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Energy consumption optimization of a brackish water solar desalination plant working on reverse osmosis process

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Abstract— *Nowadays, brackish and sea water desalination has became one of important fresh water sources in arid and semi-arid regions suffering from water scarcity. The reverse osmosis process which is one of desalination process requires large amount of electric energy, it's around 3.5–5.0 kWh/m³. Hence, solar energy-powered reverse osmosis systems are promising technologies for brackish and seawater desalination notably for small remote communities. These systems can be designed according to water demand and energy resource. This work aims to minimize the specific energy consumption (SEC) of a solar desalination plant working on reverse osmosis process to produce fresh water from brackish water (BWRO). Two scenarios are taken into account; (1) BWRO without recovery device, (2) BWRO with energy recovery device (turbine). A mathematical model and an algorithm in the Matlab area have been developed and validated. The results show that the minimum value of specific energy consumption for the proposed plant is about 0.1269 kWh/m³ for 47% of water recovery*.

Keywords— Reverse Osmosis process renewable, energy specific energy consumption, modelisation, optimization

I. INTRODUCTION

Faced with growing water demands in the world and particularly in Algeria, producing fresh and drinking water of acceptable quality with minimal cost is the main objective of all researchers [1]. The use of membrane process desalination is increasingly important to solve the water supply problem for human consumption.

The energy requirements for seawater desalination using thermal-based technologies are on the order of 7-14 kWh/m3 when compared to 2-6 kWh/m3 for membrane based technologies [2,3]. The energy requirements are lower for RO, but energy consumption still remains the major operational cost component due to the high pressure pumps required to feed water to the RO process [4].

Renewable energy technologies are the best energy supply option for desalination systems, where energy supply from an electricity grid is not readily accessible.

Photovoltaic (PV) technology can be connected directly to RO desalination processes to supply the energy need of the pumps (water feed pump, cleaning, booster and high pressure pumps) as shown in figure1.

It's important to note that energy consumption for RO desalination processes can be reduced by using energy recovery devices (ERD).

In this context, we present, in this study, a mathematical model to optimize a BWRO plant coupled with a solar energy system (Photovoltaic system).

The optimization of the BWRO/PV systems is done by using projected gradient Algorithm. The model aims mainly to calculate the optimal configuration of the system with minimum specific energy consumption after determining the optimal number PV panels and different operating parameters of desalination plant.

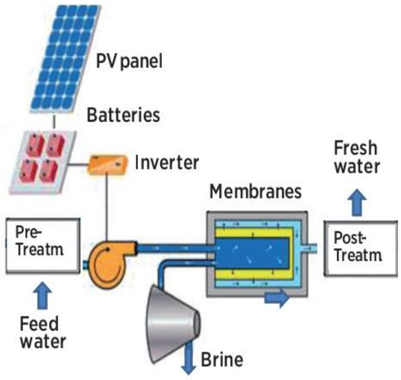

Figure. 1 Coupled PV and RO desalination plant [5]

II. MODELLING – METHODOLOGY

The mathematical model developed in the present work consists of global model divided into two sub-models; one for photovoltaic generator and the second is dedicated for the reverse osmosis unit, where two cases are considered with and without recovery energy device.

A. *Modeling the PV modules*

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 plants. The energy production unit consists of a number of photovoltaic modules, which convert solar radiation into direct electric current (DC) [6]

Energy storage (batteries) is required for PV output power smoothing or for sustaining system operation when insufficient solar energy is available [7].

The model starts from a minimum number of PV modules which are able to provide the power supply for the RO unit

A simplified simulation model is used to estimate the hourly output power of the PV generator, Photovoltaic power is given by [8]:

$$P_{pv} = S_{PV} G_i \times \eta_{pv}(T_{pv,i}) \quad (1)$$

The PV generator efficiency is expressed as:

$$\eta_{PV}(T_{a,i}) = \eta_{PV} \times [1 - \beta \times (T_{PV,i} - T)] \quad (2)$$

T_{PV} is calculated using the N_{oct} (Normal Operating Cell Temperature), it can be defined as follows :

$$T_{PV} = T_a + G_i\left(\frac{N_{oct} - 20}{800}\right) \quad (3)$$

The everage number of the PV modules

$$N_{PV,m} = \frac{\bar{P}_{RO}}{\bar{P}_{PV}} \quad (4)$$

These different parameters are obtained from the PV module manufacturers.

We combined equation 2 and 3 in 1:

$$P_{pv} = S_{PV} \times G_i \times \eta_{PV} \times [1 - \beta \times \left(T_a + G_i\left(\frac{N_{oct} - 20}{800}\right) - T\right)]$$

B. *Reverse Osmosis unit modelling*

The reverse osmosis model is performed for different configurations of the reverse osmosis process from 1 to n stage, and also for process without energy recovery and process with energy recovery system

1. *Process without recovery energy*

Generally in this state, the high pressure pump acts as an energy recovery device it must ensure a water flow rate at a given pressure, while absorbing the minimum energy

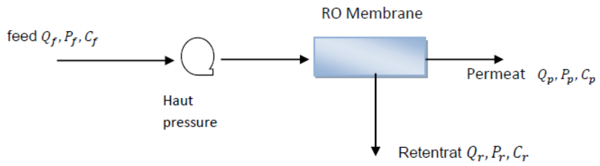

Figure 2. Reverse osmosis process without energy recovery

We define the specific energy consumption by the energy required for producing one cubic meter of permeates with a salinity desirable [9]. In a reverse osmosis process without recovery energy device, the selection of the high pressure pump is very important [10.11].

The specific energy consumption is defined as follows:

$$SEC = \frac{w^0_{pump}}{36.6\, \eta_p Q_p} \quad (6)$$

The work of the high-pressure pump w^0_{pump} is given by the following relationship:

$$w^0_{pump} = p_f Q_f \quad (7)$$

The recovery ratio of the membrane is given as following:

$$y = \frac{Q_p}{Q_f} \quad (8)$$

According to the equations 1, 2 and 3, the specific energy consumption is calculated as following:

$$SEC = \frac{P_f}{36.6\,\eta_{pump}\,y} \quad (9)$$

2. Process with recovery energy device

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 [12].

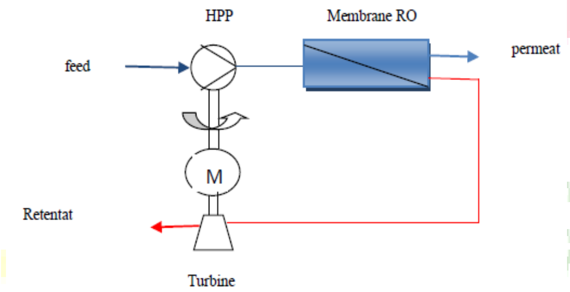

Fig 3. Reverse osmosis process with turbine as recovery device

The specific energy consumption of the turbine is expressed as follows:

$$SEC_{turb} = \frac{1}{36.6}(P_f - \Delta P) \times \eta_{turb}\left(\frac{1}{y} - 1\right) \quad (10)$$

Therefore, the specific energy consumption of the process is equal to the difference between the pump power and the energy recovered by the turbine [16]:

$$SEC_{turb} = \frac{P_f}{36.6\eta_p y} - \frac{1}{36.6}(P_f - \Delta P) \times \eta_{tub}\left(\frac{1}{y} - 1\right) \quad (11)$$

The RO unit power is expressed as:

$$P_{RO} = SEC_{RO} \times Q_p$$

C. Mathematical solution method

One way to solve a problem of constrained optimization is to fit a projection gradient algorithm so as to comply, at each iteration and constraints [13].

The principle of the method is based on the gradient calculation of the objective function based on various parameters and recalculates, under constraints in order to assess the specific energy consumption

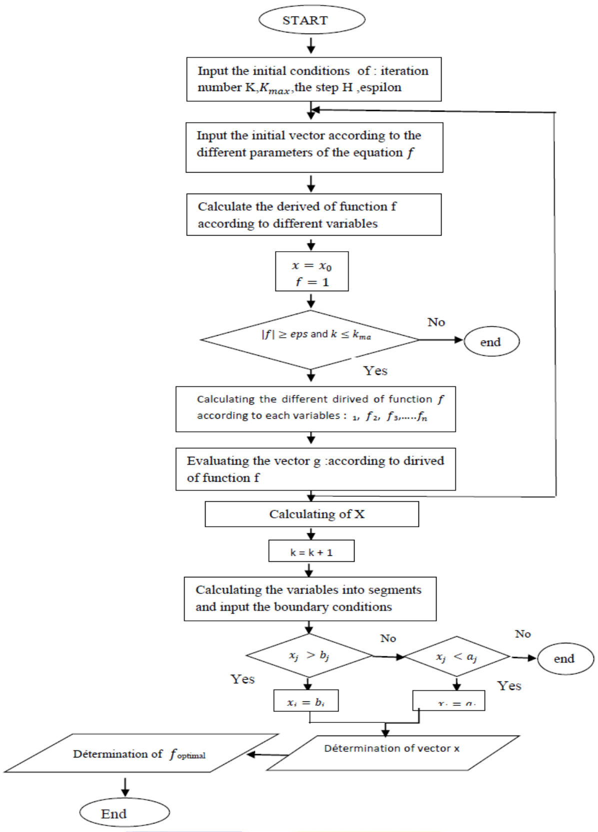

Fig 4. Flowchart of projection gradient method

D. The case study

To validate the proposed optimization methodology on real site, a model from reference [14] has been selected .The characteristics of the PV/RO desalination brackish water unit are illustrated in table 1.

TABLE I
Characteristics of the PV/RO unit in Kser Ghilene village [14]

Characteristics	*Values*
Working temperature C^0	35
Feed water concentration (TDS) ppm	3500
feed water flow rate (m^3/h)	2.25
Recovery ratio (%)	32.23
feed Pressure (bar)	6
product flow water (m^3/h)	0.625
power (kw)	2.06
specific energy consumption (kwh/m^3)	0.98

Table 2
Characteristics of haut pressure pump

Characteristics	*Values*
Model HYDRA_cell	
Efficiency %	72.25
Flux max (m^3/d)	20

Table 3
Characteristic of the PV module

Characteristics	*Values*
Model PW 6-230	
Efficiency %	10
Nominal Power	230
Surface (m^2)	1.84

Table 4

Characteristics of the PV/RO plant obtained from the model

Characteristics	*Values*
Feed Pressure (bar)	5.8522
RO Efficiency %	47
HPP efficiency	85
Turbine efficiency	90
Specific energy consumption (kwh/m^3)	0.1269

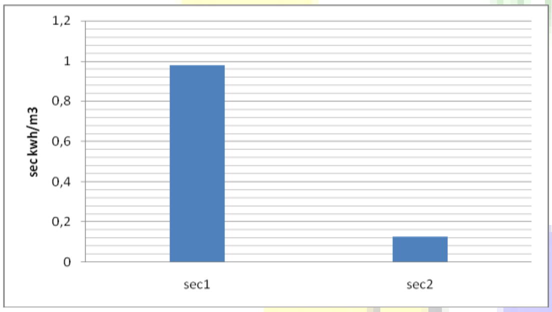

Fig 5. The specific energy consumption of the plant
Sec1 : Actually energy of unit ,sec2 :energy obtained from the model

In order to optimize the specific energy consumption of the plant, the model can reduce the energy to up 87%and the optimal recovery of the unit go to 47%.

III. Conclusions

In this paper, a global model of a small scale reverse osmosis unit has been developed. It incorporates two sub-models for two cases. The equation set has been solved using the projection gradient method under Matlab Environment. The results have been presented and analyzed.

In the next step, and in order to validate the obtained results, the Kser Ghilene Village data has been chosen. The results show that the specific energy of the plant can be reduced to 87% with a recovery 47%.

The model can be used to carry out a parametric study to predict the influence of some parameters on performances of BW/RO unit.

Nomenclature

G_i	Global irradiation
N_{oct}	Nominal cell operating temperature
P_f	Water pressure at membrane entrance
P_0	Raw water pressure
P_{pv}	Photovoltaic power
Q_f	Volumetric feed flow rate
Q_p	Permeate flow rate
S_{pv}	Surface of PV generator
T_a	Ambient temperature
W_{pump}	Rate of work done by the pump
η_p	High pressure pump efficiency
η_{pv}	PV generator efficiency
β	Temperature coefficient witch supposed constant for silicon solar cells

References

[1] Val S. Frenkel. «Seawater Desalination: Trends and Technologies,Desalination » Trends and Technologies, Michael Schorr (Ed.), ISBN: 978-953-307-311-8,2011.

[2] Veerapaneni, S., B. Long, S. Freeman and R. Bond. 2007. Reducing Energy Consumption for Seawater Desalination. J.AWWA., 2007(6):95-106

[3] David Hasson, Victor Lumelsky, Gal Greenberg, Yosef Pinhas, Raphael SemiatDevelopment of the electrochemical scale removal technique for desalination applications Desalination 230 , 329–342,2008

[4] A .Subramani, Mhammad Badruzzaman,Joan , Oppenheimer ,Joseph G. Jacangelo ,Energy minimization strategies and renewable energy utilization for desalination: A review ,water research journal 1907-1920,2011.

[5] A. Al-Karaghouli, “Renewable Energy Opportunities in Water Desalination,” in Desalination, Trends and Technologies, M. Schorr, Ed. InTech, 2011.

[6] Bourouni, K., Chaibi, M. Solar energy for application to desalination in Tunisia: description of a demonstration project. *Renewable Energy in the Middle East*, 125-149.2009

[7] Clarke, D. P., Al-Abdeli, Y. M., & Kothapalli, G. (2011). Modelling Small-Scale Stand-Alone (PV) Energy Systems with Reverse Osmosis Integration. Paper presented at the International Congress on Modelling and Simulation,2011

[8] Mariem Smaoui, Achraf Abdelkafi, Lotfi Krichen ,Optimal sizing of stand-alone photovoltaic/wind/hydrogen hybrid system supplying a desalination unit, Solar Energy 120 (2015) 263–276

[9] Marjorie Gavach, « Detoxification of condensats of distillery by reverse osmosis exchanges of ions and their combination Application in the recycling in alcoholic fermentation », 27 mai 2010

[10] Alain maurel, «Desalination of the sea water and the waters of brackish: and other processes non-conventional of water supply soft »,2nd edition 2006

[11] Hanane Dach, « Comparison of the operations of nanofiltration and reverse osmosis for the selective desalination of brackish water: of the

scale of the laboratory to the industrial pilot », doctorat , université d'Angers, mai 2008

[12] Alice Daussy, Maxime Guérin, Tries Guth, « seawater desalination in Malte and Israël », technology university Compiègne, 2011

[13] Yan Yue Lu,Yang D H ,« optimum design of reverse osmosis system under different feed concentration and product specification » journal de science membranaire 287 ,219-229 ,2007

[14] Erik D, Juan MP. « A case suey: energy use and process design considerations for four desalination projects in California. In: IDA World Congress –Perth Centre Convention et Exhibition (PCEC). Perth, Western Australie, Septembre 4-9, 2011

[15] K. Bourouni , T. Ben M'Barek , A. Al Taee, «Design and optimization of desalination reverse osmosis plants driven by renewable energies using genetic algorithms", Renewable Energy journal, 36 ,936-950, 2011