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Homer's Feasibility Analysis of a Hybrid System with a Grid Connection Option for the Mauritanian Northern Coast

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Abstract

On Mauritania's northern coast, wind and solar resources are abundant and must be used effectively. These resources have the potential to completely or partially replace the existing or projected diesel generators. The main objective of this case study is to study the possibility of using a hybrid system (HS) of the type (diesel, wind and storage). The most important part of this case study intended for this area will be to add the solar in a first phase and then the incorporation of an interconnection with the nearby network in a second phase. This interconnection will be secured by mean of medium voltage lines of 33 kV, where the nearest point is located 35 km away. Indeed, the study of the optimization model is carried out through Homer, which was developed by National Renewable Energy Laboratory [NREL]. Thus, it should be noted that the HS is analyzed on the basis of costs ($/kW) and price ($/kWh) and greenhouse gas emissions. Therefore, in order to achieve these techno-economic optimization objectives, this paper introduces a sensitivity analysis that has been proposed to determine the effect of costs on each HS configuration. In the end, HSs are needed for maximum use of renewable resources at the studied site for an uninterrupted power supply.

Keywords

Homer, Feasibility Analysis, Hybrid System, Wind, Solar, Grid

1. Introduction

So far, electricity production has been based on the use of fossil fuels. For Mauritania, wind energy is abundant, mainly in the north. On the other hand, solar energy is particularly present throughout the Mauritanian territory. In addition, it should be noted that in Mauritania there is an abusive use of diesel generator as a primary and secondary source of energy in industries, institutions, malls and isolated communities [1]. Thus, this feasibility analysis by Homer of a HS seeks to set up a hybridization of electricity. But it is also an opportunity to find the most economical investment and with the lowest possible cost of the kWh. In addition, this use of diesel is accompanied by harmful emissions of greenhouse gases in a protected area such as the coast of Mauritania. Then the solution of the electricity production for the north Mauritanian coast can be done by the feasibility analysis by Homer of a HS with the possibility of connection to the power grid. The aim of the H S design is also to highlight the performance, flexibility of planning for uninterrupted energy supply as well as the environmental benefits [1] [2] [3] [4]. This is why, in addition to the integration of solar in this graph of HS that initially proposed, some procedures have been undertaken to add an interconnection to the nearest power grid. A number of case studies have been proposed by Homer in search of the most appropriate combination. In this regard, HS is considered the best option for areas where solar and wind power can be combined [4] [5] [6]. It is possible to add other measures that secure the continuity of electrical supply. Thus, the main objective of this study is initially to design of a HS (wind turbines, diesel with storage, off-grid). Then, in a second step, incorporate a solar component. Subsequently, a supplementary step is added, that of an interconnection with the existing network through a MT lines (33 KV), 35 km away from the site. All this is done as part of a research to meet the optimum energy needs of the villages and the existing infrastructures on the site. In addition, the HS offers an uninterrupted supply through the use of the Homer optimization model, developed by the National Renewable Energy Laboratory (NREL) [7].

2. Site Description and Components of the Hybrid System

2.1. Presentation of the Site

The locality of BLAWAKH (**Figure 1**) is located in the northern zone of the Mauritanian coast of the Atlantic Ocean, bordered by the city of Nouakchott from the south and Nouadhibou from the north (latitude 18.52˚ and longitude 16.07˚).

The population of this town is about 440 habitants. The town has a naval training center. The activity of the populations of this zone is exclusively dominated by the exploitation of the resources of the fishing. The main difficulties that face the inhabitant, due to the absence of electricity, are the lack of appropriate storage of their fishing products and the shortage of drinking water. Finally, the reasons for installing a hybrid power generation system are dictated by the use of existing resources on the site. It must be remembered that the site is protected and is fragile for its biodiversity.

2.2. Studied System

The electrical system studied is proposed as a departure for Ballawack which is descripted in Figure 1 and the configuration to equip the locality is mentioned in Figure 2.

Hybrid system: Power of a 100 kW wind turbine (4 wind turbines), with diesel emergency units (1500 turn/minute, 2 × 100 kW), with a 10 m^3 fuel storage tank. In addition, there is a storage system Li-Ion battery, whose power is aligned with the power capacity of the inverter (150 kW). In addition, it is proposed 4 wind turbines (the power of each wind turbine is 100 kW).

Medium Voltage (MV)/Low Voltage (LV) Networks: Whatever the configuration that will be proposed, the internal distribution in the village is carried out through pole transformers of 50 kVa (33 Kv/0.4kV). Among these transformers, a transformer for desalination and ice plants of 300 kVa (33 kV/0.4kV) is proposed.

Figure 1. Location of Ballawack (Latitude-18.519001, Longitude-16.0722400) [Source [1]: UNDP-GEF-TVIG-2005].

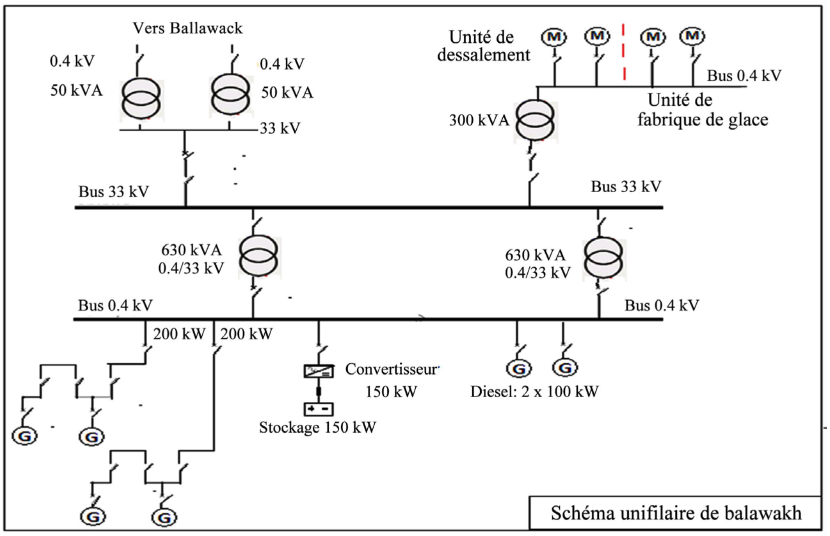


Figure 2. Diagram of the proposed system.

Low Voltage (LV) Networks: It should be noted first that the supply of locality, desalination and ice factory is carried out through the LV (three phase of 0.4 kV). The LV networks are offered in twisted 70 mm^2 aluminum cables, with 54.6 mm^2 almélec neutral conductors, with two 16 mm^2 (NF C 33-209) aluminum public lighting conductors laid on wooden poles. The LV networks are offered in twisted 70 mm^2 aluminum cables, with 54.6 mm^2 almélec neutral conductors, with two 16 mm^2 (NF C 33-209) aluminum public lighting conductors laid on wooden poles.

Desalting units: The reverse osmosis desalination units are each located in a container with an electrical power supply of 25 kW. They are fed through a 0.4 KV cable. In addition, reverse osmosis desalination units must produce 100 m^3/d. For a specific demand of 6 kWh/m^3, the salinity (TDS) of the well water is <40.000 mg/l with a temperature <25˚C. The quality of the produced water is <500 mg/l TDS. It is proposed an inlet pressure coming from well pumps of a value of 4 bar. It should also be noted the existence of a reservoir that plays the role of water storage, equivalent to the peak demand of 5 days. Not to mention, the presence of a water tower and a water distribution network in the locality.

Ice making (02 units): The total power of the two ice units is 70 kW (1st unit (ice plant size with 4 T/d, with an ice plant power of 17 kW) and 2nd unit (ice plant size (8T/d), with a power from the ice factory (50 kW)). It is also proposed for the evaporation temperature (−21˚C), with a maximum ambient temperature (35˚C), without forgetting a temperature of water (25˚C) and a Refrigerant (R404 A). Ice storage is carried out through a container with its own refrigerant circuit (container size (40 feet). The maximum ambient temperature is 35˚C. There is also a refrigerant type (R134 A). Not to mention the data that is: the storage capacity (16.00 T), the internal temperature (−5˚C), the electrical power of storage cooling (22 kW) and the ice density (0.55 T/m^3). All parts that touch the ice are made of stainless steel. The container is placed on concrete blocks.

How does HS works: the expected energy demand is partially secured by the wind system. With this in mind, steps are taken to minimize the use of diesel generators. Similarly, the electrical energy storage system will locally store excess energy from wind turbines and provide AC power in low or no wind periods, or when power demand is high. In addition, the capacity of the battery is used to improve the quality of the network and to give an appropriate energy control. The Bidirectional Converter must provide the following functions: Initialization of the network, operation of the bidirectional inverter (Operation at 50 Hz with ±5 Hz as operating range). The control of the inverter, so that the system appears as the source of the AC voltage with a low apparent internal impedance (in other words, as a "stable" voltage source). The control of the inverter, so that the system appears as the source of the AC voltage with a low apparent internal impedance (in other words, as a "stable" voltage source). While, peak demand during engine start for 200 ms is covered by power (120 kVa (storage) + 80 kVa (generator set) + 320 kVa (wind)). This, for a total of 520 kVa that covers the engine startup. For example, during the start of the big ice machine, it is asked very important currents.

3. Data Collection (Wind and Solar Data)

Homer software requires a number of data entries that include data related to energy consumption, equipment (solar panels, wind turbines, generators, inverters, batteries or other equipment) and resources. Necessary such as the solar or wind data, as well as the fuel-related data used by the generator. It is important to include some economic parameters as well.

Evaluation of the solar resources of the North site (see **Table 1**): The index of clarity given in the table is the ratio of solar radiation hitting the horizontal surface of the Earth (HRM) on the Extraterrestrial solar radiation (G extra). What gives (EQ1). Then it should be noted that the average index of clarity throughout the year exceeds 0.60 (index). In this same vision, the average monthly irradiation varies from 4.8 kWh/m^2/d to a value greater than 7, 80 kWh/m^2. The average annual irradiation is close to 5.5 kWh/m^2/d.

North site Wind Resource assessment (see **Table 1**): Wind velocity data are obtained from a measurement companion that was conducted near the site. The average monthly speed for the site is important during the months of April to September [APR, Sept]. In this range, it is at a speed slightly above 6.4 m/s, remaining below 7 m/s.

For the remainder of the year, the wind speed can go down to 4.8 m/s (the Gamesa wind turbine has a speed of 3 m/s starting speed). In addition, it should be noted that the average annual speed is close to 6 m/s (double the starting speed of the wind turbine). It can be concluded that the Ballawack site enjoys a wind potential favorable to the application of wind turbines. This deposit can be operated in order to produce the complementary electrical energy to the diesel production to form the HS.

Choice of the wind turbine (source: simulation Homer):

- General description: Website: www.Windenergysolutions.nl, curant type AC (Grid voltage: 400 V, Grid frequency 50 Hz, phases: 3 phase + neutral,
- Generals ratings: 100 kW rated, 2 bladed upwind turbine, 30 m diameter, asynchronous generator, formerly known as the LW30/100 langerwey. LW30/100 is a two bladed, reliable 100 kW midsize wind turbine with a rotor diameter of 18 meters. The mechanical part of the LW30/100 is based for the electrical parts providing power conversion and control.

Some data are provided above, to provide information on the power curve of this turbine (LW30/100). Thus, **Figure 3** which is proposed by Homer software shows a curve divided into four parts: Part 0A or the wind turbine is stopped [8]. This zone applies to wind speeds that are less than or equal to 3.5 m/s (minimum wind speed required for start-up). This also implies that in this zone the power generated by the turbine is zero. On the other hand, in the AB part, the wind turbine develops a power proportional to the wind speed (wind speed of operation). The zone (AB) must also stop at a wind speed.

Table 1. The solar radiation & wind speed readings.

Months	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clearness (Kcl)	0.67	0.80	0.87	0.94	0.96	0.98	0.94	0.90	0.87	0.80	0.67	0.60
Daily Radiation kWh/m^2/d	5.00	6.00	6.80	7.50	7.80	7.96	7.20	7.00	6.60	6.00	5.00	4.80
Wind Speed. m/s	5.20	4.80	5.90	6.50	6.70	6.70	6.72	6.70	6.68	5.90	5.40	5.02

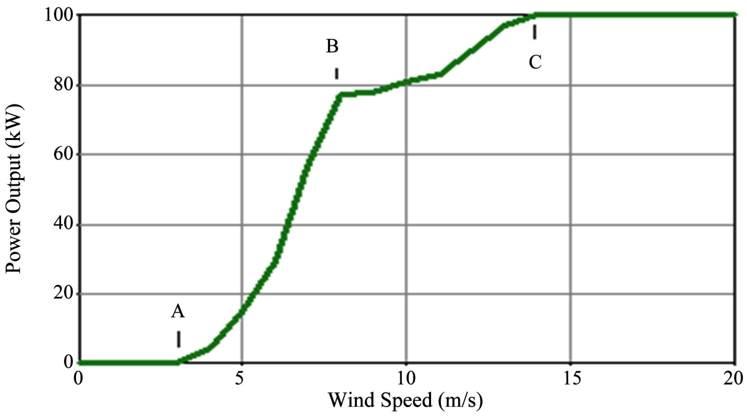


Figure 3. Wind turbine 100 kW—Gamesa curve (source: Homer simulation).

Modeling of wind generator system

Power output of wind turbines for allocation depends on wind speed at hub height which can be calculated using power-law equations:

$$\frac{V}{V_O} = \left[\frac{h}{h_O}\right]^{\alpha} \tag{1}$$

With V = wind speed at the height (h) of the turbine in relation to the ground.

V_O = wind speed measured at the height (h_o) on the site.

a = value that depends on the roughness of the site (For Ballawahk, it is between 0.10 and 0.13).

h = height at which we want to estimate the wind speed.

h_0 = reference height.

The maximum power available in a site for a wind speed is:

- Proportional to the product of the surface swept by the blades,
- Proportional to the cube the speed of the wind.

This power is given by the following relation:

$$P_w = \frac{1}{2}\rho \cdot S \cdot v^3 \tag{2}$$

$$\rho = 1.25\,\text{kg}/\text{m}^3, \text{masse volumiquedel'air} \quad \text{with} \quad S = \pi \cdot R^2 \tag{3}$$

Different wind turbines have different power output and performance curves [9]. Therefore, the equation of a wind system is strongly influenced by the power curve of the wind turbine used (Figure 3). The curve of Figure 3 can be approximated and modeled through the curve of Figure 4.

$$P_{kW}=\begin{cases}0, & if\ V\langle V_a \text{ and } V\rangle Vc\\ av^{"}{}_{"}-bP_{st}, & if\ V_a\langle V\langle V_b\\ P_{st}, & if\ V_b\langle V\langle V_C\end{cases}\tag{4}$$

With *a* to *b*, which are given by:

$$a=\frac{P_{st}}{\left(V_c-V_a\right)}\text{ and } b=\frac{V_a^3}{\left(V_b^3-V_a^3\right)}$$

It is important to note that Table 1 (reading wind speed) that the wind speeds on the site is in the range greater than 4.80 m/s. This means that the turbine will be running most of the time [10].

4. Estimation of the Profile of the Electrical Loads of the HS

In the village of Balawakh the proposed charge comprises two units of desalination of water by reverse osmosis and two units of ice-making, not forgetting the demand of the populations and the training center of Naval. For Figure 5: it should also be noted that the power call (more than 300 kW) will be dedicated to the interval [8, 16 h] for the desalination units of water by reverse osmosis and those for the manufacture of ice.

Beyond the interval [8, 16 h] are the secondary loads (night lighting, TV and others). The average daily demand evolves with a power close to 90 kW in the interval [0 h, 8 h]. For the hours [16, 24 h] the application already registers a demand close to 200 kW.

For Figure 6: The average daily demand per month evolves with a power close to 90 kW in the interval [0 h, 8 h] for secondary loads. It should be noted that at 8 a.m. the application already registers 200 kW. Then, in the following interval between [9 am, 4 pm], the demand is at its maximum by being close to 325 kW for the loads of desalination of water by reverse osmosis and ice making. To then record a value approaching the 200 kW between [4 pm, 24 h] for secondary loads.

In conclusion, it is possible to say that the application (Figure 5) follows the form shown in Figure 6 (annual expense profile). This shape holds a power close to 200 kW from 0 h to 6 h. The demand continues with a maximum beyond 300 kW which ends at 4 pm. It falls with the same law, as in the screen after 16 h, and then approaching the 200 kW in the continuation of its development.

Methodology

The methodology is defined for the achievement of the objectives presented previously as:

- To meet the optimal energy needs of the existing infrastructures of coastal towns by reducing the pressure on the use of fossil fuels (diesel), which is widespread,

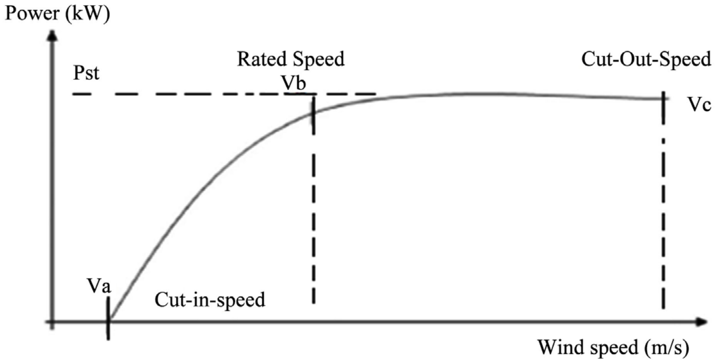


Figure 4. Wind turbine power curve.

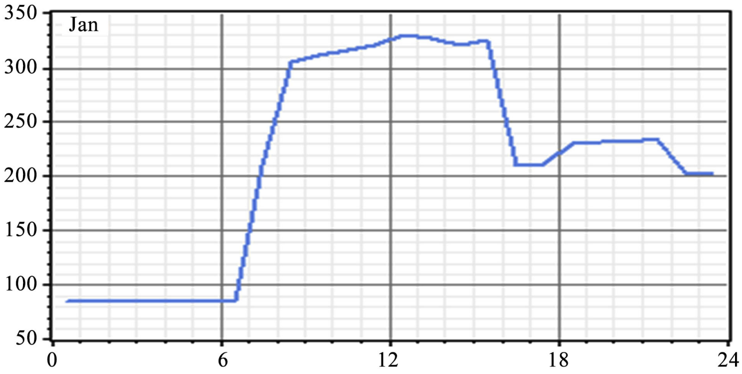


Figure 5. Load profile for the village of Ballawakh.

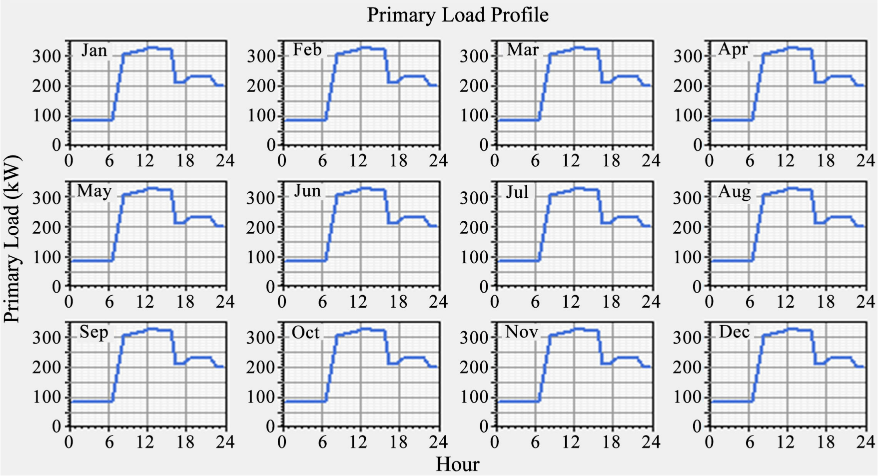


Figure 6. Annual profile of loads.

- Propose optimized solutions through the proposal of technologies that are the most profitable. These HS offer better performance, flexibility of planning and environmental benefits for power generation for the North Shore,
- Propose the right size that should have the components,
- Incorporate solar options and network interconnection into the initial solution (**Figure 1**) to test the sensitivity level for choosing the optimal solution. Thus, time to create an HS that can use the existing renewable resources

(wind and solar) of the North Shore,

- Finally, offer uninterrupted power through the use of the Homer optimization model. To arrive at solving the objectives that are presented previously, it is established a methodology through the development an analysis methodology. Then, propose configurations that meet the profitability by a study of sensitivity and environmental impact study of an HS which touches most of the energetic potentialities existing on the site. Thus, it is proposed in the rest of this work the results of simulations through a discussion of the HS analysis.

5. Results of Simulations and Discussion of HS Analysis

In this work, Homer has shown in Figure 2 that is retained for this site, for different configurations of HS in situation off/with network. In this work, Homer has shown in Figure 2 that is retained for this site, for different configurations of SH in situation off/with network.

However, the reliability of the HS (Figure 2) cannot be guaranteed due to the variable nature of the availability of wind velocity unless other options such as solar insertion and interconnection are integrated into the HS (Figure 7). So, Figure 7 happens to give: a 1st option takes into account the insertion of solar (500 kW) in an off-grid situation (see red arrow in the lower part of Figure 7) and a 2nd option that incorporates in Figure 7, the solar option (500 kW) in addition to the network option (250 kW) in the global system (see red arrow in the part of Figure 7).

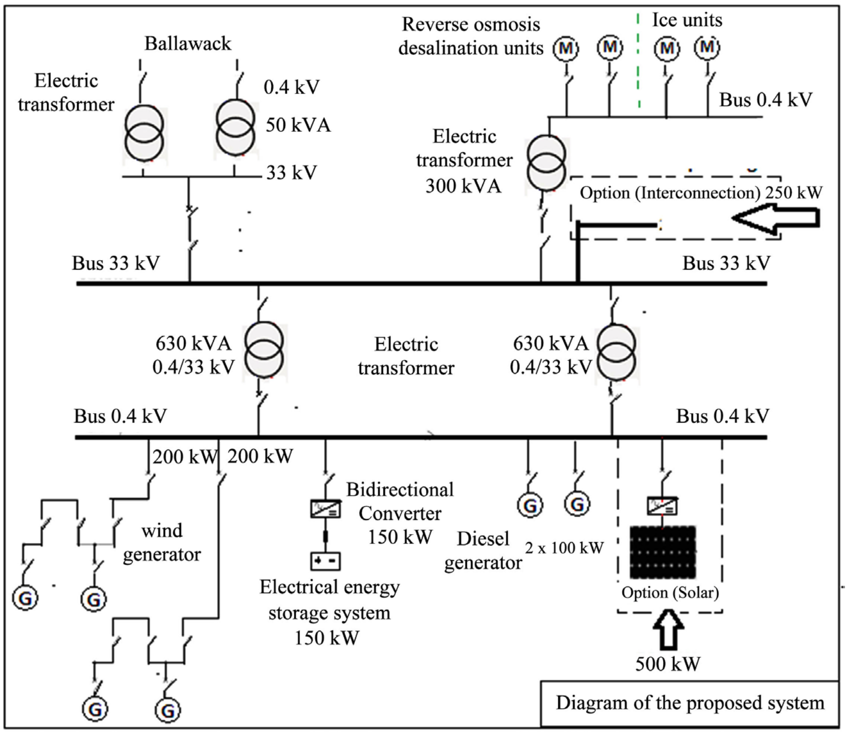


Figure 7. Variant proposed hybrid, system, two new options (solar and interconnection).

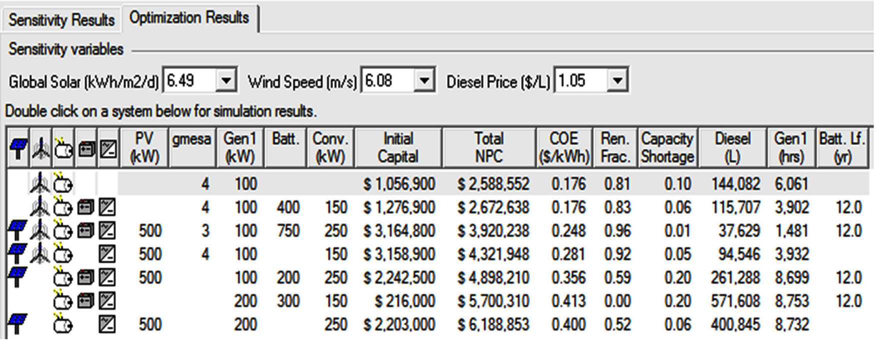
5.1. Incorporation into the Initial HS of the Solar Option (Off-Grid)

The various configurations of the hybrid system that are obtained by homer in off-grid situations with solar incorporation (off-grid) are proposed in Figure 8. Among the reentry data, it is necessary to report a global insolation (6.49 kWh/m^2/d), wind potential with 6 m/s and a diesel price of $1.05//l.

Indeed, these configurations in Figure 8 are presented in order of economic priority: these configurations move from the most economical to the 1st rank (wind with 4 turbines each of which is 100 kW), Diesel (100 kW), without a solar component and without storage with a price ($0.176/kWh). By cons, by going to look just from the side of the least economical configuration to the 7th rank (solar (500 kW and diesel 200 kW)), without wind and without storage system, according to the determining price of ($0.400/kWh). It is important to note in this case that this $/kWh price has risen from simple to more than double or 2.27. This vision is reinforced by the column of NPC (Net Present Cost) which also goes from the most economical (to the 1st row) with 2,588,552$ to that which is positioned at 7th rank, with 6,188,853$. This passage from NPC from 1st row to 7th is doubled to 2.39. This shows that the systems still follow the same order of the most economical at least economical. In addition, going back to the 2nd row, Homer offers a configuration with a price of $0.176/kWh (4 turbines each of which is 100 kW and a diesel group of 100 kW, but this time with a storage system (400 batteries)). Then, it is proposed by Homer on 3rd and 4th row: The presence of solar (500 kW) with storage taking into account the price ($0.248/kWh) for the 3rd row a price of $0.281/kWh (750 batteries) or without storage for the 4th row. It should be noted that the 5th rank gives a configuration with a price ($0.356/kWh) of solar (500 kW), without wind turbines with diesel (100 kW) and storage (200 batteries). In the end, the 6th rank configuration offers a price (a diesel system (200 kW) and storage (300 batteries). Before proposing a conclusion on these results, it is important to propose in Table 2, above the list of HS components (off-grid). It should also be noted that the HS Configuration (solar, wind and diesel) was 3rd and 4th row (Figure 8).

Table 2. List of system components with the costs of each.

Component	PV panels	Wind turbine	Battery	Converter
Size/type	250 w	100 kW	Vision 6FM200D 200 Ah/12volt, 2.4 kW	150 kW
Capital cost	3965$/kW, for 500 kW Is 198 25 00$	261,600$	250$	800$/kW
Replacement cost	3965$/kW	261,600$	250$	800$/kW
O&M cost	1$/year	$15/year	$10/year	10$/year
Life time	25	20	10	15
Quantity	0 to 500 kW	0, 1, 2, 3 and 4 turbines	0 to 750 elements	0, 150, 200 and 250 kW



Sensitivity variables

Global Solar (kWh/m2/d) 6.49 Wind Speed (m/s) 6.08 Diesel Price ($/L) 1.05

Double click on a system below for simulation results.

PV (kW)	gmesa	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)	Batt. Lf. (yr)
	4	100			$ 1,056,900	$ 2,588,552	0.176	0.81	0.10	144,082	6,061	
	4	100	400	150	$ 1,276,900	$ 2,672,638	0.176	0.83	0.06	115,707	3,902	12.0
500	3	100	750	250	$ 3,164,800	$ 3,920,238	0.248	0.96	0.01	37,629	1,481	12.0
500	4	100		150	$ 3,158,900	$ 4,321,948	0.281	0.92	0.05	94,546	3,932	
500		100	200	250	$ 2,242,500	$ 4,898,210	0.356	0.59	0.20	261,288	8,699	12.0
		200	300	150	$ 216,000	$ 5,700,310	0.413	0.00	0.20	571,608	8,753	12.0
500		200		250	$ 2,203,000	$ 6,188,853	0.400	0.52	0.06	400,845	8,732	

Figure 8. Initial HS with solar incorporation (off-grid).

For **Table 2**: The solar system requires a very high initial cost (**Table 2**): $3965/kW, for 500 kW or $1,982,500). Thus, the price of solar if it is compared to that of wind turbine for the number of the most important impeller (**Table 2**: 261,600$ for 100 kW, or $1,046,400 for 400 kW). From these results, this system can give with a reasonable investment and the expected amount of renewable energy.

In consequence, it can supply the proposed load of 350 kW, taking into account the starting peaks of the engines (water production by reverse osmosis and ice factory). However, the reliability of the HS cannot be guaranteed due to the variable nature of the availability of solar radiation and wind velocity unless the technological option of interconnection is envisaged. Thus, it is possible to see that the price of solar is 1.9 times more important than the wind for the components of the maximum equipment that are proposed in the configurations. It is possible to return to the total cost (**Table 2**: For the 500 kW solar is $1,982,500). Then the price of the kWh is affected. Pa elsewhere, for the Wind system (**Table 2**: 1,046,400$ for 400 kW), the cost is much lower than that of the solar system. On the other hand, the costs of the operations side are still high for wind power ($15/year versus $1/year). But they are weak for the solar, in addition the batteries are also a large part of the operating costs. In conclusion, for this case, wind turbines require more maintenance than solar panels. The diesel system requires a minimal initial investment and most of the total cost of the system comes from operating costs that are mostly related to fuel use. Wind and solar systems all have a large proportion of similar energy excesses while the diesel system is well suited for the use of all the energy produced.

5.2. HS with Solar with Incorporation of Interconnection (Network)

Indeed, **Figure 9** expresses the power sharing in question with a connection option with the network. This power sharing can be done according to several configurations of choice, with several options. In this context, the criteria that will be selected will be based on the minimization of the cost at the level of each of the main equipment (wind-solar-diesel and storage) of the HS. This minimization of the cost is studied in the following with the integration of the interconnection of the network. In this context, it is important to remember that it has been noticed the existence of an MT-33 kV network at a distance of 35 km from the Ballawakh site. In this respect, it is proposed in **Figure 9**, eight different configurations for the HS: Considering that the different HSs that are proposed each integrate a connection to the network.

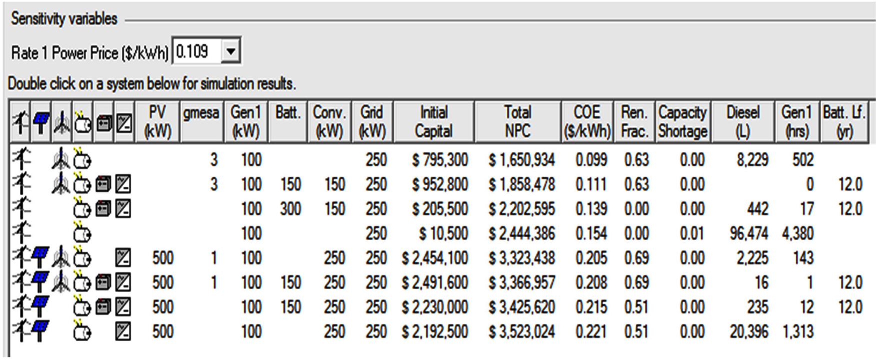
It is also proposed to transform **Figure 9** into **Table 3** to bring out the different costs and prices related to the eight (8) Configurations of Grid only system & hybrid power system.

In addition, **Table 3** gives the results of the HS sensitivity study connected to the network. The network is present at the level of each configuration. The table also presents at each of these configurations a wind power plant or a solar power plant with or without a battery storage system. But the two most optimal variants are with a wind system (the 1st configuration with the network is proposed without storage: network with possibility of supply (250 kW), 3 turbines of 100 kW each with a diesel group of 100 kW. Secondly, the 2nd configuration offers the storage system of 150 kW (150 batteries)). In the suite, looking on the side of the 5th configuration it is noticed the solar (500 kW), a turbine with a power of 100 kW without storage. The 6th configuration records only one difference in the presence of storage (150 batteries). On the other hand, the network still offers a power of 250 kW. The two following configurations (6th and 7th) are diesel component (100 kW) with a storage system. The configuration at Tier 8 offers a solar option (500 kW) and a generator (100 kW). This 8th configuration marks the difference with the absence of the turbine and the storage system.

5.3. Study of the Impact of the Incorporation of the Network into the HS

To carry out this impact study of the incorporation of the network into the HS (Wind-solar-diesel and Storage). The study of **Figure 2** (initially selected) is transferred to **Figure 7** with the new incorporation of a solar option and an option with the incorporation of an interconnection. Which allows to give for the interconnection, the purchase price of electricity to the network. This feed-in tariff for grid electricity is set by the Mauritanian electricity company (Somelec) for a medium voltage (MV) substation installed. This rate is equivalent to \$0.109/kWh, *i.e.*: [\$1 = 355.50 UM]. By cons, the cost of electricity network with 35 km of line MT will be proposed by Homer. Thus, the simulation by Homer gives the configurations in **Figure 9**, for a buy-back price of electricity to the grid which will be varied as follows (rate price: 0.109, 0.150, 0.200 and 0.250 \$/kWh). Homer sorted out the best variants following the redemption price of electricity to the grid that were varied (**Figure 10**). The first remark deduced from **Figure 10**, for these best variants is the absence of storage and solar after the incorporation of the interconnection. Indeed, Homer always gives the optimized solution with the smallest power of the wind field (3 Gamesa wind turbines of 100 kW each for the 1st configuration, for the other configurations it is proposed 4 Gamesa wind turbines of 100 kW each). Therefore, in **Figure 9**, it is not advantageous to add wind turbines in addition to a system that is connected to the network. Electricity costs and surrender costs, currently available in Mauritania, must be taken into account.

On the other hand, wind turbines were selected for the first following variant (3 windmills of 100 kW each) and 4 turbines of 100 kW each for the other configurations. It should be noted that the wind turbine and coupled with diesel for the 4 configuration, despite the increase in the purchase price of electricity. So



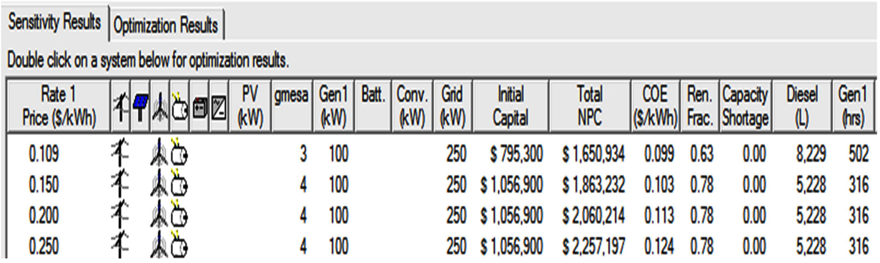
Sensitivity variables

Rate 1 Power Price ($/kWh) 0.109

Double click on a system below for simulation results.

PV (kW)	gmesa	Gen1 (kW)	Batt.	Conv. (kW)	Grid (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)	Batt. Lf. (yr)
	3	100			250	$ 795,300	$ 1,650,934	0.099	0.63	0.00	8,229	502	
	3	100	150	150	250	$ 952,800	$ 1,858,478	0.111	0.63	0.00		0	12.0
		100	300	150	250	$ 205,500	$ 2,202,595	0.139	0.00	0.00	442	17	12.0
		100			250	$ 10,500	$ 2,444,386	0.154	0.00	0.01	96,474	4,380	
500	1	100		250	250	$ 2,454,100	$ 3,323,438	0.205	0.69	0.00	2,225	143	
500	1	100	150	250	250	$ 2,491,600	$ 3,366,957	0.208	0.69	0.00	16	1	12.0
500		100	150	250	250	$ 2,230,000	$ 3,425,620	0.215	0.51	0.00	235	12	12.0
500		100		250	250	$ 2,192,500	$ 3,523,024	0.221	0.51	0.00	20,396	1,313	

Figure 9. List of HS solutions with network incorporation (Homer Simulation).



Double click on a system below for optimization results.

Rate 1 Price ($/kWh)	PV (kW)	gmesa	Gen1 (kW)	Batt.	Conv. (kW)	Grid (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
0.109		3	100			250	$ 795,300	$ 1,650,934	0.099	0.63	0.00	8,229	502
0.150		4	100			250	$ 1,056,900	$ 1,863,232	0.103	0.78	0.00	5,228	316
0.200		4	100			250	$ 1,056,900	$ 2,060,214	0.113	0.78	0.00	5,228	316
0.250		4	100			250	$ 1,056,900	$ 2,257,197	0.124	0.78	0.00	5,228	316

Figure 10. Sensitivity results following the variation of the electricity redemption price to the network.

Table 3. Price of variants in presence (Network/PV/wind/Diesel).

Costs Cases	Initial Capital t($)	Total NPC($)	Total O&M Cost ($/yr)	Diesel (L)	COE ($/kWh)
Power Price (0.109$/kWh)					
1	795,300	1,650,934	78,990	8229	0.099
2	952,800	1,858478	83,847	Negligible	0.111
3	205,500	2,202,595	223,327	442	0.139
4	10,500	2,444,386	182,044	96,474	0.154
5	2,454,100	3,323,438	81,288	2225	0.205
6	2,491,600	3,366,957	83,164	16	0.208
7	2,230,000	3,425,620	124,860	235	0.215
8	2,192,500	3,523,024	120,172	20,396	0.221

the HS was scanned as being connected to the network. In the case of **Figure 10**, number 3 and 4 were the number of wind turbines analyzed in Homer. It has been reported that it is not advantageous to add wind turbines to a system that is connected to the network. Indeed, the cost of repurchase of the kWh of the network is below the prices of the HS kWh in the other configurations. For example for the redemption price (for rate price of the network of 0.109$/kWh, it is obtained a price of HS of 0.099$/kWh. Similarly, for rate price of the network of 0.150$/kWh, it is obtained a price of HS $0.103/kWh). It is found however that the cost (rate) of the electricity of the network remained lower than the price ($/kWh) of the HS.

In conclusion of this part, if it is studying the situation connected to the network for this site with the wind turbines, with the electricity costs (rate price) present and the cost of buying electricity from the network in the range (0.109, 0.150, 0.200 and $0.250/kWh), the HS is favorable for a proposed competitive price.

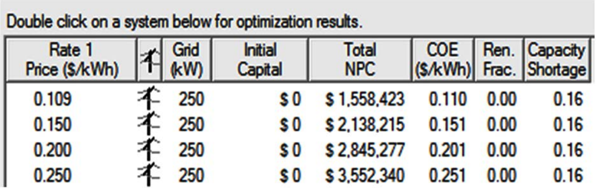
Comparing with the network alone (**Figure 11**) and the HS situation connected to the network (**Figure 10**). It is then obtained for the HS connected to the network (**Figure 10**) an interesting situation compared to the network-only connection. For, prices are decreasing first compared to the purchase price of the network and second in relation to the COE price ($/kWh) of the network.

5.4. HS with Greenhouse Gas Emissions

It is important to remember that **Table 4** is taken from **Figure 10**. It marks the presence of a network connection on the 8 configurations. It also gives two configurations 3, 4 and in addition to the network variant alone, respectively for emissions of carbon dioxide (1,258.278, 1,276.135 and 1,049.768 (kg/yr)). This is explained by the fact that these variants are totally diesel and the network can have a diesel origin.

Table 4. Emission of greenhouse gases in the presence of the network of Variants (Network/PV/wind/Diesel).

Pollutant	Carbon dioxide	Carbon monoxide	Unburned hydrocarbons	Particulate matter	Sulfur dioxide	Nitrogen oxides
Variants	**Emissions (kg/yr)**					
1	401,945	53.5	5.92	4.03	1692	1284
2	393,820	0	0	0	1707	835
3	1,258,278	2.87	0.318	0.217	5452	2691
4	1,276,135	627	69.5	47.3	4941	7763
5	412,581	14.5	1.6	1.09	1775	991
6	409,652	0.101	0.0112	0.00759	1776	869
7	672,192	1.52	0.169	0.115	2913	1438
8	700,312	133	14.7	9.99	2911	2554
Emission in the presence of the network of variants (option with network only)						
Network only	1,049,768	0	0	0	4551	2226



Double click on a system below for optimization results.

Rate 1 Price ($/kWh)		Grid (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
0.109		250	$ 0	$ 1,558,423	0.110	0.00	0.16
0.150		250	$ 0	$ 2,138,215	0.151	0.00	0.16
0.200		250	$ 0	$ 2,845,277	0.201	0.00	0.16
0.250		250	$ 0	$ 3,552,340	0.251	0.00	0.16

Figure 11. Option sensitivity results with network alone (Homer Simulation).

In this respect, the other HS configurations (diesel in the presence of solar and wind) (1, 2, 5, 6, 7 and 8) have the lowest emissions for carbon dioxide respectively (401,945; 393,820; 412,581; 409,652; 672,192 and 700,312 (kg/yr)). This is explained by the presence of solar and wind that mitigate emissions. The network has low emission rates for Carbon monoxide, Unburned hydrocarbons and Particulate matter. This leads to the conclusion that the best variants are those related to HS (1, 2, 4, 5, 6, 7 and 8) that have the lowest emissions for Carbon dioxide, Sulfur dioxide. To conclude this part, it is possible to say that the HS marked by variants with presence of solar and wind in addition to the network are to favor, because their emissions (greenhouse gases) are low. On the other hand these same gases are important quantities for the configurations with strong presence of diesel, for the configurations 3 and 4.

6. General Conclusion

By making an overview of all the results and simulations, we deduce first of all that the consumption profile, the deposit (wind and solar) can influence costs and excess energy. While the cost of electricity ($/kWh) is simply linked to the potential (solar or wind). For remote areas, the first thought is that the cost of extending the network is high. It is then sought through this work to compare the HS with the network which is at a distance of several tens of Km from the site to be electrified. This comparison also affected the cost of the grid, which proved to be high compared to the cost of the HS (wind, solar and diesel). Thus, HS could be a technology to reduce diesel consumption.

On the one hand, in the case of off-grid systems, the cost of energy for wind and diesel is similar. The only difference comes from the source of the costs. Thus, the wind system has significant upfront costs, while the diesel group has significant diesel costs. Subsequently, the insertion in a first phase of the solar system, to then introduce an incorporation of an interconnection is carried out for a comparison of the initial costs. Thus, the Homer software was used to analyze and simulate the possible alternatives to make the best choice for a northern location. Therefore, different configurations and conditions were considered as a possibility to cover the demand of the locality on the coast. In addition, the simulation makes it possible to choose the optimal case for the HS. It is also shown that the optimal case is the combination of several variants (wind, diesel with a solar option), without forgetting the option of interconnection to the network. It should also be noted that the network has low emission rates for carbon monoxide, unburned hydrocarbons and particulate matter. Thus, the best variants that have the lowest emissions for Carbon dioxide, Sulfur dioxide remain those with HS component (wind, solar and diesel). In the end, it is to identify options that can play the role of electricity generation alternative in the North coast; likewise, it was analyzed the relevance of these different options for decision-making for the benefit of decision-makers.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Rapport PNUD-GEF, TVIG (Tennessee Valley Infrastructure Group) (2005) Electrification hybride de type éolien/diesel et électrification solaire.

[2] Ramli, M.A.M., Hiendro, A. and Twaha, S. (2015) Economic Analysis of PV/Diesel Hybrid System with Flywheel Energy Storage. *Renewable Energy*, **78**, 398-405. https://doi.org/10.1016/j.renene.2015.01.026

[3] Al Busaidi, A.S., Kazem, H.A., Al-Badi, A.H. and Khan, M.F. (2016) A Review of Optimum Sizing of Hybrid PV-Wind Renewable Energy Systems in Oman. *Renewable and Sustainable Energy Reviews*, **56**, 185-193. https://doi.org/10.1016/j.rser.2015.08.039

[4] Fathima, A.H. and Palanisamy, K. (2015) Optimization in Micro Grids with Hybride Energy Systems—A Review. *Renewable and Sustainable Energy Reviews*, **45**, 431-446. https://doi.org/10.1016/j.rser.2015.01.059

[5] Hassan, Q., Jaszczur, M. and Abdulateef, J. (2016) Optimization of PV/WIND/DIESEL Hybrid Power System in HOMER for Rural Electrification. 7th European Thermal-Sciences Conference (Eurotherm 2016). *Journal of Physics*: *Conference Series*, **745**, Article ID: 032006. https://doi.org/10.1088/1742-6596/745/3/032006

[6] Ramdhane, I.B., *et al.* (2017) Optimization of Electrical Production of a Hybrid System (Solar, Diesel and Storage) Pilot Using Homer in Biret, Southern Coast of Mauritania. *International Journal of Physical Sciences*, **12**, 211-223. https://doi.org/10.5897/IJPS2017.4632

[7] National Renewable Energy Laboratory (NERL) (2005) Hybrid Optimization Model for Electric Renewable (HOMER). http://www.nrel.gov.international/tools/tools.html

[8] Puglia, G., *et al.* (2017) A Design Approach of Off-Grid Hybrid Electric Microgrids in Isolated Villages: A Case Study in Uganda. *Energy Procedia*, **105**, 3089-3094. https://doi.org/10.1016/j.egypro.2017.03.646

[9] Sajed Sadati, S.M., *et al.* (2018) Sizing of Photovoltaic-Wind-Battery Hybrid System for a Mediterranean Island Community Based on Estimated and Measured Meteorological Data. *Journal of Solar Energy Engineering*, **140**, Article ID: 011006.

[10] Maouedj, R., *et al.* (2015) Technical Economic Analysis of a Standalone Hybrid Photovoltaic-Wind System. Application in Electrification of a House in Adrar Region. *Renewable Energy*, **74**, 1192-1204.