Design and Simulation of Fuel Cell Energy System to Power RO Desalination Plant

Kevin GeorgeChittu, S. BerclinJeyaprabha

Abstract*-- Desalination is the only solution to this crisis as it provides clean drinking water from largely available sea water. Also it is necessary to drive this desalination plant by a non-conventional source in order to prevent the CO_2 emission that affects the environment. Various renewable energy sources are available for this purpose such as solar energy, wind energy, geothermal energy, bio gas etc. By using proper channel to trap these energies we can power the desalination easily and effectively. Some of the sources like wind turbine, solar thermal systems, photovoltaic (pv), biogas plant, fuel cell are the widely used for desalination. Combining these sources with some of the desalination techniques such as Multi-stage flash evaporation (MSF), Multi effect boiling (MEB), Vapor compression (VC) and Reverse Osmosis (RO) will give optimum results. In this proposed system RO method of desalination and polymer electrolyte membrane fuel cell as the power source is used.

Keywords*--Fuel Cell, RO System, Desalination, RenewableEnergy

I. INTRODUCTION

The surface of the earth is covered by 97.5% of water mainly salt water. Of which fresh water is 2.5% which can be used for our daily needs. From this fresh water 68.9% fresh water are found in glaciers. Only available fresh water is 29.9% in the form of ground water, 0.3% in fresh water lakes and river storage and 0.9% as soil moisture, swamp water and permafrost [1].

Recently it has been concluded that there will be an increase of two folds in the requirement for drinking water at the end of this decade. The only solution to this crisis is desalination as it provides clean drinking water from largely available sea water [2]. Also the necessary part is to drive the desalination plant by a non-conventional source in order to prevent the air pollution by the CO_2 emissions. The available renewable energy sources for this purpose are solar energy, wind energy, geothermal energy, bio gas etc. By properly trapping these energies we can power the desalination easily and effectively. Some of the sources that are widely used for desalination are wind turbine, solar thermal systems, photovoltaic (pv), biogas plant, fuel cell. Combining these sources with some of the desalination techniques such as Multi-stage flash evaporation (MSF), Multi effect boiling (MEB), Vapor compression (VC) and Reverse Osmosis (RO) will give best results. In this proposed system RO method of desalination and fuel cell as the power source is used [3].

Manuscript received on March, 2013.

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II. RENEWABLE ENERGY IN INDIA

Renewable energy in India is a sector that is still not developed. In early 1980's, India became the first country to set up a ministry of non-conventional energy resources. However its success has been very noticeable. In use of renewable energy (RE) India has been far behind other nations in recent years. The share of RE in the energy sector, as on March 2011, is 10.63%of total generation capacity of India. In India, renewable energy comes under the purview of the Ministry of New and Renewable Energy.The major source of RE in India are the following solar energy, wind energy and fuel cell [3].

Announced in November 2009, the Government of India proposed to launch its Jawaharlal Nehru National Solar Mission under the National Action Plan on Climate Change with plans of generating 1,000 MW of power by 2013 and up to 20,000 MW grid-based solar power, 2,000 MW of off-grid solar power and cover 20 million sq. metresusing collectors by the end of the final phase of the mission in 2020. As of December 2010 the installed capacity of wind power in India was 13,065.37 MW, mainly spread across Tamilnadu (4132.72 MW), Maharashtra (1837.85 MW), Karnataka (1184.45 MW), Rajasthan (670.97 MW), Gujarat (1432.71 MW), Andhra Pradesh (122.45 MW), Madhya Pradesh (187.69 MW), Kerala (23.00 MW), other states (4.30 MW). It has been estimated that 6,000 MW of additional wind power capacity will be installed in India by 2012.Wind power accounts for 6% of India's total installed power capacity, and it generates 1.6% of the country's power. Although research on fuel cell has been going on for decades, but recent studies show fuel cell technology to be a potential leader in the alternative energy revolution [4].This clean renewable energy source is seen as alternative to fossil fuel which is still been used in running world's economy. The potential of the fuel cell for an emerging economy like India who is heavily dependent upon imported fossil fuels for running wheels of its economy.

III. FUEL CELL

By definition a fuel cell is an electrical cell, which can be continuously fed with a fuel so that the electrical power output is sustained indefinitely. Electrical energy are produced by converting hydrogen, or hydrogen-containing fuels, directly along with heat through the electrochemical reaction of hydrogen and oxygen into water. The process is known as electrolysis in reverse [4].

Overall Reaction: $2H_{2(gas)} + O_{2(gas)} \rightarrow 2H_2O + energy$

Due to the electrochemical conversion of hydrogen and water gases into water, fuel cells have many advantages over heat engines which include high efficiency, virtually

silent operation and no pollution. If the production of hydrogen is from renewable energy sources, then the entire system is truly sustainable. Formation of water and carbon dioxide are the two principle reactions in the burning of any hydrocarbon fuel. With the formation of water becoming more significant, there is an increase in the hydrogen content in a fuel resulting in lower carbon dioxide emissions. The percentage of hydrogen content in the fuels has increased with use of fuel resulting through time. Some of the various types of fuel cells have been described below.

A. Solid Oxide Fuel Cell

Solid Oxide Fuel Cells (SOFCs) are very high temperature fuel cells which uses a solid electrolyte to conduct oxygen ions. There are two types of SOFCs that are being developed are (a) tubular and (b) planar types. The tubular configuration is only for SOFCs and the planar configuration is used in all other types of fuel cells. The two general temperature ranges are intermediate temperature (approx. 650 – 800°C) and high temperature (approx. 800-1000°C). The cell is constructed with two porous electrodes that sandwich an electrolyte. Air flows along the cathode. When an oxygen molecule contacts the electrolyte interface, it receives electrons from the cathode. The oxygen ions then diffuse into the electrolyte material and migrate to the other side of the cell where they contact the anode. The oxygen ions then encounter the fuel at the anode/electrolyte interface and react catalytically, giving off water, heat, and electrons. Carbon dioxide is another product of SOFC operation where hydrocarbon fuels are employed. The electrons transport through the external circuit, providing electrical energy. The concentration of reactants at the anode and cathode influence the efficiency of the cells; referred to as concentration polarization. Therefore, at part load, fuel cells are efficient, because reactants are not depleted on anode and cathode surfaces as rapidly as at full load [5].

B. Direct Methanol Fuel Cell

The Direct Methanol Fuel Cell (DMFC) is closely related to PEM systems: the structure of the fuel cell is almost identical and Nafion has often been used as a membrane. DMFCs overcome a perceived barrier for PEM-systems; the storage and production of sufficiently pure hydrogen presents many challenges. Therefore, the possibility to use methanol directly as a fuel has been studied. The advantages of methanol are a 6 times smaller storage capacity compared to hydrogen required for a same amount of energy, the possibility to use liquid storage at atmospheric pressure, and no need for the construction of hydrogen infrastructure. Methanol undergoes electrochemical reaction with water to CO_2 at an operating temperature of 80 to 130°C. This low temperature makes short startup time possible. The main drawbacks of the DMFC are the excessive use of expensive materials like platinum (up to ten times more than high performance PEMFCs) and ruthenium, and the toxicity of CH_3OH. Low cell voltage, which results in low current density, is caused by cross-over of neutral methanol from anode to cathode side. Compared to other fuel cell types, the development of the DMFC has only just begun. Initial developments suggest that the DMFC will be used as a substitution for the classical batteries in small scale, portable appliances (e.g. cell phones, laptops, CD players, etc.). In June 2004, Toshiba presented 'the smallest fuel cell in the world', which could feed a CD player for 20 hours. Another market which shows great interest in the DMFC is the automotive market. This product is still at the research and development stage, but has a very large estimated potential [5].

C. Polymer Electrolyte Membrane Fuel Cell

The fundamental structure of a PEM fuel cell can be described as two electrodes (anode and cathode) separated by a solid membrane acting as an electrolyte (Fig. 1). Hydrogen fuel flows through a network of channels to the anode, and there it dissociates into protons which in turn, flow through the membrane to the cathode and electrons that are collected as electrical current by an external circuit linking the two electrodes. The oxidant (air in this study) flows through a similar network of channels to the cathode where oxygen combines with the electrons in the external circuit and the protons flowing through the membrane, thus producing water. The chemical reactions occurring at the anode and cathode electrode of a PEM fuel cell are as follows:

***Anode reaction*:** $2H_2 \rightarrow 4H^+ + 4e^-$
***Cathode reaction*:** $O_2 + 4H^+ + e^- \rightarrow 2H_2O$
***Total cell reaction*:** $2H_2 + O_2 \rightarrow 2H_2O + elect. + heat$

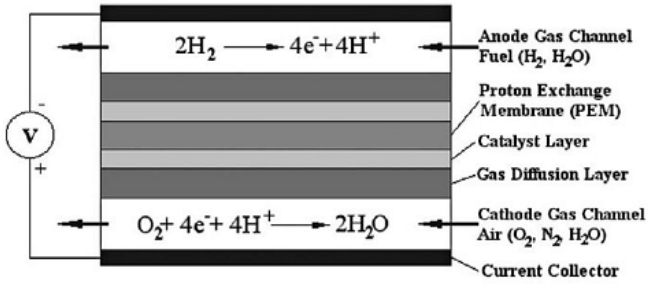

Fig. 1Schematic of a PEM Fuel Cell

Electrons flowing from the anode towards the cathode provide power to the load. A number of cells, when connected in series, make up a stack and deliver sufficient electricity. A I-V curve, known as a polarization curve, is used to express the characteristics of a fuel cell as shown in Fig.2. The behavior of a cell is highly non-linear and dependent on a number of factors such as current density, cell temperature, membrane humidity, and reactant partial pressure. The cell voltage decreases with increasing current[5],[6].

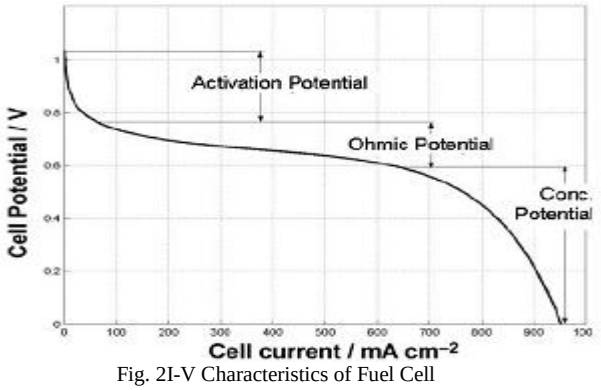

Fig. 2I-V Characteristics of Fuel Cell

V. MATHEMATICAL MODELLING OF PEMFC

A PEM fuel cell generally performs best at temperatures around 70-80°C, at a reactant partial pressure of 3-5 atm, and a membrane humidity of ~ 100 %. V-I Characteristics of a 1.2 W PEM fuel cell is shown in Fig.3 [7],[8].

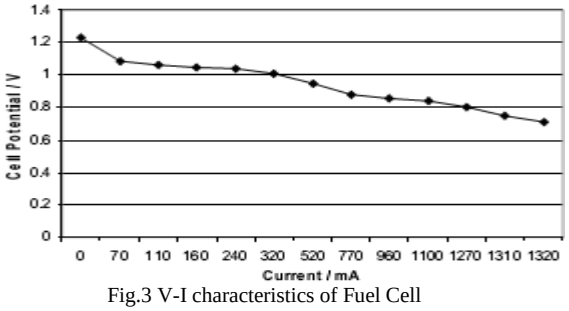

Fig.3 V-I characteristics of Fuel Cell

TABLE I
Fuel Cell Model Parameters

PARAMETER	SYMBOL	VALUE	UNIT
Reference Voltage	E_0	1.229	V
Universal Gas Constant	R	8.314	$J/mole\,K$
Faraday Constant	F	96485	$C/mole$
Stack Temperature	T	353	K
Cell Pressure	P	1.2	atm
Membrane Thickness	t_m	175e-4	cm
Double Layer Capacitance	C_{dl}	0.035x232	F
Time Constant	τ_{H+}	12.78	S
Relational Parameter	α_{H+}	5.78	cm^6/A^3
Diffusion Coefficient	D_{H+}	0.85e-6	cm/s

The cell potential (V_{cell}), at any instance can be found using Eq. 1. When a cell delivers power to the load, the no-load voltage (E), is reduced by three classes of voltage drop, namely, the activation (V_{act}), ohmic (V_{ohm}), and concentration (V_{conc}) over voltages.

$$V_{cell} = E - V_{act} - V_{ohm} - V_{conc} \quad (1)$$

The Nernst equation (Eq. 2) gives the open circuit cell potential (E) as a function of cell temperature (T) and the reactant partial pressures

$$E = E_0 - 0.85 \times 10^{-3}(T - 298.15) + \frac{RT}{2F}\ln\left(\frac{P_{H_2}P^{0.5}{}_{O_2}}{P_{H_2O}P^{0.5}}\right) \quad (2)$$

E_0 represents the reference potential at unity activity, R is the universal gas constant and P is the total pressure inside the stack. Relevant parameter Values are given in Table 1. The activation drop can be analyzed by Tafel's equation and the empirical model outlined is considered in this regard. Eq. 3 gives the activation voltage drop (E_{act})

$$E_{act} = -0.9514 + 0.00312T - 0.000187T(ln(I)) + 7.4 \times 10^{-5}T\left(ln\left(C_{O_2}\right)\right) \quad (3)$$

I(mA/cm^2) is the cell current density, the oxygen concentration (C_{O_2}) is given as a function of stack temperature in Eq. 4

$$C_{O_2} = \frac{P_{O_2}}{5.08\times10^6\exp(-498/T)}\text{mol/cm}^3 \quad (4)$$

Since, the activation overvoltage appears as a voltage drop in Eq. 1 and Eact in Eq. 3 is negative throughout the whole range, Eq. 5 is used to avoid a double negation for this term.

$$V_{act} = -E_{act}\ \text{V} \quad (5)$$

The effects of double layer capacitance charging at the electrode-electrolyte interfaces can be expressed by Eq. 6

$$\frac{dV_{act}}{dt} = \frac{1}{C_{dl}} - \frac{V_{act}}{R_{act}\,C_{dl}}\ \text{V} \quad (6)$$

Here C_{dl} is the double layer capacitance and R_{act} is the activation resistance, found by dividingV_{act}, with I.

$$R_{act} = \frac{V_{act}}{I}\text{k}\Omega/\text{cm}^2 \quad (7)$$

It should be noted that, here, $\boldsymbol{R_{act}}$ stands for the effective resistance for a given cell current, I, and contributes to the activation overvoltage $\boldsymbol{V_{act}}$. On the other hand, Eq. 6 is used to determine $\boldsymbol{V_{act}}$ at any instance of time. Therefore, these equations need to be used separately and cannot be interchanged. At intermediate current densities the voltage drop is almost linear and ohmic in nature. Membrane resistance (R_{mem}) is found by dividing the thickness, tm, by the membrane conductivity, σ (kΩ^{-1}.cm^{-1}).

$$V_{ohm} = IR_{mem} \quad (8)$$

$$R_{mem} = \frac{t_m}{\sigma} \quad (9)$$

The membrane water content depends on various factors, such as water drag from the anode to the cathode due to moving protons, external water content of the reactants, and back diffusion of water from the cathode to the anode. Since the effect of water drag is a significant factor, it could be hypothesized that the membrane proton concentration is a function of the cell current density only. An empirical differential equation could be solved to determine the proton concentration, C_{H+}, and Eq. 10 and 11 could be used to estimate the membrane conductivity, σ.

$$\frac{dC_{H+}}{dt} + \frac{C_{H+}}{\tau_{H+}} = \frac{1+\alpha_{H+}\times I^3}{\tau_{H+}} \quad (10)$$

$$\sigma = \frac{F^2}{RT}D_{H+}C_{H+} \quad (11)$$

At higher current densities, the cell potential decreases rapidly due to mass-transport limitations. This linearity is termed as the concentration over potential and modeled as

$$V_{conc} = ae^{(bI)} \quad (12)$$

Here, the coefficient a (V), and b (cm^2 /mA) vary with temperature and given as

$$a = 1.1\text{x}10^{-4} - 1.2\text{x}10^{-6}\,(T-273)$$

$$b = 8\text{x}10^{-3}$$

Equation (1)-(12) could be solved for cell potential, V_{cell}, as a function of current density, cell temperature, reactant pressure, and membrane hydration. If all the cells are in series, stack output is the product of cell potential and number of cells in the stack (N).

$$V_{stack} = V_{cell} \times 35\ \text{V} \quad (13)$$

The reactant flow model parameter is as shown in the Table II below.

TABLE II
Reactant Flow Model Parameters

PARAMETER	SYMBOL	VALUE	UNIT
Ambient Pressure	P_{amb}	1	atm
Anode Volume	V_a	0.0159	m^3
Anode Flow constant	k_a	0.004	$mol/s \cdot atm$
Cathode Volume	V_c	0.0025	m^3
Cathode flow constant	k_a	0.01	$mol/s \cdot atm$
Percentage of H_2 (Purity)	PC_{H_2}	99%	-
H_2 flow rate conversion factor	CF_{H_2}	6.85 x 10^{-4}	-
Percentage of O_2 (Purity)	PC_{O_2}	21%	-
O_2 flow rate conversion factor	CF_{O_2}	6.804 x 10^{-4}	-
Cathode vapour content	P_{H_2O-C}	1%	-

To determine instantaneous conditions inside the cell, the conservation of gas reactants arecalculated using the following formulas [8].

A. Anode flow model equation

$$\frac{V_a}{RT}\frac{d}{dt} = \dot{m}_{H_2-in} - \dot{m}_{H_2-out} - \frac{I}{2F} \quad (14)$$

$$\dot{m}_{H_2-out} = k_a\left(P_{H_2} - P_{amb}\right)$$

$$\dot{m}_{H_2-in} = FR_{H_2} \cdot PC_{H_2} \cdot CF_{H_2}$$

B. Cathode flow model equation:

$$\frac{V_c}{RT}\frac{dP_{O_2}}{dt} = \dot{m}_{O_2-in} - \dot{m}_{O_2-out} - \frac{I}{4F} \quad (15)$$

$$\dot{m}_{O_2-out} = k_c\left(P_{O_2} - P_{amb}\right)$$

$$\dot{m}_{O_2-in} = FR_{O_2} \cdot PC_{O_2} \cdot CF_{O_2}$$

$$\frac{V_c}{RT}\frac{dP_{H_2O-C}}{dt} = \dot{m}_{H_2O-in-C} - \dot{m}_{H_2O-out-C} + \frac{I}{2F} \quad (16)$$

$$\dot{m}_{H_2O-out-C} = k_c\left(P_{H_2O-C} - P_{amb}\right)$$

VI. SIMULATION OF PEMFC

A fuel cell system mainly consists of a fuel processing unit (reformer), fuel cell stack and power conditioning unit. A simple representation of a fuel cell system is given in Fig. 4 The fuel cell uses hydrogen as input fuel and produced DC power at the output of the stack

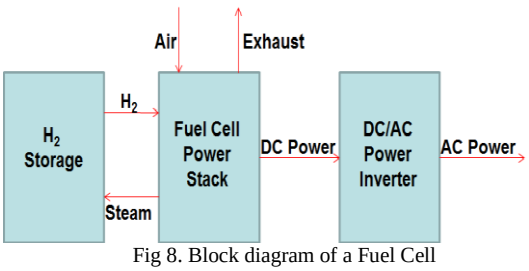

Fig 8. Block diagram of a Fuel Cell

A PEM fuel cell system block diagram is shown in Fig 8. The fuel cell system model consists of the dynamics of reactant flow, fuel cell model and power conditioning unit. The fuel cell subsystem which contains membrane resistance subsystem is shown in Fig. 10. The fuel cell's inputs are hydrogen, oxygen and vapor pressures, cell current density of the stack. Hydrogen, oxygen and vapor pressures could be found Eq. 15, 16 and 17. These terms could be used in Eq. 2 to determine the open circuit cell potential. The cell potential products number of cells in the stack. So, the stack voltage is obtained by this product. Also, the stack voltage is input of the power conditioning unit. The power conditioning subsystem Simulink implementation is shown in Fig 9. The power conditioning unit occurs of a single phase inverter to convert DC power into AC, a 5 kVA transformer in order to increase low output voltage in 220 V, 50 Hz grid power [8-10].

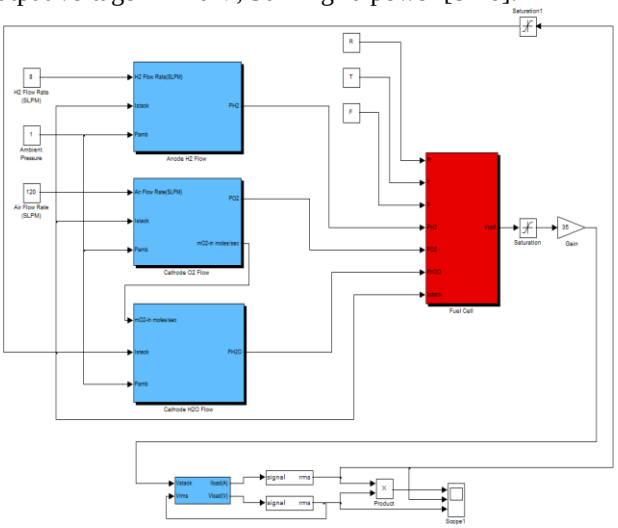

Fig. 9 Simulink model of aPEM fuel cell system

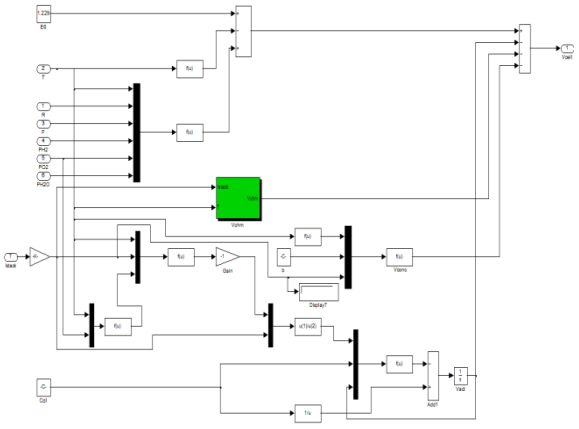

Fig. 10 Simulink model of a single fuel cell

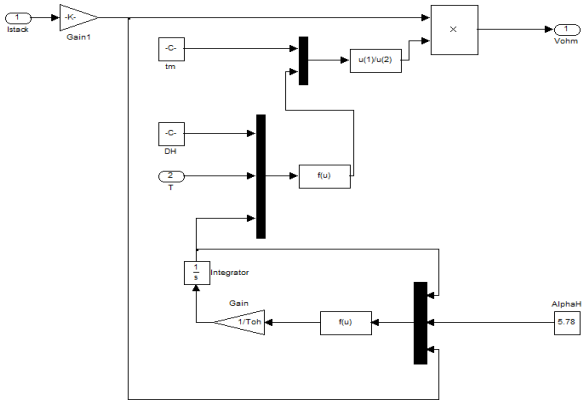

Fig 10 Simulation model of Membrane Resistance

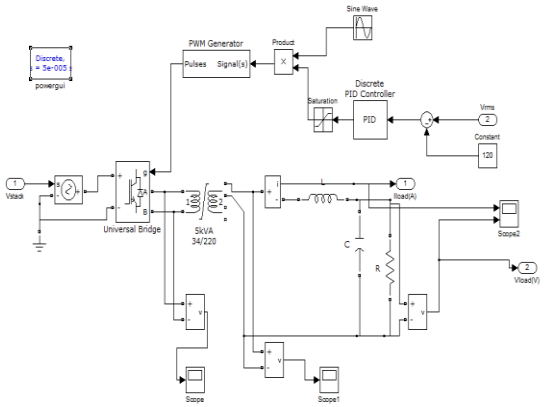

Fig. 11 Simulink model of a Power Conditioning System

VII. SIMULATION OF REVERSE OSMOSIS PLANT

Simulation of RO system is done using IMSDesign® software by Hydranautics. In order to use this we have to know about the chemical parameters of the water that is to be purified are required to be found using the water samples. Few of the parameters along with their value are given in the Table III below [11].

TABLE III
Parameters of Input Feed Water

IONS	PERMEATE (mg/L)
Ca	1.406
Mg	0.843
Na	8.573
K	1.912
NH_4	0.0706
Ba	0.009
HCO_3	9.75
SO_4	0.837
Cl	7.413
F	1.166
NO_3	7.791
B	0
SiO_2	0.64
CO_2	3.29
TDS (Calculated)	1135 ppm
pH	6.65

IMSDesign® - a comprehensive software design program that allows the user to design a membrane system using Hydranautics' membranes. Hydranautics, offers the latest comprehensive system design software package. The expectation of performance over time and under a variety of conditions is clearly demonstrated. Parameters like salt passage increase and flux decline due to fouling are easily accessible to the user - not obscured within the framework of the program. IMSDesign gives a complete user control over the information used in the membrane selection process. This control gives the user full confidence in the projected performance of any Hydranautics membrane [12].

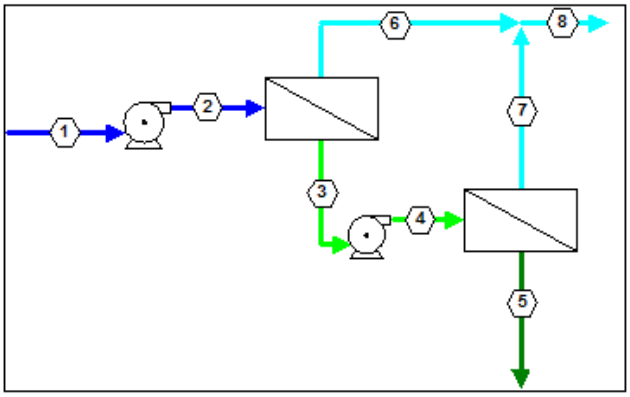

Fig. 11 Flow diagram of RO Plant

The various pressures and the relative level of flow, pressure and TDS at various points of the above flow diagram is as shown in Table IV given below [12],[13].

TABLE IV
Different levels of flow, pressure and TDS
at various points

	1	2	3	4	5	6	7	8
Flow (m^3/hr)	2.3	2.3	2.2	2.2	2	0.1	0.2	0.4
Pressure (bar)	0	2.7	2.4	8.4	8.1	0	0	0
TDS (ppm)	1135	1135	1184	1184	1330	53.9	31.7	29.3

VIII. SIMULATION OUTPUT AND WAVEFORM

Matlab-Simulink™ is used to simulate the PEM fuel cell system. Additional limiters are placed in various key locations in order to prevent problems arising from algebraic loops and extreme numerical values. The simulation is done for 2 s. The hydrogen flow rate is maintained at 8 standard litre per minute (SLMP). The air flow rate is fixed at 120 SLMP. Simulation results are as shown below.

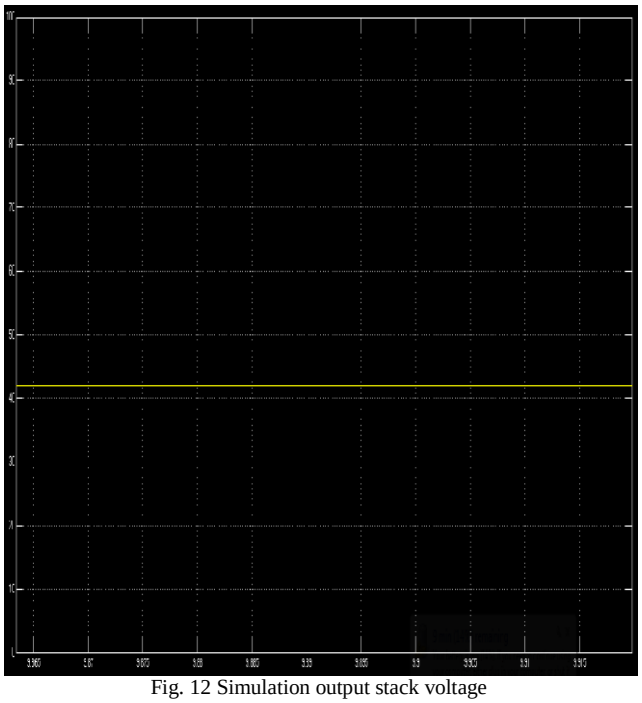

Fig. 12 Simulation output stack voltage
of the fuel cell (42V)

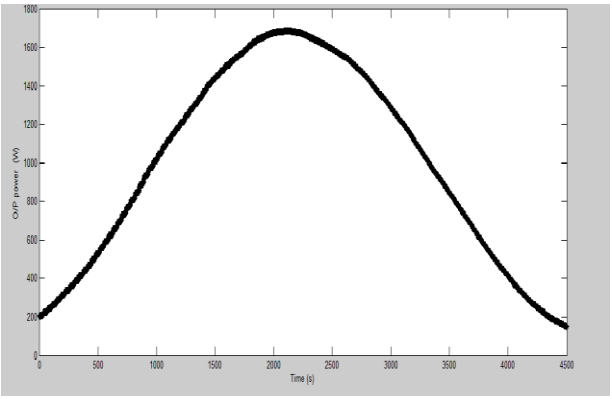

Fig. 13 Simulation output waveform of Power conditioning circuit

The calculation result of the output water is as shown in Fig. 14 below.

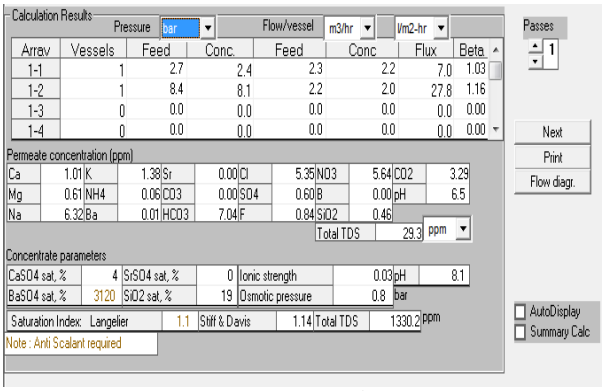

Fig. 14 Calculation result of output water

IX. CONCLUSION

Configuration suggested, even if it is not entirely autonomous requires nevertheless a less important surface of solar panel to work. On the other hand, there remains the problem of the source out of hydrogen. If hydrogen is not produced by electrolysis but by hydrocarbon reforming, that implies CO2 emissions, with inexhaustible resources. Moreover, 95% of hydrogen currently product use this last method. For a massive recourse to the hydrogen consumption, it will be necessary to consider new methods of production, such as the construction of nuclear plants dedicated to the production of hydrogen with electrolysis high temperature for example. Other ways are currently at the stage of research such as for example the photolysis, or the biological production of hydrogen (micro algae, bacteria, etc). Ecologically, we consider that renewable energies remain a future solution with a slightly higher price than it is currently known. Moreover, no single massive solution seems to take shape today: the solutions multi sources must be developed. Initially, a study on the energy management of the whole of the system can appear very beneficial. The problems of management of energy were already tackled for systems multi sources, and this work can contribute very well to improve the use of each component intervening in the configurations of this study. Parallel to the management of energy, the choice of the converters ensuring the electric connections between the sources and the load will allow the concretization of this study. The electrolyser can be used to generate H2 using power from PV. The generated H can be stored in a tank for lower solar radiation levels or at night Fuel Cell operation.

REFERENCES

[1] Gupta Akhilesh, R.K. Mall, L. S. Rathore, Ranjeet Singh, R. S. Singh, "Water resources and climate change: An Indian Perspective*"Current Science*, vol. 90no. 12, 2000.

[2] Annette Prüss, David Kay, Jamie Bartram, and Lorna Fewtrell "Estimating the Burden of Disease from Water, Sanitation, and Hygiene at at a Global Level" *Environmental Health Perspectives*, vol. 110no. 5, 2002, pp. 537-542

[3] Soteris A. Kalogirou,"Seawater Desalination using Renewable energy Sources" *Elsevier,Progress in Energy and Combustion Science*, vol. 31, 2005, pp. 242–281

[4] Abderrahmane Belkaid, Khaled Halbaoui, Mustapha Chelali, Rabah Benabid and Said Touati, "Pre-Feasibility Design and Simulation of Hybrid PV/Fuel Cell Energy System for Application to Desalination Plants Loads" *ScienceDirect, Procedia Engineering*, vol. 33, 2012 pp.366 – 376

[5] P. Lisbona, L. Serra and J. Uche "High-temperature fuel cells for fresh water production" *Elsevier,Desalination* vol. 182, 2005, pp. 471–482.

[6] Ines Ben Ali, JamelBelhadj, Mehdi Turki and Xavier Roboam, "Energy Management of a Reverse Osmosis Desalination Process Powered by Renewable Energy Sources" *Electrotechnical Conference MELECON)*,2012pp. 800-805[*16th IEEE Mediterranean*]

[7] P.Alvfors, J.Ekmanc, L. Hedström, M.Rissanen, B.Stridh, C.Wallmark "Description and modeling of the solar–hydrogen–biogas-fuel cell system in GlashusEtt", *Journal of Power Sources*, Vol. 131, 2000, pp. 340–350

[8] Bilal Gumus, MuhsinTunayGencoğlu and Zehra Ural "Dynamic Simulation of a Pem Fuel Cell System", *Proceedings 2nd International Hydrogen energy congress and Exhibition IHEC*, 2007

[9] C. de Prada, L.Palacin, J. Salazar, F.Tadeo, "Operation of Medium-size Reverse Osmosis Plants with Optimal Energy Consumption''*Elsevier*, vol.23, 2010, pp.2245–2262

[10] A.Al Taee, T.Ben M'Barek, K.Bourouni "Design and optimization of desalination reverse osmosis plants driven by renewable energies using genetic algorithms" *Elsevier, Renewable Energy*, vol. 36, 2007 pp. 936-950

[11] Craig Bartels and Mark Wilf "Optimization of seawater RO systems design", *Elsevier,, Desalination* vol. 173, 2005, pp.1-12

[12] B.Haganesh andSakthivel Mohan "Study on subsurface water quality in selected places in coimbatore" *ISSN*,vol.2, no. 4, 2012, pp. 2250-3498

[13] P.Lalitha, R.Shyamala and M.Shanthi "Physicochemical Analysis of Borewell Water Samples of Telungupalayam Area in Coimbatore District, Tamilnadu, India*"ISSN*, Vol. 5, No.4, 2008, pp. 924-929.