Renewable Solar Energy Coupled to a Brackish Water Desalination Plant: Efficiency and Optimization

Asma ADDA[1,*], Salah BEZARI[2], Hadjer MAOUZ[1], Salah HANINI[1]

[1] Laboratory of Biomaterials and Transport Phenomena (LBMPT), University of Médéa, Ain D'Heb 26000, Médéa, Algeria
[2]Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, 47133 Ghardaïa, Algeria

[*]Corresponding author; Email: a.docsolaire2017@gmail.com.

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ABSTRACT

In order to reduce fossil energy consumption at desalination plants, it has become necessary to replace fossil energy with clean energy. Currently, the reverse osmosis systems connected to solar energy is a promising technology for desalination of seawater / brackish water, especially in arid and semi-arid areas that have a large solar deposit and are remote from the public grid. The objective of this work is to show the efficiency of introducing renewable energy in brackish water desalination plants by the effect of comparing the energy consumption for a system without renewable energy source and system powered by the photovoltaic system (solar energy). As well as a program developed on Matlab software environment in order to, optimize the energy consumption of a desalination plant for the proposed plant is about 0.1269 kWh/m^3.

I. Introduction

The membrane technologies processes are used largely on desalination is increasingly important to solve the water supply problem for human consumption. The profitability, reliability and durability of the desalination process and the use of new technology, are the challenges of research and developments that have always been oriented and continue to be, to obtain the gains having the repercussions most important on the cost of producing fresh water from seawater. Reverse osmosis (RO), for desalination of seawater and brackish water, might be considered the suitable, as well as the most useful of membrane separation techniques. Because the process is most effective and economic among all desalination processes available. On the other hand, in arid regions with intense solar radiation, the focus has been on integrating the desalination process and solar energy, as water scarcity is more likely to occur in these regions [1]. Solar energy is first-class with 51% of the global renewable desalination capacity, after wind energy, which accounts for 30% [2]. Using the photovoltaic system power can be considering as the most feasible solution in the remote area be cause the access to the grid electricity is diffecult. Recently, there have been intensive efforts to develop and install desalination plants on a large scale, mainly powered by renewable energy sources [3-6], for low-density residential areas deprived of electrical power grid connections. The development of these technologies will be important and promising for developing countries that are currently suffering from water shortage and cannot access to energy resources or their energy reserves are almost exhausted. For this, Algeria has installed eleven (11) large-scale plants to produce nearly 2.11 million m3/day (or 770 million m3/ year) from seawater and brackish groundwater. Most of plants are based on reverse osmosis process [7]. Despite Algeria has a great solar potential but it is not exploited. There are not many desalination plants powered by renewable or solar energy. In this paper, a comparative study between desalination plant powred with renewable energy and an unit powred whith electrical grid will be done. However, the consumption energy is the most

important part of the water cost. Developping a program on MATLAB software to optimize the energy consumption of desalination plant.

II. Methodology and Modelling

RO process is the most energy intensive process within the desalination treatment plant, consumption energy is the most important part of the cost. While the recovery energy device can reduce energy consumption of RO process up to 60%. Therefore, reducing energy consumption is one of the most effective ways to reduce the cost of seawater /brackish water reverse osmosis desalination, which is a more economical and sustainable water supply method specially for the remote area. Small-scale reverse osmosis desalination equipment is used in this work. When there is grid power supply and photovoltaic power generation. Reducing system energy consumption of small reverse osmosis desalination the main. Therefore, how to achieve the maximum desalination rate with the least energy is the most important part of the desalination process.

In this article, a mathematical model developed in Matlab software consists in minimizing the energy consumption of reverse osmosis process. For this purpose, two different models are proposed, the first model is intended for modeling the energy consumption of a RO plant powered by the electrical grid, and the second model is recommended for the optimization of the parameters of the desalination plant powered by the PV system.

II.1. Presentation of RO/PV desalination unit

The use of solar energy in desalination introduces environmentally friendly and more economical technologies. Solar photovoltaic (PV) systems convert solar irradiation directly into electricity through solar cells. However, the desalination unit consists of a small-scale unit located in Hassi-Khebi (Wilaya of Tindouf) powered by a solar photovoltaic (PV) generator. The unit produces drinking water for around 800 inhabitants of this village from brackish water from a borehole with a salinity of 3.2 g / L.The main advantage of PV/RO systems is their ability to develop small size desalination plants. The electricity from PV systems can be used to drive high-pressure pumps in RO plantsbispresented in figure 1.

Ro unit

Photovoltaic system

Figure 1. Reverse osmosis plant with photovoltaic solar energy.

Energy is provided to the water treatment system through a solar array with minimal battery storage. To provide sufficient power for the proper operating of the desalination process under a well-determined flow rate and pressure, the batteries will have to be dimensioned according to the necessary needs.

Algeria considering as a big African country has a huge solar potential with an average amount of radiant solar energy of about 2 400 kWh / m2 [8]. Figures 2, 3 show the variation of the meteorological data concerning the average monthly global solar radiation, ambient temperature, relative humidity and precipitation

However Through figure 2, an increasing solar potential is considerable towards the south of Algeria. In Tindouf we note extremely important values of solar radiation reaching up to 6.5 Kwh/m^2/day [9]. We can see that a very high monthly ambient temperature around 35.5 °C corresponds to a minimum relative humidity of around 19% in the same time a low precipitation (figure 3).

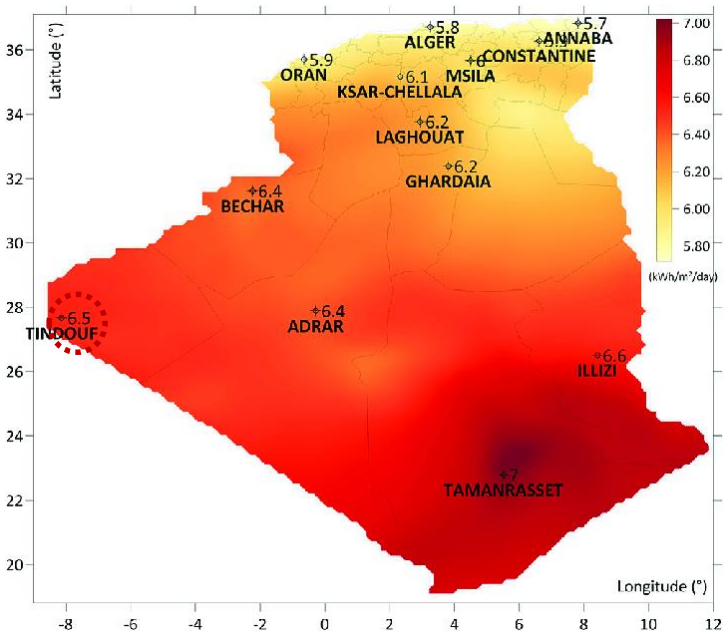

Figure 2. Clear sky global irradiation map [9]

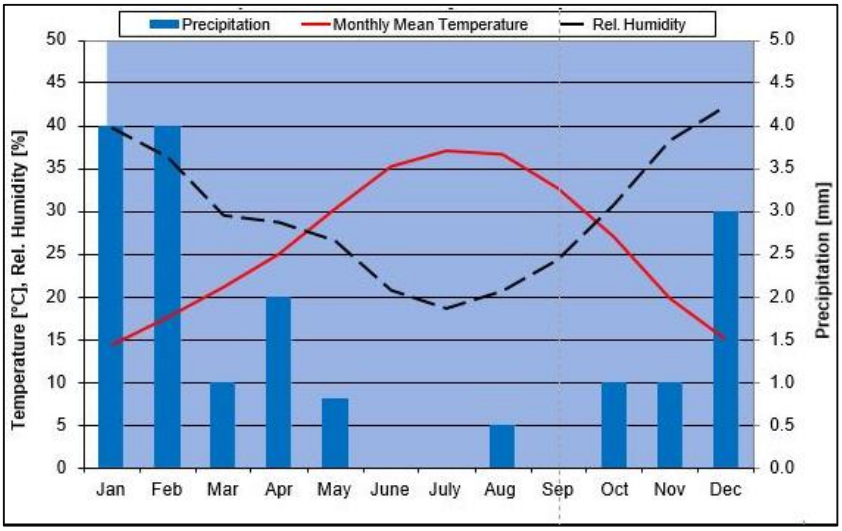

Figure 3. Metheological data.

II.2. Modeling the energy consumption of RO system without photovoltaic system

In order, recovery energy from the reject stream (brine) of the reverse osmosis process, several devices have been designed. The turbine was the first system installed and coupled with a high-pressure pump with up to 85% efficiency. However, the turbine is the classical device used as recovery device only in small plants to reduce the consumption energy of the process of desalination worldwide [10].

The energy requirements of an RO unit taken into account the type of energy recovery system installed in the desalination plant. In our case, our brackish water desalination plant is equipped with a turbine.

the reverse osmosis process is the suitable for the desalination process, before allowing water to enter the membrane it passes through a treatment station called the pretreatment step, the water delivered to the reverse osmosis membranes through high-pressure pumps under pressure, which requires important energy of all the equipment [11].

The hydraulic turbines are mounted on the same shaft as the high-pressure pump and their role is to recover the energy from the brine in Figure 4.

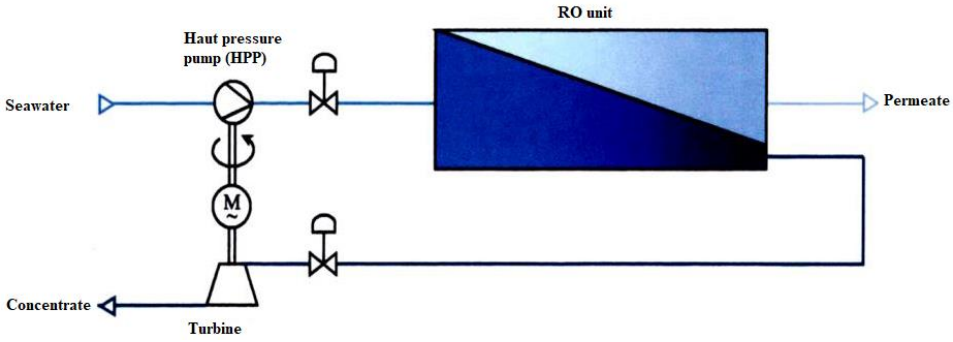

Figure 4. Reverse osmosis plant without photovoltaic solar energy.

The specific energy consumption is defined by the energy required to produce a cubic meter of permeate with a desirable salinity [12].

ΔP is the pressure drop in the modules and η_{turb} the efficiency of the turbine, the energy recovered by the turbine is defined by [13] :

$$sec_{turbine} = \frac{1}{36.6}(P_f - \Delta P).\eta_{turb}\left(\frac{1}{y} - 1\right) \quad (1)$$

The energy consumption of the plant equipped with a turbine is presented as follow:

$$sec\ _{des,turb} = \frac{P_A}{36{,}6.\eta_p.y} - \frac{1}{36{,}6}.(P_A - \Delta P).\eta_{turb}(\frac{1}{y} - 1) \quad (2)$$

The RO unit power is expressed as:

$P_{dess} = sec_{dess} \times Q_p$

Where

P : feed pressure

ΔP : The pressure drop in the modules

ηturb : turbine recovery efficiency

ηp : high pressure pump efficiency

Y : recovery ratio.

II.3. Modeling of the energy consumption of RO process with photovoltaic system

In this case, the energy source is the solar energy presented as photovoltaic panels coupled directly to the RO unit. The choice of PV technology for the desalination process is based on dominant application and the promising future of such technology. The PV system is designed to operate for several hours a day .Therefore, the number of batteries corresponding to the given power drive the BWRO unit, a small amount of battery capacity is included in the power system model. The battery should be charged in the morning after which the system will boot up and turn on.

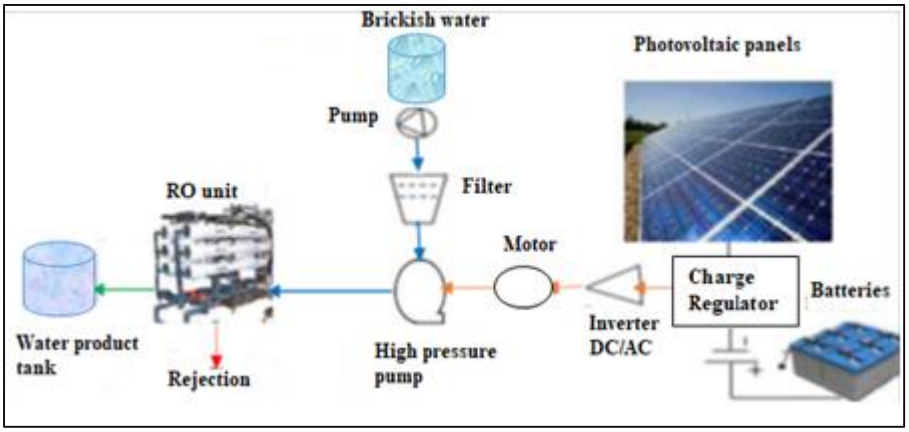

Figure 5. Small-scale BWRO driven by a photovoltaic solar panel

A simplified simulation model is used to estimate the hourly output power of the PV generator; Photovoltaic power is given by:

$$P_{PV,tot} = \frac{P_{DES}}{t_{hd}/24+(1-t_{hd}/24)\alpha_{BCH}\alpha_{BDCH}} \quad (3)$$

Where P_{DES} the energy required by desalination (kWh/jour), α_{BCH} the battery charging efficiency and α_{BDCH} is the battery discharge efficiency [11]

III. Results and Discussion

The methods used in this case to solve the optimization problem under constraints are to adapt an algorithm for projected gradient so that each iteration step and constraints are respected [14].

The validation of the program allows to predict and ensuring the reliability of the method of resolution and established a program in order gives predictions in our study. The execution results of the program are expressed for the two configurations (without photovoltaic system and with renewable energy).

The characteristics of the PV/RO desalination brackish water unit are illustrated in table 1.

Table 1. Characteristics of the PV/RO desalination brackish water unit

Characteristics	Values
Working temperature ^{0}C	35
Feed water concentration (TDS) ppm	3500
feed water flow rate (m^3/h)	2.25
feed Pressure (bar)	6
product flow water (m^3/h)	1
power (kw)	2.06
specific energy consumption (kwh/m^3)	0.98

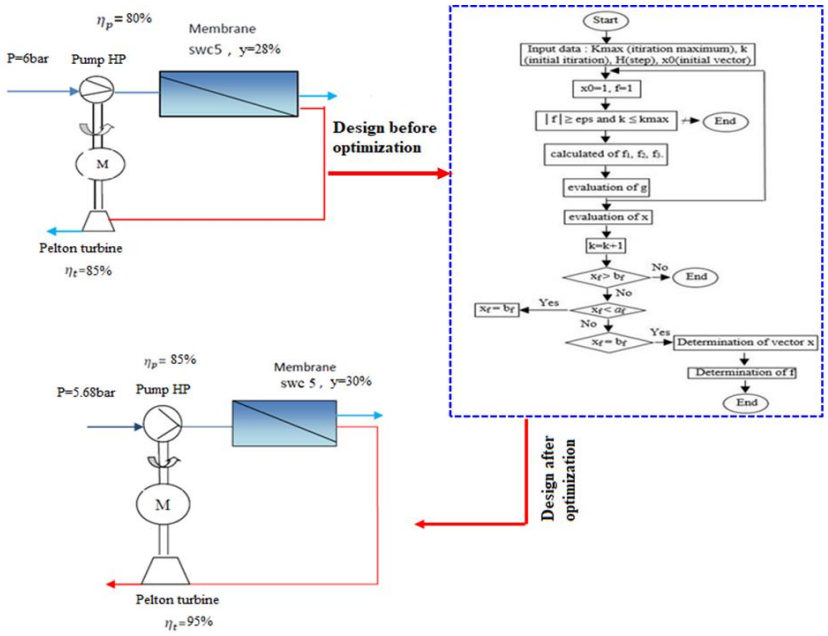

Figure 6. Diagram schematic of oprtimization process.

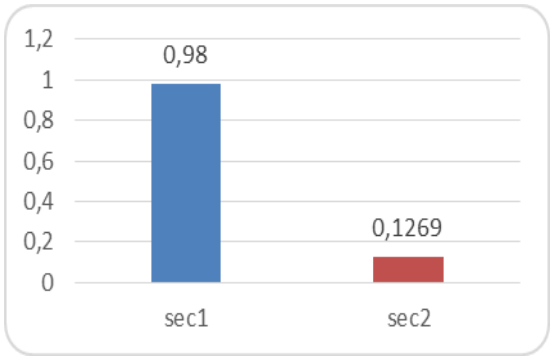

Figure 7. Optimization of the specific consumption energy.

In order to optimize the specific energy consumption of the station, the model can reduce energy by up to 87%. The energy consumption of the desalination station powered by photovoltaic system is reduced compared to station without solar energy system.

IV. CONCLUSION

Renewable energy sources (RES) to power desalination processes are a promising option, especially in remote and arid regions where the use of conventional energy is expensive or unavailable. The desalination is an energy intensive process and demands sustainable energy supply for water desalination. The solar potential energy can be utilized for water desalination to reduce cost energy and reduce the greenhouse effect. In this paper, a mathematical model developed in Matlab software consists in minimizing the energy consumption of reverse osmosis process. For this purpose, two different models are proposed, the first model is intended for modeling the energy consumption of a RO plant powered by the electrical grid, and the second model is recommended for the optimization of the parameters of the desalination plant powered by the PV system. The results have been presented and analyzed. In order to validate the obtained results, the Hassi khebi unit data has been chosen. The results show that the specific energy of the plant can be reduced to 87%.

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