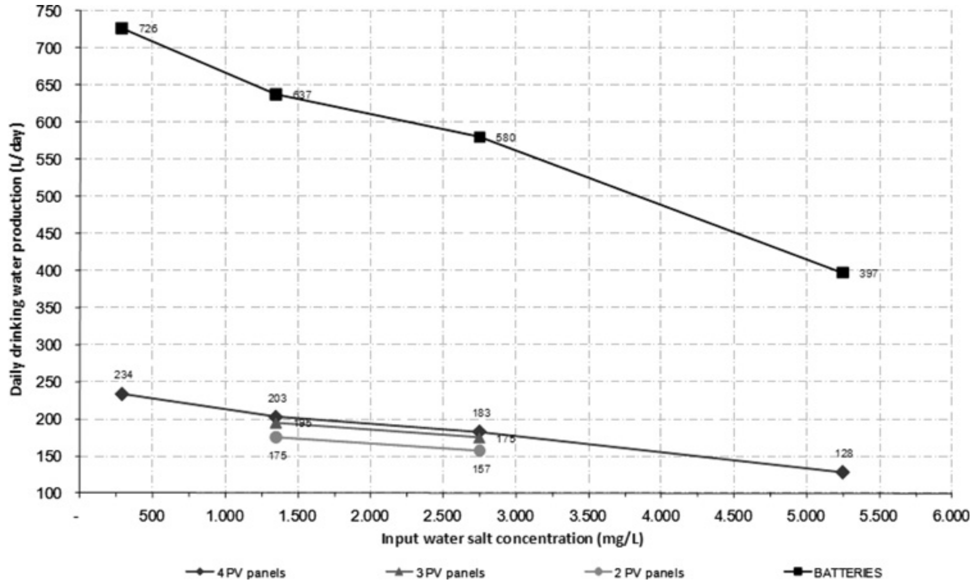

Fig. 8 *Daily drinking water production against input water salt concentration*

- The use of batteries increases drinking water production about three times, compared with the configuration with no energy storage. This behaviour is expected, since batteries allow 24 h per day plant operation, whereas in the configuration with no batteries solar irradiation-dependent operation is limited to about 6–8 h per day.
- There is no significant variation of drinking water production with the use of either three or four PV panels; that is a motivation for investigating optimal sizing, considering technical and economical aspects.

Fig. 9 shows the relationship between input water salt concentration and membrane recovery ratio (drinking water production/input water flow) for the used configurations. According to the measurements, variations in plant energy supply bring no significant change to this ratio for the same salt concentration. That is not the case when the input water salt concentration is increased, resulting in lower RO plant efficiency.

A very important operational aspect is the SEC, the energy required to produce 1 m^3 of drinking water. Fig. 10 shows the relationship between plant SEC and input water salt concentration for the used configurations. Important to remember, since the SEC is given by the ratio between electricity consumption and drinking water production, when both variables change in a proportional way there is no significant variation in the SEC. Thus, the following comments can be made:

- As expected, there is a direct relationship between SEC and input water salt concentration; that is true mainly for high salt concentration values.
- For the same input water salt concentration, there is no significant change in the SEC for the configurations that use no energy storage. That means that the reduction in drinking water production and the reduction in the electricity supplied by a decreasing number of PV panels occur in a proportional way.

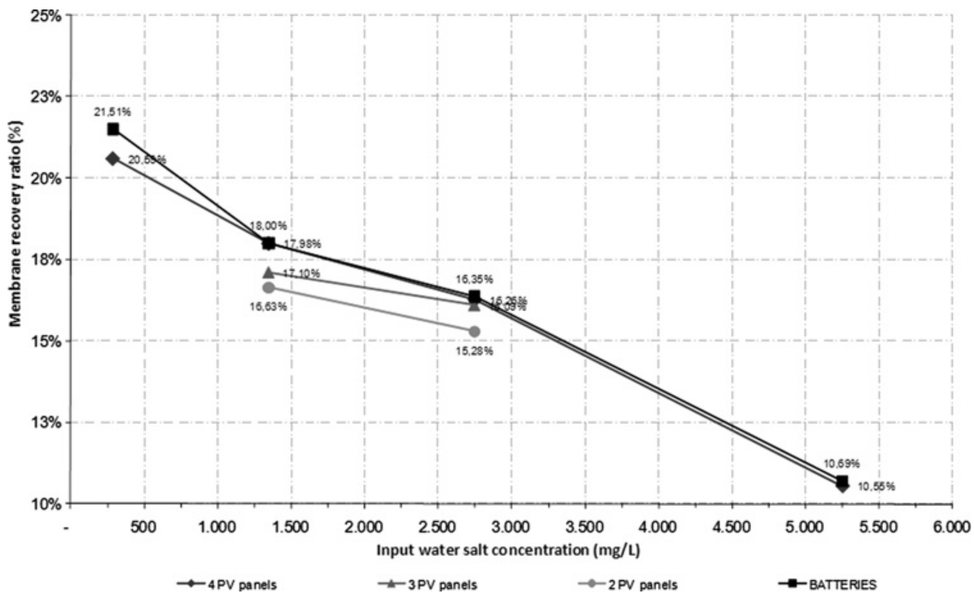

Fig. 9 *Relationship between input water salt concentration and membrane recovery ratio*

doi: 10.1049/iet-rpg.2012.0228

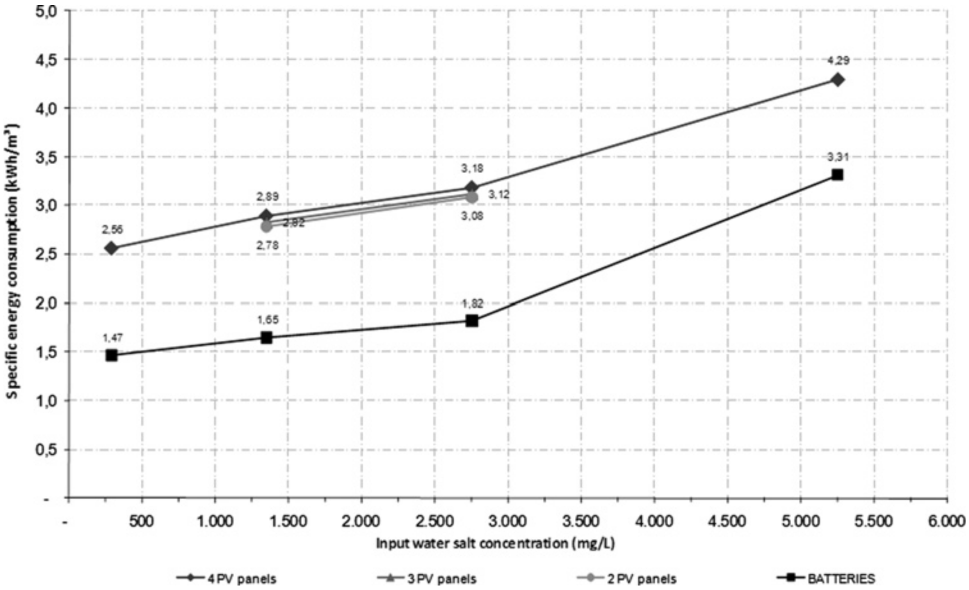

Fig. 10 *Relationship between plant SEC and input water salt concentration*

- For all the used input water salt concentrations, the plant configuration with batteries has a better efficiency, meaning that the increase in energy consumption because of the 24 h per day operation is proportionally lower than the increase in drinking water production.

Table 2 shows the capital investment (CI) of the developed PV–RO and pumping plant with no batteries. All costs are obtained in local market (Fortaleza, Brazil), considering an exchange rate of US$ 1.00 = R$ 1.78.

Important to remember, the configurations with no energy storage use a variable number of PV panels (2, 3 or 4), with an influence on total cost. In this way, the CI can assume the values of US$ 2642 for the two PV panels configuration, US$ 3307 for three PV panels and US$ 3972 for four PV panels. According to that, the PV panels represent 49, 59 and 65% of the total cost for the two, three and four PV panel configurations, respectively.

Table 2 CI of the PV–RO and pumping plant with no batteries (four PV panels)

Item	Cost, US $	Percentage, %
PV panels (four unities)	2584.00	65
motor-pump 1	174.00	4
motor-pump 2	230.00	6
RO plant	443.00	11
other components (electrical and hydraulic)	541.00	14
CI	3972.00	100

The operation and maintenance (O&M) costs for the useful life period are described in Table 3. As before, all costs are obtained in local market (Fortaleza, Brazil), considering US $ 1.00 = R$ 1.78. It should be noted that the O&M costs do not change with the number of PV panels, since this component has an insignificant participation in O&M costs.

The total cost for the 20 years useful life period is given by the sum of the CI and the O&M costs. In this way, according to the number of PV panels, the total cost assumes values of US$ 7308 for two PV panels, US$ 7973 for three PV panels and US$ 8638 for four PV panels.

The annual equivalent value is calculated assuming an annual interest rate of 5.32% (according to present values found in Brazil) and useful life of 20 years. In this way, according to the number of PV panels, the annual equivalent value becomes US$ 602 for two PV panels, US$ 657 for three PV panels and US$ 712 for four PV panels. Table 4 shows the annual equivalent value, the annual drinking water production and the specific cost for the used configurations.

The analysis of the results shown in Table 4 allows the following comments:

- Increasing salt concentration rises the system specific cost, because energy consumption increases with salinity;
- For the same salt concentration, increasing the number of PV panels causes the specific cost to increase; that is not the case for the two PV panels configuration because of the fact that this configuration, having a lower annual equivalent value, has a proportionally higher reduction in drinking water production compared with the three PV panels configuration.

Table 3 O&M costs

Item	Cost, US$	Periodicity, years	Annual cost, US$	Useful life, years	Cost in the useful life period, US$	Percentage, %
RO membrane replacement	281.00	2	140.50	20	2809.00	60
filters	58.00	1	58.00	20	1157.00	25
others	35.00	1	35.00	20	700.00	15
O&M costs			4666.00			100

Table 4 Specific cost for the used configurations with no energy storage

Number of PV panels/ batteries	Input water salt concentration, mg/l	Annual equivalent value, US$	Annual drinking water production, m^3/year	Average specific cost, US$/$m^3$
4/no	288.98	712	85.410	8.34
4/no	1347.03	712	73.913	9.63
3/no	1347.03	657	71.029	9.25
2/no	1347.03	602	63.948	9.42
4/no	2748.00	712	66.722	10.67
3/no	2748.00	657	63.693	10.32
2/no	2748.00	602	57.305	10.51
4/no	5247.03	712	46.574	15.29

The use of the battery bank, as might be expected, causes an increase in the specific cost since batteries are expensive devices, requiring periodic maintenance and replacement. Therefore considering the use of energy storage, average specific cost values of 8.85, 10.09, 11.10 and 16.20 US$/$m^3$ are found for input water salt concentrations of 288, 1347, 2748 and 5247 mg/l, respectively.

Regarding technical and financial aspects, the use of three PV panels without the battery bank is the configuration that represents the best option. This configuration has an input water salinity of 2748 mg/l, a value close to the average of 3000 mg/l normally found in the wells in the Brazilian northeast region. For this configuration, the plant produces 175 l/day, enough to the drinking water consumption of 70 people (considering a consumption of 2.5 l/day per person, as recommended by the World Health Organisation), a permeate salinity of 324.60 mg/l, below the limit recommended by the National Environment Council of Brazil (CONAMA) of 500 mg/l and a specific cost of 10.32 US$/m³, which represents US$ 0.21 per 20 l of drinking water. To compare, drinking water is sold in 20 l bottles, in Fortaleza, at a price of around US$ 2.11.

4 Conclusions

The developed PV–RO and pumping unit, which made possible the production of drinking water by desalination of brackish water, has several innovative features for the Brazilian semi-arid such as: use of two motor-pump unities, one responsible for pumping water and the other responsible for pressurising the water to the RO membranes, the possibility of using batteries or not, flexibility in changing the number of PV panels and the versatility of changing the salinity of the input water. These features allow studying the system under different configurations, to perform a technical analysis and to choose the configuration with the best cost/benefit.

The technical and financial analysis shows that the unit produces satisfactory and competitive results, comparing with different plants in the world. Considering the specific cost for the configurations with no energy storage (Table 4), except for the case with salt concentration of 5247 mg/l, the values found (up to 10.67 US$/$m^3$) are competitive with values mentioned in [7] of a specific cost up to 10 US$/$m^3$. Considering the use of energy storage, the values found (up to 10.09 US$/$m^3$) are competitive only for input water salt concentrations of 288 and 1347 mg/l. Considering the SEC, the range of values found (1.47–4.29 kWh/m^3) fits to the range (2–8 kWh/m^3) mentioned in [14] for a variety of feed waters of the Australian outback. In addition to that, the range found is close to the optimal value of 3.03 kWh/m^3 mentioned in [11] for the Brazilian semi-arid.

Assuming a 2748 mg/l brackish water well, the configuration that brings the best cost/benefit is the batteryless plant using three PV panels, which provides a daily production of 175 l of drinking water at 324.60 mg/l, enough to supply the drinking water consumption of 70 people, with a specific consumption of 3.12 kWh/m^3 and presenting a competitive specific cost of 10.32 US$/$m^3$.

One aspect to be analysed in the future is the influence of economy of scale in such projects, considering the high potential for desalination in arid and semi-arid areas. Owing to the high social motivation for the use of PV–RO plants, the influence of governmental incentives on the cost should also be considered. A self-financing mechanism should be developed for future plants in rural communities, with the goal of obtaining financial resources for O&M cost items such as RO membranes.

5 Acknowledgments

The authors thank the financial support of Banco do Nordeste for the present project and CNPq for the scholarship given to Lucas Carvalho.

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