Optimal Sizing of a Pv-Wind Hybrid System Using Measured and Generated Database

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Article Info

Article history:

Received 03 April, 2021
Revised 17 May, 2021
Accepted 03 June, 2021

Keywords:

Extrapolation of wind speed,
HOMER software,
Optimization and sizing,
PV-wind hybrid system,
Vertical profile.

ABSTRACT

Renewable energy hybrid systems give a good solution in isolated sites, in the Algerian desert; wind and solar potentials are considerably perfect for a combination in a renewable energy hybrid system to satisfy local village electrical load and minimize the storage requirements, which leads to reduce the cost of the installation. For a good sizing, it is essential to know accurately the solar potential of the installation area also wind potential at the same height where wind electric generators will be placed. In this work, we optimize a completely autonomous PV-wind hybrid system and show the techno-economical effects of the height of the wind turbine on the sizing of the hybrid system. We also compare the simulation results obtained from using wind speed measured data at 10 meters and 40 meters of height with the ones obtained from using wind speed extrapolation on HOMER software.

I. Introduction

Faced with the depletion of fossil energy resources on a global scale and with environmental problems, alternative resources have been developed based mainly on sun and wind, photovoltaic and wind energy were seen as a promising solution to answer the growing energy demand. Wind and photovoltaic energy sources are inexhaustible, the conversion processes are non-polluting, and their availability is free [1].

For remote systems such as telecommunication relays in the middle of the desert, Satellite Earth Stations, or at isolated sites that are far from a conventional power system, hybrid systems were and still seen as attractive and preferred alternative sources. For stand-alone applications, the cost of storage is still the main economic constraint. Combining both wind power and photovoltaic power would lead to minimize the storage requirements, and therefore the overall cost of the system [2]. Samira bediar et al [3], provides a simulation for Photovoltaic's panel/Wind Turbine/battery assisted by a diesel generator for alimentation a farm and irrigation it in Adrar city. The data reveal that the highest energy usage occurred in July with 14.25 kW and the lowest occurred in November with 5.01 kW. Furthermore, the simulation results reveal that at the site, the percentage of the Photovoltaic generator's average power output to the system's average demand is 91.8 percent, indicating that the site is well-suited to the operation of a power generating system without a grid. The variability in the form of energy available for a PV-wind system requires precise sizing of the wind turbine, battery bank, and PV array so that the system meets load demand at any time of the year [4]. It is in this problem that this paper is located: to study and optimize a completely autonomous PV-wind hybrid system and show the effect of the height of the mast of the wind turbine on the sizing of this system, and also compare the results obtained in using measured and other data extrapolated by the HOMER software.

II. Mathematical modeling

II.1. Photovoltaic system

Nelson and Senjyu used a simple model of PV power as a function of the area, blobal irradiance and efficiency [2] [5] [6]:

$$P_{pv}(t) = n \times A_p \times N_{pv} \times G(t) \quad (1)$$

Where: n: Energy conversion efficiency. A_p: The area of a single PV panel. N_{pv}: The number of PV panels. $G(t)$: The global irradiance.

II.2. Wind system

As different generators have different output power curves, the model used to describe this performance is also different. In literature of Suryoatmojo et al, the use of the following equation was to simulate the power output of wind turbine [4] [5]:

$$P_{wt} = \begin{cases} 0, & v < v_c \\ \frac{1}{2}\rho \times A \times v^3 \times \eta_{wt} & v_c \leq v < v_R \\ P_R, & v_R < v \leq v_F \\ 0, & v > v_F \end{cases} \quad (2)$$

Where: ρ is the air density; A is the rotor swept area; v is the inflow wind speed and η_{wt} is the efficiency of the wind turbine.

II.3. Storage system

The power generated by hybrid system at any time t can be expressed by the following equation [1] [4]:

$$P_G(t) = P_{pv}(t) + P_{wt}(t) \quad (3)$$

The state of charge SOC of battery bank during charging process can be calculated from the following equation [8] [9] [10]:

$$SOC(t) = SOC(t-1)(1-\sigma) + \left(E_G(t) - \frac{E_L(t)}{\eta_{ond}}\right)\eta_{Bat} \quad (4)$$

$SOC(t)$ and $SOC(t-1)$ are storage bank state of charge at any hour t and $t-1$, σ is hourly self-discharging rate, $E_G(t)$ is global energy generated, $E_L(t)$ is load power demand at hour t, η_{ond} and η_{Bat} are the efficiency of the inverter and charge efficiency of battery bank respectively.

During discharging process the SOC will be calculated from the following equation [4] [9]:

$$SOC(t) = SOC(t-1)(1-\sigma) + \left(E_G(t) - \frac{E_L(t)}{\eta_{ond}}\right) \quad (5)$$

III. HOMER optimization

III.1. Site description

The site chosen for our study is an isolated rural Saharan village called "Ilamane". Its geographical coordinates are as follows: Latitude: 23.12 ° N, Longitude: 5.27 ° E. This village is located in the state of Tamanrasset and it is a compound of few houses.

III.2. Load profile and meteorological data

The following figure represents the annual load profile of the site to be satisfied [Power: 0-7(kW)]:

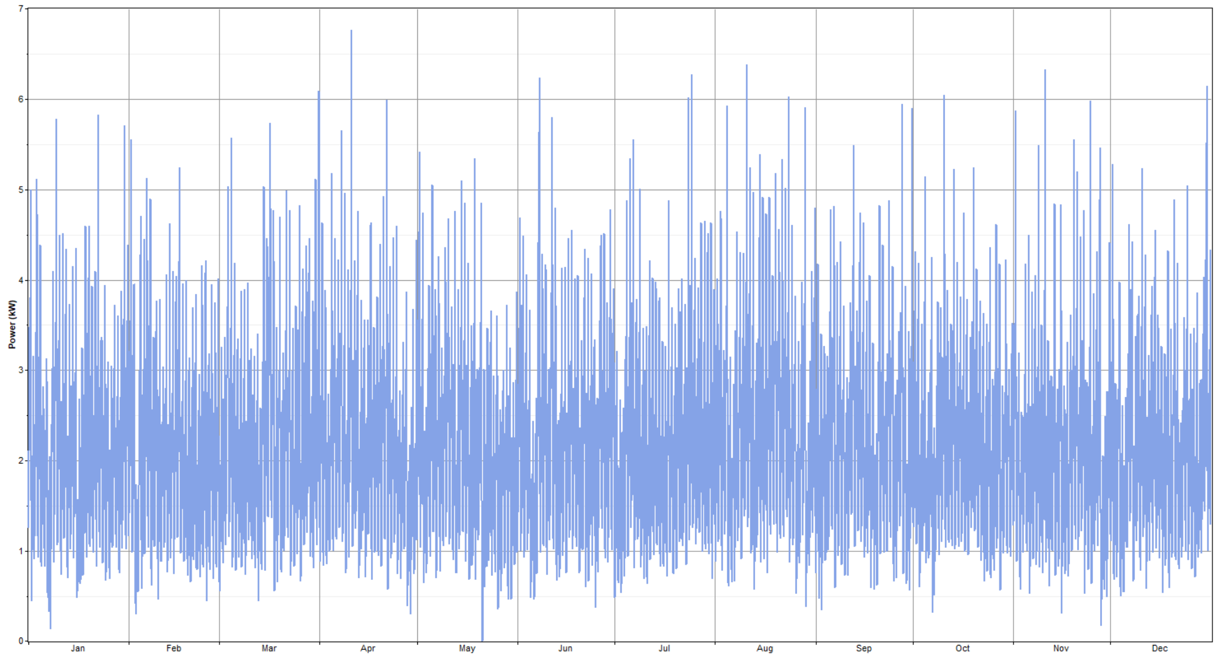


Figure 1. Load profile of the village (kW).

The performance of photovoltaic modules and wind turbine is directly correlated with climatic data, which are in principle solar irradiation and wind speed. These data were taken using an acquisition system.

*Global solar irradiance: 0.0-1.2(kW.m^{-2})

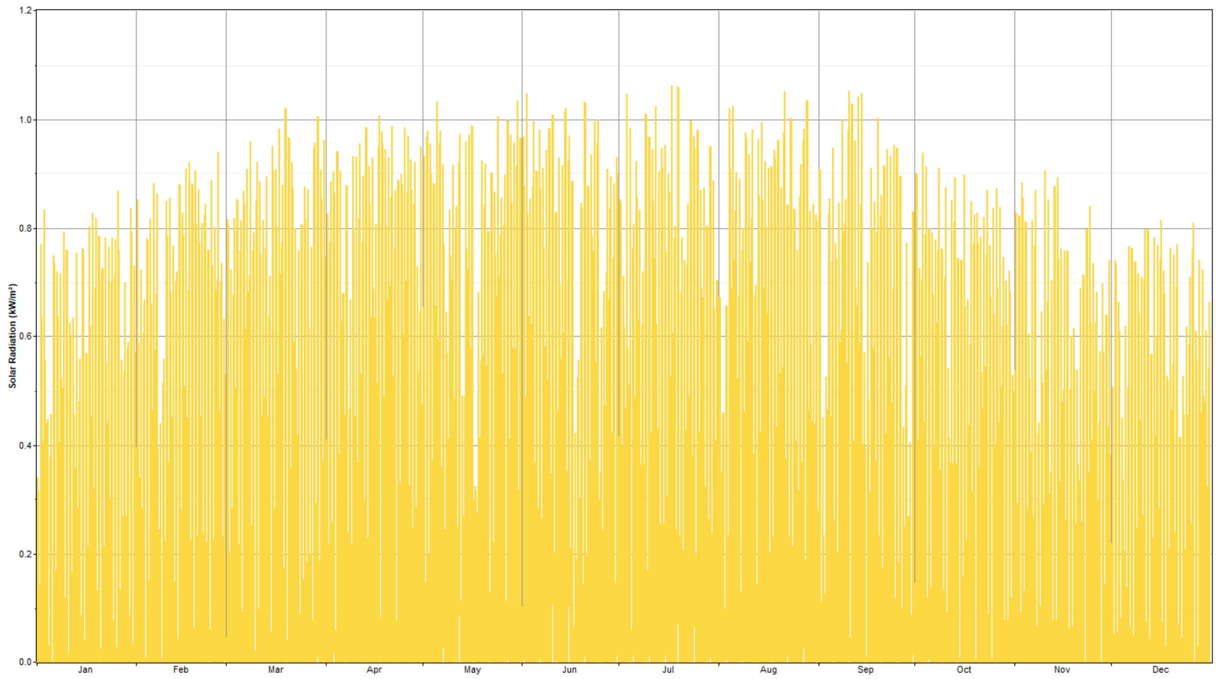


Figure 2. Global solar irradiance expressed in Watt per square meter (kW.m^{-2}).

*Wind speed: 0-20(m.s[-1])

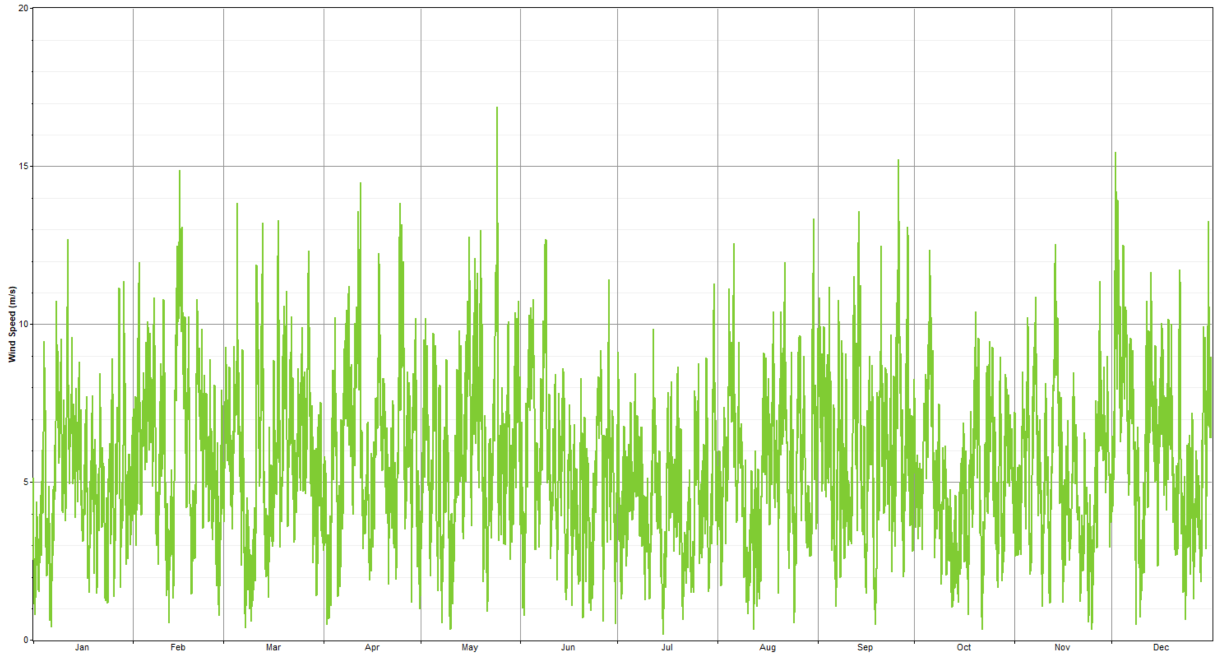


Figure 3. Wind speed at 10 meters altitude expressed in (m.s[-1]).

* Wind speed: 0-20(m.s-1)

Figure 4. Wind speed at 40 meters altitude expressed in (m.s[-1]).

For a precise optimization of any PV-wind hybrid system in the Sahara, it is essential to take into account the effect of temperature on the photovoltaic production and that is what HOMER software allows users to do as it shown on the figure below:

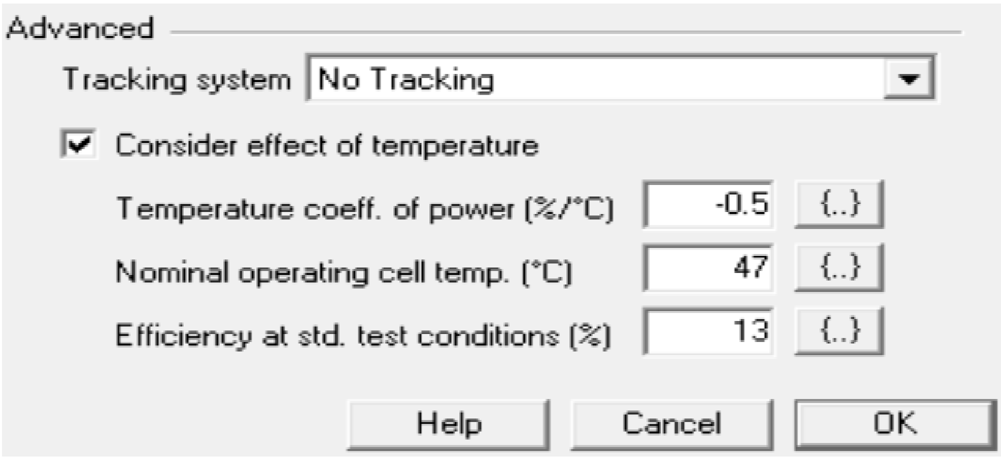


Figure 5. Effect of temperature by HOMER.

The uploaded measured temperature data are displayed on Figure 6 [Temperature (C°); 0-60]:

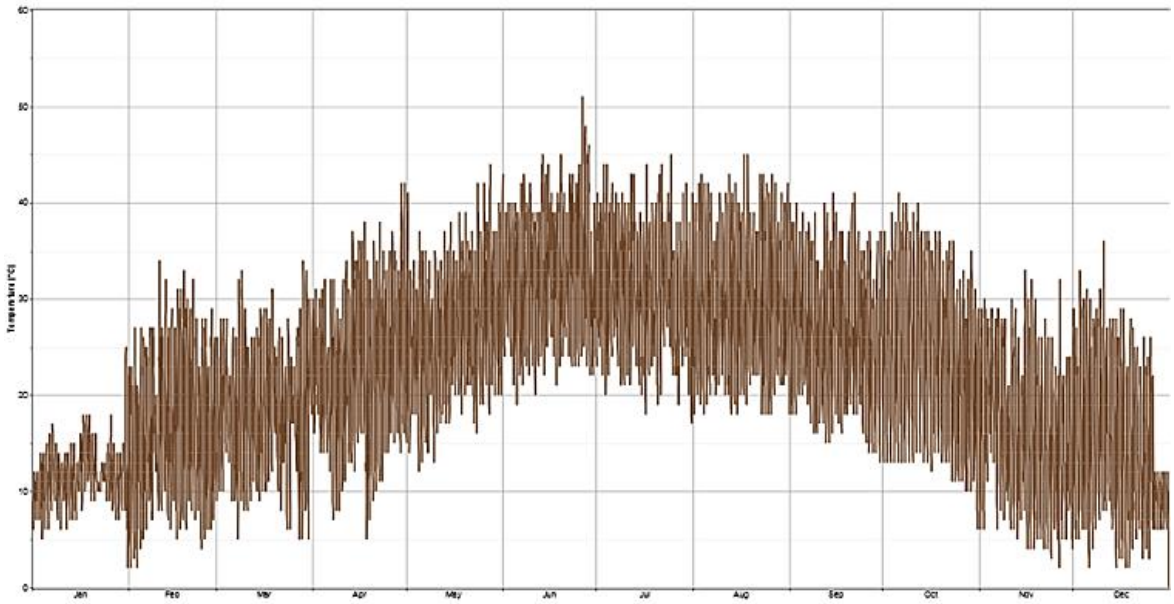


Figure 6. Ambient temperature expressed in Celsius degrees (C°).

III.3. System sizing on Homer

In the purpose to assess how easy would be the optimization of renewable energy hybrid systems on HOMER software to use in practice, we had to layout a simplified implementation flowchart of the process:

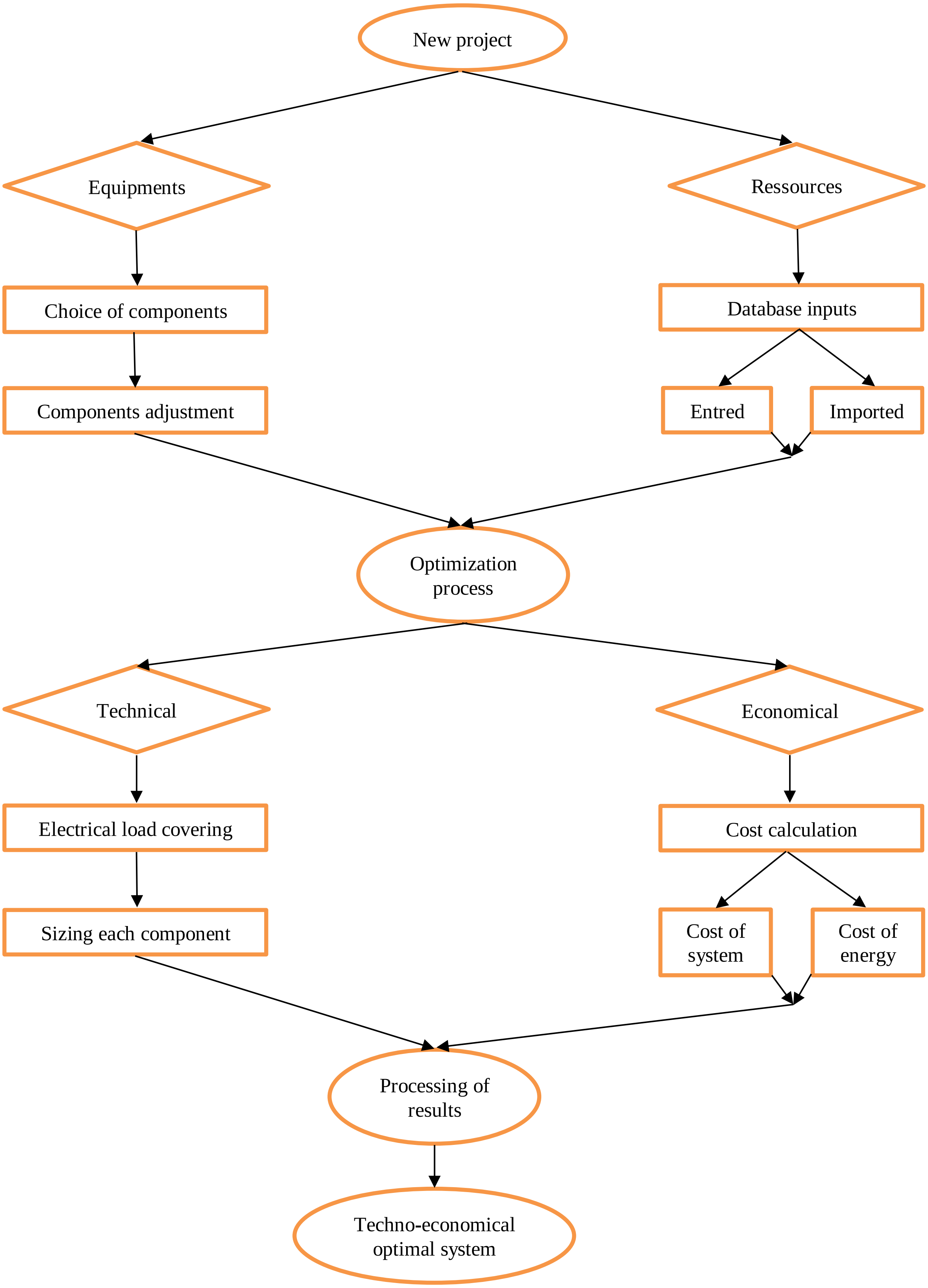


Figure 7. Flowchart of the optimization process on HOMER.

The configuration of the installation to be sized is as follows:

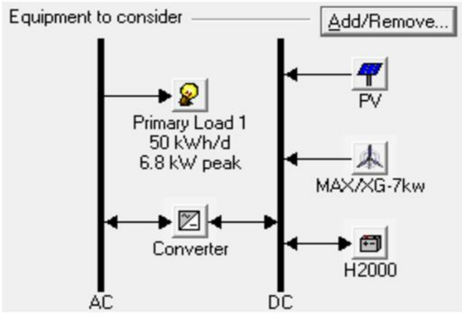


Figure 8. Configuration of the PV-wind system to be optimized.

Irradiance data is possibly introduced in three different ways, but in our case, we imported a data file of hourly measured irradiance.

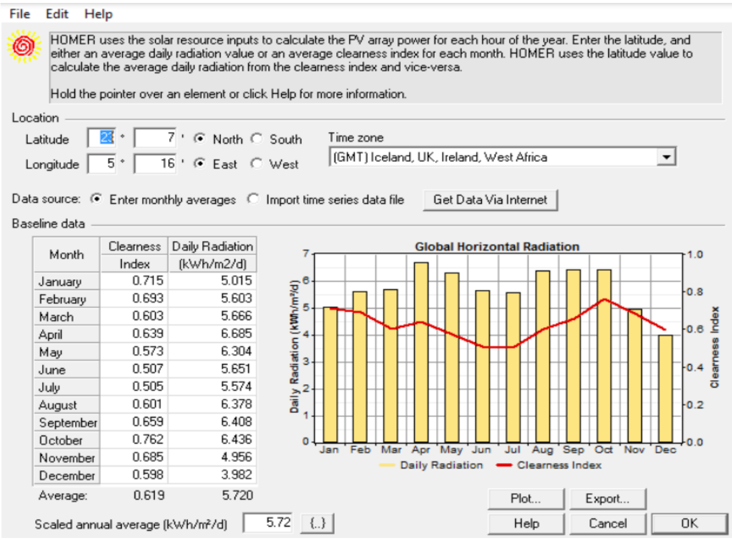
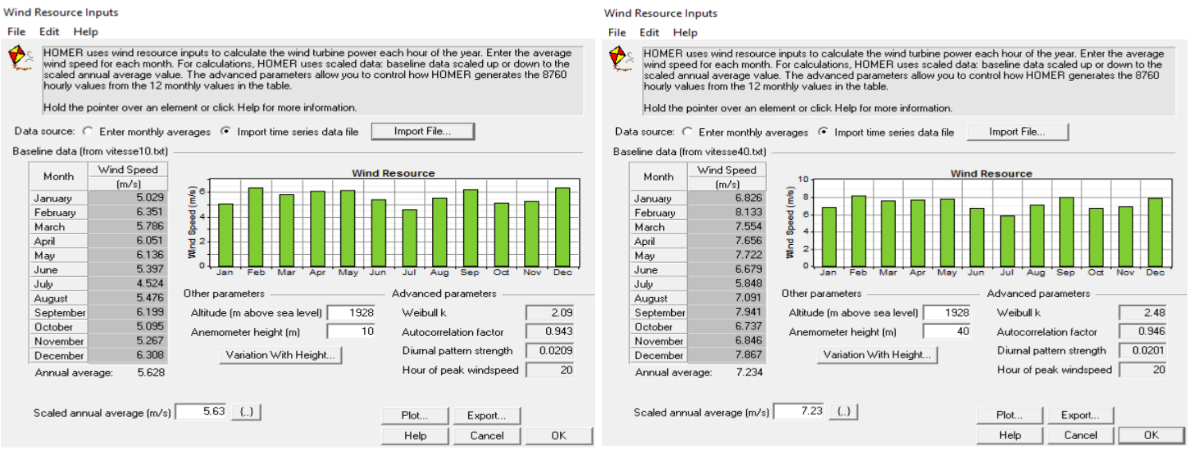


Figure 9. The irradiance data of the installation site.

In same way, hourly wind speed measured data at 10 and 40 meters were entered as presented in figures below:

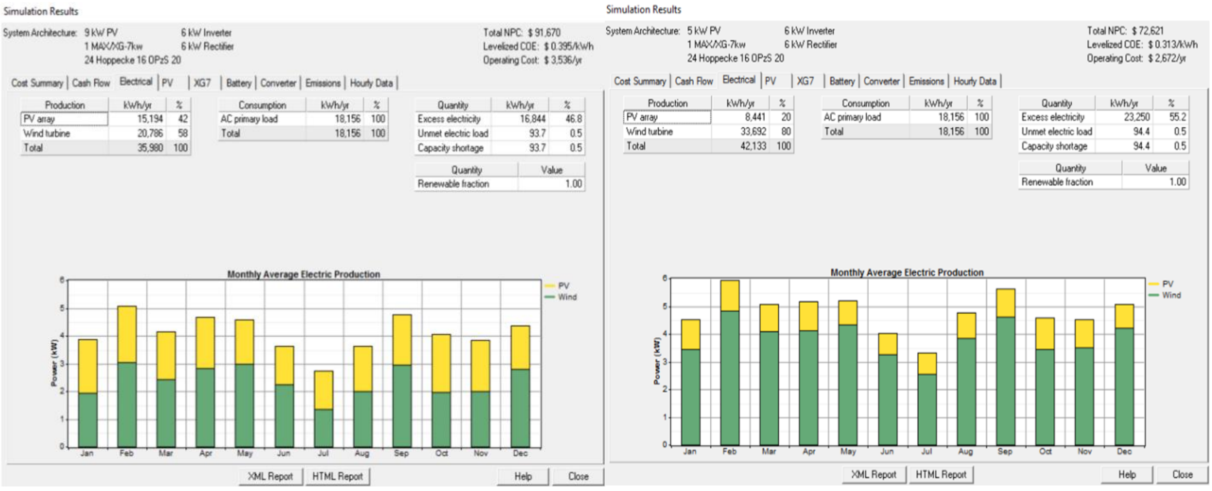


(a) (b)

Figure 10. Wind measured data of the site,
(a) At 10 meters, (b) At 40 meters.

IV. Results and discussion

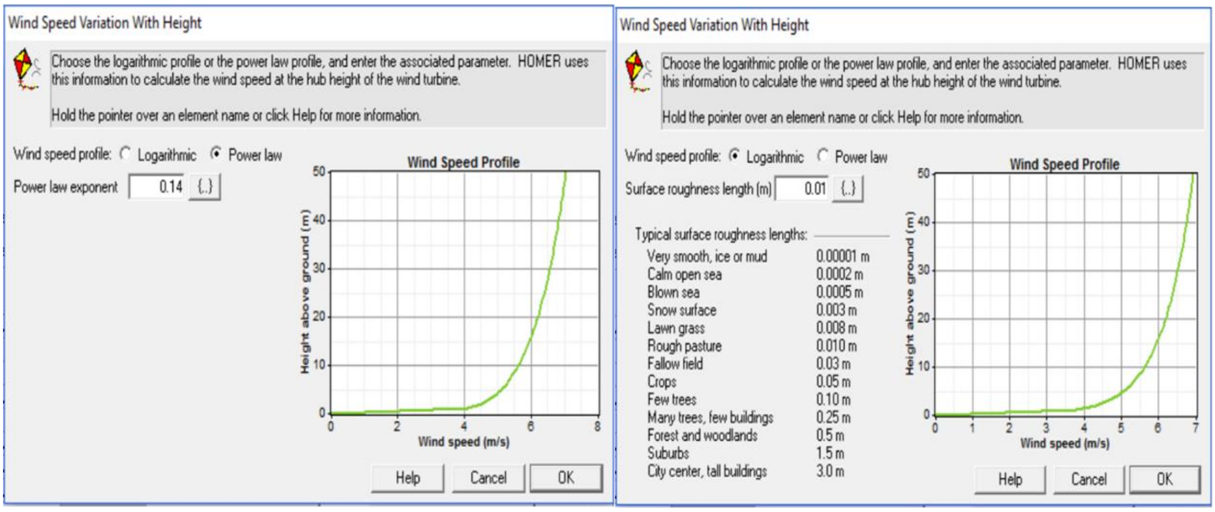
Once all measured data were uploaded on the software, the sizing can be done by clicking on the "Calculate" button, the possible results and the optimal one found by HOMER will be displayed, on figures below we display only the optimal techno-economical results of using 10 and 40 meters measured wind speed data:



(a) (b)

Figure 11. Optimal techno-economical results for measured data,
(a) At 10 meters, (b) At 40 meters.

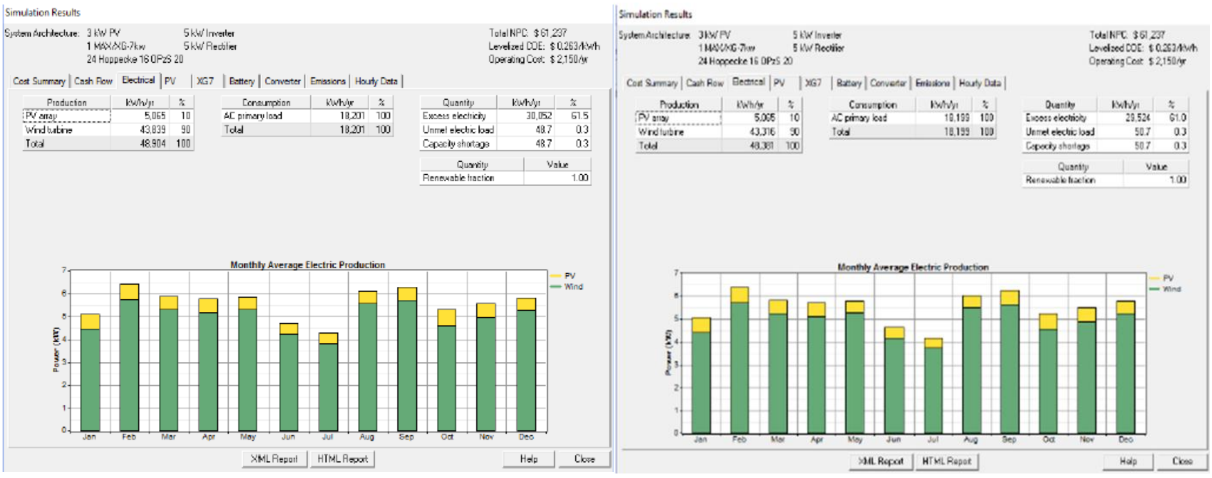
The extrapolation of the wind speed data at 10 meters to 40 meters of height was done on HOMER following to power law 1/7 and logarithmic law as it is showed on settings area of wind speed variation with height below:



(a) (b)

Figure 12. Wind speed variation with height following,
(a) Power law 1/7, (b) Logarithmic law.

Therefore, the optimal results for the PV-wind hybrid system optimization using extrapolated wind speed data following power law 1/7 and logarithmic law are printed in figure 13:



(a) (b)

Figure 13. Optimal techno-economical results for extrapolated wind speed data following, (a) Power law 1/7, (b) Logarithmic law.

After simulation and optimization of the wind-PV hybrid system with batteries, the main techno-economical results obtained from the optimizations cases are displayed in the table below:

Table 1. Main techno-economical results of the four optimized systems.

	Measured at 10 (m)	Measured at 40 (m)	Extrapolated at 40 (m)
Optimized system	*Wind turbine: 7kW *PV array: 9kW *Storage: 4kWh *Converter:6kW	*Wind turbine: 7kW *PV array: 5kW *Storage: 4kWh *Converter: 6kW	*Wind turbine: 7kW *PV array: 3kW *Storage: 4kWh *Converter: 5kW
Total energy produced (kWh/year)	35980	42133	Power law 1/7: 48904 Logarithmic: 48381
Variation rate	-14.6%	-	Power law 1/7:+16.1% Logarithmic: +14.8%
Wind turbine production (kWh/year)	20786	33692	Power law 1/7: 43839 Logarithmic: 43316
Variation rate	-38.3%	-	Power law 1/7:+30.1% Logarithmic: +28.6%
Energy sources	*Wind: 58% *PV: 42%	*Wind: 80% *PV: 20%	*Wind: 90% *PV: 10%
Total cost during 25 years ($)	91670	72621	61237
Variation rate	+26.2%	-	-15.7%
Cost of energy ($/kWh)	0.395	0.313	0.263
Variation rate	+26.2%	-	-16.0%

• In the first simulation of the system for an altitude of 10 meters, the software sized the system for almost the same powers of the wind generator and the photovoltaic generator with a smal advantage for wind (58%).

• For the second simulation concerning the wind speed data measured at an altitude of 40 meters, the system largely favored wind power with a rate of 80% and just 20% for PV, which reduced the installation and the energy cost respectively.
• For the third and fourth simulation concerning the extrapolation of the wind speed for 40 meters of altitude using the data measured at 10 meters either by the power-law 1/7 or by the logarithmic law the results were almost the same or the wind power was much favored and the energy cost was to estimate the cheapest 0.263 ($ / kWh).
• It is clear that the configuration of the system for different altitudes is different and the HOMER software favors wind energy when the wind generator is installed higher.
• The results obtained by HOMER for the altitude of 40 meters using measured data of the wind speed and extrapolating for this altitude are considerably different. The difference is focused on wind turbine production that vary from 20786kWh/year for 10 meters measured wind speed to the 43839kWh/year for 40 meters extrapolated wind speed by power-law, that represent a rise of 111% of the yearly produced energy.
The variation rates were calculated comparing to the reference value concerning the optimization of the hybrid system for 40 measured wind speed data as concluded on comparison lines on the previous table and these rates showed that the extrapolation results are closer to the reference value.

III. Conclusion

Research on hybrid renewable energy systems has shown the advantage of combining different types of generators. In addition to wind and photovoltaic, the use of a conventional energy source (such as electrochemical storage), is very interesting to make the system more efficient in the worst periods of the year. The objective of this system is to produce electricity to meet the demand for a consuming load (50 kWh / day and a peak of 6.76 kW) in an isolated site "Ilamane" in Tamanrasset in southern Algeria.

Optimization of the PV-wind hybrid system was done on the software HOMER and simulated in different cases, the techno-economical results of the four simulations were presented, compared and discussed in our work them in order to optimize the performance of the autonomous hybrid system.

We concluded that extrapolation of wind speed following the power or the logarithmic laws for altitudes highter than 10 meters helps to make a more accurate sizing than any other one that ignores the effect of altitude of the wind turbine. However, it remains less precise than using hourly measurements of wind speed at that altitude, so it is preferebal to use wind speed measured data at the same height where the wind turbine will be placed.

The transition to renewable energy sources and especially to wind power and photovoltaic in Algeria is promising despite the fact that the price of kWh produced by renewable source remains a little expensive in Algeria but more sustainable, and hybrid systems remain the optimal solution for an electrical installation in the south of the country.

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