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Energy Optimization of a Purely Renewable Autonomous Micro-Grid to Supply a Tourist Region

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ABSTRACT

An autonomous micro-grid is generally based on fossil fuels. Recently, these systems are favored integrating existing renewable energies in very specific areas to achieve the sustainability of the energy sectors. Hydrogen is considered as means of storing and transmitting energy, especially nowadays, and the sufficiency required by remote areas can be achieved by using hybrid techniques. Our search is the electrification of a tourist site in the region of Kenadsa. In Bechar city, which is located in the south west of the Algerian state. Using an independent small electric network based on the hybridization of renewable energies. The hybrid energy system must be provided with a cost-effective energy solution for the project by optimizing its components, controlling, sizing them with better selection. This research evaluates the technical and economic feasibility of renewable energy systems. This work aims to reduce the total net cost of the pre-determined system as well as the cost of energy and unfulfilled load and to make CO2 emissions lower, this kind of studies is carried out using the simulation program HOMER Pro. At the end we ca say that the proposed system has good results for electrifying remote areas and at a conservative cost of electrical energy in order to establish sustainable areas.

1. INTRODUCTION

Scientists are striving to remove the carbon emissions, toxic gases and decentralization, so microgrids must be a part of this work of transforming the traditional operation of energy systems to reach a higher decentralized approach. Generally, microgrids consist of low voltage (LV) distribution systems with energy resources REDs (micro-turbines, fuel cells, photovoltaics, etc.) in addition storage devices (flywheels, energy capacitors and batteries) and flexible loads. These systems can operate non-autonomous (connected to a network) and independently (island mode) [1] and small network resources can operate with clear advantages for the overall performance of the system, if it is managed effectively. Micro networks can also play great and important role in future smart networks, depending on their control capabilities. They can also perform the following functions [2]:

- If necessary, disconnect from the network and work independently.
- When the network is disturbed, the load must be lightened.
- For faster system recovery and responsiveness, it must act as a network resource.
- Increasing the security of the supply like enhancing the network bearing capacity.

The great and essential need of the energy which is causing on other major problem (pollution). For this reason, we can say that renewable energies are the best solution at the present time and in the future as well, and the feature of not running out of these resources, such as solar energy and wind energy makes us gradually abandon traditional storage sources such as batteries and fuel cells. Electrical energy can be converted into hydrogen using an electrolyzer for later use in fuel cells for long-term storage [3]. Hydrogen and oxygen interact in the presence of an electrolyzer using an electrochemical device that produces electricity in direct current called a fuel cell [4]. The fuel cell shares with an electrolyzer (to generate hydrogen from water) and storage tanks (stores the hydrogen generated) [5]. When the electrical load exceeds the energy generated by solar energy uses fuel cells like batteries. The electrolyzer charges the tanks with hydrogen, then the cells flush the tanks replenish energy. Kenadsa is distinguished by its possession of many renewable resources, especially that the chosen site is located near Jurf Al-Tourba dam to provide water used to produce hydrogen, as the solar wealth to feed the photovoltaic cells. Therefore, the independent system must be built in order to connect to electricity, but it must be noticed that the feeding fees and investment costs for hybrid systems are very high [6], this project aims to conduct evaluations in order to find out the optimal and total cost by adopting a specific system. The worst distribution of the electricity is caused many factors such as the ground factor and the isolated area, but the most important of them is the cost of paying a long distance from the network for the economic investment program [7]. In order to ensure sufficient power generation to meet demand in parallel with consideration of cost, a hybrid renewable energy system is the ideal one. And thus, we can save on expenses and maintenance costs and the replacement of components [8]. This article includes engineering analysis to study the coordinates of the specific site of the project, as well as the characteristics of the electrical load, after which the technical and economic analysis is carried out using HOMER software (Hybrid Optimization Model for Electric Renewable). The proposed model is simulated to obtain the best costs for photovoltaic cells and hybrid hydrogen systems by measuring the economic cost of electricity and determining the overall competitiveness of the energy sources used. It is represented as the cost per kilowatt hour of an operating system over its lifetime [9]. The key input for measuring the leveled cost of energy (LCOE) includes capital cost, fuel cost, operation and maintenance (O&M) cost as well as financing cost [10].

2. MODELING OF THE HYBRID SYSTEM IN HOMER

The hybrid system in Figure 1, which is an independent system consisting of photovoltaic cells, a fuel cell, an electrolyzer, a hydrogen tank and a converter. This type of system is used especially in remote, sunny areas where there is a riverbed. PV, fuel cell and electrolyzer are connected by DC bus. The converter is connected between the AC and DC bus. The AC output is connected to the load. Solar photovoltaics generate electricity during the day, while hydrogen systems generate electricity during the day and at night. The fuel cell acts as a backup power source for this hybrid system to ensure continuous power during any failures or power outages.

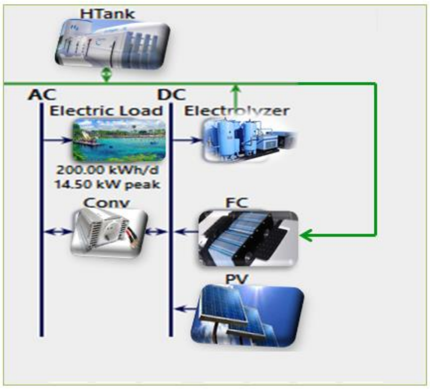

Figure 1. Hybrid PV/fuel cell power system model

Any excess energy produced will be stored in the fuel cell. A converter is included in this model as a device that converts electricity from DC to AC to supply a load. The hydrogen system consists of PEM fuel cells, electrolyzers and hydrogen tanks. The electrolyzer produces hydrogen gas when the electrical demand is higher than the required load power. Hydrogen is stored in hydrogen tanks until used and used when needed. The excess energy from the hydraulic system is used to produce hydrogen. Electrolyzers run on DC power; therefore, rectifiers are used to convert the AC power produced by the hydraulic system to a DC output. The converter should have high power to allow any conversion.

3. METHODOLOGY

This study is based on integrating and modeling a scenario based entirely on renewable energies, i.e. 100%, then it is simulated using HOMER Pro and evaluated later. This study is based on developing a hybrid and renewable system in a remote and energy isolated area using photovoltaic cells like Hydrogen-based energy, i.e., PV-P2H2P, to obtain the best and optimal solutions, taking into account that P2H2P systems store energy to save it when there is a lack of supply from photovoltaic cells. The scenario was simulated to optimize the capacities of the system components over the 25-year project life.

3.1 Case study: Hypothesis

This work was done by using version 3.14.3 of HOMER pro. Figure 2 shows the location of a proposal for a tourist park located at the Djorf el torba dam in the Kenadsa region, Bechar state.

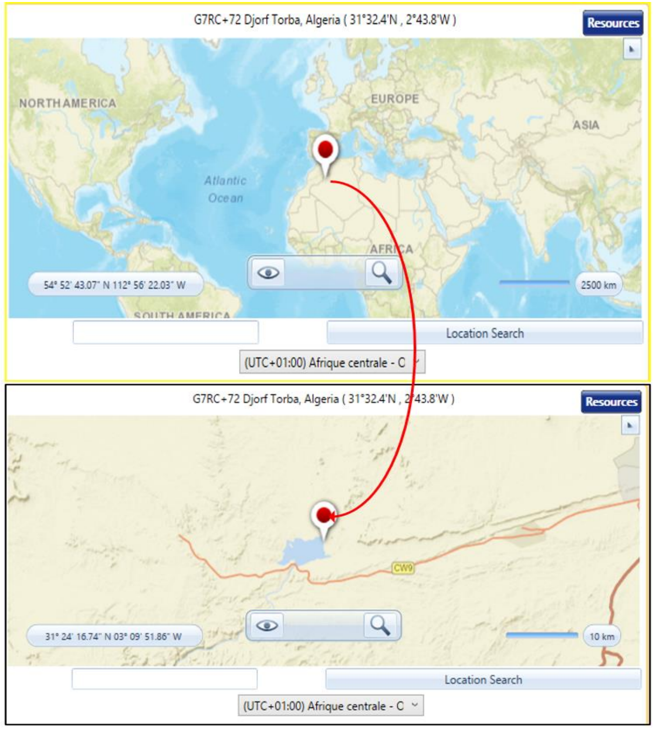

Figure 2. Location of the tourist park

3.2 Resources of the study area

The annual mean temperature and solar radiation are shown in Figures 3 and 4, depending on the data on these two data for the selected study area from NASA's Surface Weather and Solar website.

3.3 Micro-grid: Concepts and components

The average load shown in Figure 5 was entered into the software, which takes this data as a basis for estimating the rest of the information over one year. This first part of the process made it possible to establish that the park consumed 200 kW, a value to be considered in the planning and design of the MR is composed of a PV system, a fuel cell, an electrolyser, a hydrogen tank and a storage system; the system is not connected to the conventional network. The life of the project has been set at 25 years.

3.4 System architecture

The total input data for the hybrid system used is shown in Table 1, and we find in it the cost of volume, capital, replacement and maintenance, as well as the lifetime.

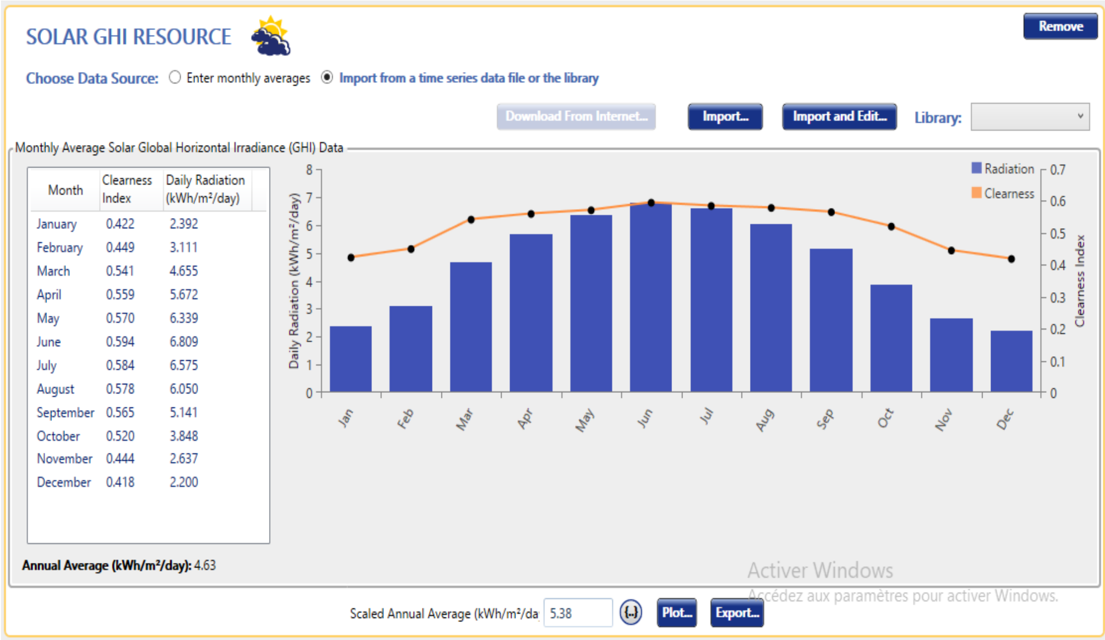

Figure 3. Global monthly data on the horizontal radiation of the tourist park in Djorf el torba

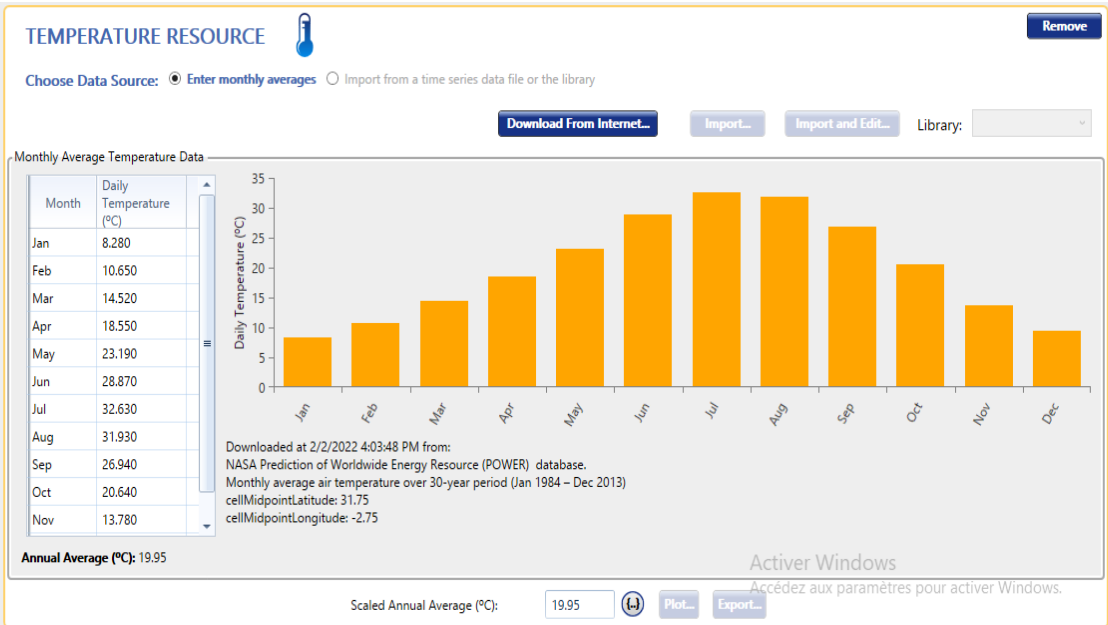

Figure 4. Monthly average temperature data of the tourist park in Djorf el torba

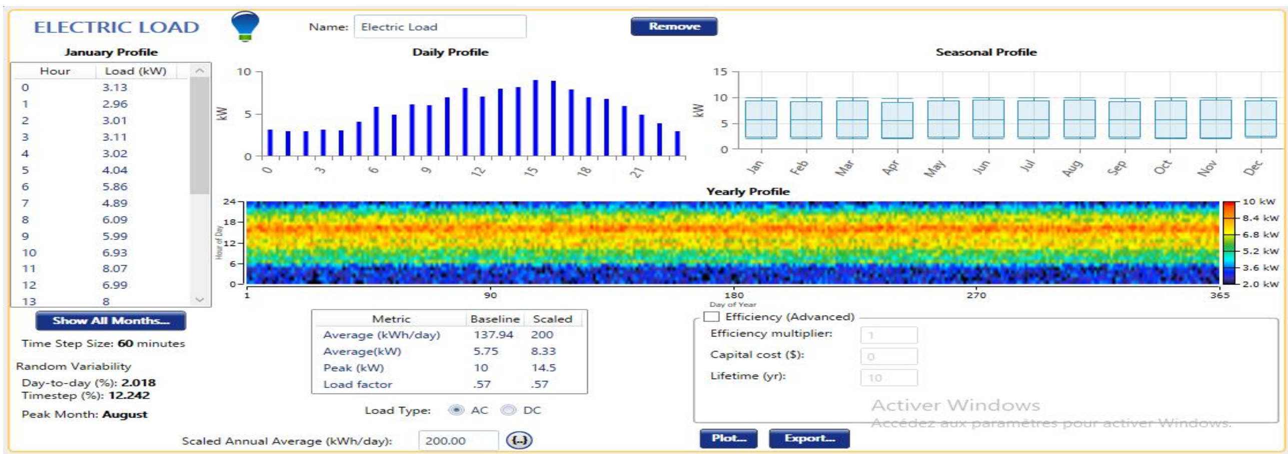

Figure 5. Load profile

Table 1. System architecture

Component	size	Capital cost ($)/kW	Replacement cost ($)	O&M cost ($/yr)	Lifetime
PV	1 KW	3000.00	3000.00	10.00	25 years
Fuel cell	1 KW	3000.00	3000.00	0.10	40000 h
Electrolyzer	1 KW	2000.00	2000.00	0	15 years
Hydrogen tank	1 Kg	1500.00	1500.00	30	25 years
Converter	1 KW	800.00	800.00	1	15 years

4. CALCULATION OF SOLAR PV SYSTEM AND P2H2P SYSTEM

To find out if the physical nature of the selected area is capable of containing the hybrid system, the terrain and meteorology must be determined in order to build an independent system. PV panel that is selected for this work is Flat plate where its maximum power output is 140 W.

4.1 Photovoltaic calculation (PV)

Area for 1. *PV* module:

$$A=L\times W=1.6475\ m\times 0.9875m=1.6269m^2 \tag{1}$$

Power. produced by 1 m^2. of *PV* module:

$$P\ m^2 = \frac{P_{max}}{A} = \frac{140}{1.6269} = 86\ W/m^2 \tag{2}$$

PV efficiency, η:

$$\eta = \frac{P_{1m^2}}{STC} \times 100\% = \frac{86}{1000} \times 100\% = 8.6\% \tag{3}$$

Energy of *PV*, E_{pv}:

$$\begin{aligned} E_{pv} &= ASR \times ACI \times \eta = 4.953 \times 0.497 \times 8.6\% \\ &= 0.21\ KW.\frac{h}{m^2}/day \end{aligned} \tag{4}$$

Power supply for 1 panel *PV*, *E*:

$$E = E_{pv} \times A. = 0.21 \times 1.6269 = 0.3416\frac{KWh}{day}. \tag{5}$$

Number of panels used:

$$N = \frac{P_{pv/day}}{E} = \frac{10KW}{0.3416.} = 29.2 = 30\ panels \tag{6}$$

At the normal operating temperature of 25°C, we can calculate the number of panels to generate 10 kilowatts of electrical energy, which is 30 panels, and this measurement is done according to the standard conditions of STC of 1000 watts/m^2.

4.2 Fuel cell system calculation (FC)

Fuel cells are one of the most attractive and promising technologies for using hydrogen, where hydrogen and oxygen are combined without combustion in an electrochemical reaction (the reverse process of electrolysis) and generate electricity, i.e. a red-ox reaction occurs [11], As shown in Eq. (7), as follows:

$$\begin{gathered} \text{Anode: } 4H^+ + 4e^- \rightarrow 2H_2 \\ \text{Cathode: } 2H_2O \rightarrow O_2 + 4H^+ + 4e^- \\ \text{Overall: } 2H_2O + 4H^+ + 4e^- \rightarrow 2H_2 + O_2 + 4H^+ + \\ 4e^- 2H_2O \rightarrow 2H_2 + O_2 \end{gathered} \tag{7}$$

FC systems are among the proposed systems as a backup application in remote areas. They are environmentally friendly and non-polluting, and use hydrogen as their primary fuel and convert it directly into electrical energy depending on an oxidizing element such as methane, ethanol, biomass, etc. We use in our study these fuel cells from The PEM type are the commercially available cell in industrial applications and its dynamic response is faster from 1 to 3 seconds [12] and its performance under unbalanced supply is reliable and widely used [13].

Eq. (8) determines the critical capacity of the fuel cell:

$$P_{FC} = P_{tank-FC} \times \eta_{FC} \tag{8}$$

4.3 Electrolyser/hydrogen tank

The electrolyzer performs the electrolysis of the water, and the dust flows from one electrode to another in the water, so we get oxygen and hydrogen, and then the latter is stored in hydrogen tanks to be used as fuel for the cell [14].

Eq. (9) expresses the power transferred from the electrolyzer to the hydrogen tank:

$$P_{elec-tank} = P_{ren-elec} \times \eta_{elec} \tag{9}$$

where, η_{elec} is the efficiency of the electrolyser assumed to be constant.

Eq. (10) expresses the energy stored in the hydrogen tank:

$$\begin{aligned} E_{H_2,tank}(t) &= E_{H_2,tank}(t-1) \\ &\quad + \left[P_{elec-tank}(t) - (\frac{P_{tank-FC}(t)}{\eta_{storage}})\right] \\ &\quad \times \Delta t \end{aligned} \tag{10}$$

where, $P_{tank-FC}$ is the output power of a fuel cell, $\eta_{storage}$ is the hydrogen storage efficiency of about 95% in all operating conditions [15].

Eq. (11) presents how to calculate the stored mass of hydrogen:

$$m_{tank}(t) = E_{tank}(t)/HHV_{H_2} \tag{11}$$

where, HHV_{H2} is the upper calorific value of hydrogen storage considered to be 38.9 kWh/kg [16].

The hydrogen tank has many upper and lower part limits. Due to some problems such as reducing the hydrogen pressure, the hydrogen tank cannot be completely filled when it exceeds the rated capacity.

Eq. (12) and Eq. (13) express the limits of the upper and lower parts of the tank:

$$E_{tank-min} \leq E_{tank}(t) \leq E_{tank-max} \tag{12}$$

$$E_{tank}(t=0) \leq E_{tank}(8760) \tag{13}$$

4.4 Bidirectional conversion system

The major parts of the components of the proposed system are a bidirectional converter. The main function of the transformer is to provide the necessary power from DC sources to the load by regulating the flow of current in both directions when the additional power is charged with the battery, and its work depends on the maximum and minimum power levels.

5. RESULTS AND ANALYSIS

The proposed scenario for upgrading the small standalone hybrid network shown in Figure 6 that uses 100% renewable energies has been evaluated and analyzes for system performance and optimum sensitivity using HOMER Pro, where possible combinations are identified based on the constraints and inputs provided and on the basis of their capital expenditures, CAPEX, OPEX, NPC and COE.

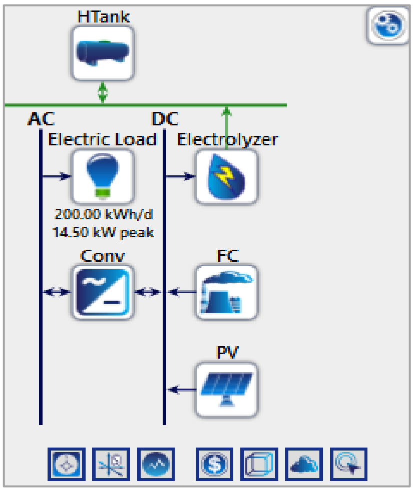

Figure 6. The proposed 100% hybrid PV–hydrogen model

5.1 Simulation results using HOMER Pro

The hourly simulation presents configurations of size and cost parameters and this is shown in Table 2, after which a specified number of groups are presented and the results of each group are discussed.

5.2 Panel PV / P2H2P system

In this system, the photovoltaic solar panel works with the fuel cell in order to assess the technical and economic sustainability of a 100% renewable system under the 2021 electricity tariff. Table 3 shows the outputs obtained from the optimal PV / P2H2P system; The 20 kW, 70 kW, 20 Kg, 120 KW and 13.5 kW capacities of the fuel cell, electrolyser, hydrogen tank, PV and converter were successively selected as the optimum size in the system design. The COE and NPC of the systems are estimated at 1,029,499.00 $ and 0.9025 $ / kWh, respectively.

With this system, the power supply comes from the PV module and the fuel cell. The average monthly power generation of the site systems comprised 85.2% and 14.8% of solar PV and fuel cell power, respectively, as shown in Figure 7. Due to sufficient solar potential of the site and due to the economic competitiveness of photovoltaic solar panels, the renewable energy fraction becomes 100%, as shown in Table 3.

Figure 7 shows the energy production of photovoltaics and fuel cells and their contribution to power generation and consumption over a one-year period. The study area has almost 5 months (Mar, Apr, May, Sep, Oct) identical to the climate which shows that they have the same temperature which varies between 250°C and 350°C, not only in the summer season concerning the 3 months (June, July, August) or the temperature is very high and exceeds 450°C; for the other months the region get under a very cold climate so the park welcomes fewer visitors in this period of the year, From the month of March when the school holidays begin the park can carry many visitors from the region and the country which shows the increase in consumption in that month.

The summary of the annual electricity production and use of PV / P2H2P systems at the site is presented in Table 4.

The total capital cost of the system is estimated at 600,816.00 $, by calculating the replacement, operating, and maintenance capital cost of individual components for one year and then for 25 years, and this is shown in Figure 8.

Table 2. Optimization results

Architecture					Cost				System		FC					
PV (kW)	FC (kW)	Electrolyzer (kW)	HTank (kg)	Conv (kW)	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (kg/yr)	Hours	Production (kWh)	Fuel (kg)	O&M Cost ($/yr)	Fuel Cost ($/yr)	Capital ($)
120	20.0	70.0	20.0	13.5	$1.03M	$0.902	$27,200	$600,817	100	2,113	5,592	35,216	2,113	11,184	0	360,000
120	20.0	70.0	20.0	13.8	$1.03M	$0.902	$27,205	$601,000	100	2,113	5,592	35,222	2,113	11,184	0	360,000
120	20.0	70.0	20.0	14.2	$1.03M	$0.902	$27,229	$601,367	100	2,114	5,596	35,230	2,114	11,192	0	360,000
120	20.0	70.0	20.0	14.7	$1.03M	$0.903	$27,247	$601,733	100	2,114	5,598	35,232	2,114	11,196	0	360,000
120	20.0	70.0	20.0	15.1	$1.03M	$0.903	$27,274	$602,100	100	2,114	5,603	35,232	2,114	11,206	0	360,000
120	20.0	70.0	20.0	15.6	$1.03M	$0.904	$27,288	$602,467	100	2,114	5,604	35,232	2,114	11,208	0	360,000
120	20.0	70.0	20.0	16.5	$1.03M	$0.905	$27,312	$603,200	100	2,114	5,605	35,232	2,114	11,210	0	360,000
120	20.0	70.0	20.0	18.3	$1.04M	$0.907	$27,352	$604,667	100	2,114	5,605	35,232	2,114	11,210	0	360,000
120	20.0	70.0	20.0	19.3	$1.04M	$0.907	$27,372	$605,400	100	2,114	5,605	35,232	2,114	11,210	0	360,000
120	20.0	70.0	20.0	20.2	$1.04M	$0.908	$27,392	$606,133	100	2,114	5,605	35,232	2,114	11,210	0	360,000
120	20.0	70.0	20.0	22.0	$1.04M	$0.910	$27,433	$607,600	100	2,114	5,605	35,232	2,114	11,210	0	360,000
120	20.0	80.0	20.0	13.3	$1.06M	$0.927	$27,894	$620,633	100	2,130	5,634	35,493	2,130	11,268	0	360,000
120	20.0	80.0	20.0	13.8	$1.06M	$0.926	$27,936	$621,000	100	2,131	5,643	35,514	2,131	11,286	0	360,000
120	20.0	80.0	20.0	14.2	$1.06M	$0.926	$27,953	$621,367	100	2,132	5,645	35,526	2,132	11,290	0	360,000
120	20.0	80.0	20.0	14.7	$1.06M	$0.926	$27,973	$621,733	100	2,132	5,648	35,528	2,132	11,296	0	360,000
120	20.0	80.0	20.0	15.1	$1.06M	$0.927	$28,001	$622,100	100	2,132	5,653	35,528	2,132	11,306	0	360,000
120	20.0	80.0	20.0	15.6	$1.06M	$0.928	$28,015	$622,467	100	2,132	5,654	35,528	2,132	11,308	0	360,000

Table 3. Financial characteristics of optimized PV/P2H2P systems.

PV (kW)	Fuel cell (kW)	Electrolyzer (kW)	Hydrogen tank (kg)	Converter	NPC (USD)	COE (USD/kWh)
120	20	70	20	13.5	1,029,499.00	0.9025

Table 4. Annual electricity generation and use of on-site grid/PV systems.

PV Production (KWh/an)	FC Production (KWh/an)	Demand (KWh/an)	Total use (KWh/an)
202.100	35.222	72.456	237.322

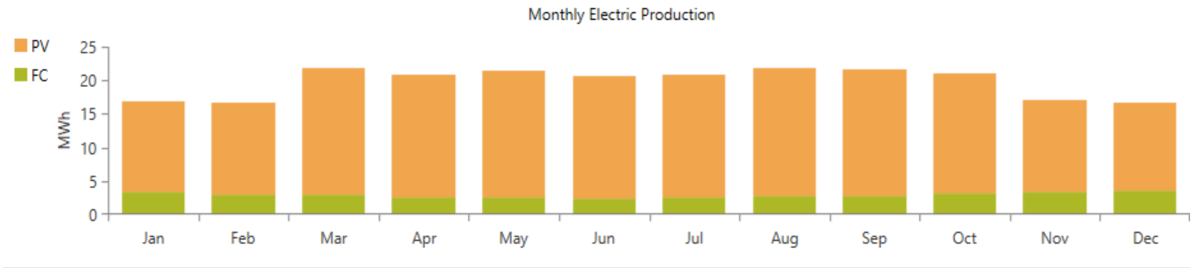

Figure 7. High average power generation for the PV / P2H2P system

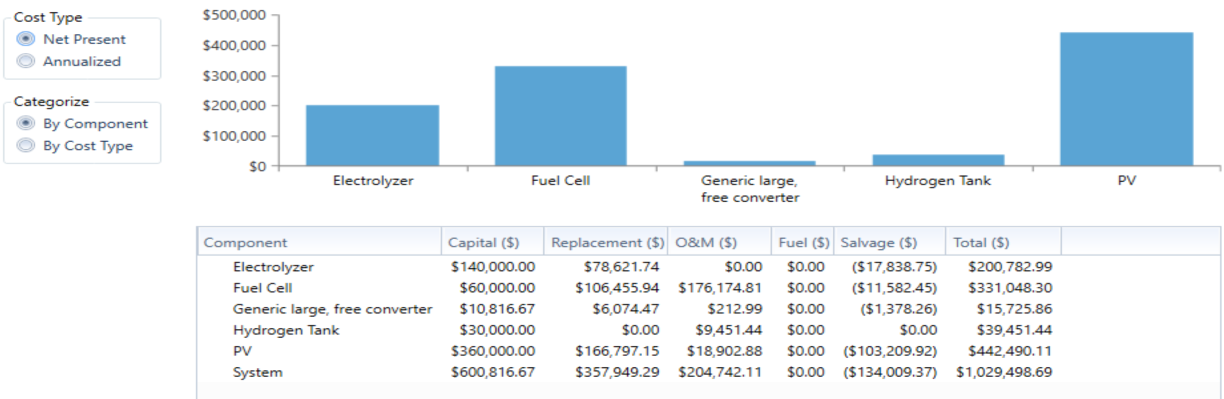

Figure 8. Current total net cost of the hybrid energy system

But the cost of operating this technology and maintaining it is also relatively higher, and thus we conclude that the factor that determines the total cost of the system is the inclusion of the fuel tank, so that the current net cost of the system is estimated over 25 years is 1,029,498.69 $.

5.3 Emissions

Selling electricity to the grid reduces grid emissions. HOMER attributes these reductions to the energy system. The system can even achieve negative emissions of one or more pollutants if large quantities of low-emission electricity are sold to the grid. Gaseous emissions from the hybrid system are presented in Table 5.

Table 5. Emission constraint of the system

Quantité	**Valeur (kg/yr)**
Carbon Dioxide	-21.6
Carbon Monoxide	13.7
Unburned Hydrocarbons	1.52
Particulate Matter	1.04
Sulfur Dioxide	0
Nitrogen Oxides	123

6. CONCLUSIONS

This article aims at the development and a hybrid energy system that eliminates the need of building an electrical network or connect it to an isolated area, and this makes the cost very high, and all this depends on renewable energies. The selected area provides two sources of energy, namely the sun to supply photovoltaic cells and the dam to feed Hydrogen fuel cells are an important feature of this system. It should also be noted that the stand-alone system has a very high cost compared to its low efficiency, and this is a major weakness. Simulation of this system over 25 years showed that it contains less NPC and COE. Another model can also be proposed and evaluated based on the available renewable energy resources and that in a similar load definition file, changes in the input data must be taken into account. In order to achieve an ideal hybrid and independent power system, it is necessary to determine the estimated system life cycle cost of 25 years and the total net current cost (TNPC) taking into account the high rates of feed-in tariffs and the cost of capital. We note that the flat total cost of energy is suitable for the completion of this project and that the increase in operating and maintenance costs can lead to a rise in low energy prices (LCOE). The cost can be reduced for each energy rate by extending the life of the system. Economically, there can be an increase in costs and

This increase the annual inflation rate, leading to an increase in the annual interest rate. The use of excess renewable energies should be ideal, by using the excess stored hydrogen in the energy, water and waste areas, and also using it as a fuel for transportation, cooking and heating, and the surplus of drinking water can be used by reverse osmosis.

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