Technical and Economic Feasibility Study of a Hybrid Hydrogen-based Renewable Energy System

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Abstract: Traditional electrical grids rely heavily on Hydrocarbons. The latter turn out to be a significant cause of environmental damage, as well as being rapidly depleted. Remote regions and settlements cannot benefit from this kind of electric energy as they are disconnected from the electrical network. Hybrid renewable energy systems (HRES) proved as being a great option in such cases. The objective of this article is to construct and optimize an autonomous hybrid renewable power plant to meet the demand for electricity for an isolated drilling location in Adrar region in the south of Algeria. To address the issue of intermittent power from wind and solar sources, a hydrogen-based arrangement is included in the already existing hybrid renewable energy system. The system modeling and running are carried out using HOMER package to identify the best cost-effective HRES arrangements.

Keywords: Renewable sources; Hydrogen energy, dimensioning; Technical and economic Study; HOMER

1. INTRODUCTION

Renewable electricity sources have attracted growing global interest in recent years owing to their capabilities of responding to the ecological worries (CO_2 emissions which contribute to temperature rise) and their ability to meet the increasing need for electricity. Moreover, the low expenses for both operation and maintenance together with the ease of deployment have resulted in an increase in the adoption of renewable energy sources (RES). Energy from renewable sources has achieved substantial advances in technology as an environmentally friendly source of energy at no expenses associated with fuel, and research in both academia and industry is under way. In 2016, green electricity represented more than 62% of total established electrical power generation output, an enhancement of 9% over the previous year's figure [1]. Based on previously collected records from the International Energy Agency (IEA) [2], energy from renewable sources is clearly dominating power generation. Ambitions to reduce emissions of carbon dioxide and government assistance to promote RES have encouraged a greater incorporation of environmentally friendly energy sources into energy systems. Yet, contemporary technological issues related to irregular renewable energy sources (RES) have limited RES adoption in the currently deployed power network.

Due to being situated at far distances from the central electricity network, the expensiveness of electrical cables, technical barriers in distant regions, as well as issues with the supply of electricity resulting from natural challenges, accessibility to electrical power is currently a top priority in isolated regions. Energy from renewable resources, such as PV and wind, has been shown to be a viable remote energy supply alternative [3,4]. This configuration may provide a more compatible electricity supply and would be more cost-effective than the habitual grid connection alternatives for remote localities, mainly in telecommunications, harmful chemical manufacturers in inaccessible mountain regions, and small islands, among others.

Microgrids (MG), regardless of being grid-tied or autonomous, are the foundation of the smart grid scheme. They constitute a possibility for effectively utilizing RES to guarantee the trustworthiness of the electricity delivery in distant locations, thereby lowering the adverse effects of risk on the network. Individual users, such as buildings, a geographic area, or an isolated town, together with the renewable energy production estimated in that area, storage capability, and the demand for electricity, can all influence the MG's capacity to be installed in grid-independent usage. A variety of nations use MG hybrid energy systems as a substitute to the autonomous diesel-generator for transmitting and delivering electricity to faraway regions [5-10].

According to the literature, there are several approaches to using algorithms for optimization to address the challenge of designing renewable energy systems [11]. A graphic visualization is one strategy. This method works successfully for problems that involve two design parameters by monitoring graphically the way one varies with respect to the other. The constraints are represented graphically on the same graph. As soon as the goal function lines have been plotted, the optimized location on the graph can be determined through studying the promising area [12, 13]. The probabilistic technique is a different methodology, which calculates the optimal size of a hybrid PV/wind energy source per hour or per day average power on a monthly basis, the day of minimum PV power per month, and the day of minimum wind power per month. The expenditure and duration required to collect ecological and consumption data are reduced using this approach [14,15]. Another method is known as the deterministic strategy, in which each set of state variables is solely calculated by parameter settings and sets of past states of these variables, resulting in a typically unique solution for some settings, in contrast to the probabilistic technique [16].

The conventional iteration technique is an algebraic process that generates a series that evolves rough solutions for the optimization issue till a stopping setting rule is met. Should this approach be used, the computational complexity grows significantly as the number of optimization variables gets higher [17-18]. Artificial intelligence (AI) consisting of tools such as artificial neural networks (ANN), genetic algorithms (GA), fuzzy logic (FL) and hybrid systems has been used as a tool to optimize HRES. The use of intelligent technologies results in practicable systems with better performance that classical methods are not able to achieve [19]. Examples include: Genetic Algorithms [20], Particle Swarm Optimization [21], Cookoo Search algorithm [22] and Artificial Neural Networks [23]. Some dedicated software packages have been also proposed including HOMER (Hybrid optimization method for electric renewable) [24], iHOGA (Hybrid optimization by genetic algorithm) and HYBRD2 [25].

Various literature reviews and surveys have been made over the past few years. Fodhil et al. [25] described an approach for grid-independent PV/diesel/battery HRES dimension optimization based on PSO and constraint strategy, with the goal of concurrently reducing the whole system expenditures, unfulfilled demand, and the release of CO2. Mohammed KEBBATI [26] investigated the conceptualization, simulation, and management of a grid-connected hybrid PV-Wind system (an ADRAR case study). Abdelkader et al. [27] suggested a multiple-purpose Genetic Algorithm-based methodology for optimizing the proper size of PV/Wind/Battery/Supercapacitor HRES while minimizing the load's COE and LPSP. likewise, Eriksson and Gray [28] used a Normalized Weighted Constrained MOPSO to optimize a hybrid PV/wind/diesel/battery/hydrogen storage HRES while taking into account several goals (LPSP, COE, NPC, and Electricity Carbon Footprint). They noticed that traditional storage systems, such as batteries, are still more feasible than hydrogen storage. Optimization of Off-grid Hybrid Renewable Energy Systems Regarding the Effects of Building Energy Efficiency and Environmental Change: A Case Study of Algeria [29] was published by Charafeddine Mokhtara, Belkhir Negrou, Noureddine Settou, Belkhir Settou, and Mohamed Mahmoud Samy. Mohseni et al. [30] presented a hydrogen-based HRES. Mokhtara et al. [31] created a combined supply-demand energy management approach to optimizing the design and arrangement of an isolated HRES for electrifying residential buildings in desert environments.

Hossain et al. [32] presented an additional review paper that investigated the effects of renewable energy use for electrifying rural areas on nationwide. A few investigations have also provided an inventory of various modeling resources and approaches that can be used in HRES setting up [33]. Bahramaraet al. conducted an in-depth review on the utilization of HOMER software for most effective HRES designing [34]. An assessment of HRES dimensioning techniques, arrangements, and management strategies was presented in [36]. Al-falahiet al. performed an assessment of recent advances in size optimization techniques and software packages for sizing autonomous solar and wind HRES [36]. Siddaiah and Saini also put

stress in their survey on HRES setting up, arrangements, representation, and optimization methods for autonomous usages [37].
Housing infrastructures represent approximately 43% of total electrical consumption in Algeria [38]. Building power usage has risen rapidly in almost all developing nations over the past few years as a result of the deployment of emerging innovations, a hunger for recreational activities, and the need for heating and cooling. The Algerian consumption of electricity in its construction industry, for instance, grew by 8% in 2018 as compared with 2017 [38,39]. The main issue with this growth is that in the majority of countries, fossil fuels constitute the most common source of electrical power production [40]. (Over 97% in Algerian) [41]. In addition, there is still a substantial percentage of infrastructure in remote rural regions that are not connected to the electrical system. As consequently, they need to depend on diesel-powered sources to fulfill their power demands. Due to the excessive price of diesel fuel, that will likely continue to rise and related adverse health effects, using diesel generators is turning unprofitable [42] and contributes significantly to climate change, which has turned out to be the world's critical ecological problem [43]. Moreover, the decline of fossil fuel stocks is a major concern. Thus, integrating energy from renewable sources such as solar and wind is becoming increasingly essential.

There are a lot of communities and houses that do not have access to utilities because they are in remote places, especially in the Southern region of Algeria. There are a lot of temporary buildings in these places, such as drilling camps that move every three months from one place to another depending on what they are doing (exploration, drilling, work-over, etc.). Drilling camps are like small towns that have everything workers need to live in, like bedrooms, bathrooms, kitchens, cafeterias, catering facilities, and other services. So, the diesel generator is the only way these camps can get the electricity they need. ENTP, which works in the drilling field and owns about 67 drillers, has said that a drilling camp uses an average of 250 m^3/year of fuel; giving rise to 17,000 m^3/year for all of its own camps. So, the cost of diesel is $2.55 million a year, and the cost of transportation is estimated at $60,000. These expenses make a total of $2.56 million per year [44].

Considering that the Algerian authorities contribute to diesel fuel price, these expenses have an impact on the country's financial situation, which is entirely dependent on petroleum revenues. Despite rising fuel prices, traditional generators are difficult to utilize due to worries about the environment and the reality that Hydrocarbons tend to get worn-out. Thus, more renewable power supplies will be required to generate electricity. Algeria is fortunate since it has an immense quantity of solar power capacity, which is over thirty times the value of electrical power used by the entire world in an entire year [45]. As a consequence, the Algerian authorities have launched a variety of measures and initiatives to promote the utilization of energy from renewable sources, expand the nation's electrical sources, and ensure that the most isolated regions have a supply of electrical power. In 2015, Algeria revised its Renewable Energy and Energy Efficiency Scheme. The plan has been launched in the year 2011. The most recent edition of the plan aims to generate approximately 27% of all electrical power utilizing renewables [46]. Apart from that, the objective of the scheme is to reduce the release of greenhouse gases by 7% by 2030 [47].
The Algerian authorities are more interested in developing power from the sun over the remaining renewable sources. Electricity from wind, biomass, and geothermal is widely used. As a result of this scheme, ENTP has determined its objective of accomplishing the ENTP Green Cabin project that constitutes a model for a self-sustaining Saharan cabin powered solely by electricity from the sun. However, since this kind of renewables is unforeseeable and merely operates on occasion, it disrupts the energy equilibrium and is not able to entirely substitute hydrocarbons. As a result, an exciting option is the hybrid renewable energy system, which combines renewable and traditional sources of energy and/or a system for storing electricity. HRES, particularly solar-wind hybrid renewable energy systems, are currently being employed extensively to deliver electricity to isolated locations because they are more dependable and tend to be cheaper than diesel-only engines [48]. However, scientists encounter an important obstacle when attempting to determine the adequate means to estimate the dimensions and arrangement of HRES whilst considering numerous restrictions. Several studies have been

reported on this subject using algorithms for optimization (particle swarm optimization, genetic algorithms, and Ant colony algorithms) or commercially available packages such as HOMER, RETSCREEN, and HOGA [49-52].

This research paper addresses the optimization process and conceptualization of an autonomous (stand-alone) HRES, as well as the mathematical representation and computer imitation of the entire structure using pertinent information to estimate its efficacy and energy share. The scenario in this research was chosen in accordance with the accessible wind and solar energy capacity. The main objectives of this research are to minimize the price of power production by optimizing the dimensioning of the hybrid system elements, in addition to maximizing the usage of solar energy systems while cutting down the release of contaminants. This research additionally seeks to promote the hydrogen technology as a potential remedy that cures the unpredictable character of solar and wind supplies.

2. THE HYDROGEN ENERGY SYSTEM

The power to hydrogen (P2H) system works by electrolyzers retaining excess renewable energy to produce hydrogen, which can thereafter be employed for a variety of uses. It may be utilized to power fuel cells, store hydrogen in tanks, feed into gas grids, or combined with carbon dioxide to create synthetic methane. Rather than lowering extra production, a P2H system acts as a carrier, converting it into a chemical energy carrier (hydrogen for instance).

The produced hydrogen gas is expected to be kept within a form of storage medium, such as hydrogen storage tanks, which are analogous to batteries yet use compressed hydrogen as the energy carrier. The hydrogen in the tanks might be utilized to run a fuel cell, generating electricity. As a result, a P2H system consists of three primary elements: an electrolyzer (which produces hydrogen from extra power), a hydrogen reservoir (which stores hydrogen for usage within the system if required), and a fuel cell (which transforms stored hydrogen into electricity)[53]. This section describes the various technologies used in the P2H process.

Electrolyzer Technologies

The primary component of P2H systems is the transformation of electricity into chemical energy via water electrolysis. When a voltage is made available to the two electrodes, water splits into hydrogen and oxygen elements, which are produced at the cathode and anode. The method of electrolysis has the following reaction equation:

$H_2O \rightarrow 2H_2 + O_2$ $\Delta H^o = 286 kJ/mole$ (at 25°C, 1 bar) (1)

- The electrolyzer also includes an ion-conducting electrolyte and a diaphragm that acts as an electric isolating component and differentiates the resulting gases in the previous process to prevent a flammable mix.

The requirements that follow must be met by the electrolyzers used in P2H systems:

- They ought to be extremely adaptive for them to react to varying renewable energy inputs.
- High efficiency to avoid energy waste.
- Allow an energy-saving backup state.
- Long lifespans and low expenditures on investment enable affordable production of hydrogen. Electrolyzers are classified into two categories depending on the electrolyte used:

a. Electrolyzers with a proton-conducting polymer electrolyte membrane, such as proton exchange membrane (PEM).

b. Electrolysis at high temperatures using a solid oxide electrolyte

Alkaline electrolyzers employ an aqueous alkaline electrolyte containing 20-40% potassium hydroxide (KOH). KOH conducts OH- ions and operates at temperatures ranging from 70°C to 140°C under pressures ranging from 1 to 200 bar [42]. They often reach stack efficiencies of 60-71 % (HHV).Modules with commercially available capabilities of up to 760 Nm3/h are available. The main disadvantage of employing these electrolyzers in P2H systems is their restricted part-load features. The electrolyzer diaphragm's gas conductive properties limit the lowest possible load, where the gas conductance establishes a crucial H2 amount in the O2 stream for small gas circulation. Furthermore, alkaline electrolyzers are more slowly in when it comes to interactions than PEM electrolyzers because of their peripheral momentum [43]. The overall price of these electrolyzer systems, involving electrical power, command of the system, and gas drying, is estimated to be within the $1000/kW range in the next few years, and will likely decrease by 40-50% [44].

PEM electrolyzers have been developed throughout the past twenty years. The technology relies on the utilization of a proton-conducting polymeric membrane in a single component as both the electrolyte and the diaphragm. Temperatures of operation are restricted to approximately 80°C due to the polymeric structure [45]. The membrane allows for low part loads due to its gas impermeability. Hydrogen can be produced at pressures of up to 150-200 bar [46]. The cell productivity of these electrolyzers is identical to that of alkaline electrolyzers, but the stack productivity is smaller. The aforementioned electrolyzers have a simple layout and frequently attain high productivity levels that vary between 65 to 85% (HHV), rendering them ideal for fast fluctuations in load. The cost of these electrolyzers is an important concern. Because of the utilization of noble catalysts (Pt, Ir, Ru) and the need for titanium-based bipolar plates, present expenditure costs are close to $2500/kW. Cost reductions are possible in the years to come by using other materials, improving stack productivity, and maximizing the influence of technology being built up industrially.
In extremely hot solid oxide electrolyzers, the electrolyte is either ceramic or solid oxide (solid oxide electrolysis cell, SOEC) made up of O2- conducting yttria-stabilized zinc in liquid water. Since electrical power supplies just a part of the enthalpy needed for water to break down, this cell's electric performance can exceed 100%.

Hydrogen Storage Tanks

The hydrogen generated by the electrolyzer could be stored as a gas at elevated pressures in the hydrogen storage reservoir. The gaseous state has the benefits of simple mobility, high inactivity, and a small facilities impact, in addition to the further advantage of massive, inexpensive storage. A container with an interior space of about 12 m3 is required to store a kilogram of hydrogen at 100 kPa and 25 °C. After hydrogen is compressed to pressures of up to 350 bar [47], the required volume for storage falls by 99.6%. Pressure increases storage volume whereas boosting compression work and safety issues. To save compression power, a buffering tank can be placed after the electrolyzer, and compression may start as the reservoir has been charged completely [47]. Pressurized hydrogen can be stored in sealed tanks with massive densities ranging from 20 to 50 kg/m3. The abundance and intermittent fluctuation of renewable energy sources, together with the level of system independence, decide on the dimension of a long-lasting hydrogen storage reservoir.
Hydrogen can also be kept in a liquid state at very low temperatures; nevertheless, liquefying hydrogen may demand up to 40% of its total amount of energy [47]. Liquid hydrogen is in frequent use in usages that need excessive purity, including the manufacturing of semiconductors, or in uses that need significant storage size, such as the aerospace sector.

Fuel Cells

Fuel cell (FC) technologies are classified into three types based on the fuel and electrolyte used.

- AFC (alkaline) .
- PAFC (phosphoric acid) .
- SOFC (solid oxide) (SOFC).
- carbonate molten (MCFC).
- membrane for proton exchange (PEMFC).
- methanol (direct) (DMFC).

The PEMFC type fuel cell is considered in this study. Polymer electrolyte membranes are used in these fuel cells to conduct protons for ion exchange. PEMFC uses hydrogen in the anode chamber, where it is oxidized, while reducing oxygen in the cathode chamber. The cell reaction is as follows:

Cathode: $O^2 + 4H+ + 4é$
Anode: $2H^2 + 4H+ + 4é$

In total, $2H^2 + O^2 = 2H^2O$

The chemical process in the fuel cell produces water, electricity, and heat as side products. In these cells, the catalyst generally consists of platinum nano-particles that are gently painted over carbon-based paper. The catalyst is hard and permeable in order to let out a large portion of the platinum's coating as possible to hydrogen and oxygen. These fuel cells function at cold temperatures of 60 to 100 °C and have electrical productivity of 40 to 65% [48]. Catalyst advancement at an affordable rate played a major role in lowering whole fuel cell expenditures (for example, the quantity of platinum used in PEMFC dropped by 10-100% [50]), and prices will likely decline much more quickly [51] supplied from an extremely high-temperature heating element. Continuous operating is preferred for such electrolyzers as ceramics can be thermally stressed, limiting their suitability for P2H uses since this adaptable manner of working necessitates multiple start-up and interruption cycles.

3. SPECIFICATIONS OF OVERALL SYSTEM ELEMENTS

Whenever HOMER is used for dimensions optimization, the mathematical models of electrical system parts are necessary to assess outcomes within different situations. In the subsequent sub-sections, the electrical system's elements are mathematically represented and their characteristics are provided. This part describes the settings that are required for every one of the network's elements that must be entered into HOMER Pro. PV panels, battery bank, converters, wind sources, gasoline source, fuel cell, electrolyzer, and hydrogen reservoir sizing were all optimized using these input parameters.

Photovoltaic Array

The PV panels can produce an amount of electricity as:

$$P_{PV} = Y_{PV} * x_{PV} * \frac{G_T}{G_{T,STC}} * [1 + \alpha_P * (T_c - T_{c,STC})] \quad (2)$$

Where

x_{PV}: the power lowering coefficient of the PV panel (%) .

YPV : the manufacturer's output power of the PV panel (kW) .

GT : the radiation from the sun onto the PV panel in the present iteration (kW/m2).

$G_{T,STC}$: the radiation from the sun at standard test conditions (1 kW/m2) .

α_P: the temperature coefficient of power (%/°C) .

Tc : the PV cell temperature in the current time step(°C) .

$T_{c,STC}$: the PV cell temperature under standard test conditions (25 °C).

Because the nominal power considers both of these attributes, HOMER Pro does not include the dimensions or the productivity of the solar panel. The lowering coefficient is an adjustment employed to compensate for cable power losses, deposits on the PV panels, and everything as well which might lead the panel's production to vary from the desired value at the rated situations.

The highest output value that is defined as the voltage level where the photovoltaic panels generate the highest amount of power is calculated using radiation from the sun and temperature. A maximum power point tracker (MPPT) is a semiconductor chip installed to link the PV panels and the remaining system's DC parts to separate the array voltage and ensure that it matches the highest possible energy output level. HOMER Pro essentially supposes the existence of an MPPT in the structure while ignoring the effect of the voltage on the PV panels [48]. PV cell temperature refers to the temperature of the PV cells. HOMER Pro approximates the cell temperature iteratively and employs it to get the PV panel's output electricity [49].

A Typical flat-plate PV array was utilized. Table 1 presents the cost and power parameters of the array that are input to HOMER.

Table 1 HOMER Input Parameters for PV Arrays

Parameter	Value	References
Initial Expenditures ($/kW)	1200	[50]
O&M Expenditures ($/kW/year)	10	[50]
substitution Expenditures ($/kW)	1200	Approximated
lifespan (years)	25	[50]
Productivity (%)	15.5	[50]
Lowering Coefficient (%)	88	Default Settings
Highest Production (kW)	224	Default Settings

Storage Pack

A Storage (battery) pack consists of a gathering of single battery elements. An individual battery is modeled by HOMER Pro as an item that can preserve a particular quantity of DC electricity given a set round-trip energy efficiency (RTE), with limitations on the rate at which it can be charged or discharged, the extent to which it can be discharged without harming it, as well as how many times one can cycle through it prior to being in need to be changed.

The extra electricity produced by renewables and/or else by a gasoline source is used to power the storage pack, at the same time as power demands are satisfied by either a storage pack or a gasoline source. Equation (3) [51] is employed to determine a battery's level of charge as this is being charged.

Table 2 illustrates the storage's requirements.

$$E_b(t+1) = E_b(t) * (1-\sigma) + \left(E_g(t) - \frac{E_l(t)}{\eta_{inv}}\right) * \eta_{BC} \quad (3)$$

In the discharge stage, yet, the battery level of charge may be calculated using Equation (4) [51].

$$E_b(t+1) = E_b(t) * (1-\sigma) + \left(\frac{E_l(t)}{\eta_{inv}} - E_g(t)\right) / \eta_{BD} . \quad (4)$$

The battery level of charge Eb(t) on an hourly basis (t) is bounded by a lower and an upper storing capability limits, *Ebmin* and *Ebmax*, as defined in (5).

$$If\ Ebmin \leq Eb(t) \leq Ebmax \quad Ebmin = (1 - DOD) * Ebmax \quad (5)$$

Here:
DOD: Depth of discharge
η_{inv}: Efficiency of the inverter
η_{BC}: Storage charge efficiency
η_{BD}: Storage discharge efficiency
σ: Battery's self-discharge (not considered in this research)
E_g : Produced electricity
$E_l(t)$: Demand at the hour t

Table 2 Parameters of Storage Pack

Parameter	Value	References
Initial Expenditures ($/kWh)	350	[52]
O&M Expenditures ($/kWh/year)	10	[52]
Substitution Expenditures ($/kW)	350	Approximated
Lifespan (years)	15	Default Settings
RTE (%)	90	[52]

Bidirectional Converter

The two-way converter regulates the flow of electricity in both directions (between the AC and DC bus lines). The major role of the converter is to deliver energy from DC supplies to the load. The highest possible energy consumption of the network determines the dimension of the converter [53]. The capital and substitution expenses of the converter are constant and are at $115/KW. The converter has 95% productivity and a 15-year lifespan.

Wind Turbine

Wind turbines (WT) are an inexpensive accessible resource of renewable power which can be exploited to produce electrical energy through the transformation of energy from motion into electrical power. This form of energy is more productive in places with strong winds, such as Algeria's southern regions.

The HOMER program determines wind turbine output of electricity using information on wind speeds at the hub height and the wind turbine power curve provided by the company that makes it. For this reason, a WES 80 KW wind turbine was chosen. Investment and replacement expenses, as well as maintenance and operation expenses, for the WT are $1700/KW and $15/kW/year, respectively. The selected WT has a lifespan of 20 years and a hub height of 30 meters.

Table 3 The selected Wind source parameters

Specification	Value	Source
Initial Expenditures ($)	1700	[53]
O&M Expenditures ($/op.hr)	15	[53]
Substitution Expenditures ($)	1700	Approximated
Hub Elevation (m)	30	Approximated
Lifespan (year)	20	Approximated

Diesel Generator

The generator produces electricity by burning fuel, but it also induces heat that might be deployed in Combined Heat and Power (CHP) usage. The main mechanical features of the gasoline-based source are its lowest and highest electricity production, a predicted lifespan in hours of usage, gasoline kind and pattern that link the value of used gasoline to the total produced electricity value. HOMER Pro estimates the source's gasoline usage level F as follows, assuming the gasoline pattern is modeled as a straight line that intersects with the y-axis:

$$F = F_0 * Y_{gen} + F_1 * P_{gen} \quad (6)$$

Here
F: the slope of gasoline graph
F0: the gasoline graph point of intersection with the y-axis
P_{gen}: The source produced electricity (kW)
Ygen: the manufacturer's indicated production of the source (kW)

Table 2 Gasoline Generator input parameters

Specification	Value	References
Initial Expenditures ($)	500	[49]
O&M Expenditures ($/op.hr)	0.030	[49]
Substitution Expenditures ($)	500	Approximated
Lowest demand rate (%)	25	Default Settings
Lifespan (h)	60000	Approximated

The rated prices of Gasoline in Algeria are set at 0.19 $/L for the time being and are expected to rise to 0.65 $/L by the year 2030 [49].

Electrolyzer

An electrolyzer generates hydrogen through water electrolysis using electricity. The consumer sets the greatest electrical supply

of the electrolyzer that turns out to be an adjustable attribute in HOMER Pro. The user additionally sets the possibility that the electrolyzer operates on alternating current or direct current, along with the productivity at which the electrical power is transformed into hydrogen. The productivity of an electrolyzer is defined by HOMER Pro as the quantity of electrical power in the hydrogen produced (depending on a larger temperature setting) over the quantity of electrical energy utilized.
Because of its advanced technological capabilities and adequate performance under different loads, a polymer electrolyte membrane (PEM) kind electrolyzer shall be studied. The parameters of the considered electrolyzer are presented in Table 5.

Table 3 Parameters of the Electrolyzer

Specification	Value	References
Initial expenditures ($/kgH$_2$)	1500	[44]
O&M Expenditures ($/kgH$_2$)	10	[45]
Substitution Expenditures ($/kW)	1500	Approximated
Lifespan (years)	20	[46]

Reservoir for hydrogen capture

The hydrogen reservoir preserves the hydrogen generated by the electrolyzer for future utilization in a hydrogen-fueled generator or fuel cell. The volume of the hydrogen reservoir, which acts as a factor in the decision-making process is determined by the user. HOMER Pro supposes that the operation of introducing hydrogen to the reservoir does not need power and that there is no tank loss. The consumer can set the starting quantity of hydrogen in the reservoir as a fraction of the tank's dimensions or as a single value in kilos. Additionally, the consumer may propose that the quantity in the tank at the end of the process matches or surpasses the reservoir level at the start of the year. The present research takes into account the storage of hydrogen in the form of a dense gas in long-term reservoirs. The specifications of the considered reservoir are detailed in Table 6.

Table 4 Parameters of Hydrogen Capture resevoir

Specification	Value	References
Initial Expenditures ($/kgH$_2$)	500	[44]
O&M Expenditures ($/kgH$_2$)	0	[45]
Substitution Expenditures ($/kW)	500	Approximated
Lifespan (years)	25	[46]

Fuel Cells

Fuel Cell structures have proved to be incredibly pollutant-free as they produce no contaminants besides being highly effective. The principal energizing material for fuel cell structures is hydrogen. The electrical power preserved in hydrogen fuel is immediately transformed into electricity owing to the action of an oxidant, which could be Oxygen in the air. Due to its reliable operation under an imbalanced hydrogen production, the proton exchange membrane fuel cell (PEMFC) was selected for the purposes of this research. The maximum electricity output of the fuel cell is defined as a setting parameter in HOMER Pro. The proton exchange membrane fuel cell (PEMFC) is extensively deployed in industrialized processes and has a rapid real-time reaction [26]. Table 7 lists the input specifications for the fuel cell.

Table 5 Input Parameters of Fuel Cell

Specification	Value	References
Kind	PEMFC	Considered
Initial Expenditures($/kW)	2000	[44]
O&M Expenditures ($/kW/op.hr)	0.010	[46]
Substitution Expenditures ($/kW)	2000	Approximated
Productivity (%) at manufacturer's settings	50	[46]
Lifespan (h)	30000	[46]

Management Scheme

A distribution management plan is a collection of regulations that adjust how the structure's elements operate. HOMER Pro is capable of simulating two management plans: cycle charging and load following. Whichever technique is best relies on a variety of criteria, namely the dimensions of the sources and storage pack, gasoline cost, the expenditures in the source functioning and preservation, the percentage of electricity from renewables over the structure, and the nature of the deployed renewables. The consumer can adopt both strategies, and HOMER Pro will execute both dispatch algorithms, which permits to determine the ideal one.
When a generator is required under the load following approach, it generates just sufficient electricity to fulfill the principal demand. Less-concern goals, such as feeding the battery pack or providing deferred demand, constitute the role of renewable energy

supplies. Load following is best in structures having diverse renewable sources, since the electricity from renewables occasionally surpasses the demand.

As for the cycle charging strategy, when a gasoline source needs to run to satisfy the main demand, it does so at complete capability. Excess electricity is sent to lower-priority goals, such as satisfying the deferred demand, feeding the battery pack, and feeding the electrolyzer, in order of decreasing importance. In structures having a few or no renewables, cycle charging is usually the best option.

When determining demand importance, HOMER Pro sets a collection of rules about the manner to assign the power generated by the structure. Adding an AC bus and a DC bus makes these considerations slightly more involved. HOMER Pro works under the assumption that the electricity generated at any bus should initially satisfy the main demand at that bus, before the main demand at the other bus. Next, it serves delayed demand at the same bus, and after that, delayed demand on the other bus. Afterwards, it proceeds to charging the storage pack, then the electrolyzer, and finally dumps the demand that might occasionally feed the thermal load.

4. RESULTS AND DISCUSSIONS

Problem Specifications

Adrar is an Algerian region in the country's southwest Sahara geographical area. Figure 1 depicts Adrar's position. This region has important oil and gas planting sites. The NASA repository (from 1983 to 2005) is employed by HOMER to derive required environmental data for Adrar. The per-hour statistics on surrounding temperature and wind speed, with the mean monthly clearness measure and radiation from the sun, are shown in Figures 3, 4, and 5.

Fig. 1 Adrar's position within the Algerian map

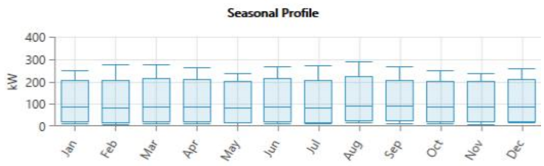

Fig. 2 Typical annual demand in Adrar region

CDER (Renewable Energy Development Center) specified a load information set for an Adrar drilling base with an average per day AC load of 2426.45kWh and a maximum load of 405.71 kW. Figure 2 depicts the load pattern. The consumption in general is greater during the Summer time of June to September, with August having the highest mean load and January experiencing the lowest typical load.

The data concerning wind velocity recordings in the considered area are got from NASA Surface Meteorology and are graphically summarized in Figure 3. The mean annual Wind velocity is: 6.35 (m/s).

Fig. 3 Annual Wind Speed in Adrar

Figure 4 additionally presents the clarity measure, which gauges the percentage of sunlight that escapes the earth's atmosphere and hits the ground. It exhibits an elevated level when it is warm and sunny and the lowest value when it is cloudy. The average solar scaled value is 5.78 (kWh/m^2/day).

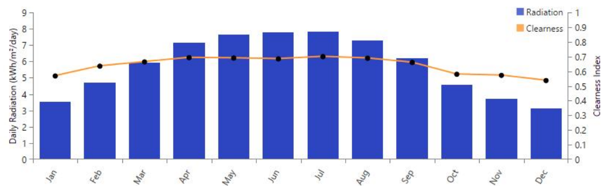

Fig. 4 Annual resources in terms of Solar Irradiance in Adrar

As shown in Figure 5, the temperature information is given in NASA's Surface Meteorology and Solar Energy database where the mean temperature is 24.78 (°C).

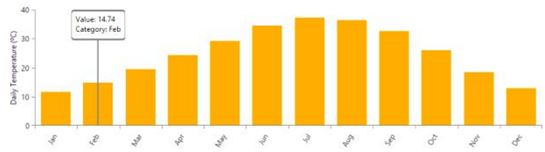

Fig. 5 Annually recorded Temperature values in Adrar

Configuration of the simulated Microgrid

Photovoltaic (PV) elements, a lithium-ion electrically energized storage pack, a wind turbine, a gasoline source, and power to-hydrogen system (P2H) which consists of an electrolyzer, a hydrogen capture reservoir, and a fuel cell are all part of the microgrid structure considered here. Figure 6 illustrates the arrangement of components.

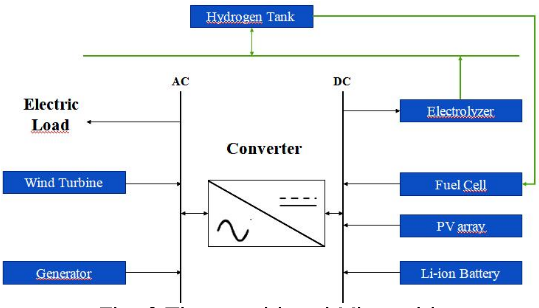

Fig. 6 The considered Microgrid

Two possible situations for autonomous microgrid deployment are planned for the present research, each with a distinct setup. The power equilibrium, costs, and harmful pollutant release levels of these cases were compared throughout a 20-year project lifespan using HOMER Pro to identify the largely effective blend of electrical power technological developments that meet the demand for electricity.

Situation 1: HRES with no hydrogen technology.

Situation 2: HRES including Electricity to Hydrogen conversion.

Optimization outcomes for both situations

Tables 8 and 9 present the optimization outcomes for situations 1 and 2, respectively following on the input specifications. It turns out that the arrangement DG/PV/WT/LI exhibits the smallest NPC for situation 1 and the combination DG/PV/WT/HS posses the lowest NPC for situation 2.

1. *Numerical outcomes of Situation 1*

Table 8 Performance results for situation 1

Option	NPC (M$)	COE($)	OC ($/y)	ICC($)	RF%
DG/PV/WT/LI	0.675	0.0658	22466	41446	81.9
DG/PV/WT	1.01	0.0986	53965	38658	63.5
DG/PV/LI	1.61	0.157	62402	88905	55.6
DG	2.64	0.258	208856	22500	0
DG/PV	2.65	0.259	208492	24053	0

2. *Optimization outcomes of Situation 2*

Table 9 Performance outcomes of Situation 2

Option	NPC (M$)	COE($)	OC ($/y)	ICC(M$)	RF%
DG/PV/WT/HS	1.21	0.118	9112	1.11	90.8
DG/PV/LI/WT/HS	1.23	0.120	14112	1.07	88.1
DG/PV/LI/HS	4.10	0.400	19136	3.88	92.6
DG/PV/HS	4.28	0.417	40375	3.81	80.5

Table 10 summarizes the comparative study between the best combinations for the two situations.

The second situation possesses the largest Net Present Cost throughout the project's 20-year lifespan. Likewise, it has the greatest carbon footprint owing to the use of diesel fuel for combustion. The first situation is, however, the most effective approach because it has the smallest Net Present Cost and the least releases.

Because its layout is centered around the use of wind turbines and a generator powered by diesel, the results in table 10 indicate that the most efficient approach is dependent on wind speed and the cost of fuel. These values are not stationary. To obtain the optimum dimension of the investigated microgrid, a sensitivity evaluation, which will be explained in the following section, should be done.

Sensitivity Analysis

In HOMER, it is possible to carry out many simulations and assesses the impact of each modification on inputs and outputs. This study uses the monthly average wind speed and fuel price as sensitive elements for power generation and economic impact.

A great percentage of the structure' cost incurred overall initial expenditures and price of electricity in Situation 2 for the Electrolyzer and the Fuel Cell. Hence, a sensitivity investigation about the effect each element's initial expenditure having on the overall structure's net present value and the Levelized cost of energy (LCOE) is much needed.

The outcomes of the sensitivity investigation changes the optimal solution for the system according to the two variables considered earlier. When the fuel price increases, the system is based on renewable energy sources (Wind turbine), and the DG will be the infeasible solution. Therefore the HS will be used since it has a storage tank and is based on a wind electrolyzer to work as a backup system. This Consideration gives three results, as shown in Table 11.

Table 10 Comparative study of the best systems in both situations

		Situation 1	Situation 2
System Component	Solar PV capacity (kW)	X	X
	DG1 capacity (kW)	450	450
	Li-ion storage rate (kWh)	2x100	X
	Fuel cell power (kW)	X	250
	Electrolyzer power (kW)	X	100
	H_2 reservoir dimension (kg)	X	1000
	Converter capacity (kW)	152	114
	Total Net Present Cost ($)	674628	1.21M
Economics	Cost of Energy (20years)($/kWh)	0.0658	0.118
	Initial Capital Cost ($)	414464	1.11M
	Operational Cost($/yr)	0.166935	0.015775
	Renewable Energy Fraction (%)	81.9	86.0
	Capacity shortage (kWh/yr)	0.02	0.02
	Capacity shortage (%)	0.02	0.02
Electrical	Excess electricity (kWh/yr)	7608465	9739868
	Excess electricity (%)	89.4	86.0
	Dispatch strategy	CC	CC
	Total electricity production (kWh/yr)	8507096	11319982
Diesel	DG1operating (hours/yr)	853	1004
	Fuel cell operating (hours/yr)	X	2,127
Fuel Cell and Electrolyzer	Fuel cell capital cost ($)	X	2000
	Fuel cell H_2 fuel (kg)	X	13,975
	Electrolyzer Capital Cost ($)	X	$150,000.00
H_2 storage tank	H_2 tank autonomy (hr)	X	330
Battery	Battery autonomy (hr)	1.58	X
	Battery usable capacity (kWh)	160	X

Table 11 Sensitivity Analysis on Fuel Prices and Wind Speed

Fuel Price ($/L)	Wind Speed (m/s)	Optimal Configuration
0.19	6	DG/PV/LI/WT
	6.35	DG/PV/LI/WT
	6.7	DG/PV/LI/WT/HS
0.65	6	DG/PV/LI/WT/HS
	6.35	DG/LI/WT/HS
	6.7	DG/LI/WT/HS
1	6	PV/LI/WT/HS
	6.35	LI/WT/HS
	6.7	LI/WT/HS

5. CONCLUSIONS

The goal of this research has been to utilize a combined PV/diesel system alongside batteries to create economical structures that reduce the production of greenhouse gases in comparison to autonomous gasoline equipment. A combined PV/diesel structure has enormous promise and deserves to be improved upon for application as electricity generation for remote loads or communities. The generation of hydrogen from alternative sources of energy might represent a potential answer to long-term electricity storage, providing a form of energy with a wide range of applications and outstanding ecological features. Hydrogen, especially, can be converted into synthetic methane employing carbon dioxide from anaerobic digester facilities, which is then pumped into pipelines that carry natural gas and used in heating and fuel cell automobile uses with practically no greenhouse gas emissions. Based on the findings and conclusions, expanding the production of electricity from renewable sources could make it possible for the replacement of fossil fuel-intensive energy sources while substantially lowering greenhouse gas releases. Energy from renewable sources develops steady prices for electricity as well as employment and financial advantages. The control approaches employed in mixed systems are determined by the research's objectives. The majority of investigators concentrate on the combination of renewable energy system techno-economic targets since that kind of research ensures the technical advantages (a rise in lifespan, meeting demand, boost effectiveness) while minimizing financial consequences (reducing structure expenditure, enhancing saving expenses, lowering electricity cost).

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