An Economic and Environmental Study of a Hybrid System (Wind and Diesel) in the Algerian Desert Region using HOMER Software

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ABSTRACT

This paper presents a new of economic and environmental study of a hybrid system (wind turbine and diesel generator) in Algerian desert regions using HOMER software. The principal interests of the hybrid system are clean production at the place of consumption, the combined use of resources, energy storage, and supply security. Using an experimental device outfitted with Homer software, models were developed and successfully compared to reality. The obtained results confirm that the proposed system proved to be accurate enough to distinguish energy transfers and fast enough to enable optimizing the sizing and handling of the system's energy transfers. The purpose of this paper is to confirm the robustness of the HOMER software and to check the technical, economic, and environmental criteria of the integrated system.

Keywords-HOMER (Hybrid Optimization of Multiple Energy Resources); Wind Turbine (WT); Diesel Generator (DG); hybrid system (wind-diesel); economic environemental analysis; Cost of Energy (COE)

I. INTRODUCTION

Algeria wants to play a role in the energy transition in Africa and its energy sector development is at a critical stage. The country is noteworthy for its relative size, wealth, location, gas reserves, renewable energy potential, and greenhouse gas emissions [1-4]. Knowing the disposition of the hybrid systems integrated with renewable energy their contribution on the economic and environmental sides is to compensate the diesel generators in the isolated areas. In recognition of these environmental and economic advantages, several studies have been carried out in this field. Among the most important of these programs is HOMER [5]. In [6], the analysis of a Wind Turbine (WT) and Diesel Generator (DG) hybrid system was conducted on the economic and environmental sides with HOMER by analyzing the Cost Of Energy (COE) and the quantity of CO_2 associated with this system when it works with the DG only and when it works in its general form. The comparison of COE produced for various cases of operation was used to prove the role of the storage systems. An open topic is the efficiency of the hybrid system to supply an independent electricity network in isolated areas and to provide all the conditions and requirements of the main electricity networks (quality - protection) to compensate for the use of standalone DGs. In these regions, the cost of delivering large production units, the cost of fuel, the difficulty to obtain it, and environmental risks are major setbacks [7-12]. From an economic and environmental standpoint, authors in [13] investigated the costs of electric energy when the system was only powered by DGs and the quantity of CO_2 associated in both cases with HOMER for the electrical installation with a continuous and variable load throughout the year as wind speed changed [13].

Quite recently, considerable attention has been paid to the optimization of hybrid renewable energy systems for off-grid rural electrification [14]. To solve this issue, many researchers have proposed similar methods of optimization in different countries, such as Chad [15] and Côte d'Ivoire [16]. The techno-economic assessment of a 100kW solar rooftop PV system for five hospitals in central and southern Thailand was studied in [17]. It is critical to provide an energy supply that can deliver uninterrupted electric power to meet the load demand as a hybrid system (WT and DG), as has been studied using WT models in different comparative models of wind characteristics between south-western and south-eastern Thailand [18].

Based on the approach presented in the literature, the purpose of this paper is to establish rules and tools for optimizing energy management and the sizing of a WT and DG, coupled to the network, and equipped with an electrochemical storage device. The optimizations will be carried out based on consumption and production deposit data. The optimization criterion will be economic with a view to minimizing the total COE of the system, from its installation to its use over a long period.

II. A REVIEW OF POWER IN ALGERIAN DESERT

The Algerian desert contains several regions in the south that rely in unconnected to the national transport network DGs for the provision of electric power [1]. Algerian isolated desert areas contain climate-convenient locations of renewable energy sources, particularly solar energy, and, to a lesser extent, wind energy (Table I). Figure 1 presents the seasonal variations in the amount of solar energy in the Algerian Sahara. Hybrid systems integrate renewable energy sources. They are being exploited in the Algerian Sahara, where hybrid compact energies and renewable desert areas are isolated. Figure 3 depicts some of the processes involved in the development of hybrid systems that combine renewable energies, i.e. solar and DG, wind and DG, and storage systems.

TABLE I. CHANGES IN WIND SPEED IN SOME ALGERIAN DESERT AREAS

Region	Wind speed (m/s)
Adrar	7
Tindouf	6
Tamanrast	5
Djelfa	4
Ghardaia	3

(a)

(b)

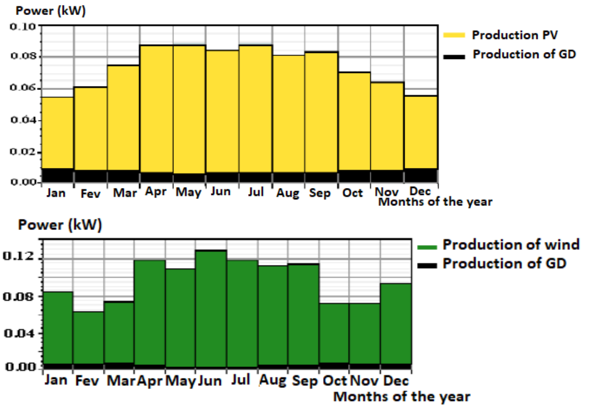


Fig. 1. Yearly produced power from the system: (a) PV and GD, (b) WT and DG.

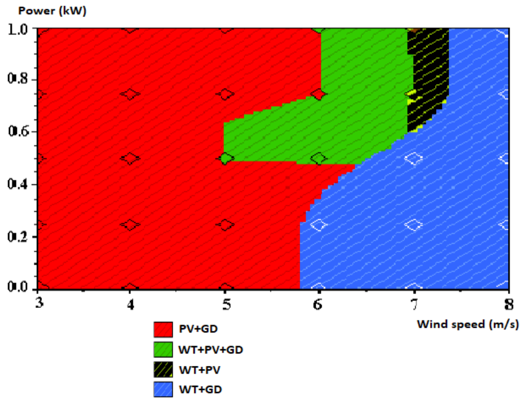


Fig. 2. Produced power from various system resources to feed the network in desert areas in Algeria.

The system uses wind energy for the most part of the year due to its better performance compared to the other renewable energy sources (Figure 3). Other hybrid systems involved in feeding the network in these areas include the solar (PV) and DG systems in Tamanrasset, Tindouf, and Djelfa. Several isolated areas in Algeria are located in the desert. The majority of these areas rely on DGs to provide electrical power rather than utilizing hybrid systems that integrate renewable energies. Despite their high climatic efficiency, these regions use solar and private pneumatic energy to a lesser extent. So, Algeria's use of hybrid compact renewable energy systems is limited. Through this study, the effectiveness of hybrid systems for integrating renewable energy with environmental and economic advantages will be demonstrated in order to encourage its integration in the grid, especially in the isolated desert regions of the country. Hybrid system utilization and optimization are required in order to compensate the use of

DGs in the supply of electric power while maintaining the economic, environmental, and performance quality of these technologies [1].

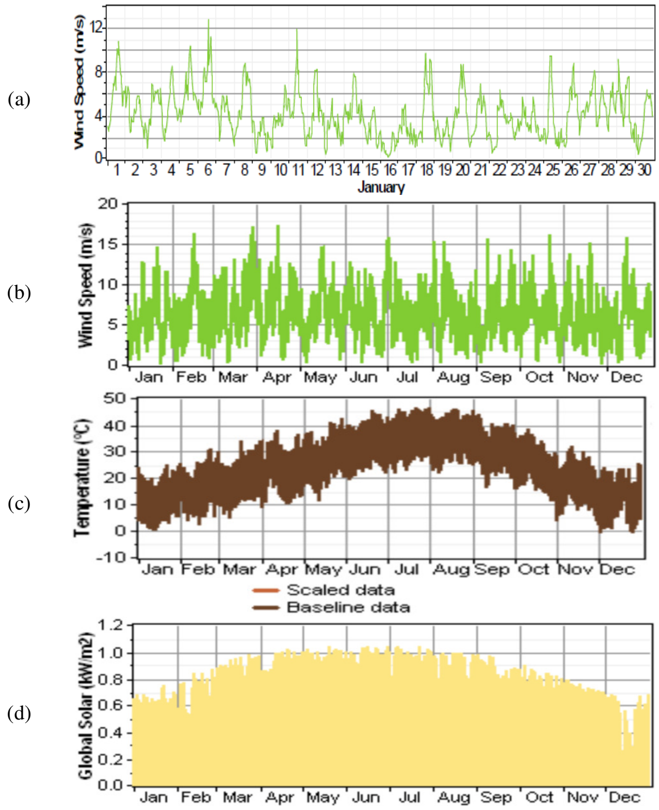


Fig. 3. Seasonal variations of the amount of renewable energy in the Algerian Sahara: (a) Wind speed in Tindouf, (b) wind speed in Adrar, (c) temperature changes in Adrar, (d) solar energy in Adrar.

III. ECONOMIC AND ENVIRONMENTAL ANALYSIS OF THE WIND TURBINE AND DIESEL GENERATOR HYBRID SYSTEM

A. HOMER Software Overview

HOMER (Hybrid Optimization of Multiple Energy Resources) is optimization and simulation software for the study of the production of multi-source energy (PV, wind, network, storage, diesel, etc.). It is mainly intended for mini-network simulation, whether connected or unconnected (off-grid). The main features of this tool are:

- Supports hourly load profiles as well as controllable loads.
- It is able to simulate the behavior of many pieces of production equipment (PV, wind, hydro, biomass generator, diesel, vegetable oil) or storage equipment (electrochemical, flywheel, fuel cells).
- Economic optimization of production systems by comparison of different configurations and architectures.
- Sensitivity analysis with respect to certain input parameters (oil prices, lifetime of the modules, solar radiation, load).
- The user receives the architecture and economic configuration based on HOMER's modeling. It is an aid to decision-making for the design of a mini-network.

B. Basic Standards of Economic Analysis in HOMER

All studies conducted to determine the economic dimensions of a specific installation focus on achieving the lowest possible cost while meeting the requirements (load). A very important factor is the COE which summarizes the standards of economic analysis on HOMER and is subject to the amount of energy produced and the amount of energy consumed at the time. HOMER determines the COE as the average cost of electrical energy produced for 1kWh and sets its value to a cost per kilowatt-hour per dollar ($/kWh).

C. Description of the Electrical Installation Studied on HOMER

Figure 4 shows an electrical installation studied on HOMER including a type AOC 15/50 WT with a power of 65kW and 2 DGs with power of 150kW and 75kW, respectively. The AC power and the variable load equipment operate variably throughout the year at a rate of 4.9MWh/day, with the storage battery type S4KS25P having an estimated capacity of 1900Ah.

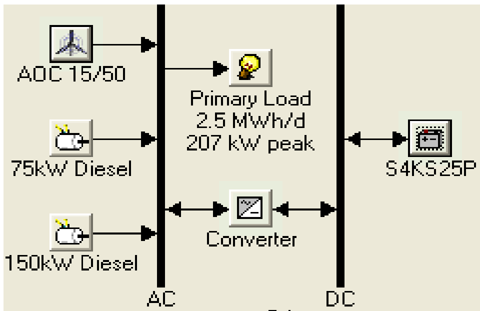


Fig. 4. The electrical installation to be studied on HOMER.

D. Load Variations

The variation of the load of the installation using HOMER is shown in Figure 5. The DMAP is a diagram that shows the time distribution for the variables of each hour during the day of the year using tinted rectangles depending on the value of this variable at that time, as shown in Figure 6. The DMAP is a diagram that depicts the breakdown for the variable at each hour of the year. The wind speed changes for the installation study, in which the property of the power produced by the AOC 15/50 WT is used in terms of wind speed, are shown in Figure 7.

IV. SIMULATION RESULTS

A. Produced Power by the System throughout the Year

Figure 8 depicts the contribution of the WT to the electrical energy produced by the system, as it effectively compensates for the GDs most of the year, thus reducing the quantity of fuel used, which leads to a reduction in the cost of electrical energy and gas emissions, as shown in Tables II-IV.

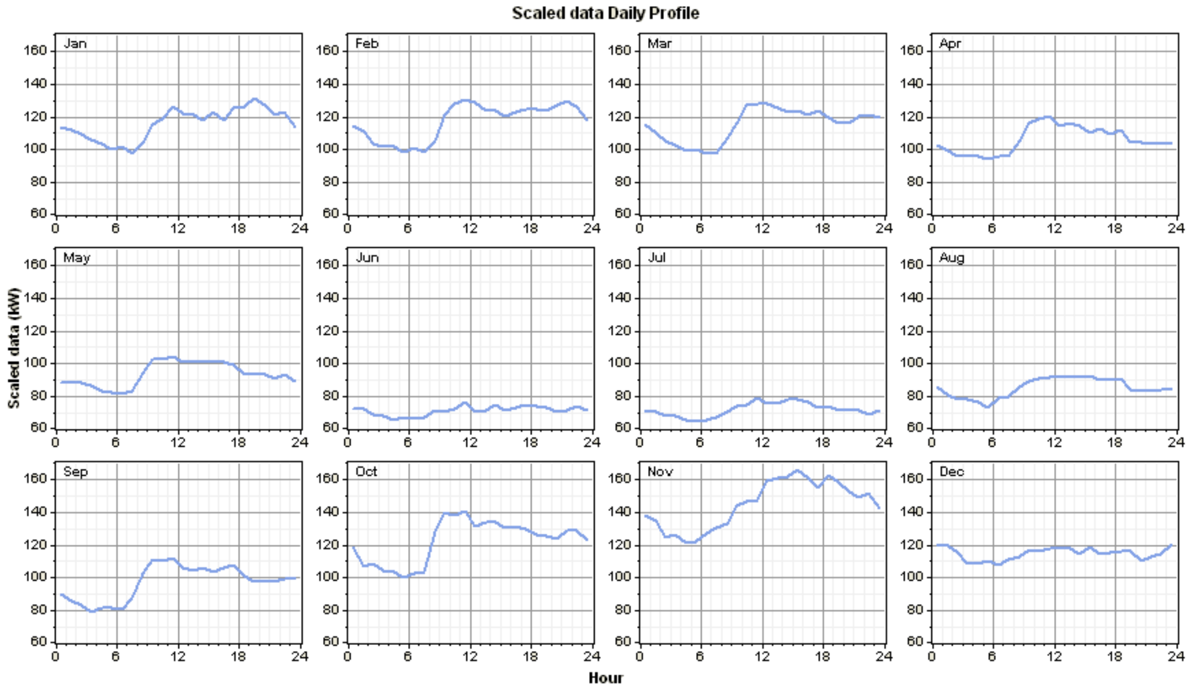
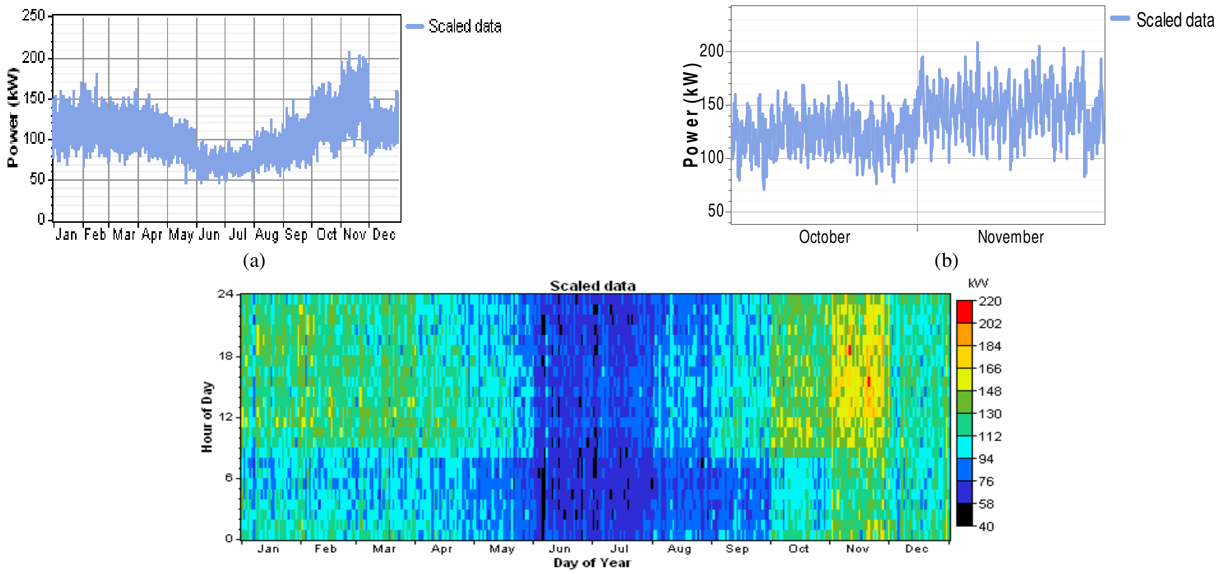


Fig. 5. Daily load changes.



(a) (b) (c)

Load variations: (a) Annual variations, (a) Load changes during October and November, (a) DMAP to load variations.

B. Economic Analysis

Table II shows the cost of the power produced and the quantity of fuel used for the hybrid system in various operating scenarios as calculated by the HOMER program. According to Table II, the significant difference occurs when the system is integrated with the WT (WT and two DGs) and is such that the cost of electrical energy in this case is up to 0.217$/kWh with 131.527L fuel used and a total of 356,700.6kg/year gas emissions compared to their operation by DGs only. The cost of gas emissions increased in this case to 0.273$/kWh at 282.154L of fuel used per year, totaling 763.035kg.

TABLE II. ECONOMIC ANALYSIS

Coefficients / Case study	COE ($/kWh)	Diesel (L)
Two DGs, WT, Battery, Inverter	0.201	134.635
Two DGs and WT	0.217	131.527
Two DGs, WT, and Inverter	0.269	274.608
Two DGs	0.273	282.154

C. Environmental Analysis

Table III shows the amount of gases produced by the system over a year for various operating scenarios. The summary of the total gas emissions is given in Table IV, showing the importance of the storage system in all operation cases. When the system runs by the DG and the storage system, the cost of electric energy is up to 0.269$/kwh with 274.608L fuel used and 742857kg/year gaseous emissions.

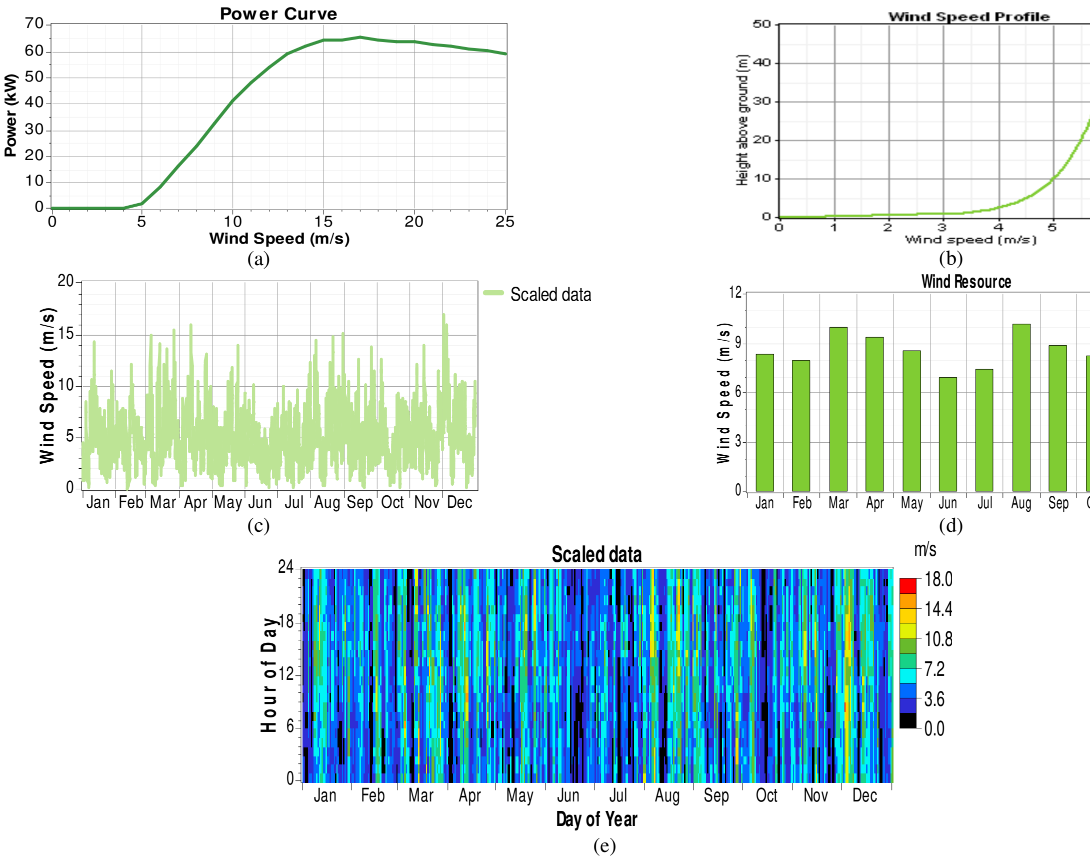


Fig. 6. Characteristics of the wind turbine: (a) Property of the power for the wind turbine used, (b) wind speed according to the height of the turbine used, (c) changes in wind speed during the year, (d) average wind speed during the year, (e) DMAP for wind speed changes.

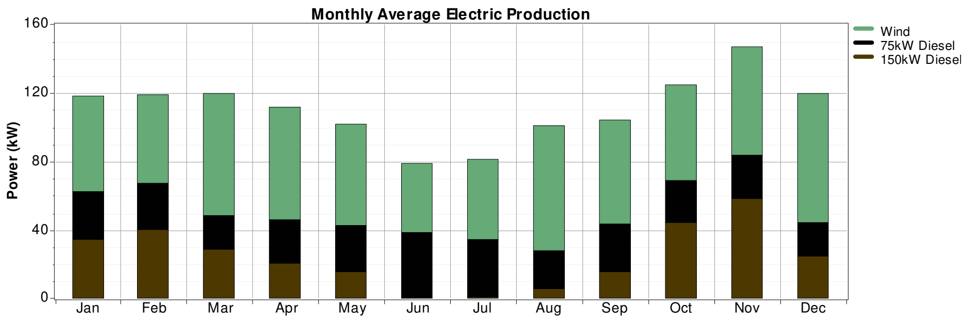


Fig. 7. Power produced by the system during the year. Environmental rating analysis.

TABLE III. ECONOMIC ANALYSIS

Case study \ Gas generated (Kg / year)	CO_2	CO	Unburned hydrocarbons	Particulate matter	SO_2	Nitrogen oxides
Two DGs, WT, Battery, Inverter	356.011	879	97.3	66.2	715	7.841
Two DGs and WT	347.336	857	95	64.6	698	7.650
Two DGs, WT, and Inverter	723.354	1.785	198	135	1.453	15.932
Two DGs	743.003	1.834	203	138	1.492	16.365

TABLE IV. TOTAL GAS EMISSIONS

Case study of the system	Total gaz emissions (kg/year)
Two DGs, WT, Battery, Inverter	365599.5
Two DGs and WT	356700.6
Two DGs, WT, and Inverter	742857
Two DGs	763035

V. CONCLUSION

This paper analyzes the economic and environmental impacts of hybrid distributed generation (wind turbines and diesel generators) in the Algerian desert region. The dynamic models for the main system components were developed in HOMER software (Hybrid Optimization of Multiple Energy Resources). The overall energy management strategy for coordinating the power flows among the different energy sources is presented in terms of Cost Of Energy (COE). The simulation results show that the studied hybrid power system with renewable sources has lower operating costs. The economic and environmental reasons and the technical challenges of connecting the hybrid system units in the Algerian desert region are analyzed based on cost factors. The obtained results demonstrate the significant economic and environmental benefits of the hybrid system, ensuring the continuity of electrical energy production throughout the year with the flow of load changes and wind energy at the same time, and the importance of the battery storage system. From these results, this work can be completed using dynamic models for the system components, namely the PV energy conversion system, fuel cell, electrolyzer, power electronic interfacing circuits, battery, hydrogen storage tank, gas compressor, and gas pressure regulator, to exploit the best optimal hybrid system in the Algerian desert region.

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