Evaluation of Electricity Excess in Hybrid Energy System

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Abstract: ***Objectives**: In the present work, a technico-economic study of a hybrid system (wind-photovoltaic-diesel) with fully autonomous electric power supply was carried out using HOMER software in the Tindouf region of Algeria. **Methods / Statistical Analysis**: This study have made based on available climatic data, after studying and analyzing the various possible configurations, we have opted for an optimal configuration consisting of three types of generators: photovoltaic, wind, converter, with a storage system and Connected to the network. The use of a storage system makes it possible to better exploit the renewable potentials available by charging the batteries at times of high production by the wind or PV. **Finding**: The results showed that the integration of renewable energies in the hybrid system represents a rate of 97.3%, of which 82% in wind turbine, and 16% in photovoltaic; AC primary load is 39%, dirty grid is 61%, the power converter develops its maximum power with full batteries and satisfied and accomplished load. **Application / Improvements**: At the same time, an excess of electrical production is reached during the whole year; day and night, with a rate of 59.2%.*

Keywords: Hybrid energy system; solar energy; wind power; inverter; excess electricity

1. Introduction

In today's societies; All activities; whether professional or private, are consuming electrical energy. The production of this energy in the isolated sites is provided by a generator consisting of a thermal engine, which actuates an alternator their size and weight can vary from a few kilograms to several tens of tons [1].

As a result, renewable energies have an inexhaustible and promising source to meet both the population's energy needs and the ever-increasing environmental constraints [2].

The interest of hybrid plants is the decrease in the release of greenhouse gases into the atmosphere.

The use of a hybrid facility is therefore a strategic choice, which is justified by a positive impact either economically or environmentally.[3] this choice becomes very important if the environmental criterion passes first, To remedy the problem of air pollution and as a result of global warming for which a lot of money is wasted without remedying its influences.

Estimating the wind and solar potential available at a given site is probably the most important step in considering the implementation of a system exploiting these two sources of renewable energy.

Hybrid energy systems (wind power and photovoltaics) that are well suited for grid-connected or decentralized production can help solve several energy supply problems. Thus, they can also find application in telecommunications facilities and military surveillance [4, 5].

The hybrid energy system has undergone new developments in the last few years in terms of production management methods, as well as optimization of sizing by specialized software (HOMER, SOMES, RAPSIM. . .).

2. Hybrid Systems

1. Hybrid Energy System Classification:

Hybrid energy systems are classified according to several criteria. However, the most common classifications are chosen [6-7].

a. The Operating Regime:

There are two main groups of hybrid energy systems. In the first group, we find hybrid systems, working in parallel with the electricity grid, also called connected network. These systems help to meet the burden of the country's electricity system. Hybrid systems in the second group operate in isolated or stand-alone mode. They must meet the needs of consumers located in sites remote from the electricity grid.

b. Content of the hybrid energy system:

In this classification according to the content of the system, three criteria can be taking into account. The first criterion is the presence or absence of a conventional energy source. The latter can be a diesel generator, a micro gas turbine. . . etc.

The second criterion concerns the presence or absence of a storage device. The presence of storage makes it possible to ensure a better satisfaction of the electrical charges during periods of absence of a primary resource, to invert to electricity.

The last possible classification is that relating to the type of renewable energy sources used. The structure of the system may contain a photovoltaic system, a wind turbine, a hydraulic generator, or a combination of several renewable sources. The choice of sources is based on technical and economic analysis.

2-Description of Hybrid Energy System

The hybrid power system contains mainly two buses, a DC bus for DC sources and loads and batteries. And an AC bus for AC generators and distribution systems, the interconnection between the two buses is carried out using power electronics converters [8-9-5].

Autonomous hybrid energy systems generally combine two complementary technologies; one or more conventional energy sources (diesel generator), with at least one renewable energy source. The latter like the wind or the photovoltaic does not deliver a constant power. Their association with conventional sources allows uninterrupted electrical production[4].

Most hybrid systems have a battery storage system. The use of hydrogen makes it possible to have a much greater autonomy. But still remains the disadvantage of the limited storage capacity, as well as their high cost. For this purpose, the aim is to minimize the use of storage, and this is one of the objectives of the use of hybrid energy systems [4-5].

In general, there are three main aspects to consider for a hybrid energy system:

- The configuration of the hybrid energy system, which results from a dimensioning according to the available resources, as well as the constraints of use.
- Maximizing the use of renewable resources.
- The quality of the electrical energy supplied to the user.

3. Configurations of Hybrid Energy Systems:

For the hybrid energy system, there are two main configurations: DC bus architecture and mixed CC-AC bus architecture [10-6].

a. DC bus architecture:

In this case, the power supplied by each source is centralize on a DC bus. Thus, AC production systems use rectifiers. The control system is relatively simple, which is the great advantage of such architecture[9]. The disadvantages are mainly the low efficiency due to the battery, and losses in the power converters.

b. Mixed architecture with DC / AC bus:

This architecture has superior performance compared to the DC bus configuration [9]. Indeed, in this case the wind turbine can directly power the AC load, which makes it possible to increase the efficiency of the system. When there is a surplus of energy the batteries charge[5]. For converters, it is possible to have a single bidirectional between the two DC / AC buses, which replaces the two previous converters.

3. Homer Simulation

1. Geographical situation:

Tindouf, also written Tindouf, is the westernmost province of Algeria, having a population of 58, 193 as of the 2008 census (not including the Sahrawi refugees at the Sahrawi refugee camps).2 Its population in reality could be as high as 160, 000 because of the Sahrawi refugee camps. Despite the barren landscape, Tindouf is a resource-rich province, with important quantities of iron ore located in the Gara Djebilet area close to the border with Mauritania. Prior to Algerian independence, the area served as a strongpoint of several tribes of the nomadic Reguibat confederation. The province houses army and airforce bases for the Algerian military, and is strategically important due to its proximity to the Moroccan border, and its location at a four-country border crossing (figure 1).

Its geographical coordinates are 27° 39' 7" North, 8° 12' 52" West

Figure 1: geographical site of Tindouf-Algeria

2. Load charge:

For our study, we choose to provide AC energy to military campus with charge shown in table 1. Hourly and seasonal profiles are shown in figure 2.

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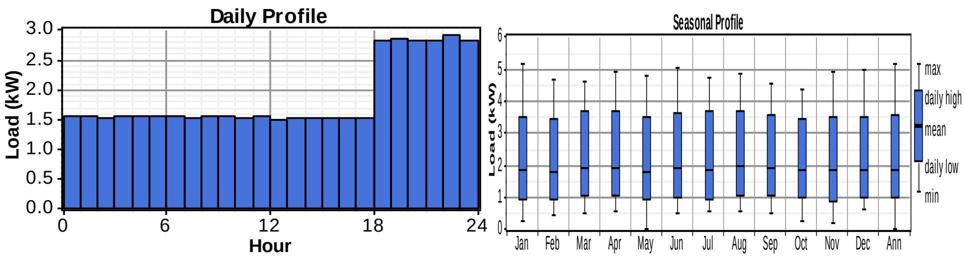
Table 1: daily energy consumption

Equipment	Number	Power (W)	Mean daily use (h/day)	Daily energy (Wh)
Fluoresent lamps	20	18	5	1800
TV/Magnetoscope/PC	10	75	6	4500
Domestic appliances	1	3000	2	6000
Fridge/deep-freeze	5	266	6	8000
Dish-washer/cloth-washer	2	600	2	2400
Other uses	1	3000	7	21000
Total daily energy				43700 Wh/day
Total monthly energy				1311 kWh/month



(a) Daily profile (b) Seasonal profile

Figure 2: Charge profile

3. Hybrid System Configuration:

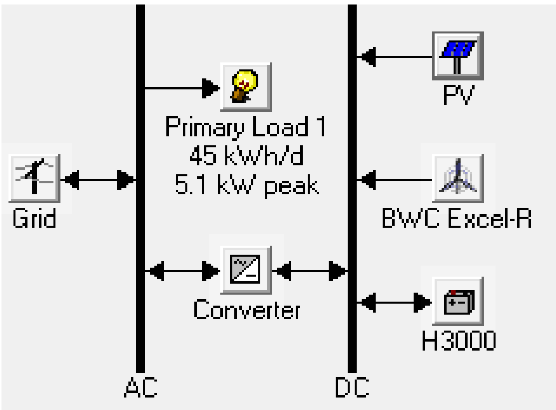


Figure 3: Hybrid system configuration

Our hybrid energy system (figure3), was component with PV pannel, wind turbine, batteries, inverter and primary load, on grid system.

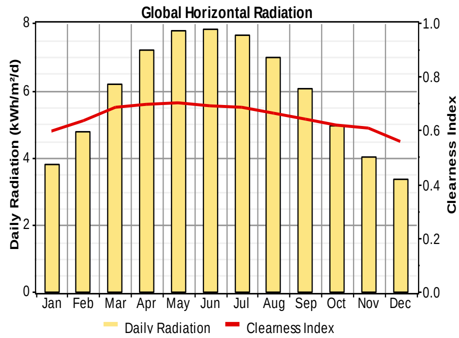
To supervise the output of our system, we follow simulation with two softwares, PVsyst, and Homer Software; with metheorological tools of Tindouf site.

From Homer results we choose, to discuss hourly value, because it’s very clear and better explanatory.

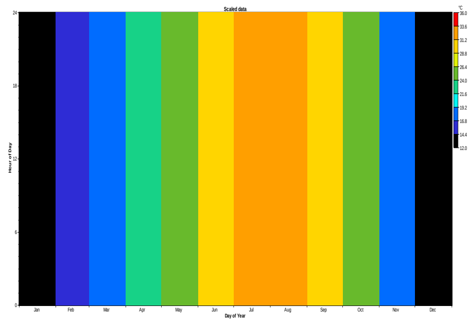
We explain and discuss step by step all components for our hybrid system.

4. Solar power evaluation

a. Solar irradiation and temperature:



(a)



(b)

Month	Temperature (°C)
January	12.6
February	15.4
March	18.7
April	21.7
May	24.8
June	29.2
July	33.4
August	33.2
September	29.4
October	24.2
November	18.6
December	14.2

(c)

Figure 4: Solar Data

(a) Monthly Solar irradiation-and clearness index
(b) Temperature profile in Tindouf site.
(c) Table of temperature value.

Global irradiation: Irradiation is the measure of the energy density of sunlight; it is measured in kWh /m^2. The irradiation is often expressed as "peak power hours", which corresponds to the duration in hours at a constant irradiance level of 1kW / m^2, necessary to produce the daily irradiation. The number of hours of peak power is obtained by integrating the irradiance over all hours of clarity (Figure 1 (a)), for our Tindouf site, daily solar radiation varies from 3.8 to 7.8 Kwh /m^2.

Irradiation Incident: The variation in incident energy (sunshine) causes a variation in the current proportional to the latter and a relatively low voltage variation. This physical phenomenon is interesting when recharging batteries [11]. The short-circuit current is directly proportional to the incident radiation. On the other hand, the open circuit voltage increases rapidly for low illumination levels which is 0.55, and then slowly for higher levels which is 0.72 (Figure 4 (a)).

Temperature: Since the band gap energy decreases with increasing temperature (Figure 4 (b)), more photons have enough energy to create electron-hole peers. As a result, the short-circuit current increases slightly. Isc increases by about 0.07% / EK[12].

The open circuit voltage Voc decreases with the rise in temperature which is in our case between 25.4° and 36° c. This decrease is around 0.4% / EK. The power drops by 0.5% / EK. (Figure 4 (c)).

b. PV power yield:

The efficiency of photovoltaic conversion remains relatively low. This presupposes the use and implementation of techniques to optimize the promotion of this technology by making the most of the power that can be produced.

Irradiance and irradiation depend on location, climatic conditions and time of year. They also depend on the shade of trees and buildings that might exist and the inclination of the surface.

When using photovoltaic panels, it would be useful to be able to accurately determine the duration of sunlight at a particular location on a particular day.

The maximum output power of the cell is given by:

$$P_{MPP}= V_{MPP}.\ I_{MPP}= V_{oc}\ I_{sc}\ FF \qquad 1$$

P_{MPP}, I_{sc}, V_{oc} Are parameters specified by the manufacturer. These values are given for a given amount of sunshine operating temperature and air mass (AM1.5). The yield of the PV cell is given by:

$$P_{MPP} = Voc.\ Isc.\ FF/Pin \qquad 2$$

P_{in}: solar provided power.
FF: forma’s factor
Isc: current of short ciruit
Voc: Voltage of open circuit

c. PVsyst sizing:

After sizing by PVsyst software, we have determined the power of 9808 w, so 10Kw in photovoltaic can be able to produce our load; a result is shown in figure 5:

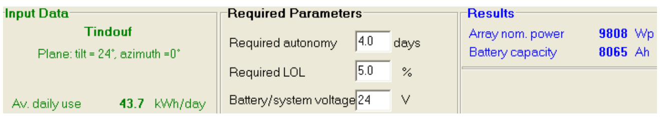
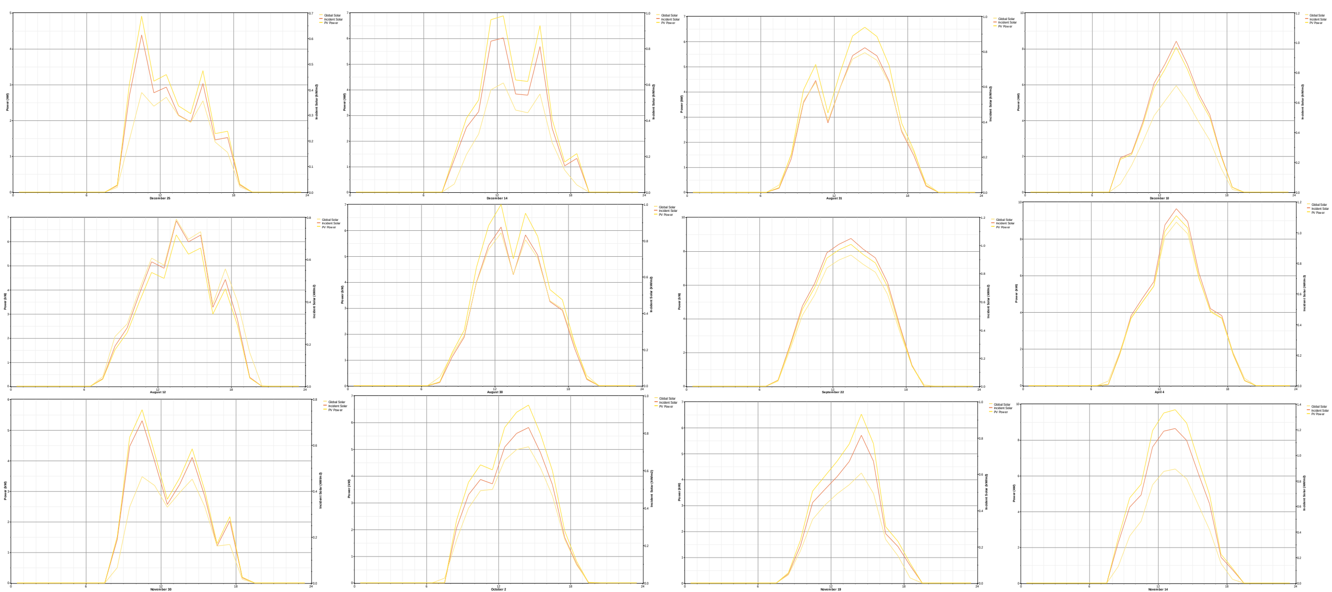


Figure 5: Result of Pvsyst pre-sizing

We considered 10Kw in solar panels, and without solar tracking with the influence of temperature.

d. Hourly values of PV power:



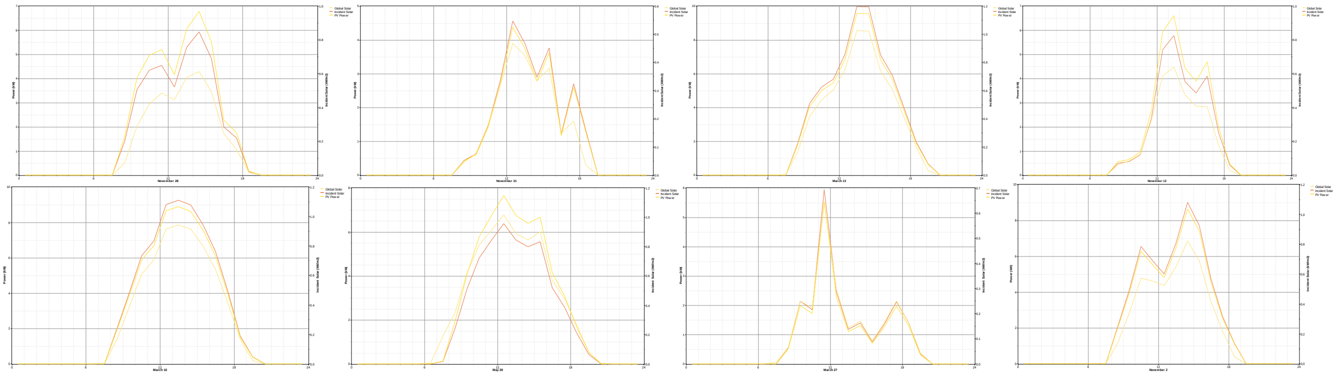


Figure 6: Hourly values of PV power result

From figure 6; it's remarked that during the months of January; February, August, September, October, December. According to the graph of solar radiation figure4 (a), the illumination index is lower, so PV power production is less than the global solar radiation and follows the pace of the incident radiation whereas in the rest of the months, The production is equal to or greater than 6kw. Nocturnal phase production is zero; The maximum developed during the summer is superior to that of autumn, spring and winter.

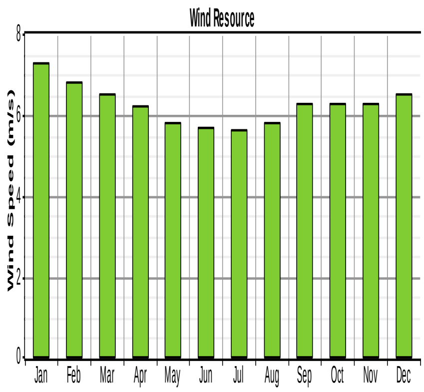
Production reaches its maximum in the period from 10 am to 2 pm during the winter and in the nocturnal phase the production is zero, the maximum developed during the summer is greater than that of autumn and spring. The temperature of the site varies during the year, it reaches values below 25 ° C, during the period from January to May and from October to December, with values ranging from 12.6 ° to 24.8 ° C (figure 2 (c)); Our PV system can produce power higher than its peak power, which in our case is equal to 10 kW.

While in the rest of the months the temperature is above 25 ° C, ranging from 29.2 ° C to 33.4 ° C, which decreases the efficiency of our PV system, and produces less than 10Kw.

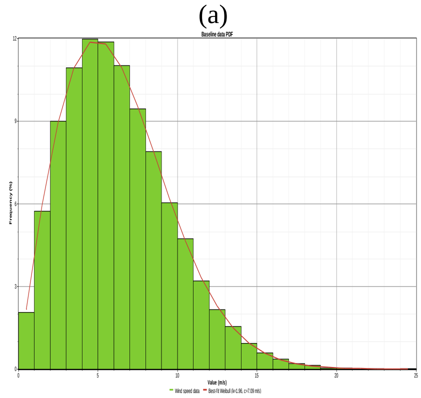
5. Wind power evaluation

a. Wind speed

Note that the wind blows at speeds of less than 6m /s, for four months (from May to August); and during eight months, the wind blows at more than 6m / s speeds, (from September to April), and can reach 7.2m/s. Figure 7 ((a), (c)).



(a)



(b)

Month	Wind speed (m/s)
January	7.2
February	6.85
March	6.6
April	6.3
May	5.8
June	5.6
July	5.4
August	5.3
September	6.2
October	6.55
November	6.7
December	6.95

(c)

Figure 7: wind data

a) Monthly evolution of the mean wind speed for Tindouf site at 11m from the ground.
b) Weibull curve
c) Wind speed value in Tindouf site

Wind speeds for the site of Tindouf are in continuous variation with time, one notices that the average speed for this site is of 7.2m / s. Which is explained by the presence of strong winds during the spring period and the lowest speed is recorded during the winter season about 6 m/s. The following figure 8, shows hourly variation of wind speeds.

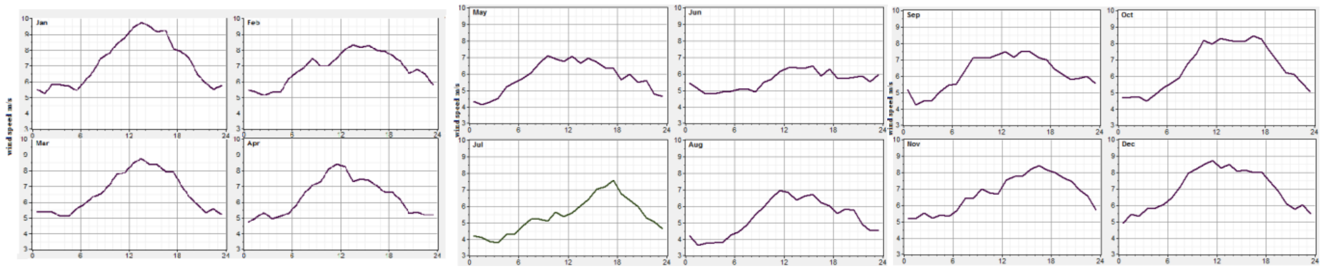


Figure 8: Variation of measured wind speeds for Tindouf region

Note that the Weibull distribution is not symmetric which is not explained by the inclination of the pace. This makes it possible to say that Tindouf site is sometimes characterized by strong winds figure 7 (b).

The Weibull distribution gives us an idea of the frequency with which the wind blows for such a speed.

The values of the Weibull parameters k and C as well as the average wind speed for Tindouf site were determined by HOMER (Table 2).

Table 2: Weibull parameters of Tindouf site

Parameter	**K**	**C (m/s)**
Value	1.96	7.09

b. Wind power:

Wind energy is a non-degraded "renewable" energy, geographically diffused, and especially in seasonal correlation (electrical energy is much more demanded in winter and it is often at this period that the average wind speed is the most high).

According to the EULER theorem, the force exerted by the air on the wind turbine is given by:

$$F = \rho \cdot SV \cdot (V_1 - V_2) \qquad 3$$

The power Paero extracted is given by the second law of Newton:

$$P_{aero} = F \cdot V = \rho \cdot SV^2 (V_1 - V_2) \qquad 4$$

The variation of the kinetic energy E_ (c) of the mass of air that passes through the wind turbine is also the absorbed power:

$$\frac{\Delta E_c}{\Delta t} = P_{aero} = \frac{1}{2}\rho \cdot SV \cdot ({V_1}^2 - {V_2}^2) \qquad 5$$

We can deduce:

$$V = \frac{V_1 + V_2}{2} \qquad 6$$

The power Pmt corresponding to a theoretical wind undisturbed through this same surface S without decreasing its speed V_1:

$$P_{mt} = \frac{1}{2}\rho \cdot S \cdot V_1^3 \qquad 7$$

The power coefficient is defined as the ratio between the extracted power and the theoretical total available power Paero / Pmt. It varies as a function of the orientation of the blades (β) and the specific speed ratio (λ)

$$C_p = \frac{P_{aero}}{P_{mt}} = \frac{\left(1+\frac{V_1}{V_2}\right)\left(1-\left(\frac{V_1}{V_2}\right)^2\right)}{2} \qquad 8$$

This coefficient has a maximum of 0.59, called the Betz limit which is never reached. By combining equations (7) and (8), the mechanical power P_aero available on the shaft of a wind turbine is expressed as follows:

$$P_{aero} = \left(\frac{P_{aero}}{P_{mt}}\right) P_{mt} = C_p(\lambda) P_{mt} = \frac{1}{2} C_p(\lambda) \cdot \rho \cdot S \cdot V_1^3 \qquad 9$$

With:

$$\lambda = \frac{\Omega_{turbine} \cdot R}{V_1} \qquad 10$$

$\Omega_{turbine}$: Speed of turbine rotation

R: Length (radius) of Blade

To extract the maximum aerodynamic power, it is necessary that Cp is maximum and λ optimal.

Thus, it can easily be deduced that if the generator operates at a fixed speed, the theoretical maximums of the power curves are not exploited. Therefore, in order to have an optimized energy transfer, the speed of rotation of the generator must follow the curve passing through the maximums for different value of the wind speed, in other words the variable speed operation allows an optimal exploitation of the power Aerodynamics available [13].

For a wind speed V1, the optimum rotational speed (Ωopt) value is obtained from equation (10).

$$\Omega_{opt} = \frac{\lambda_{opt}}{R} \cdot V_1 \qquad 11$$

For our system; Four BWC excel-R synchronous wind turbines, with a 7.5 kw DC power, were installed at a height of 25m, with a starting speed of 3m/s, and developing a power of 1.379 kw at 6m/s. Figure 9.

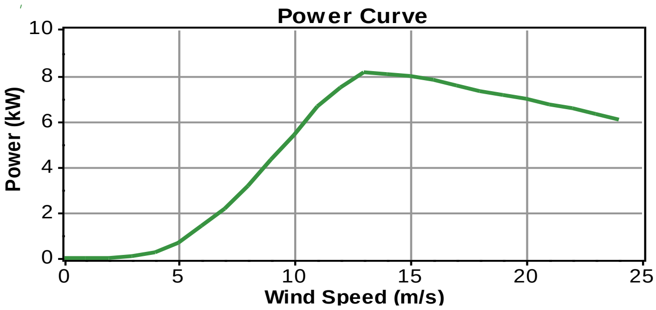


Figure 9: Power curve of wind turbine

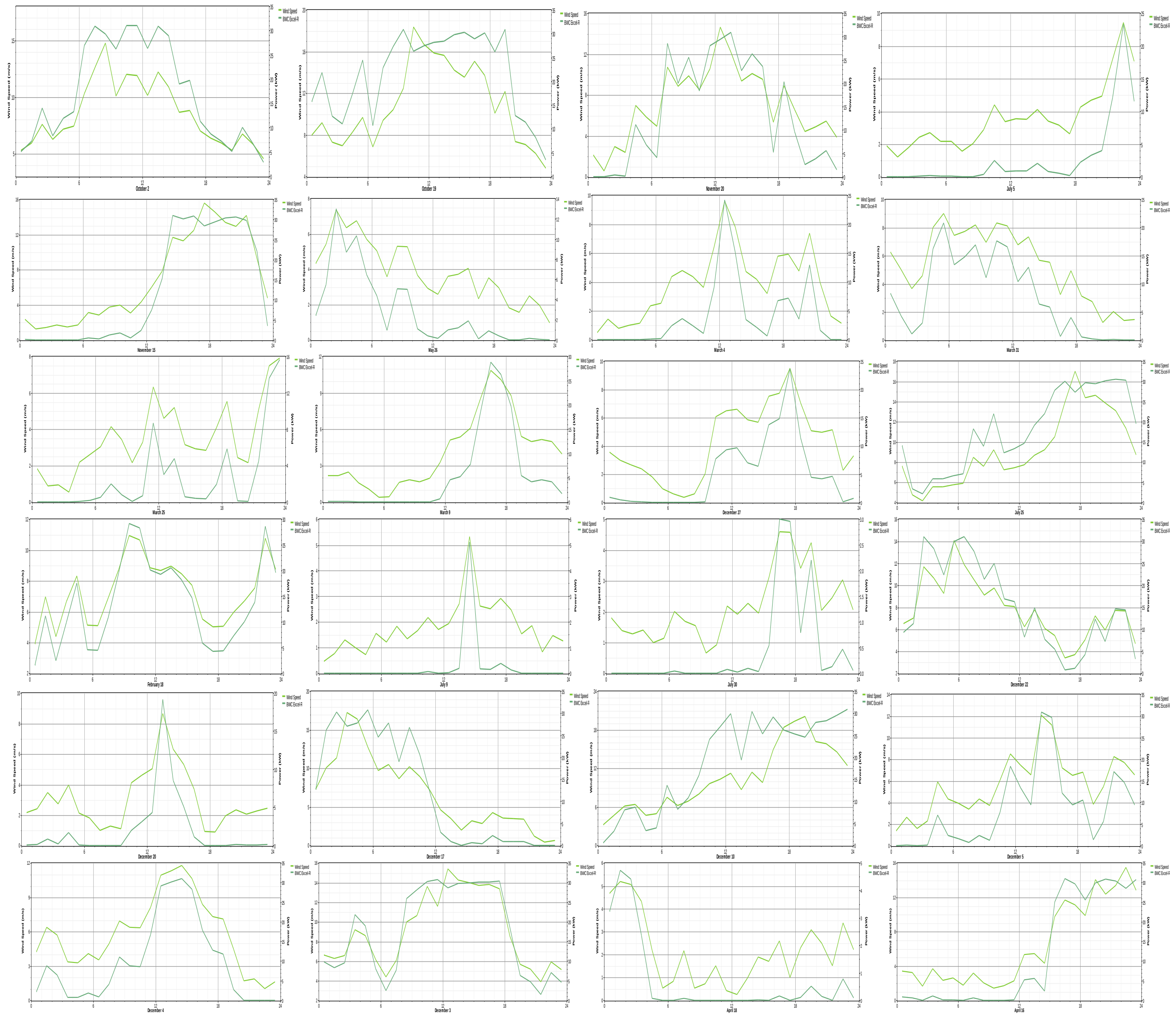


Figure 10: Hourly results value of wind power

The wind data is important, the power developed by the wind turbine, follows the lighter speed; but the power developed is zero in cases where the wind speed is less than the speed at which the wind turbine starts. The most important thing is that the energy production continues at night when the solar is zero (figure 10).

6. Battery storage:

Since solar energy is not available at night, it is necessary to equip autonomous photovoltaic systems with batteries that store energy and return it in time.

Before presenting the way to determine the various parameters of this model, we recall some electrical parameters used to characterize a battery, the latter are:

Nominal capacity (Q): This is the maximum number of ampere hours (Ah) that can be extracted from the battery, for given discharge conditions.

The state of charge "SOC" (State of charge) is the ratio between current capacity "q" and nominal capacity "Q".

$$SOC = q / Q \quad (0 \leq SOC \leq 1) \qquad 12$$

If SOC = 1; the battery is fully charged and SOC = 0, the battery is fully discharged.

Load (or Discharge) is the parameter that reflects the ratio between the rated capacity of a battery and the current to which it is charged (or discharged). It is expressed in hours. For example, for a 150 Ah battery discharged at 5 A, the discharge regime is 30 h.

Lifetime is the number of charging / discharging cycles that the battery can support before losing 20% of its nominal capacity.

According to the PV Syst software dimensioning, (figure 11) it is noted that the battery charge state is 67.1%. Which ensures a long battery life, and probability of loss of load is 5%.

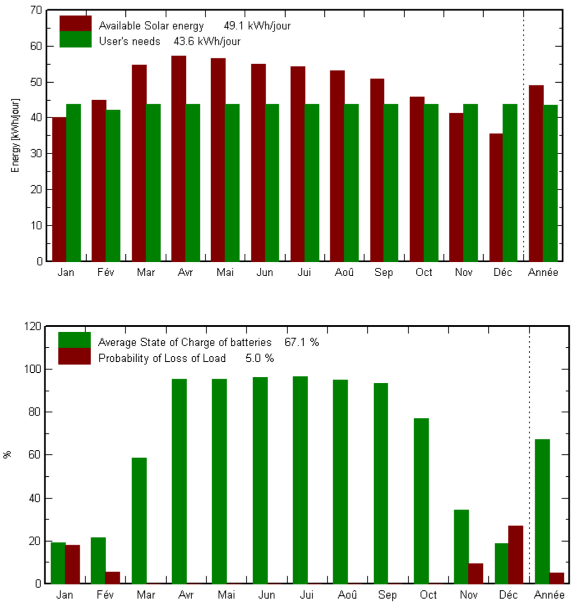


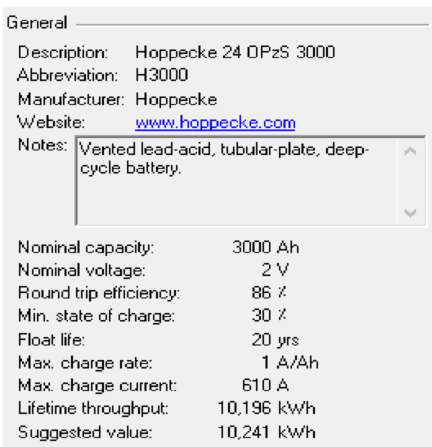
Figure 11: solar energy production and loss of load

Table 3: SOC of battery and missing-excess of system

Month	Incident Kwh/m². day	PV available Kwh	Demand user Kwh	Excess Kwh	Missing Kwh	State of Charge %	Pr. LOL %	Fuel (liter)
January	5.1	1242.9	1354.7	00	243.0	19	17.9	162.0
February	5.7	1299.8	1223.6	00	69.8	22	5.5	46.5
March	7.0	1696.2	1354.7	00	00	59	00	00
April	7.3	1714.5	1311.0	221.9	00	95	00	00
May	7.2	1755.7	1354.7	238.8	00	95	00	00
June	7.0	1647.9	1311.0	180.3	00	96	00	00
July	6.9	1683.8	1354.7	169.9	00	97	00	00
August	6.8	1648.6	1354.7	136.9	00	95	00	00
September	6.5	1522.6	1311.0	49.3	00	93	00	00
October	5.8	1420.5	1354.7	00	00	77	00	00
November	5.2	1234.7	1311.0	00	114.3	35	9.2	76.2
December	4.5	1103.7	1354.7	00	363.6	19	26.8	242.4

According to the table; SOC of battery exceeds 90% from April and reaches 97% for the month of July and varies between 19 and 35% for the period between November and February (table 3), failing to meet the demand; requiring backup energy, which is expressed in fuel oil and which is replaced by wind energy in our hybrid system.

For our system we choose battery H3000; with follow technical characteristics of lifetime (20 years), discharging current; and trip efficiency (86%); shown in figure 12.



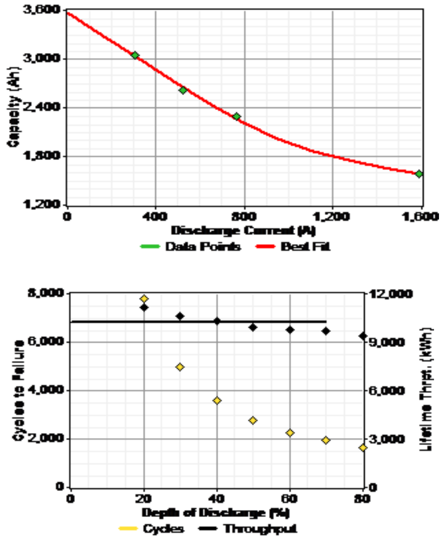
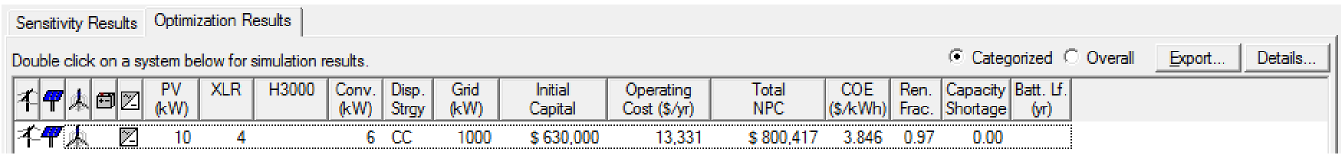


Figure 12: Technical data of chosen battery

7. Optimal solution:

Homer gives us optimal solution of hybrid energy system with better yield as follow:



PV (kW)	XLR	H3000	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Batt. Lf. (yr)
10	4		6	CC	1000	$ 630,000	13,331	$ 800,417	3.846	0.97	0.00	

Figure 13: Optimal solution of hybrid system from Homer software

Our simulation gives us an optimal technical and economical solution, of purposed hybrid system, taking all technical characteristics of each element and component.

So as shown in figure 13, optimal case is to consider 10 Kw of PV power; 4 wind turbine XLR, inverter with 6 Kw.

Table 4: Evaluation of hybrid energy system

Production	**kWh/Year**	**%**
PV array	17.704	16
Wind turbine	91.055	82
Grid purchases	2.964	3
Total	11.724	100
Consumption	**kWh/year**	**%**
AC primary load	16.279	39
Grid sales	25.080	61
Total	41.359	100
Quantity	**kWh/year**	**%**
Excess electricity	**66.099**	**59.2**
Quantity	///////////////	**Value**
Renewable fraction	//////////////	**0.973**

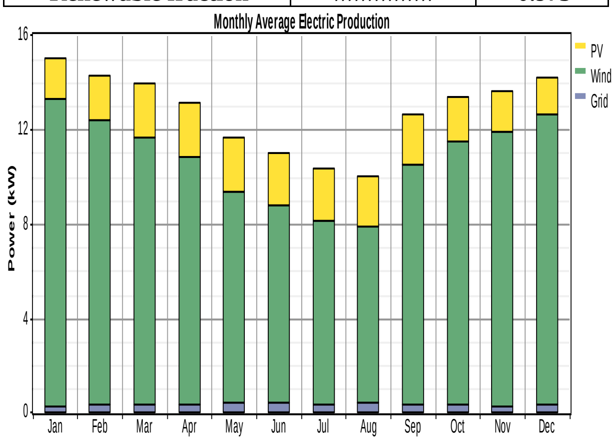


Figure 14: Monthly electric production

From figure 14; we can deduce that wind turbine produce a big quantity of energy for our system and PV power is less than; but grid presents just a little value.

And we can evaluate this production from table 4; who‘s 16% for PV system; 82% for wind turbine, and just 3% was provided by grid.

The energy allows to primary load is 39%, and a grid sale is 61% from converted energy.

And we can produce a strongly excess electricity value who can reach 59.2%, what must be valorizing for other load, but the size of our inverter is insufficient to transmit it to grid.

8. Inverter:

We choose an inverter for 06kw, who can operate simultaneously with AC generation.

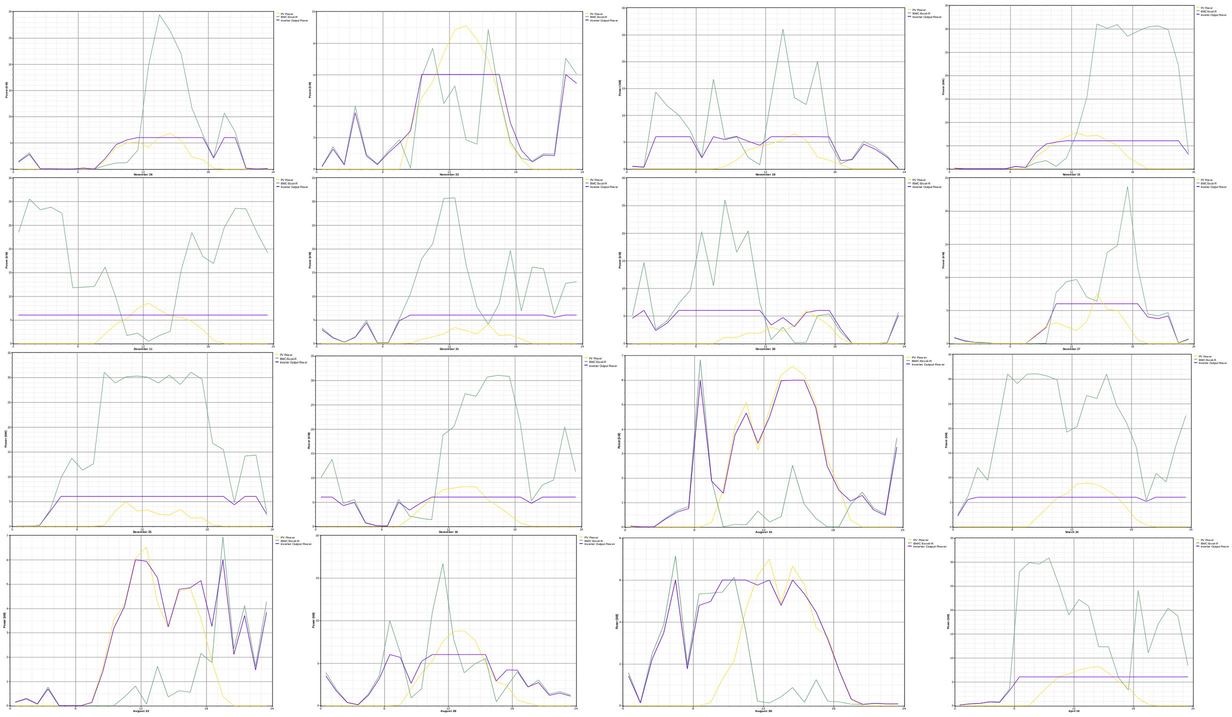


Figure 15: Hourly value of inverter output

From figure 15above, it can be seen that during the day, when the PV system produces power is equal to that of the energy converter, the latter develops its maximum power which is 6 kw.

When the PV power is lower than that of the converter, and the power wind is zero, converter develops a power less than its limit.

The same case of PV and wind less than the power of the converter, we have two cases:

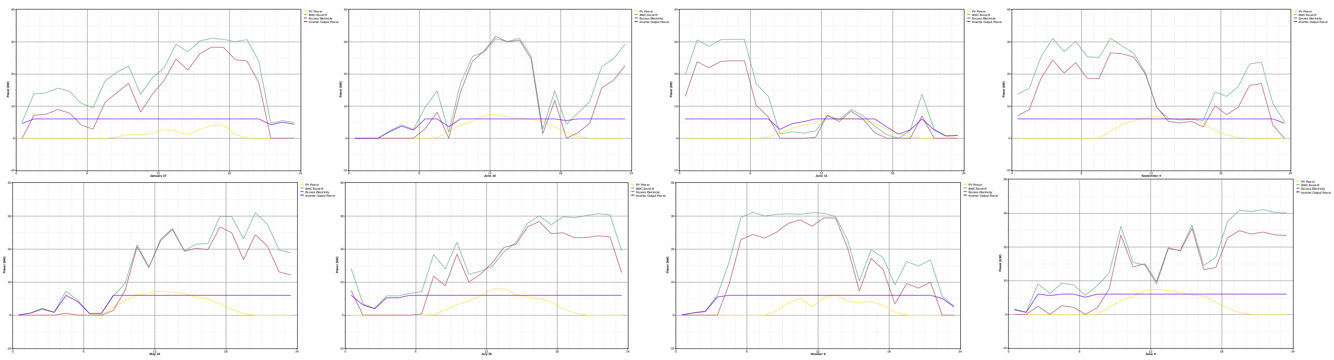
$$PV + Wind \leq inverter \quad (13)$$

The converter develops a power less than or equal to its maximum value, but the excess is zero.

$$PV + Wind > inverter \quad (14)$$

Our converter develops its maximum.

9. Electricity excess:



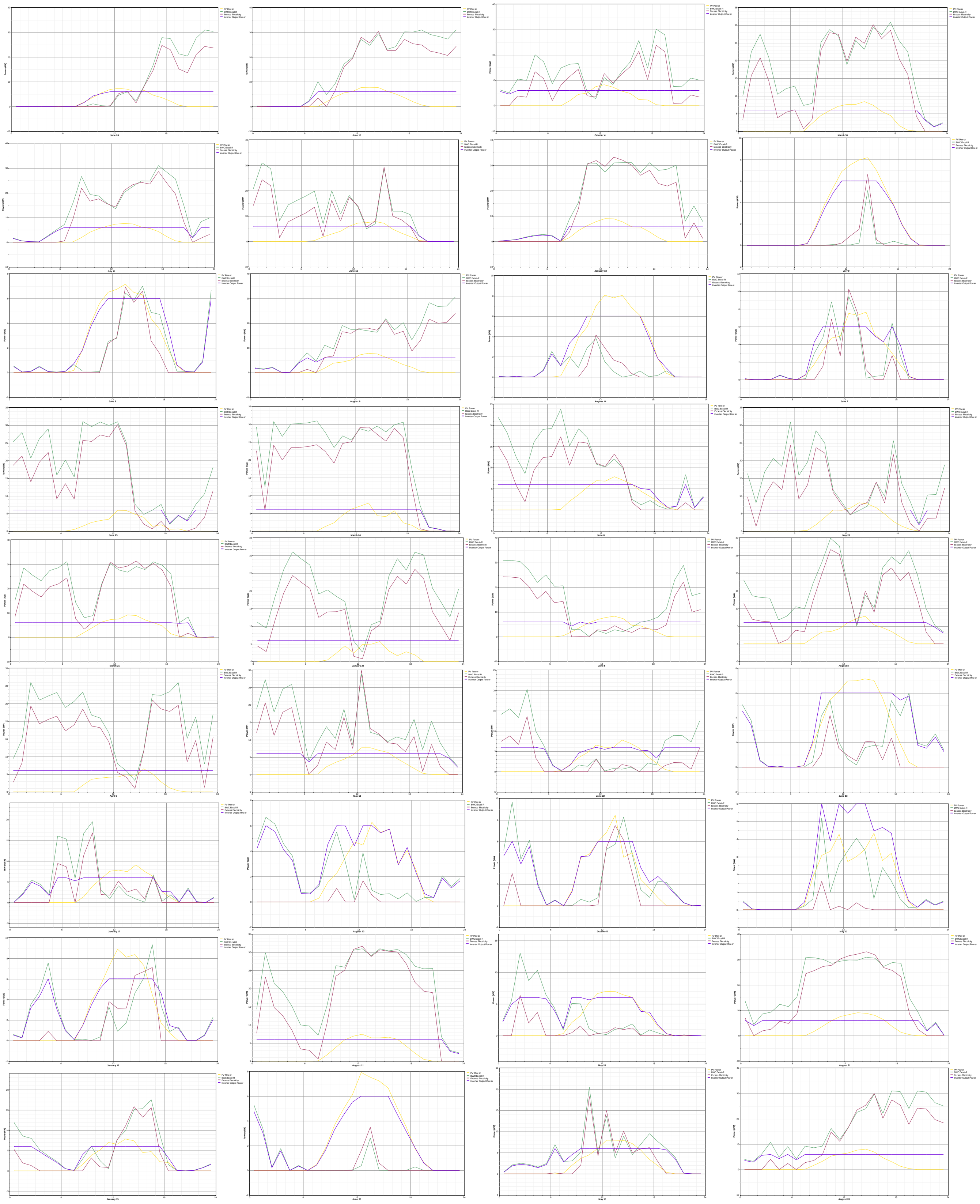


Figure 16: Hourly value of electricity excess

From the results resume in figure 16; we can deduce, that when our inverter develops her maximum power which is 6 kw; everything else that is developed by the wind generator becomes an excess of energy.

In other hand, when our converter develops a power less than its limit, the energy excess is zero.

The converter develops its maximum power, when the total value of PV power and wind power is bigger than Maximum power of inverter, the excess is always positive.

And during the night it follows exactly the wind production, if this production is superior to that of the converter, there is an excess; If it is less than or equal, all the electrical production of the wind turbine is converted.

But in the case where this production is zero, there will be no conversion of energy.

From Figure 14; where the solar production is higher than that of the converter power, and the wind turbine develops a production less than converter power; the excess is equal to:

$$\text{Excess} = (\text{PV}+ \text{wind power})\text{-inv} \qquad \textbf{15}$$

4. Conclusion

The excess production of a hybrid system always depends on the sum of production of the two systems; It may be null; Than in the nocturnal phase when the wind turbine does not develop energy and is always positive in other cases reaching very large values equal to the sum of the two sources.

This excess is useless, it can't be converted for the burden of the consumer, nor can it be injected into the network; Since the converter is sized according to the peak load, so the chosen wind turbine develops very high powers for the wind speeds of the site, and which exceeds the maximum load, this is proposed to ensure overnight production where the photovoltaic is zero.

So to remedy this excess which is a financial and energy loss, one must make the judicious choice of the powers of the components of the hybrid system, and the optimal dimensioning.

This study will be the subject of another article to be published shortly.

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