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# Photovoltaicsystem Energy storageusing Water Electrolysis

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## ☐ ABSTRACT ☐

It is known that, the available power from a photovoltaic system is unpredicted and differs with climatic changes, so it has an intermittent nature, in other words it is unable to supply the load continuously and steadily. Because of that, storage methods of its energy must be studied to use it again in a way that could be predicted. Hydrogen production is one of these methods by connecting the PV system to water electrolysers, and this stored hydrogen could be used either in fuel cells or burning it to get thermal energy. This study focuses on PV system and the available energy taken from it, and the electrolysers and its requirements and products. Making a mathematical model would be done and plotting the curves that represent the system by programming it using MATLAB. A simple numeral example that clears the system would be calculated. By this way, the energy efficiency would be between 23 to 67 % according to the way the produced hydrogen is used.

**Keywords:** PV systems, Electrical Energy, Electrolyser, Hydrogen**.**

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# تخزين طاقة النظم الكهروضوئية عن طريق التحليل الكهربائي للماء

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## □ ملخّص □

من المعروف أنَّ الاستطاعة المتاحة من النظم الكهروضوئية لا يمكن التنبؤ بها وتتغير مع تغير الظروف المناخية لذلك فهي تتميز بطبيعة متقطِّعة أي أنّها غير قادرة على تغذية الحمل بشكل متواصل وبمعدلات ثابتة، لذلك كان لابدَّ من دراسة أساليب تخزين للطاقة الكهربائية المنتجة منها بحيث يتم إعادة استخدام هذه الطاقة بشكل يمكن توقعه، وأحد هذه الطرق هو إنتاج الهيدروجين عن طريق ربط النظم الكهروضوئية مع محلِّلات مياه تقوم بتحليل الماء كهربائياً، و بتخزين هذا الهيدروجين يمكن استخدامه بمعدلات ثابتة إمَّا في خلايا الوقود أو عن طريق حرقه مباشرةً والاستفادة من الطاقة الحرارية المنتجة. هذه الدراسة تُركِّز على النظم الكهروضوئية والطاقة المتاحة منها وعلى المحلِّلات وآلية عملها ومتطلباتها ونواتجها، ووضع النموذج الرياضي الذي يوصِّف أداءها ورسم المنحنيات التي تعبِّر عنها عن طريق برمجتها باستخدام برنامج الماتلاب MATLAB، ووضع مثال عددي بسيط يوضِّح القيم الموافقة لنظام كهروضوئي ذي استطاعة محدودة. حيث تبين أن المردود الطاقي يتراوح بين 23 إلى 67 % حسب طريقة استخدام الهيدروجين المنتج.

**الكلمات المفتاحية:** النظم الكهروضوئية، الطاقة الكهربائية، المحلِّلات، الهيدروجين

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# 1. INTRODUCTION:

Photovoltaic PV systems produce electrical energy as long as there is solar radiation, so it gives energy only during daylight, and because of climatic changes the irradiance itself differs during the day and from day to another among the year, which means that the energy produced by the PV system will fluctuate, so the system will not be able to give energy steadily. Therefore, there should be a method to deal with this intermittent nature by connecting a load that should be dynamic enough to follow the changes in the output powerof the PV system, also this load should be able to store PV system's energy to be used anytime later.These specifications are applied on PEM elecrtolysers.

Most researches are about the usage of PV energy to produce hydrogen by water electrolysis, which is divided into two methods, the first one is connecting PV system to the electric grid and storing the excessive energy from the whole system.While the other one is to store only PV energy, the storage process would be hydrogen production by water electrolysis. Then this hydrogen could be used by fuel cell systems to produce electric energy again or use $H_2$ as thermal energy source by burning it.

# 2.ELECTROLYSERSPRINCIPLES:

Theoretically, electrolysers could be considered as reversible fuel cells, as they depend on electric current flow in the presence of ions conducting material to drive water decomposition electrochemical reaction into hydrogen and oxygen, this reaction is endothermic which means it needs energy as follow: [1]

$$285.83\text{kJ/mol} + H_2O_{(l)} \longrightarrow H_{2(g)} + 1/2O_{2(g)}$$

However, because pure water is not active alone, there must be an electrolyte. So, the electrolyser consists of electrochemical cells, each cell consists of two electrodes and electrolyte. When a current is applied to the cell through the electrodes the hydrogen would be produced on the cathode (the electrode where the electrons come into), while the oxygen would be produced on the anode (the electrode where the electrons come out from). The amount of produced gases would be proportional to the current, but this simply does not mean that to produce more gases a greater current should be applied, because there are losses that should be taken into consideration. So, to use electrolysers there should be integrity between gases production rates and efficiency.

There are three different types of electrolysers: Proton Exchange Membrane Electrolysis Cell (PEMEC), Alkaline Electrolysis Cell (AEC), and Solid Oxide Electrolysis Cell (SOEC). Each type has its own components, operational conditions, advantages and disadvantages, but this study focuses only on PEMEC, because of its fast response to input changes, which makes it the most convenient to be used with renewable resources like PV systems. Also, PEMEC produces high pure $H_2$, so it can be used without purification process, and it can operates under differential pressure (which means it can produce hydrogen under higher pressure than oxygen), and its operational temperature is only about 100 $^oC$. Additionally, its efficiency is about 65 to 80%. However, the main disadvantage is its high price, because of using expensive materials for the membrane and the electrodes and the most of its cost comes from using precious catalyst which is used to activate the reactions. The reactions that happen on the electrodes are as follow:

On the anode: $H_2O \longrightarrow 2H^+ + 2e^- + 1/2O_2$
On the cathode: $2H^+ + 2e^- \longrightarrow H_2$
Overall reaction: $H_2O \longrightarrow H_2 + 1/2O_2$

## 2.1. Electrolysers Thermodynamics:

The energy associated with water composition or decomposition reaction is called the change of enthalpy ΔH, which would be in a decomposition reaction the sum of Gibbs free Energy ΔG that could be added as electrical energy, and the change of entropyT.ΔS that could be added as thermal energy.So,ΔH= ΔG+ T.ΔS, and according to Faraday's law Gibbs energy (the electric work) could expressed as: [2]

$\Delta G = n.F.E$ (1)

Where E [V] is the voltage applied to the electrolysers cell EC, and n the number of electrons associated with the reactions (equals 2), F is Faraday's constant (96485 [coulombs]). So, the potential that should be applied can be calculated as follow:

$$\mathrm{E} = \Delta \mathrm{G}/\mathrm{n.F} = (\Delta \mathrm{H} - \mathrm{T}.\Delta S)/\mathrm{n.F} \qquad (2)$$

Under reference conditions of pressure and temperature ($T_{ref}$= 25 $^{o}$C, $P_{ref}$= 1 atm), ΔS=0.163 kJ/mol.K and ΔH= 286.03 kJ/mol,so ΔG= 237.456 kJ/mol (which is the minimum energy that could be added in electrical form), and from eq.2 the potential is 1.229 [V], but if all energy comes only from electric source by other words ΔG= ΔH, then the potential could be 1.48 [V] (in case the water is in liquid form where ΔH=286.03 kJ/mol, which is referred to as higher heating value HHV), while E could be 1.25 [V] (in case the water is in vapor form where ΔH=241.83 kJ/mol which is referred to as lower heating value LHV). These values must be adapted to get the effects of the changes in operational temperature, and partial pressures of reactants and products from thier reference values. The potential's change because of the change in temperature can be calculated by considering that ΔH, and ΔS are constant as follow:[2]

$$\Delta \mathrm{E} = -\frac{\Delta \mathrm{S}}{\mathrm{n.F}}(\mathrm{T} - \mathrm{T_{ref}}) \qquad (3)$$

It can be seen that when increasing the temperature the potential is going to decrease as ΔS is positive.

Now, the changes in partial pressures affect ΔG, which is function to the specific volume V [$m^3$/mol] and to the change in pressure dP (as G=V.dP), and the final equation, that represents this relation (depending on the universe gas law V=R.T/P) is:[2]

$$\Delta \mathrm{G} = \Delta \mathrm{G^o} + \frac{\mathrm{R.T}}{\mathrm{n.F}}\ln\left(\frac{\mathrm{P_{O_2}^{0.5}.P_{H_2}^{1}}}{\mathrm{P_{H2O}^{1}}}\right) \qquad (4)$$

Where $\Delta G^o$ is Gibbs free energy under standard conditions, and R gas constant 8.3143 J/mol.K. This equation assumes that the cell is producing pure $H_2$ with pressure $P_{H2}$, and pure $O_2$ with pressure $P_{O2}$, and by knowing that splitting one mole of water with pressure $P_{H2O}$(the reactant) would produce one mole of $H_2$ and half mole of $O_2$ (the products). So, the electric potential of the cell is given by:[2]

$$\mathrm{E} = \frac{\Delta \mathrm{G^o}}{\mathrm{n.F}} - \frac{\Delta S}{\mathrm{n.F}}(\mathrm{T} - \mathrm{T_{ref}}) + \frac{\mathrm{R.T}}{\mathrm{n.F}}\ln\left(\mathrm{P_{O_2}^{0.5}.P_{H_2}^{1}/P_{H2O}^{1}}\right) \qquad (5)$$

Which is called Nerst equation, and by considering that the energy needed is coming from an electrical source only it would be:[2]

$$\mathrm{E} = 1.48 - 0.85 * 10^{-3}(\mathrm{T} - 298.15) + 4.3085 * 10^{-5} * \mathrm{T} * \ln\left[\mathrm{P}_{H2} * \mathrm{P}_{o2}^{0.5}/\mathrm{P_{H2O}}\right] \qquad (6)$$

This potentialis the minimum voltage that should be applied to the EC, and because of the losses occurred inside the cell, a higher voltage should be applied to overcome these losses, which are divided into three types: activation loss, ohmic loss, and concentration loss.

## 2.2. Electrolyser losses:

### 2.2.1. Activation loss$V_{act}$:

It represents reactions' rates on electrodes' surfaces, and reflects the extra voltage that must be applied to start the electrochemical reactions on both anode and cathode. This loss is proportional to the natural logarithm of the current density i, as the equation that is called Tafel equation:[3]

$$V_{act} = \frac{R.T}{\alpha.n.F}.\ln\left(\frac{i}{i_o}\right) \qquad (7)$$

Where (R.T/α.n.F) is Tafel's slope, α is the electrons transfer coefficient, which varies between 0 and 1 and it is often 0.5 for electrochemical reactions, $i_o$ is the exchange current density where this loss becomes zero ($i_o = 1.08*10^{-7}*\exp^{10.086*T}$). As can been seen, this loss depends also on the temperature, and occurs only when dealing with small currents and can be neglected at higher current rates.

### 2.2.2. Ohmic Loss$V_{ohm}$:

It represents the losses caused by the wiring, and electrodes' resistance, which are almost constant and neglected, but there is another part of this loss which comes from the membrane resistance, that differs depending on operational circumstances. However, this loss could be given as follow:[4]

$$V_{ohm} = i * \frac{t_{mem}}{\sigma_{mem}} \qquad (8)$$

Where i is the current density, $t_{mem}$ is the membrane’s thickness, $\sigma_{mem}$the conductivity of the membrane and is given by:[4]

$$\sigma_{mem} = (0.005139.\lambda_{mem} - 0.003260)\exp^{[1268(\frac{1}{303}-\frac{1}{T})]} \qquad (9)$$

Where $\lambda_{mem}$ represents membrane’s hydration (the level of membrane's wetness) and takes the value:[4]

$$\lambda_{mem} = 0.043 + 17.81 * a - 39.85 * a^2 + 36 * a^3 \qquad (10)$$

Where a is the membrane water activity, and because the membrane always operates under almost 100% humidification, a=1.

### 2.2.3. Concentration Loss$V_{conc}$:

As mentioned before, the production rates of gases increase with the current applied to the cell, but this true till reaching limiting current, and by drawing higher current the cell could not produce more gases, which would lower gases' concentration in gas channels. This loss could be expressed by the equation:[5]

$$V_{conc} = -\frac{R * T}{n * F}\ln\left(1 - \frac{i}{i_L}\right) \qquad (11)$$

Where $i_L$ is the limiting current density.

- After introducing the minimum voltage and the losses in the EC, the total voltage that must be applied on the cell to produce gases and to overcome the above mentioned losses, would be:[5]

$$V_{EC}= E + V_{act} + V_{ohm} + V_{con} \qquad (12)$$

## 2.3. The Electrolyser's Efficiency:

The electric efficiency could be given by dividing the minimum voltage that should be applied to start the reations, on the operational voltage as follow:[1]

$$\zeta = \frac{1.48}{V_{EC}} * 100\ \% \qquad (13)$$

(Assuming that the whole electrolysis energy comes from electrical source).

## 2.4. Reactant and Products Flow Rates:

From the overall reaction it can be seen that production rate of $H_2(P_{H2})$ equals the utilization rate of $H_2O$ ($U_{H2O}$), and both equal two times $O_2$ production rate ($P_{O2}$), so they can be given as follow:[4][6]

$U_{H2O}=P_{H2}=2*P_{O2}=N.I/2F=P/(2F*V_{EC})$ [mol/s] (14)

$P_{H2} = 1.047*10^{-8}*(P/V_{EC})$ [Kg/s] (15)

$P_{O2} = 8.2914*10^{-8}*(P/V_{EC})$ [Kg/s] (16)

$U_{H2O} = 9.328*10^{-8}*(P/V_{EC})$ [Kg/s] (17)

Where N is the number of cells connected with each other to form electrolyser stack, P the power given to the stack, while $V_{EC}$ the voltage of one cell.

## 2.5. EC model:

The previous equations from (6) to (13)were implemented in MATLAB program (appendix 2),we can simulate an electrolyser cell performance, using the values of the cell's parameters as in table.1. From this program (V-I curve) and the efficiency curve of the EC could be plotted like in Fig.1 and Fig.2 respectively, and these figures are the same as the practical ones that come from the manufacturer, which means that the program simulate the EC from the steady state aspects:

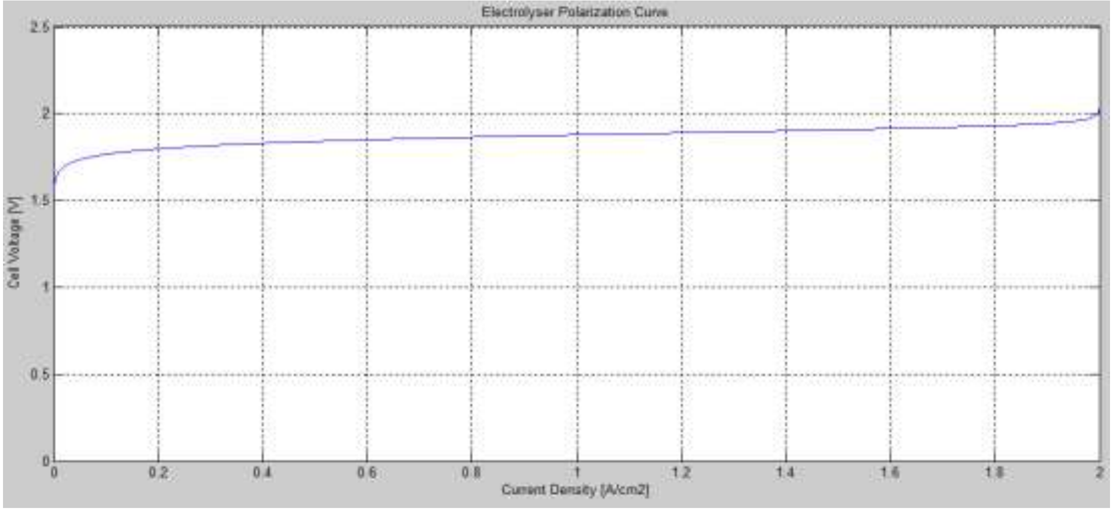

**Figure.1: EC Polarization Curve**

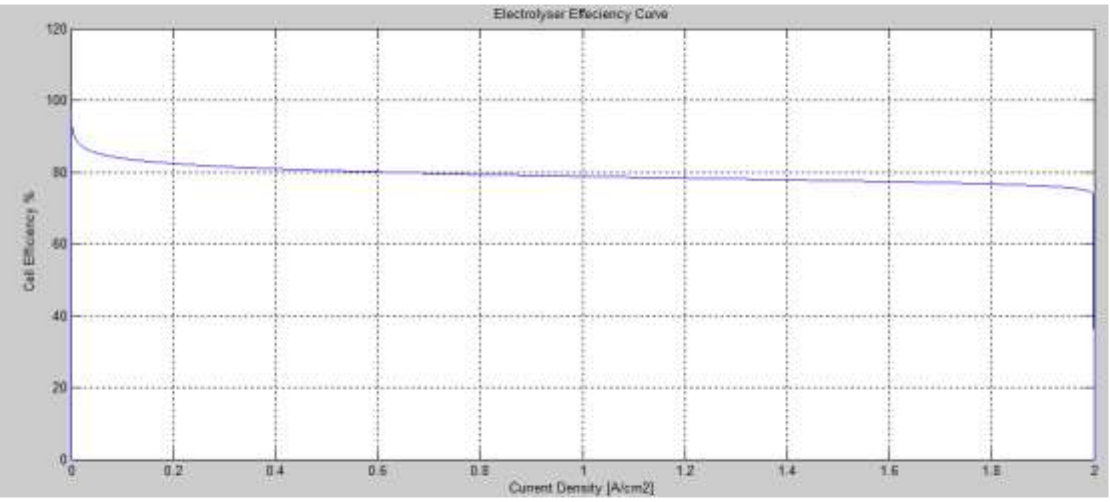

**Figure.2: EC Efficiency Curve**

**Table.1: EC parameters [4]**

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| T | 343K | $i_L$ | 2 A/cm$^2$ |
| a | 1 | A | 100 cm$^2$ |
| $P_{o2}$ | 1atm | n | 2 |
| $P_{H2}$ | 1atm | $t_{mem}$ | 50 μm |
| $P_{H2o}$ | 1atm | α | 1/3 |

As mentioned before, the EC's efficiency range is from 65 to 80 %, and as it can be seen that to get 80% efficiency the EC must withdraw 0.6 A/cm$^2$, and from Fig.1the applied voltage is around 1.85 V.

## 3. THE PV SYSTEM:

This is the source of theenergy that is going to be stored. Basically, any PV system consists of PV cells connected to each other, each cell includes a p-n junction formed from doped semiconductors. These cells extract the energy of photons with specific lengths from the solar spectrum, and use it to free electrons from the junction leaving holes instead, and by connecting external circuit (electrolyser in this study), an electric current would flow. So, the equivalent circuit of a PV cell would be current source with diode in parallel (represents the junction) with series and shunt resistances (which represent the losses), as shown in Fig.3: [7]

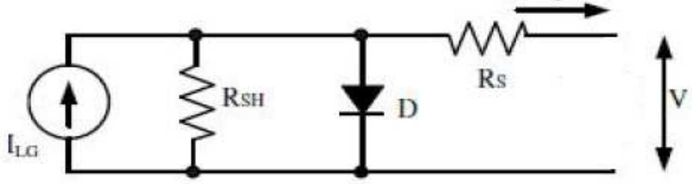

**Figure.3: Equivalent circuit of a PV cell**

The useful current driven from the cell to the load Iis given by: [8]

$$I = I_{LG} - I_{OS} \cdot \left[ \exp^{\left(\frac{q}{A.k.T}(V+I.R_S)\right)} - 1 \right] - \frac{V + I.R_S}{R_{SH}} \quad (18)$$

Where $I_{LG}$ maximum lighting current which represents the current source, $I_{OS}$ dark saturation current, q electron's charge, V cell voltage, k Boltzmann's constant which equals

$1.38*10^{-23}$ [J/K], T cell's temperature, $R_s$ the series resistance which represents the external losses (the connections), and $R_{SH}$ the shunt resistance which represents the internal losses.

While the dark saturation current is given by:[8]

$$I_{OS} = I_{OR}\left(\frac{T}{T_R}\right)^3 \exp^{\left[\frac{q.E_{GO}}{Ak}\left(\frac{1}{T_R}-\frac{1}{T}\right)\right]} \quad (19)$$

Where $T_R$ reference temperature 25 °C, $E_{GO}$ band gap voltage 1.1[ev], A diode ideality factor (also called B), $I_{OR}$ saturation current equals $2.0793*10^{-6}$[A].

The source current is given by:[8]

$$I_{LG} = [I_{SCR} + K.(T - 25)].C \quad (20)$$

Where $I_{SCR}$ shortcircuit current at standard conditions(AM=1.5, C=1000 W/m$^2$, T=25 °C), C the solar radiation power kW/m$^2$, K current thermal coefficient which represents the change in the cell's current with cell's temperature and equals0.0017A/K.

## 3.1. PV Cell Model:

By using the above equations (18) (19) (20) in writing MATLAB program (appendix 1), we can simulate the PV cell performance, using the values of the cell's parameters as in table.2. From this program the I-V and P-V curves of the PV cell could be plotted like in Fig.4, which are closed to the factory data:

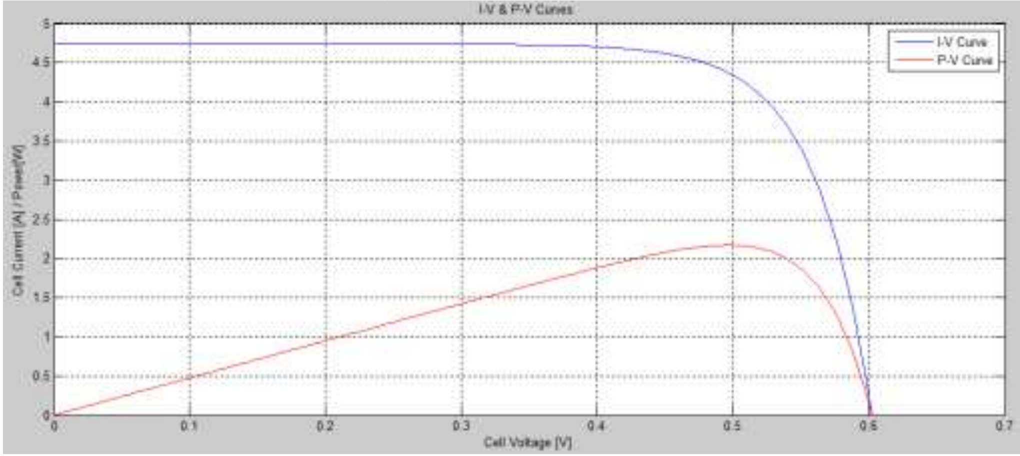

**Figure.4: I-V and P-V curves for PV cell**

**Table.2: PV cell parameters**

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| A | 1.6 | $I_{sc}$ | 4.75 A |
| T | 298 K | $V_{OC}$ | 0.6 V |
| $T_{ref}$ | 298 K | C | 1kW/m$^2$ |
| $R_s$ | $15*10^{-3}\Omega$ | $R_{sh}$ | 30Ω |

## 3.2. The Energy of a PV System:

Before calculating the energy produced by the PV system we should determine the location of the installation place, and the characteristics of the solar radiation among the year in that location. In this study the place would be Damascus city, where the average radiation's values in each month of the year at different tilt angles are as in table.3. Regardless the type of the system to store energy from as mentioned in the introduction, the tilt angle of PV modules should be determined to give the maximum annual average radiation through the whole year, which would be in our case 20 degrees, with annual radiation about 5.052 kWh/m$^2$ (or peak sun hour PSH), which represents theoretically the number of hours when the PV system gives its nominal power. So, by multiplying this value by the number of days during the year by the PV system power, it would give us the average energy that could be extracted from the sun by the PV system.

**Table.3: Solar radiation among the year in Damascus City[9]**

| **ngle** | **an** | **eb** | **ar** | **pr** | **ay** | **un** | **ul** | **ug** | **ep** | **ct** | **ov** | **ec** | **Annual** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | .27 | .84 | .99 | .56 | .61 | .49 | .51 | .79 | .57 | .98 | .74 | .12 | 4.789 |
|  | .434 | .985 | .116 | .642 | .602 | .421 | .47 | .858 | .748 | .203 | .946 | .292 | 4.893 |
| 0 | .585 | .116 | .221 | .694 | .563 | .319 | .393 | .888 | .894 | .403 | .137 | .451 | 4.972 |
| 5 | .723 | .23 | .305 | .716 | .491 | .182 | .28 | .881 | .005 | .578 | .311 | .598 | 5.025 |
| **0** | **.847** | **.328** | **.365** | **.707** | **.388** | **.011** | **.131** | **.836** | **.081** | **.727** | **.466** | **.731** | **5.052** |
| 5 | .955 | .408 | .403 | .668 | .252 | .807 | .946 | .752 | .122 | .849 | .602 | .849 | 5.051 |
| 0 | .046 | .47 | .417 | .599 | .086 | .57 | .727 | .632 | .126 | .942 | .717 | .951 | 5.024 |
| 5 | .121 | .513 | .407 | .5 | .891 | .303 | .474 | .474 | .095 | .007 | .811 | .037 | 4.969 |
| 0 | .179 | .537 | .374 | .373 | .667 | .007 | .19 | .282 | .028 | .042 | .883 | .105 | 4.889 |
| 5 | .218 | .542 | .319 | .217 | .417 | .686 | .878 | .055 | .925 | .048 | .931 | .155 | 4.783 |
| 0 | .239 | .528 | .24 | .034 | .142 | .34 | .539 | .797 | .789 | .024 | .957 | .187 | 4.651 |
| 5 | .242 | .495 | .139 | .826 | .846 | .975 | .177 | .509 | .618 | .971 | .96 | .2 | 4.496 |
| 0 | .226 | .443 | .017 | .595 | .53 | .593 | .795 | .193 | .416 | .888 | .939 | .195 | 4.319 |
| 5 | .192 | .373 | .875 | .342 | .198 | .197 | .397 | .852 | .183 | .777 | .895 | .172 | 4.121 |
| 0 | .14 | .284 | .713 | .069 | .853 | .794 | .987 | .49 | .922 | .638 | .828 | .129 | 3.904 |
| 5 | .07 | .179 | .533 | .779 | .498 | .388 | .57 | .109 | .633 | .473 | .739 | .069 | 3.67 |
| 0 | .983 | .057 | .336 | .474 | .139 | .985 | .153 | .714 | .32 | .282 | .628 | .992 | 3.422 |
| 5 | .88 | .92 | .124 | .157 | .781 | .594 | .743 | .309 | .985 | .068 | .496 | .897 | 3.163 |
| 0 | .761 | .768 | .898 | .831 | .431 | .229 | .351 | .899 | .631 | .831 | .345 | .786 | 2.897 |

# 4. Study Case:

In this study case the energy of a 1kW PV system is going to be stored entirely as hydrogen using PEM electrolyser. First we are going to determine the annual available energy from the sun from the PV system as follow:

$E_{PV}=1_{[kW]}*5.052_{[h/day]}*365_{[day/year]}$

$E_{PV}=1843.98\ [kWh/year]$

$E_{PV}=1843.98_{\ [kWh/year]}*3600_{\ [S/h]}=6.638*10^{6}\ [kW.S/year]$

Then, from eq.15 the amount of hydrogen that could be produced by the electrolyser would be:

$P_{H2} = 1.047*10^{-8}*(E_{[W.S/year]}/ V_{EC}) = 1.047*10^{-8}*(E_{PV}/ V_{EC})$ [kg/year]

Now, as mentioned to operate the electrolyser at 80% efficiency 1.85 V must be applied on each cell, so the amount of produced hydrogen would be:

$P_{H2}$=37.569 [$kg_{H2}$/year]

## 5. THE USAGE OF THE PRODUCED HYDROGEN:

### 5.1. In Fuel Cells:

When using a PEM Ballard Mark V fuel cell, that works under 1 atm partial pressures and 70 $^{o}$C operational temperature, and which has been modeled in another study to give the polarization curves as in Fig.5, it can be noticed that the cell gives its maximum power when it gives only $V_{FC}$ =0.43 V.

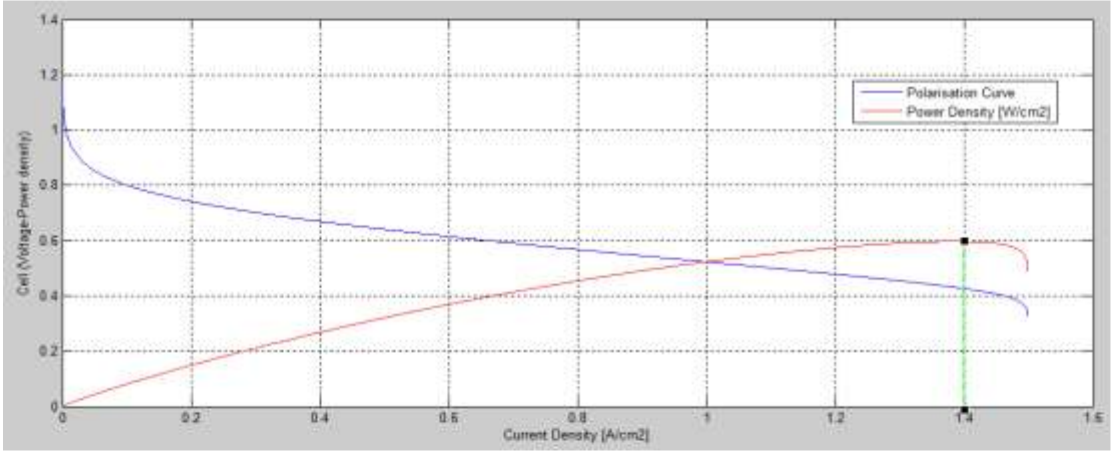

**Figure. 5: Polarization and power density curves of a Ballard Mark V fuel cell**

However, when using the produced hydrogen as a fuel source and as from eq.7 but this time the hydrogen is utilized not produced, so the electrical energy that could be given from the fuel cell, would be by using hydrogen's utilization factor $U_{H2}$:

$U_{H2} = 1.047*10^{-8} *(E/ V_{FC}) = 1.047*10^{-8}*(E/0.43)$

$E=37.569_{\ [kgH2/year]}*0.43/(1.047*10^{-8})$

$E=1542.95*10^{6}{}_{[W.s/year]}/ 3600_{\ [s/h]}$=428.597 [kWh/year]

This is the produced energy among the year (assuming that all the hydrogen would be consumed inside the fuel cells). So, the power of the used fuel cell system would be by assuming that it works all the year with 1 capacity factor:

P= E/8760=48.926 [W]

So, the 1843.98 kWh electric energy produced by a 1kW intermittent PV system could be stored and reproduced by only about 50 W FC system with 428.597 kWh energy, but this time in a continuous steady way along the year. This way has 5% electric power efficiency, and 23.24% electric energy efficiency, which considered five times bigger than the power efficiency because of the discontinuity nature of the PV system. From other hand, using fuel cells would give also thermal energy that could be extracted and used in a cogeneration mode, which may raise the energy efficiency.

### 5.2. Burning the produced hydrogen:

Gaseous hydrogen has an energy density by weight equals 33.3 [kWh/kg], which means that burning one kilogram of $H_2$gives about 33.3 kWhthermal energy. So, the total amount of energy that could be released by the produced hydrogen equals:

E= 33.3* 37.569=1251.048 [kWh/year]

Although, the energy efficiency of the whole process would be 67.85%, it cannot be used directly to do useful work, also it would be limited by the second law of thermodynamics. Moreover, burning hydrogen has its restrictions and disadvantages, which makes using fuel cells more beneficial and safer.

## 6. CONCLUSION

Hydrogen production as PV energy storage technique using electrolyser has been studied, and PEM electrolyser principles have been discussed and modeled, also the PV system characteristics have been introduced and modeled. Finally, an example of the energy available from 1kW PV system located in Damascus city has been calculated with the available amount of hydrogen that could be produced at the end of the year, and these were the results:

1- Syria has good solar potential where 1 kW PV system could produce 1843.98 [kWh/year] but as mentioned intermittent not stable and needs to be stored.

2- The hydrogen produced could reach37.569 [$kg_{H2}$/year].

3- This hydrogen could be used as mentioned either in fuel cell system to produce electrical energy but this time steadily and continuously and then the problem of the intermittent nature of PV systems would be overcome but with only about 50 W which could produce 428.597[kWh/year], by other words this storage process has 5 % electric power efficiency, and 23.24% electric energy efficiency.

4- Or using the hydrogen as fuel to burn it and use the thermal energy associated with itin different applications with 68% energy efficiency, but limited to thermodynamics laws.

However, this study needs to cover the problem of tracking the maximum power point MPP of the solar system to determine the best voltage that should be applied to the electrolyser so we can withdraw the maximum power (the best current, in other word the best gases production rates by the electrolyser) from the PV system.

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