# Development & Modelling Of An Equivalent Circuit Of Electrodialysis Desalination Photovoltaic (EDPV)

**Hanen Nafaa, Maissa Farhat , Sbita Lassaad**

**Abstract:** This paper presents an electrical model of electrodialysis desalination. This model helps to understand the behavior of a desalination system under various irradiation conditions. Additionally, it helps pick up the behavior of the photovoltaic desalination systems. The latter are an economical option in areas remote from the national grid. In this context, the effective performance of the desalination system is crucial. The problem comes from the characteristics of water in the system. The purpose of this paper is to investigate the behavior of an EDPV system under the various water flow volumes, different salinity effects, weather conditions (irradiation) and to study the performance of the system. In this study the complete electrical circuit of the entire desalination system along with the mathematical model and simulation are presented. As a result an optimal system configuration can be achieved.

**Index Terms**: Photovoltaic energy, Electrodialysis, Brackish-water, solar generator, electrodialys desalination, PV.

## 1 INTRODUCTION

W hen you open the document, select “Page Layout” from The volume of resources is 4.6 billion cubic meters yearly. 2.7 billion cubic meters for surface water and 1. 9 billion cubic meters groundwater. However, just 54 % of water-resource has a salinity lower than 1.5 g/l (Relatively high salinity)[1]. Fresh water is a central to our daily lives. The focus is to reduce the imbalance between the resources and the potential, in order to be able to serve the various users. Thus, to achieve this objective, it is necessary to limit the mobilization and integrated resource management, establish water-transfer systems, develop a program of water savings and mobilize unconventional resources [2]. Several countries made use of the desalination of the sea water. It is uncontroversial that the primary energy costs have increased rapidly in recent years [3]. This has two main repercussions: Firstly, an even greater attention should be paid to the question of the power consumption in the design, the comparison and the selection of desalination process. Secondly, we must increase the use of renewable energy sources (solar and wind) and the nuclear energy in desalination. Photovoltaics (PV) are quickly developing thanks to the declining costs. Likewise, the study of the coupling of this technology with the methods of desalination considerably increased during the last decades. Photovoltaic systems have a lot of advantages, modularity of different PV technology, low maintenance the low level of noise, the long life and the non-greenhouse gas emission. The desalination by membrane process allows filtering the salt by means of special membranes and directly produces drinking water [4]. In order to reduce costs in these systems; a photovoltaic system as a source of energy is used. These technologies are expanding faster and faster. The technical of desalination of the sea water is completely developed. However, considering the cost-cutting in this system is the first objective, and this objective has not been achieved yet, more researches is necessary. In this context, the photovoltaic network was used as a source of energy. This work, aims at stressing the applicability of PV technology in North Africa (Tunisia) through a design and implementation of photovoltaic desalination by the electrodialysis systems shown in Figure. 1.

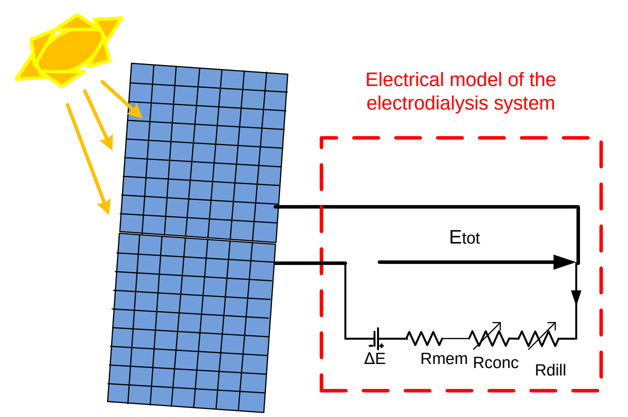


***Fig.** 1. The water desalination system.*

## 2 THE ED-STACK MODEL

The equivalent electrical circuit electrolysis system is shown in figure 2. It consists of a voltage sources, membrane resistance, dilute compartment resistance and concentrate compartment resistance.

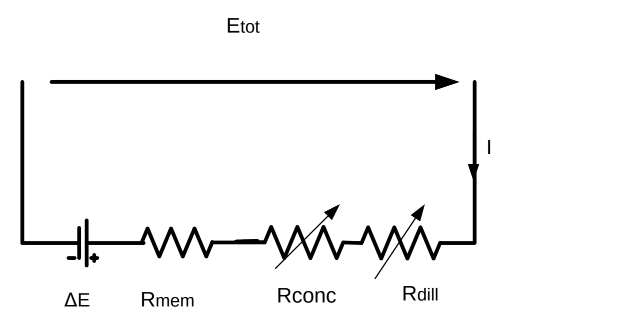


*Fig. 2. Equivalent electrical schema of the electrodialysis system.*

The values of the electric components have been developed in the next parte with:

### 2.1 Total electrodialysis stack voltage:

The total electrodialysis stack voltage is given by the following equation [5]:

$$E_{tot} = \Delta E + N\left(E^{dill}_{ohm} + E^{conc}_{ohm} + E_{mem}\right) \quad (1)$$

Where the first term $\Delta E$ refers to the electrode potentials, the second term $E^{dill}_{ohm}$ refers to the ohmic resistance drops in dilute solution compartment, $E^{conc}_{ohm}$ the ohmic resistance drop in a concentrate solution compartment and E mem the membrane potential.

The ohmic resistance can be formulated as follows:

$$E^{dill}_{ohm} + E^{conc}_{ohm} + E_{mem} = \left(R_{dill} + R_{conc} + R_{mem}\right) I \quad (2)$$

The diluate compartment resistance can be calculated by the following expression [6]:

$$R_{dill} = \frac{L}{C_{dill}\Lambda_{dill} A} \quad (3)$$

Where A is the membrane active area (m2), L is the thickness of the membrane (m), C is the salt concentration (mol m−3) and Λ is the molar conductivity of the solution (Sm2 mol−1).
With the following conditions, the concentration is homogeneous inside the compartment and the conductivity of the water is inconsequential.
The molar conductivity may be calculated with Falkenhagen equation [7]:

$$\Lambda_{dill} = \Lambda_0 - (B_1\Lambda_0 + B_2)\frac{C^{0.5}_{dill}}{C_{dill}B_0 u} \quad (4)$$

Where B0, B1, B2 are dimensionless numbers, known for aqueous solutions at a wide range of temperatures. Λ0 is the limiting molar conductivity (Sm2 mol−1), and u a temperature-independent parameter (A°).
The calculation of the resistance of concentrated solutions could be done in the same way.
The resistance in the membranes of a single cell is:

$$r_m = \rho_m \frac{l}{A} \quad (5)$$

Where the membrane resistivity depends on several factors such as the ion exchange capacity and the nature of the ionic fixed group, the swelling and the mobility of counter-ions; which are responsible of current transport).
The total membrane potential Enem is the sum of cation-exchange and anion-exchange membranes:

$$E_{mem,c} = \frac{RT}{F}\ln\left(\frac{a^{wc}_{conc}a^{wa}_{conc}}{a^{wc}_{dill}a^{wa}_{dill}}\right) \quad (6)$$

The activity is calculated by the following equation:

$$a^{wc}_{conc} = \gamma^{wc}_{conc} C^{wc}_{conc} \quad (7)$$

Where γ is the mean ionic coefficient and C is the NaCl concentration.
According to equations (6) and (7), it is necessary to know the concentration in the membrane surface. The electrolyte concentration in the cation-exchange and anion-exchange membrane surface of the dilutes compartments can be captured in the following equations:

$$C^{wa}_{dill} = C_{dill} - \frac{\Phi j}{zFk_m}\left(1 - t^-\right) \quad (8)$$

$$C^{wc}_{dill} = C_{dill} - \frac{\Phi j}{zFk_m}\left(1 - t^+\right) \quad (9)$$

In the same way, we can calculate the electrolyte concentration in the cation-exchange and anion-exchange membrane surface of concentrates compartments.
The potential of electrodes can be defined as follows:

$$\Delta E = E^e_{cat} - |\eta_{cat}| - (E^e_{an} + |\eta_{an}|) \quad (10)$$

With $\eta_{cat}$, $E^e_{cat}$ are equilibrium potentials and over-potentials, respectively.

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In electrochemistry, the law of Tafel connects the surge entered electrodes with the current density. For the overload, tension is defined through the following equation:

$$\eta = b\ln\left(\frac{j}{j_0}\right) \quad (11)$$

With j the current density (A m-2), j0 is the exchange current density (Am−2) and b is the Tafel slope (V−1).

### 2.2 Mass balance

To calculate the concentration change of NACl in both reactor compartments and in the reservoirs, the mass balances for both solutions needs to be established. The mass balance equations for the NaCl in the electrodialysis reactor for concentrate and dilute compartments are, respectively [8]:

$$\frac{dC_{con}}{dt} = \frac{Q_{conc}}{NV_k}\left(C^0_{conc} - C_{conc}\right) + \frac{\Phi I}{zFV_k} - \frac{AD_a}{V_k l_a}\left(C^{wa}_{conc} - C^{wa}_{dill}\right) - \frac{AD_c}{V_k l_c}\left(C^{wc}_{conc} - C^{wc}_{dill}\right) \quad (12)$$

$$\frac{dC_{dill}}{dt} = \frac{Q_{dill}}{NV_k}\left(C^{0}_{dill} - C_{dill}\right) + \frac{\Phi I}{zFV_k} + \frac{AD_a}{V_k l_a}\left(C^{wa}_{conc} - C^{wa}_{dill}\right) + \frac{AD_c}{V_k l_c}\left(C^{wc}_{conc} - C^{wc}_{dill}\right) \quad (13)$$

Where z the charge of the ion, F the Faraday constant, N is the number of cell pairs, A the active membrane area, Vk the compartment volume the current efficiency, I the current, t the time, $C^{0}_{conc}$, $C^{0}_{dill}$, $C_{conc}$ and $C_{dill}$ respectively refer to the solution concentration of concentrated and dilute compartments at the inlet and at the outlet of the electrolysis reactor. $Q_{conc}$ and $Q_{dill}$ l the flow rates of concentrate and dilute solutions, Da and Dc the average diffusion coefficients of the NaCl in the anion-exchange and cation-exchange membranes, respectively, la and lc the thicknesses of the anion-exchange and cation-exchange membranes, and $C^{wa}_{conc}$, $C^{wa}_{dill}$, $C^{wc}_{conc}$ and $C^{wc}_{dill}$ are the concentrations on the surface of the anion.

### 2.3 The amount of salt

The amount of salt to be eliminated N (g / m3) is expressed by:

$$\Delta N = \frac{i.r.q.s}{5.36Q} \quad (14)$$

Wherein:
S: The overall surface area of the membrane ( m2 ); Q: flow of the circuit for dematerializing (m3/h) ; I: current intensity (A); r: Faraday yield and
q: Fraction of useful membrane.
This relation shows that the amount of salt to be eliminated is directly proportional to the overall surface area of the membrane and inversely proportional to the flow of the circuit of demineralization.

## 3 PHOTOVOLTAIC SYSTEM

Photovoltaic is the direct conversion of sunlight into electricity without any heat engine. Photovoltaic devices are rugged and simple in design virtually maintenance-free and their biggest advantage being their construction as standalone systems to give outputs from micro-watts to mega-watts. Hence, they are used for power source, water pumping, remote buildings, solar home systems, communications, satellites and space vehicles and membrane desalination processes. With such a vast array of applications, photovoltaic demand is increasing every year. A PV power generation system is made up of multiple components like cells, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. These systems are rated in peak kilowatts ( kWp) which is an amount of electrical power that a system is expected to deliver when the sun is directly overhead on a sunny day.

### 3.1 Mathematical modeling of photovoltaic sources

The current-voltage characteristics of the electric circuit of solar cell can be described by the following simplified equation [9] ,[10]:

$$I_p = I_{ph} - I_{sat}\left(\exp\frac{\left(\frac{V_p + I_p R_S}{N_S}\right)q}{TKn_S} - 1\right) - \frac{\left(V_p + I_p R_S\right)}{R_p} \quad (15)$$

q: the electro charge (1.602*10-19 C)
K: Boltzmann's constant (1.38*10-23 j/K)
T: temperature, K.
A : the surface area part of the cell exposed to solar radiation, m2.
Isat: the saturation current density, amp.
Ip: the current flowing in the circuit, amp.
VP : voltage of the circuit, v.

The electric power output of PV is [11]:

$$P_p = I_p V_p \quad (16)$$

Moreover, the maximum output power is given by:

$$P_{max} = (I_p V_p)_{max} = V_{oc} I_{sc} FF$$
(17)

VOC: the open circuit voltage.
ISC: the short circuit current.
FF : the fill factor.
Pmax =Vmp * Imp, corresponding to the maximum power point, MPP
The energy conversion efficiency, η, is given by:

$$\eta = \frac{V_{mp} I_{mp}}{P_{in}} = \frac{V_{oc} I_{sc} FF}{P_{in}}$$

Taking the aforementioned equations into consideration, a model simulating the PV panel in MATLAB/SIMULINK was created. Figure 3, illustrates the I-V and P-V characteristics of the PV panels used in this research at a solar temperature 25°C and irradiation 1000W/m2,500 W/m2,300 W/m2 , if the PV panels are connected to resistive load R.

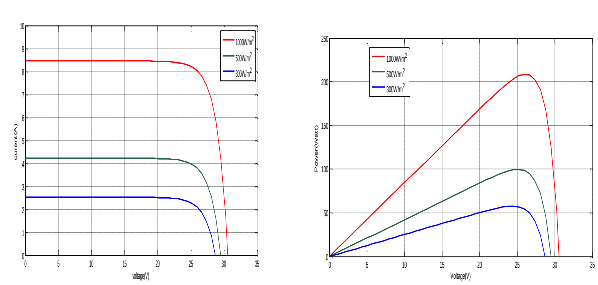

***Fig.3****(a) V-I and (b) P-V characteristic. For PV panel.*

## 4 SIMULATIONS

As noted above, the main objective of this paper is to verify the reliability of brackish-water desalination process by electrodialysis process powered by PV energy. As noted above, the main focus of this study is to verify the reliability of brackish water desalination process by the electrodialysis process powered by PV energy. For this reason a series of operations are performed:

- Influence of degree of water salinity and water flow.
- Influence of the weather conditions in the functioning of the system for a typical day.

The parameters of the system are shown in Table I and Table II, when the electrodialysis system has a maximum voltage rate to be applied. The maximum number of PV modules still needs to be determined.

In the electrodialysis used is EURODIA EUR-6-80, the manufacturer advises not to exceed the value of 1V per cell (total 80 V).

As the PV modules used are (PV-TD 195 HA6) with an open circuit voltage of just over 30V at the reference condition, two modules must be selected in series. To validate the proposed system, a digital simulation was realized, in the environment Matlab / Simulink with the following hypotheses:

✓ Electrodialysis reactor and tanks (concentrated and diluted) are in accordance with the model and perfectly mixed.

✓ Concentrated and diluted compartments are equivalents.

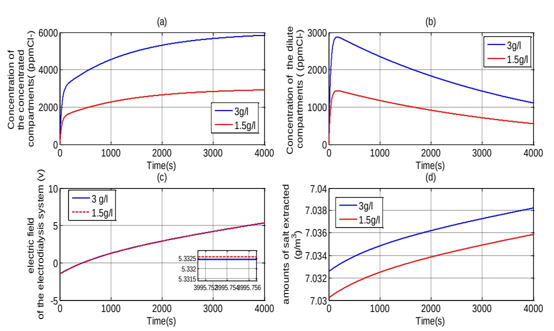


***Fig. 5**. (a) Concentration of the concentrated compartments, (b) Concentration of the diluted compartments, (c) electric field of the electrodialysis system and (d ) amounts of salt extracted.*

### 4.1 Influence of the degree of salinity of the water

47% of The maximum number of PV modules still needs to be determined of the Tunisian South, showed salinity between 1.5g / l and 3g / l. The main objective is to verify reliability of the desalination process with both concentrations limited by brackish water in a similar irradiation.

***TABLE 1***
*MODEL PARAMETERS (EURODIA EUR-6-80) [12]*

| Parameter | Value |
|---|---|
| B0 (A-1 mol-1/2) | 3.277. 10-1 |
| B1 (mol-1/2) | 2.271 10-1 |
| B2 (S m2 mol-3/2) | 54.164 |
| u(A) | 4 |
| Qd, Qc (m3 s-1) | 5 10-5 |
| N | 10 |
| Vi (m3) | 6 10-6 |
| A(m2) | 0.555 |
| la (m) | 1.4 10_4 |
| lc(m) | 1.7 _ 10_4 |
| Ø | 0.89 |
| F (C mol_1) | 96,485 e |
| z | 1 |

***TABLE 2** POWER SYSTEM PARAMETERS (PV-TD 195 HA6) [13]*

| Photovoltaic array parameters | Value |
|---|---|
| Rp | 1000 Ω |
| Rs | 0.001Ω |
| Isc | 8.48A |
| Voc | 30.6V |

Figure 4 ( a ) shows that the concentration of the diluted compartments decreases, whereas that of the concentrated compartments increases with the concentration limited by brackish water in a similar irradiation. With regard to the figure 4 ( b ), it seems that the variation of concentration of the diluted compartments is lower than that of the concentrated compartments, because of the large difference between mass diffusion coefficients and thermal diffusivities of the diluted solution .The results obtained indicate that this variation depends mainly on the state of initial concentration of water. Figure 4 (c) shows that the electric field of the electrodialysis system is independent of the salinity of the water. Figure 4 (d) shows that the amount of salt extracted from the electrodialysis system depends on the change in the salinity of the water.

### 4.2 Influence of water flow

In constant weather conditions (irradiation and temperature) and with a salinity of 3g / l, we took two flow rates for concentrated and diluted solutions (0.3m3 / s and 0.75m3 / s).

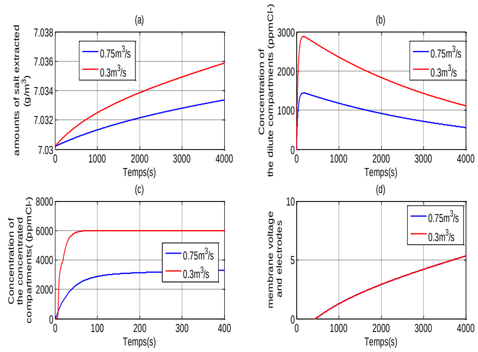


***Fig. 5**. For T = 25 °, G = 1000W / m2: (a) amounts of salt extracted, (b) Concentration of the concentrated compartments, (c) Concentration of the diluted compartments and (d ) electric field of the electrodialysis system.*

As Figure 5 (a, b, c) shows, at higher flow rates, the amount of separated salts and separation performance decreases because a larger flow rate means a lower residence time. This means that the ions that are between the membranes do not have enough time to pass through these membranes, while the potential of the membranes is constant (Figure 5 (d)).

### 4.3 Influence of weather conditions

In the case of highly sunny day irradiations, there is an obligation to use boards with two PV modules in series at the most, to avoid possible overvoltage in the electrodialysis.

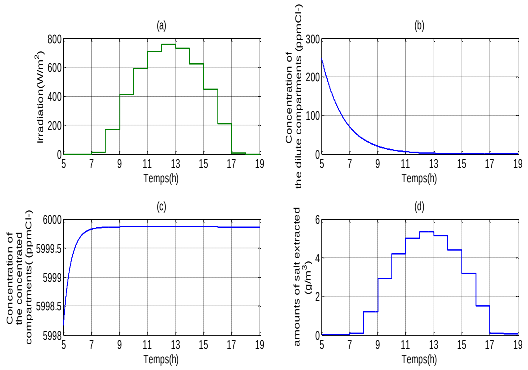


***Fig. 6**. Concentration of the (a) Variation of irradiation , (b) Concentration of the concentrated compartments, (c)*

Figure 6 (a) shows the solar irradiation. Figures 6 (b) and 6 (c) show the concentration in the diluent and concentrate (CCl-dil and CCl-conc) tanks. It can be seen that irradiation has no effect on the concentration of the two compartments. Figure 6 (d) shows that the amount of salt extracted from the electrodialysis system depends on the variation of sunshine. This is due to the proportionality with the output voltage of the PV generator, which is also directly proportional to the weather conditions. This result is confirmed by Figure 7.

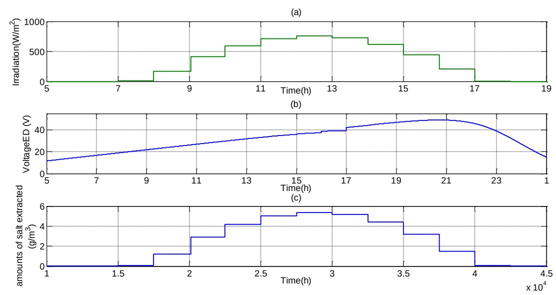


***Fig7.** (a Irradiation variation, (b) Photovoltaic generator voltage (Vpv), (c) quantities of salt extracted.*

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Figures 7 (b) and 7 (c) clearly show how the behavior of the photovoltaic generator voltage (Vpv) of the system and the amount of salt extracted from the electrodialysis system are highly dependent on solar irradiation (G). Obviously, at constant concentration, cell performance increases by increasing the voltage, which decreases the amount of salt in the produced water.

## 5 CONCLUSION

In this work an equivalent electric model for (ED-PV) Photovoltaic Eectrodialysis Desalination was developed. Furthermore, the supply of the photovoltaic energy of a desalination system by electrodyalisis was demonstrated. Also, a model of mathematical simulation under the Environment Matlab / Simulink was successfully implimented to illustrate the operating systems. The model used in this paper has studied the influence of different conditions on the PV-electrodialysis system by matching the influence of weather conditions, along with water flow rates and salinity levels .. In the reference section, give all authors' names; do not ConclusionAlthough a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. Authors are strongly encouraged not to call out multiple figures or tables in the conclusion—these should be referenced in the body of the paper.

## ACKNOWLEDGMENT

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