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Optimization of a hybrid system (PV-fuel cell) of energy production for an isolated site

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Abstract: This Recently, there has been a shift in autonomous micro-grid systems, moving away from reliance on fossil fuels. Instead, these systems are now integrating existing renewable energies in specific areas to promote sustainability in the energy sector. One promising method for energy storage and transmission is through the use of hydrogen and solar energy, especially in remote regions where hybrid techniques can meet the required energy demands. Our research focuses on electrifying a agricultural site located in the SBAA region, specifically in ADRAR city, southwest Algeria. We propose the implementation of an independent small electric network that combines various renewable energy sources (PV/Full cell). To ensure cost-effectiveness, we aim to optimize and control the system's components, carefully sizing them through a meticulous selection process. This study evaluates the technical and economic feasibility of renewable energy systems, with the goal of reducing the total net cost, energy expenses, and unfulfilled load, while also minimizing CO2 emissions. The simulation program HOMER Pro is used to conduct this analysis. Overall, the proposed system demonstrates positive results in electrifying remote areas while maintaining a conservative cost of electrical energy, ultimately establishing sustainable regions.

Keywords: agricultural site , electrolyzer, fuel cell, Homer pro software, hydrogen tank, PV energy, power to hydrogen to power, renewable energy, stand-alone micro grid.

1. INTRODUCTION

Only diesel generators can power Algeria's irrigation systems, rural areas, and arid regions without access to the electricity grid. An irrigation system powered by diesel is a major contributor to climate change, the depletion of fossil fuel reserves, rising operating costs, and diesel-related maintenance issues, all of which prompt the search for alternative energy sources for the system [1]. As of now, sun powered PV-based water system framework is considered as an elective water system arrangement. It demonstrates the financial, ecological and specialized feasibility contrasted with the diesel-based water system framework [2]. Presently, battery capacity framework is excluded from sun oriented water system framework in Algeria because of significant expense and upkeep issues. However, a small amount of water is stored in the water storage tank that is included. What's more, the significance of energy stockpiling ought to have been considered in the midst of appeal and awful climate [3]. Without a doubt, on account of long haul energy capacity, it is desirable over utilize the hydrogen framework which is more proficient, productive and solid [4]. In the second half of the 21st century, the production of hydrogen from water will gradually replace fossil fuels and become the primary energy carrier [5]. When the term "renewable energy" is used, water is typically regarded as a sustainable and clean source for the production of hydrogen [6].

By achieving a balance between the demand for water and the supply of power, energy storage is an effective solution to the storage and daylighting issues. Among power capacity innovations, electrochemical energy stockpiling has gotten more consideration because of its security, dependability, lattice similarity and high proficiency [7]. Due to its high calorific value, energy density, and emission-free or near-emission-free nature, hydrogen generation, which is based on the electrolysis of water, is one of the most widely used chemical energy storage methods [6]. The hydrogen storage tank's outflow is low in this storage system. The hydrogen stockpiling framework can likewise be utilized for dependable and nonstop capacity on the grounds that its energy conservativeness is high and easy to introduce and move anyplace [8]. Mechanically created nations have previously carried out hydrogen power module innovation in their vehicle area [9] and in the water system area utilizing an inverter [10]. In order to power rural homes, a feasibility study of a hydrogen fuel system for AC electrification in Algeria's rural areas was conducted in [11]. Additionally, a number of works in the literature on hybrid systems presented two or three different kinds of renewable energy sources for design and planning [12-13].

Instead of putting pressure on Algeria's economy, the hydrogen fuel cell irrigation system is an alternative way to meet the current demands of agriculture. In Algeria, particularly in the southern desert regions, irrigation is typically required for 10 to 13 hours per day for cultivation, while solar radiation is available for 8 to 10 hours. This alternative solution will be profitable and beneficial to the environment. The load is powered by approximately half of the solar radiation. Any storage system can reduce the size of the solar panel and the amount of land needed to install it by using 50% of the radiation that is not being used. As a result, farmers can cultivate more land. In this postulation, a substituting current siphon is chosen to plan and recreate the half breed water system framework (power device/PV) in the space of SBAA adrar Algeria.

This study is carried out by working with an optimization tool: the simulation software HOMER (Hybrid Optimization of Multiple Energy Resources) is an economic optimization model, which minimizes the cost of energy production to satisfy the final energy demand. energy based on current net cost. Thus, HOMER-based hydrogen fuel cell system for irrigation is analyzed and designed as a renewable green energy technology by reducing energy storage requirements, improving efficiency and reliability.

2. METHODS AND MATERIALS

The stand-alone hybrid system shown in Fig. 2.1 consists of several basic components, including photovoltaic cells, fuel cell, electrolyser, hydrogen tank, inverter and battery. The photovoltaic cell, power device and electrolyzer are associated through a DC transport. The transformer connects the AC output to the load while the DC output connects to the DC bus.

Photovoltaics use solar energy to create electricity during the day, whereas hydrogen systems generate power both during the day and at night. The fuel cell serves as a backup power source for the hybrid system, ensuring that electricity remains available in the case of breakdowns or power outages.

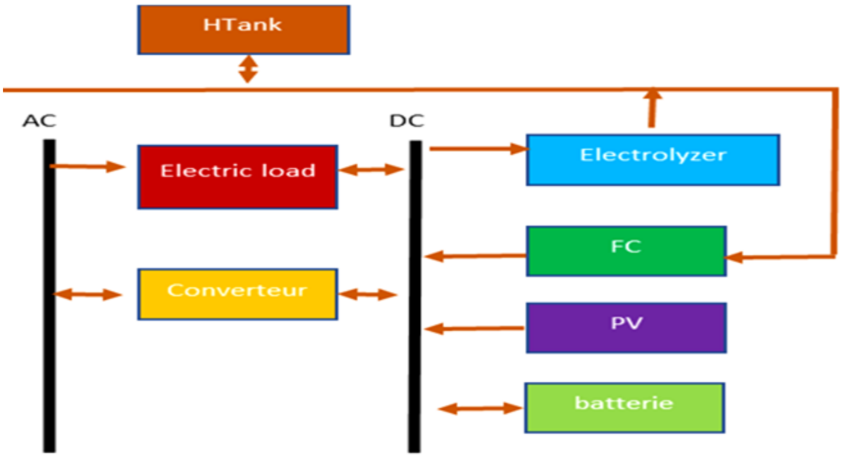


Fig. 2.1. Model of a hybrid PV/fuel cell power plant

3. DESCRIPTION OF STUDY AREA

This work was done with HOMER pro version 3.14.2. Fig. 3.1 shows the location of the agricultural zone of SBAA in the willaya of Adrar Algeria.

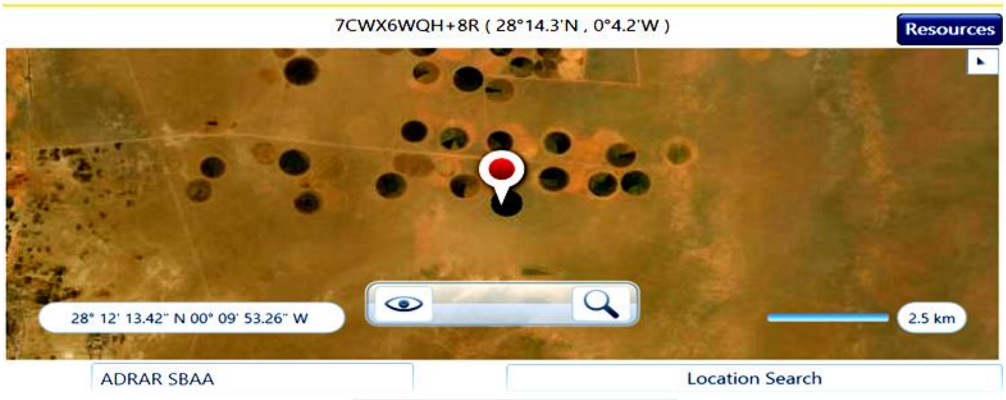


Fig. 3.1. Geographical coordinates of the agricultural region SBAA (Adrar ،Algeria)

The agricultural zone of SBAA, located in the wilaya of Adrar in Algeria, is an important region for agriculture in the region. It is characterized by a desert climate and arid geographical conditions. Despite these challenges, the area benefits from groundwater resources and adapted agricultural techniques that allow the practice of agriculture fig. 3.2.

Fig. 3.2. Real photo of the agricultural region concerned by the study

3.1. Resources of the study area

Solar radiation and mean annual temperature are shown in Fig. 3.3 and 3.4, respectively, Based on data from the NASA Surface (Weather and Sun) webpage for the research region.

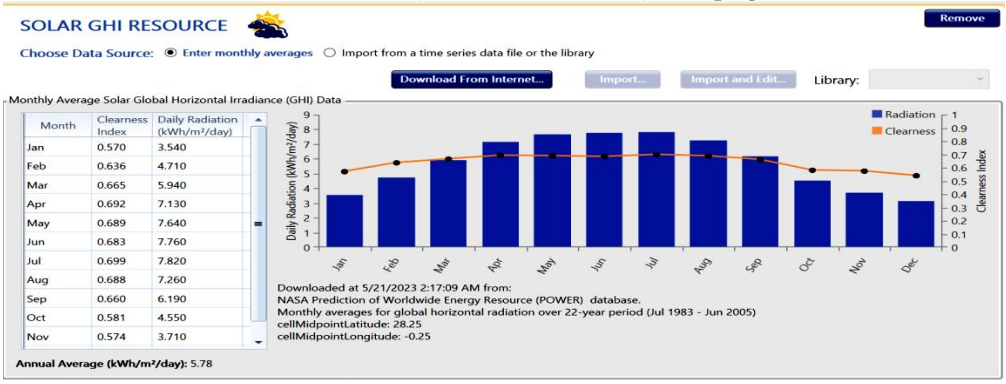


Fig. 3.3. Global monthly data on horizontal irradiance for the SBAA Adrar agricultural region

Fig. 3.4. Monthly average temperature data of the SBAA Adrar agricultural region

3.1. Concepts and components of micro-grids

The average load indicated in Fig. 3.5 has been entered into the program, which uses this data to estimate the remainder of the information over the course of a year. This first stage of the process shown that the agricultural region SBAA adrar consumes 275.04 kW, a figure that must be addressed in the planning and design of the MR, which includes a PV system, a fuel cell, an electrolyzer, a hydrogen tank, and a storage system. The system is not linked to a conventional network. The project's lifespan is set at 25 years.

Table 3.1. Electrical characteristics of pivoted system

The pivots	Pump power (W)	Power of 5 motors (KW)	Rotation time (h)
1	44741.99	1.1	13h
Number of pivots	Total irrigation area (ha)	Total load (KW)	
6	180	275.04	

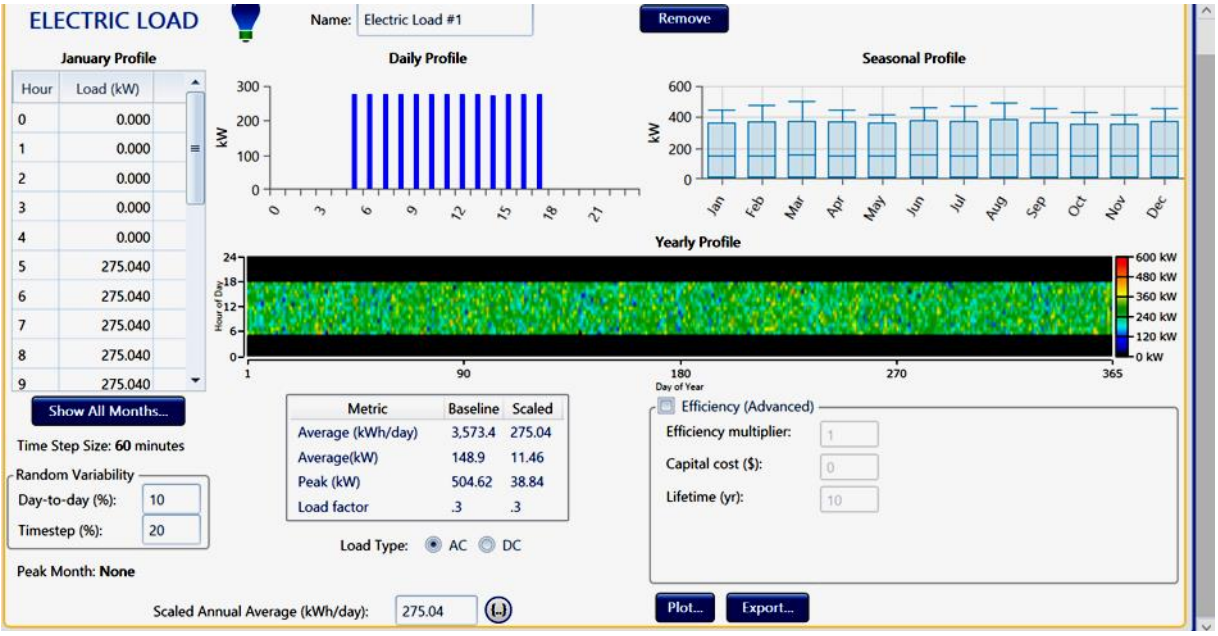


Fig. 3.5. Monthly average temperature data of the SBAA Adrar agricultural region

4. ARCHITECTURE OF THE SYSTEM

Table 4.1 shows the overall input data for the hybrid system employed, including the cost of volume, capital, replacement, and maintenance, as well as the lifetime.

Table 4.1. Architecture of the system [11]

Component	size	Capital cost ($)/kW	Replacement cost ($)	O&M cost ($/yr)	Lifetime
PV	1 KW	783.3	783.3	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	1Kw	800.00	750.00	1	15 years

5. RESULTS AND DISCUSSION

Using HOMER Pro, the suggested scenario for upgrading the small standalone hybrid power system shown in Fig. 5.1, which employs 100% renewable energy, was evaluated for system performance and optimum sensitivity. The conceivable combinations were distinguished based on the given imperatives and inputs, taking into account their capital expenditures (CAPEX), operating expenses (OPEX), net present cost (NPC), and cost of energy (COE).

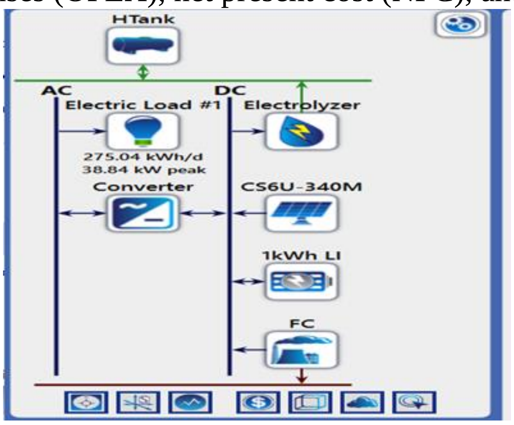


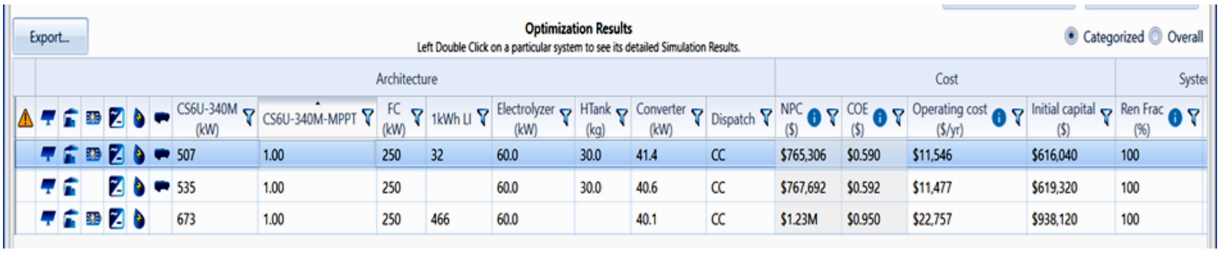
Fig. 5.1. Monthly average temperature data of the SBAA Adrar agricultural region

5.1. Results of simulation

The simulation results were obtained using HOMER Pro software, which allowed for an hourly analysis of different configurations based on size and cost parameters. Table 5.1 provides an overview of these configurations.

Following the simulations, a set of groups was established to analyze and discuss the results obtained from each group. These groups likely focused on specific aspects or variations in the system design, such as different component sizes or cost considerations.

Table 5.1. Optimization results



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Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Categorized Overall

Architecture									Cost					Syste
CS6U-340M (kW)	CS6U-340M-MPPT	FC (kW)	1kWh LI	Electrolyzer (kW)	HTank (kg)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)		
507	1.00	250	32	60.0	30.0	41.4	CC	$765,306	$0.590	$11,546	$616,040	100		
535	1.00	250		60.0	30.0	40.6	CC	$767,692	$0.592	$11,477	$619,320	100		
673	1.00	250	466	60.0		40.1	CC	$1.23M	$0.950	$22,757	$938,120	100		

5.2. PV Panel / P2H2P system

The PV/P2H2P panel system combines solar PV panels with a fuel cell to evaluate the technical and economic viability of a 100% renewable energy system under the 2023 electricity tariff. The optimized system design includes a fuel cell capacity of 250 kW, an electrolyzer capacity of 60 kW, a hydrogen tank capacity of 30 kW, a photovoltaic capacity of 507 kW, and a converter capacity of 41.5 kW. The estimated cost of energy (COE) for the system is 0.509$/kWh, with a net present cost (NPC) of 765,306.00$.

The power supply in this system is derived from both the photovoltaic module and the fuel cell. On-site power generation is predominantly sourced from the solar PV panels, accounting for 87.5% of the monthly power generation, while the fuel cell contributes 12.5%, as depicted in Fig. 5.2.

The system achieves 100% renewable energy utilization due to the favorable solar potential and economic competitiveness of solar PV panels.

Fig. 5.2 presents the energy production from both the photovoltaic panels and fuel cells, along with their contribution to energy generation and consumption over a one-year period. The study area experiences nearly 5 months (March, April, May, September, October) with similar climate conditions, characterized by temperatures ranging from 25 to 35°C. For the remaining months, the temperature exceed 45°C.

Table 5.3 provides a summary of the annual electricity production and usage for the PV/P2H2P system at the site. The total capital cost of the system, considering replacement, operation, and capital maintenance costs for one year and over a 25-year period, is estimated at $619,319.68, as depicted in Fig. 5.3.

Table 5.2. Financial characteristics of optimized PV/P2H2P systems.

PV (kW)	Fuel cell (kW)	Electrolyzer (kW)	Hydrogen tank (kg)	Converte r	NPC (UD)	COE (USD/kWh)
507	250	60	30	41.5	765,305.84	0.590

Table 5.3. Yearly power generation and utilize of on-site grid/PV frameworks.

PV Production (KWh/an)	FC Production (KWh/an)	Demand (KWh/an)	Total use (KWh/an)
185.04	**26.442**	**100.330**	**212.246**

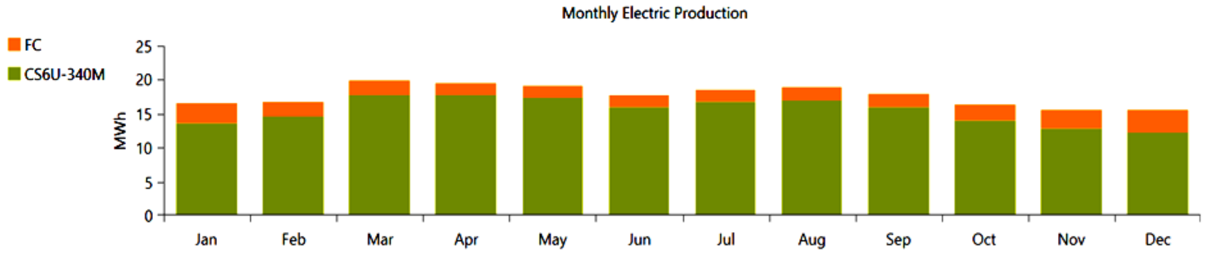

Fig. 5.2. Monthly electric production for the PV / P2H2P system.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$397,344.34	$0.00	$65,577.37	$0.00	$0.00	$462,921.71
Generic 1kWh Li-Ion	$17,600.00	$7,467.22	$4,136.81	$0.00	($1,405.41)	$27,798.62
Generic 50kW Fuel Cell	$3,000.00	$0.00	$2,191.21	$0.00	($109.60)	$5,081.62
Generic Electrolyzer	$120,000.00	$50,912.86	$7,756.51	$0.00	($9,582.31)	$169,087.06
Hydrogen Tank	$45,000.00	$0.00	$11,634.76	$0.00	$0.00	$56,634.76
System Converter	$33,095.66	$13,164.02	$0.00	$0.00	($2,477.60)	$43,782.07
System	$616,040.00	$71,544.10	$91,296.67	$0.00	($13,574.92)	$765,305.84

Fig. 5.3. The hybrid energy system's current total net cost

However, the cost of running and maintaining this technology is substantially higher, thus we conclude that the element determining the overall cost of the system is the inclusion of the fuel tank, with the current net cost of the system anticipated over 25 years being 765,305.84 $.

6. CONCLUSIONS

The objective of this work is to evaluate the feasibility of a stand-alone hybrid renewable energy system capable of meeting energy demand. A stand-alone power system can avoid the need to build an expensive grid in rural areas. The use of solar energy and hydrogen has considerable advantages as the primary power sources for this system. However, stand-alone photovoltaic systems have their own limitations, including their due high cost and low efficiency. Simulation of this system using HOMER software revealed that it has the lowest net present cost (NPC) and lowest cost of electricity (COE) over the life of the project. 25 years. The proposed and evaluated model can be reproduced under similar load profiles and with available renewable energy resources, but it must be re-evaluated if the input data changes. Given the high feed-in tariffs and capital costs, it is essential to determine the life cycle cost of the system, i.e. the total net present cost (TNPC), in order to obtain a optimal energy hybrid system. It is important to observe the actual effects on the power system and its economic parameters, as well as variations in sensitive variables that influence the simulation results. In this study, two 100% renewable energy scenarios were defined, modeled, simulated and compared for a stand-alone solution. From simulations carried out with HOMER Pro, the main conclusions are as follows: The evaluation of the two scenarios showed that the scenario based on the hybrid PV-P2H2P-battery combination (Scenario 2) is the most promising approach for the selected stand-alone micro grid site in the agricultural region of SBAA in Adrar, in Algeria .The hybrid system can further reduce the amount of excess electricity compared to a battery-only storage system. The hybrid system is able to extend the autonomy of the system compared to a battery storage system by using the stored hydrogen. Hydrogen production from renewable energy sources could be a long-term energy storage solution and provide an energy carrier for various uses, with excellent environmental characteristics. Future work aims to analyze the technical and economic advantages of integrating these new ways of using hydrogen.

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