DESIGN, TECHNO ECONOMIC AND ENVIRONMENTAL EVALUATION OF A SMALL SCALE BRACKISH WATER DESALINATION SYSTEMS POWERED BY SOLAR ENERGY IN THE ARID REGIONS OF ALGERIA.

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Abstract - The southern regions in Algeria are suffering from fresh water shortage due to their climate severity and the geographic situation. These areas have access to brackish groundwater and significant potential of solar energy. The combination of solar energy with desalination processes, such as reverse osmosis systems, presents possible solution to satisfy the fresh water needs for the population living in these remote areas. This paper presents a technical and economic evaluation of a small-scale brackish water reverse osmosis desalination unit powered by solar photovoltaic systems for fresh water production under Algerian arid climate conditions. In the first part of this paper, a mathematic model has been developed for design and sizing the photovoltaic field, taking into account two configuration; power system with batteries and without batteries. The photovoltaic system model is coupled to reverse osmosis model to determine the overall system performance (water production, Specific Energy Consumption…) and an optimization is performed in order to determine the suitable configuration. In the second part, the economic feasibility study of use solar energy has been done using some economic parameters such as, Levelized Water Costs (LCOW) Net Present Value (NPV) and Internal Rate of Return (IRR). The investigation also includes a discussion on the sensitivity of cost of unit of produced fresh water to some parameters such as the useful life of reverse osmosis system, cost of solar photovoltaic pannels and other associated parameters. The results of this investigation can be used also as indicators to identify the best locations for solar powered desalination plant implementation for fresh water production in Algeria.

Keywords - Desalination, Brackish water, Solar Energy, Photovoltaic.

I. INTRODUCTION

Algeria, like other southern Mediterranean countries suffers from the water shortage that will worsen in the years to come, with more than 42 million inhabitants and it's among most exposed to water stress by 2030. With less than 500 m^3 per inhabitant per year of drinking water, Algeria has less than 50% of the theoretical scarcity threshold set by the World Bank at 1000 m^3 per inhabitant per year [1,2]. Desalination of seawater or brackish water is one of the possible responses to adapt to the growing scarcity of water resources. Currently, Reverse osmosis membrane technology dominates the industry of desalination and brackish water treatment in Algeria and in all world countries. The Algerian government has launched a huge desalination program to build 13 big desalination plants in several regions of northern Algeria and even in the south for the brackish water treatment. For the moment, the desalination of seawater contributes, in Algeria, to 17% in the national supply of drinking water and we will exceed 25% once the units in progress put into service [1,2].

However, while desalination techniques are now well controlled, their implementation requires large amounts of energy, in the form of heat or electricity, costly and potential sources of greenhouse gas emissions. In addition to the coastal areas, these features allow a very fast installation and a perfect adaptation to the specific needs of arid and semi-arid regions suffering from a deficiency of drinking water, emphasizes. In the last few years, the solar power desalination technology of brackish water being considered as one of the promising way for fresh water production in order to satisfy the water demand growing. In this work, we present a technical and economic evaluation of a small-scale brackish water reverse osmosis desalination unit powered by solar photovoltaic systems RO/PV for fresh water production under Algerian arid climate conditions. The coupling of RO/PV using the MATLAB software has been modelled. The modelling has to be done, taking into account the types of systems used, as well as the territorial, environmental and economic stakes involved in their coupling.

II. WATER RESOURCES STATE IN ALGERIA

Due to its geographic location in the MENA region, Algeria is a water scare country. For this reason, it is considered among the poorest countries in Africa and in the World in term of water resources. The water is obtained from different sources which include rainfall, surface water resources (dams and very small rivers), non-conventional water resources,i.e. desalination and wastewater stations,

and underground water resources. The Algerian territory is divided into five hydro-graphic basins comprising the 19 watersheds in the country. The water potentials in Algeria are estimated at 15.37 Billion Cubic Meters (BCM) annually, distributed as follow:

* 10 BCM annually in the north, of which 7.4 BCM of surface water and 2.6 BCM of groundwater (80% are mobilized by wells and boreholes)

* 5.37 BCM annually in the south, of which 0.37 BCM of surface water and 5 BCM of groundwater.
Hereinafter, a brief overview of the available water resources is provided (only desalination status):

2.1. Desalination in Algeria

In order to take advantages of its coastline stretching over 1200 km, Algeria has moved towards mobilization of non-conventional water resources using seawater desalination and brackish water demineralization process.

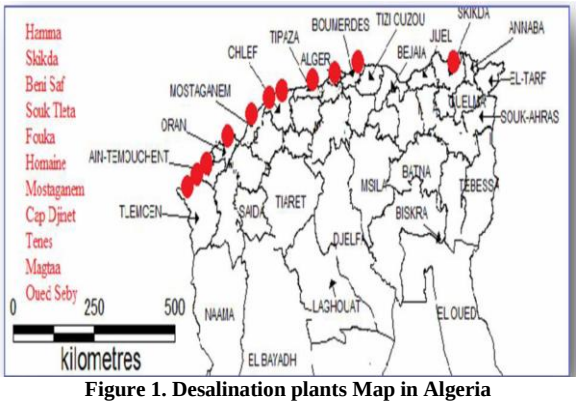


Figure 1. Desalination plants Map in Algeria

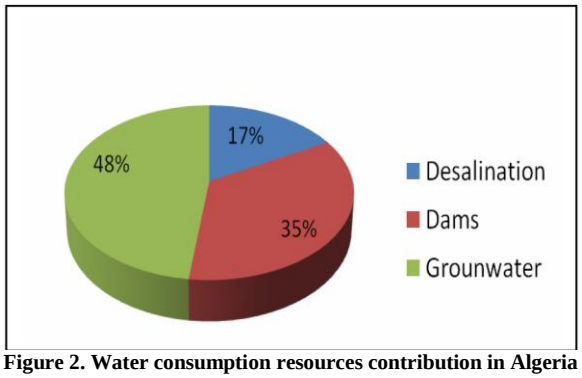


Figure 2. Water consumption resources contribution in Algeria

Since 2000, Desalination has become an imperative and inevitable solution for Algeria to overcome its current shortage of potable water. For this, more than 11 seawater desalination Mega plants have been installed in the coaster region of the country with a total daily capacity of 21.1 million m3, see figure 4. The daily capacity of these plants ranges between 100,000 and 500,000 m3 each, in addition to the 21 monobloc desalination plants with an daily average capacity of 2500 to 5000 m^3 each and a total daily capacity of 57,500 m^3.

It's worth mentioning that the desalination plants in Algeria supply nearly 15% of total water consumption per year, as indicated on figure 6. The total water production is estimated at 8.24 Million per day or 3.3 Billion M3 per year.

2.2. PV/RO modeling

To determine the performance of the proposed system (figure 3), a global model of the water transformation (brackiqh water-drink water) and the solar field is performed in MATLAB in which the system is divided into two components. The first is for reverse osmosis unit while the second one is dedicated to solar photovoltaic pannels and batteries.

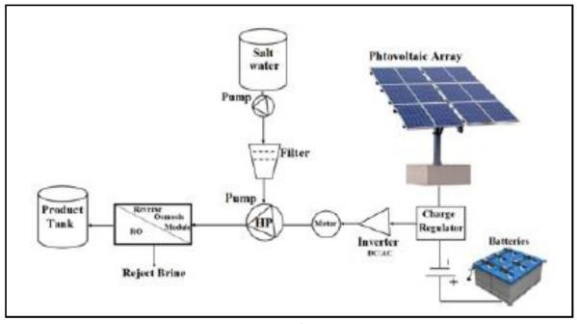


Figure 3. Schematic diagram of the PV powered RO system

The required energy production by the desalination system is given by :

$$P_{PV\ /\ RO} = \frac{P_P}{\frac{t_{hd}}{24} + \left(1 - \frac{t_{hd}}{24}\right).a_{bch}\ .a_{bcdh}}$$

(kWh/day)

Where :

P_p Energy produced by solar cells (kWh), t_{hd} : Average hours of daylight, a_{bch} : The charging efficiency of the battery, a_{bcdh} : the discharging efficiency of the battery .

In our case we took a_{bch} =0,2 and a_{bcdh} =0,8.

The total number of modules needed to feed the electrical energy of RO system is :

$$P_{PV\ /\ RO} = \frac{1}{\frac{t_{hd}}{24} + \left(1 - \frac{t_{hd}}{24}\right).a_{bch}\ .a_{bcdh}} . \frac{P_p}{P_{PVM}}$$

Where :

P_{PVM} : Average daily production of energy by PV (kWh/day)

2.2 Economic study

The desalination plant incorporates two elements; the capital cost and the annual operating costs. The capital costs cover Equipment purchasing cost, auxiliary equipment and installation charges. In our case, the land cost is not taken into account because

it's offered by the state. Annual operating cost represents the total yearly costs of owning and operating a desalination plant. These, include amortization or fixed charges, operating and maintenance costs, energy costs and membrane replacement costs. Our investigation take into consideration only stand alone plant in isolated areas in the southern region of Algeria. The levelized Water Cost (LWC) is generally used to compare different desalination plant technologies. In this economic calculation approach, the annual capital costs (fixed and variable annual costs of RO plant and of solar photovoltaic plant) are divided by the total annual fresh water production. The economical considerations of utilizing the solar energy for fresh water production by desalination are most important aspects in selecting the proper desalination processes to be used in any project and also to choose the location where the plant will be implemented. To study the economic feasibility of a power system, different methods could be used to evaluate different figures of merit of the systems. Each method has its own advantages, disadvantages, limitations and some conditions to be satisfied so that it can be applied [14]. For the evaluation of the investment, the two following indicators have been used:
The following equation is used to calculating the LEC:

$$LCW = \frac{C_{inv} + C_{chem} + C_{staff} + C_{ma\ int} + C_{mem}}{Q_{water}}$$

($/m^3)
Where:
C_{inv} : The total investment costs of the reverse osmosis and Photovoltaic plants ($/y), C_{chem} is the annual cost of chemicals ($/y), C_{staff} is the annual cost of staff ($/y), $C_{ma\ int}$ is the annual maintenance costs ($/y), C_{mem} is the annual costs of membrane replacement ($/y) and Q_{water} is the annual fresh water production (m^3/y).

Environmental analysis
The CO2 saving in the proposed system calculated from the CO2 emissions factor per kWh generated (C), take in the account the transmission and distribution losses (T&D). The saving can be calculated as below equation:

$$CO_{2\,saving} = Annual\ \ Energy\ \ Saving x\ (1 + T\ \&\ D) xC$$

In Algeria, the C is assumed to 0.7 kg CO2/kWh and the T&D losses are 15%.

III. RESULTS AND DISCUSSIONS

The type of membrane used in the considered pilot is the SW30HR380 FILMTEC. This membrane has a high flux and a good boron rejection results (99%). The operating pressure ranges between 10 and 15 bars (brackish water).

Table 1 : Characteristics of the RO unit are shown in table 1.

Characteristics	Value
Permeate Flow (l/h)	84
Feed water flow (l/h)	165
Pump Efficiency (%)	75
Solar field capacity (kW)	3

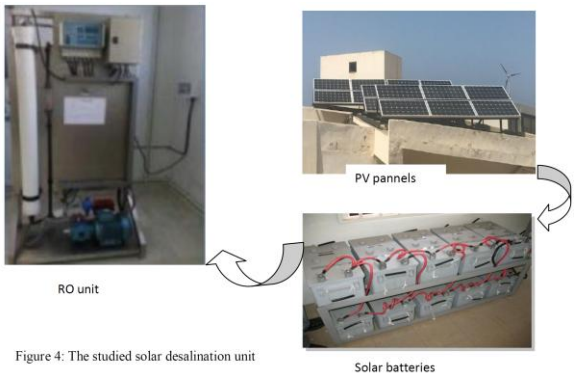


Figure 4: The studied solar desalination unit

Table 2 Component replacement rate

Component	Lifetime (years)
Photovoltaic pannels	25
Control Electronics	10
Membrane	05
Pumps	10

The system life is assumed at 25 years and the interest rate is about 4%. The system capital costs and maintenance costs are considered. We don't consider the following costs ; land, site preparation, system assembly, brine disposal and water distribution. The average replacement rate are shown on table 2.

CONCLUSION

Solar desalination is a promising way of meeting water demand in remote areas and as a way to reduce the carbon footprint of commercial desalination. Reverse osmosis process is currently the most cost-competitive solar desalination technologies approaching conventional desalination water costs.

- The investigated proposed plant in this study shows that using PV systems for brackish water desalination at current electricity tariff is not economically feasible in the high plateau regions.
- The investigated proposed plant in this study shows that using PV systems for brackish water desalination is economically feasible in the remote areas (extreme south).
- There are environmental benefits for the proposed system, as Green House Gases reduction..

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