Energetic and Cost Analysis of Two Conversion Systems Connected To The Grid By Using Homer Pro

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Received: 31.05.2015 Accepted:20.07.2015

Abstract- This paper presents a comparison between a wind turbine farm and photovoltaic park connected to the grid for the supply of a village in the region of Sfax, Tunisia. The study is based on an energetic economic approach according to wind speed, solar irradiation, temperature, time profile of energy consumption and estimated cost of the installed system. Many solutions were obtained through simulations by the Homer Pro environment. Indeed, the optimal solution had the maximum integrated renewable energy with a minimum recourse to the electric grid. Results showed the technical and financial features of different configurations obtained for the supply of our site. By treating the solutions obtained by the two systems, we find that wind energy is the best energy solution (provides 79% of energy consumed), the lowest in terms of cost per KW / H (0.036 €) and least polluting as compared to a photovoltaic park located in the same geographical site and connected to the same load.

Keywords Wind turbine farm, Photovoltaic Park, Homer pro, Optimization, Grid, Cost.

1. Introduction

Face to the growing demand in electricity and in order to minimize the exploitation of polluting fossil fuels (oil, gas…), several countries were inclined to renewable energy i.e. biofuel, wind power, photovoltaic energy, solar concentrators, hydro, geothermal, tidal and wave energy....[10,12].

Among all, wind and photovoltaic energy have raised special interest of researchers who conducted investigations in order to increase the efficiency of the electromechanical and photovoltaic conversion on the one hand and to improve the quality of energy supply on the other. This kind of sources can be used whether as an alternative or compliment to conventional generation sources. Recently, these sources become the most promising solution in the field of green energy, either decentralized through other sources of energy to power a remote site, or connected to the grid [1, 2, 3].

In this context, the present work aims at electrifying a village with an urban zone and an industrial site through the implementation of a wind turbine farm or photovoltaic park. The area is already connected to the grid, which provides the energy required to meet the needs if the weather conditions are insufficient [4,5,6,8]. The system is designed according to the wind potential of the site, the solar irradiation, the temperature, the analysis of the load profile during a year time, the capacity of the systems and the ability to receive electricity from the grid when needed while considering the renewable power as a primary source [14,15,16].

An optimal solution is selected according to the simulation results taking into account the technical and financial aspects of the simulated systems. This paper is arranged in two parts: The first part provides a general description of the studied system. The second focuses on the technical and economic assessment of the Homer pro environment simulations [17,18].

2. System configuration

Homer Pro is a simulation and optimization program known for its reliability in the design and analysis of electric energy conversion systems in two forms: decentralized to power remote sites, or connected to the power grid [9,11].

In our study, we will compare two power conversion systems, a wind turbine farm based on a double-fed induction generator and a photovoltaic park, connected to the grid shown in **Fig.1**, which aims to electrify a village in the region of Sfax. Overproduction is injected back into the grid. Indeed, meteorological parameters, load, cost and design for each device, constraint, emission, contribution to the electrification are all involved in the optimization and the choice of the desired system [13].

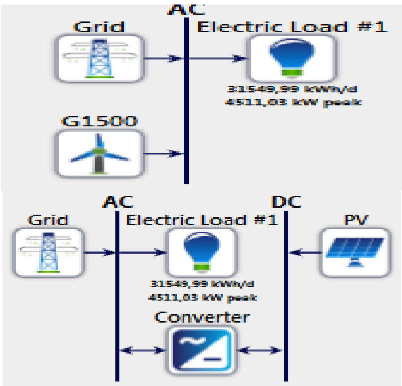

Fig. 1. Wind turbine farm and photovoltaic park configuration system.

3. Data base Parameters

3.1. Climatic data and load profile

➢ Geographical presentation of the studied site

This study deals with a site connected to the grid in the region of Sfax shown in **Fig. 2**, the second largest city and economic center of Tunisia. Its geographical location is 34° 44' north, 10° 46' east and the time zone is GMT +01: 00.

Fig. 2. Tunisian map.

As for meteorological parameters, we obtained from the Tunisian National Institute of Meteorology the average monthly temperatures, wind speed and solar irradiation during the last five years. Relying on site astronomical data, we obtained the following data:

➢ Wind

HOMER pro allows us to identify and represent the Weibull density probability function. According to site data, it is able to identify the measures of the wind distribution presented by the **Fig.3**:

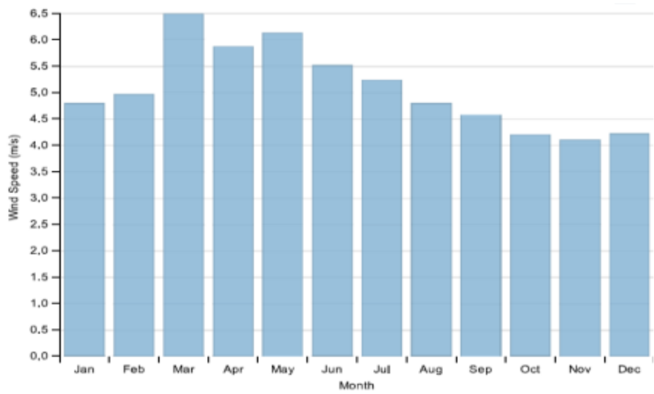

Fig. 3. Wind monthly density of Sfax [7].

To implement a wind turbine farm, it is first necessary to consider the site appropriateness. A good performance of wind is obtained for a wind speed of around 5m/s; which confirms our choice of energy conversion system.

➢ Temperature

Figure 4 shows the average monthly temperature variation during the five last years. According to the histogram, we notice that the temperature exceeds 25 °C during six months every year.

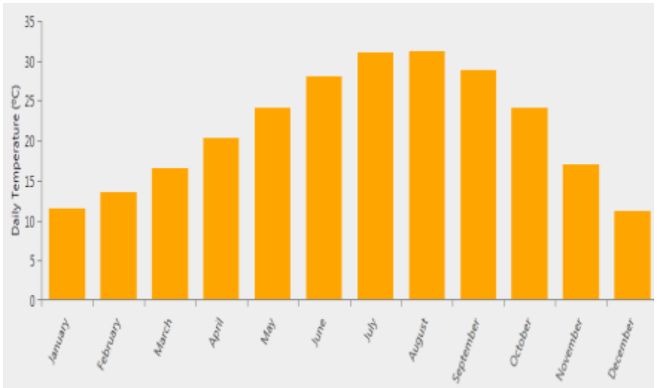

Fig. 4. Monthly temperature of Sfax [7].

➢ Solar irradiation

Average solar irradiation is recorded on the site (24 values per day) illustrated from the **Fig. 5**.

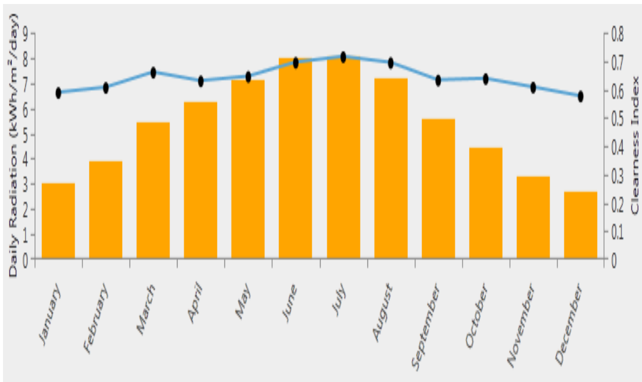

Fig. 5. Monthly solar irradiation of Sfax [7].

The monthly average of the horizontal radiation is given by the average daily solar irradiation which is around 5.751kWh/m²/day; so this is a considerably large and exploitable potential along the year.

- Load profile of the studied site

The load profile is presented in **Fig 6**. We based our study on the energy consumption of a residential village and industrial area per hour. Indeed, during the day, the oil mills and workshops operate, thus the high level of electricity consumption. On the other hand, consumption drops conspicuously during the night despite the urban use in the village. We could determine the maximum power to provide for our application site; meanwhile, the load still varies during the day and the demand for electrical energy varies over time.

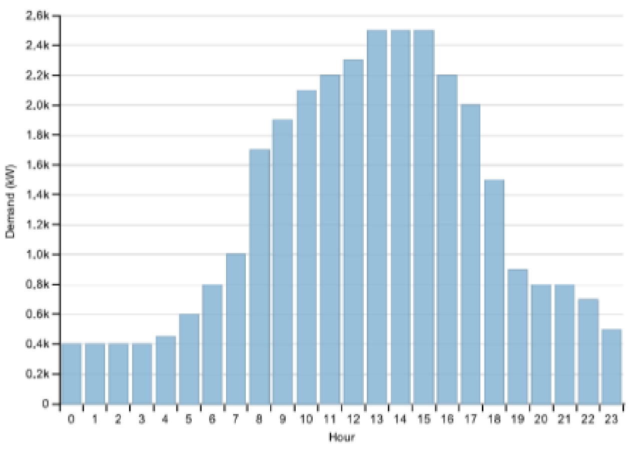

Fig. 6. Daily load profile

4. Power systems

4.1. Electric Grid

Our system models the state of grid and defines the parameters (the cost of conventional energy KW/h, the cost of renewable energy KW/h, energy demand in the three regimes (off-peak, shoulder, peak), it can even model demand and the energy state of the grid by easier and more readable figures with a possibility to specify the duration of demand peak. It was necessary to define the demand and energy costs (green or conventional) during each period (peak, off-peak, shoulder), according to the specific price list provided by the Tunisian Company of Electricity and Gas, which exclusively monitors electricity supply in the whole country in case of energy sale or purchase.

4.2. Wind turbine farm

The wind turbine is a device that converts kinetic energy of wind into mechanical energy. Using the power coefficient $C_p(\lambda)$ aerodynamic power is calculated by the following expression [23]:

$$P_{aero} = \frac{C_p(\lambda).\rho.S.V^3}{2} \qquad (1)$$

Based on the load profile, the GENRIC 1.5 MW brand was chosen as the wind turbine to implement in our site with the power curve shown in **Fig.7**.

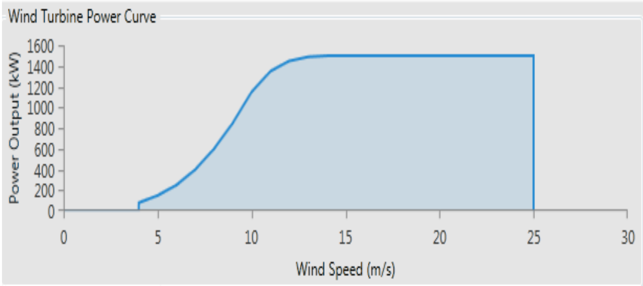

Fig. 7. Power coefficient curve.

Table 1 presents the costs chart mentions the number of wind, with 1.5 MW as power supply that can be integrated into our facility, the purchase cost, the replacement cost and its operating and maintenance costs.

Table 1. Table of wind conversion system costs

Capacity	Capital (€)	Replacement (€)	Operation Maintenance (€)	Quantity
1	1300000.00	1300000.00	13000.00	[0-5]

4.3. Photovoltaic Park

The PV panel converts solar energy into electrical energy by PV cells connected in series and / or parallel to reach the desired value of voltage and current at the output of the PV panel (PV). The PV power increases when the irradiation increases and decreases when temperature increases. It is important to consider design constraints for efficient generators [19]. The PV array is designed as follows:

- Step 1: Design of PV modules = technical characteristics of the photovoltaic modules, total power installed, Calculation of number of modules

- Step 2: Design of inverters when we chose of DC / AC inverters, technical data, checking the inverter/string compatibility

First of all, we start by fixing the module to be used. We chose to work with polycrystalline modules with 260W_p unitary powers.

The peak power to be installed is given by the following formula:

$$P_c = \frac{B_j}{\eta_{inverter} * E_j} \qquad (2)$$

P_c : The peak power

B_j : The daily needs for electricity (kWh)

$\eta_{inverter}$: Inverter efficiency

E_j : Irradiation (kWh/ m²)

The provisional number of modules is therefore calculated as follows:

$$N_{panels} = \frac{P_c}{P_{c\ unit}} \tag{3}$$

Table 2 presents the costs chart, the different power panels that can be integrated into our facility; the purchase cost, the replacement cost and its operating and maintenance costs are mentioned.

Table 2. Table of photovoltaic conversion system costs

Capacity (KW)	Capital (€)	Replacement (€)	Maintenance operation (€)	Size (Kw)
1	1300.00	1300.00	13.00	[0-2500]

4.4. Inverter

A converter is a circuit which converts whether an alternative voltage/current into continuous or vice versa. Indeed, we opted for a reversible converter that functions as an inverter for PV energy that powers an alternative charge. The string inverters architecture seems the most appropriate. However, it should be limited to the condition:

$$0.8*P_c \leq P_{inverter} \leq 1.2*P_c \tag{4}$$

Table 3 includes the different power converters that can be included in our facility, the purchase cost, the replacement cost and its operating and maintenance costs.

Table 3. Inverter system costs

Capacity (Kw)	Capital (€)	Replacement (€)	Maintenance operation (€)	Size (Kw)
1	300	300	3	[0-2500]

5. Energetic and economic approach by HOMER pro

The aim of our study is to choose the optimal system for electrical supplying a village connected to the grid in the region of Sfax. During the first part, a meteorological and technical study aims to describe the power systems that we will meet during our study. To achieve our target, the results obtained by the two systems will be treated according to three aspects such as energy aspect, economical aspect and environmental aspect:

5.1. Energy aspect

Figure 8 presents the monthly load profile. During the day, the oil mills and workshops operate, thus the high level of electricity consumption. On the other hand, consumption drops conspicuously during the night despite the urban use in the village.

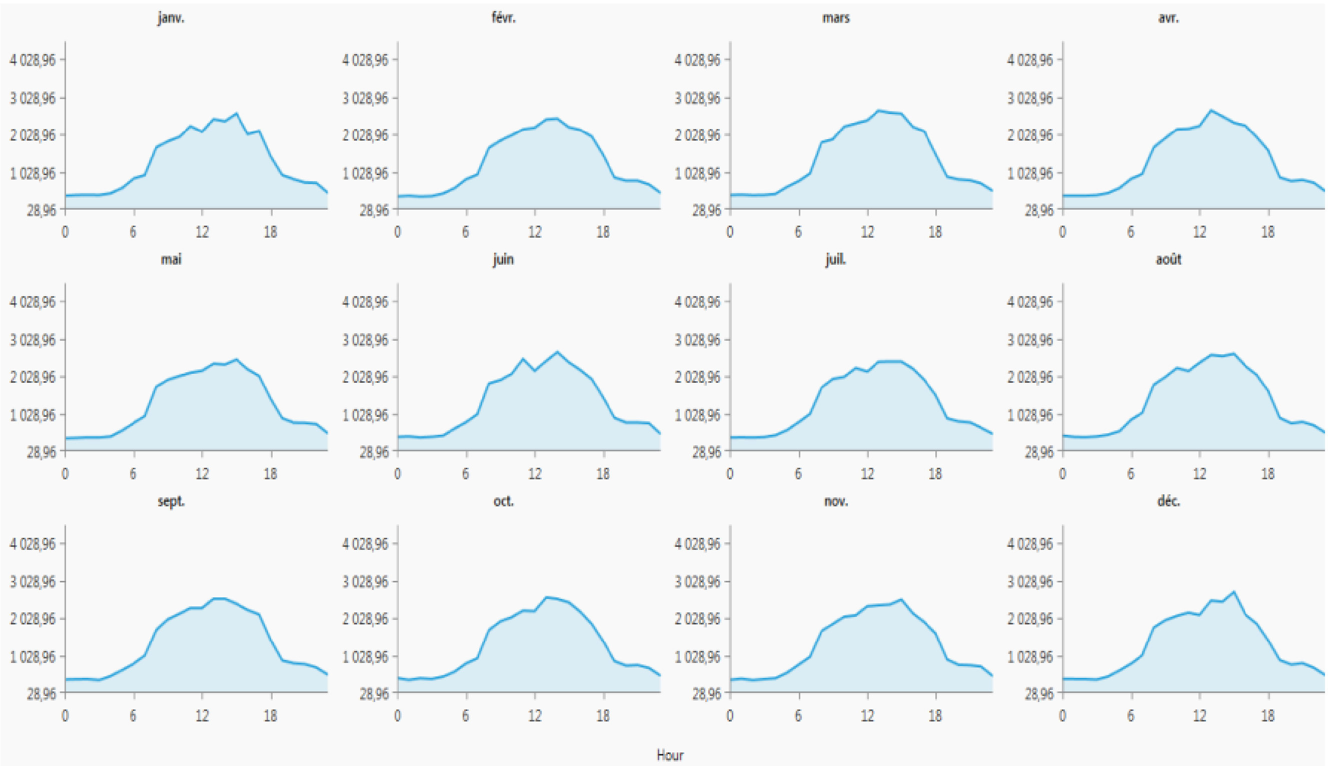

Fig. 8. Daily load profile.

Figure 9a and figure 9b show the rate of production for each kind of conversion systems. Indeed, the renewable energy conversion system is characterized by fluctuation power supply due to the randomness of the primary source (wind, temperature, solar irradiation). We will notice that the wind energy exceeds the energy request by the load in most of the time. In the other case, the production of photovoltaic energy is ensured from 6am until 6pm with a small improvement during summer. This shows that it cannot meet the energy needs throughout the day.

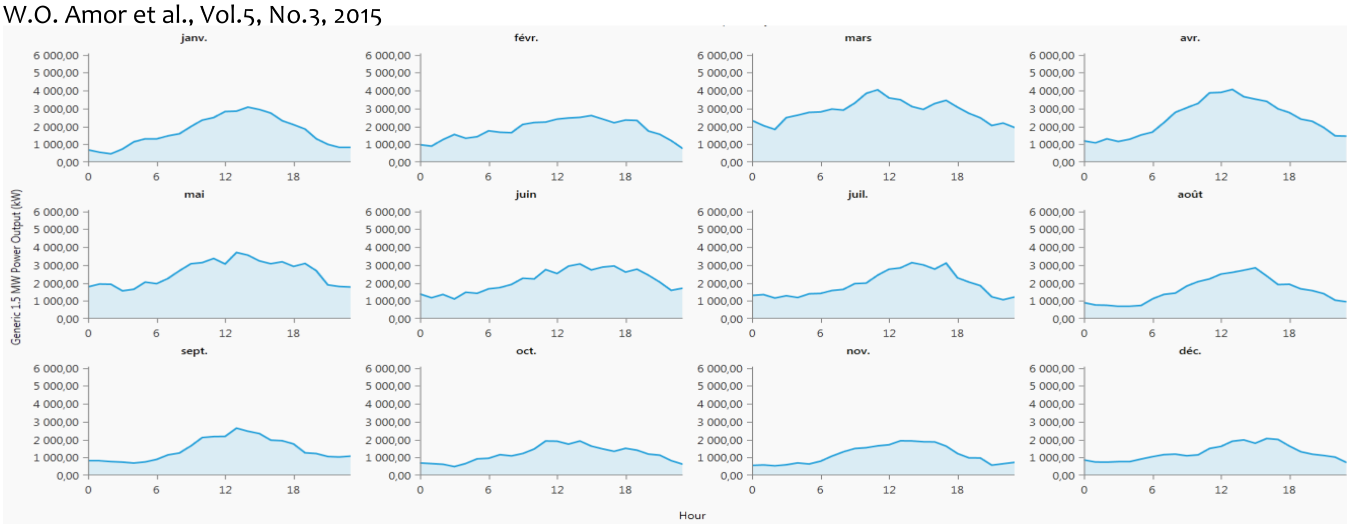

Fig. 9a. Rate of energy production from renewable sources of wind turbine.

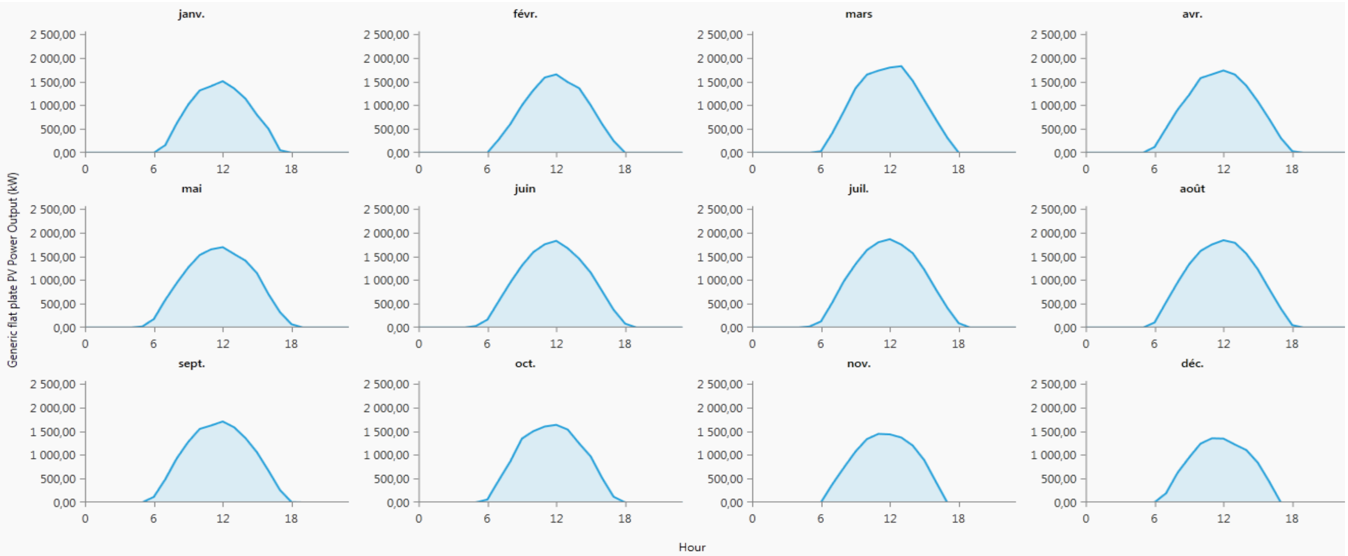

Fig. 9b. Rate of energy production from renewable sources of photovoltaic system.

Figure 10a and figure 10b present the penetration rate of electrical energy supplies by one of the two systems its ability to electrify the load. Comparing the results, we notice that the wind energy conversion system covers almost the whole day; in return, the second system provides electrification for a limited period (presence of solar irradiation) [22].

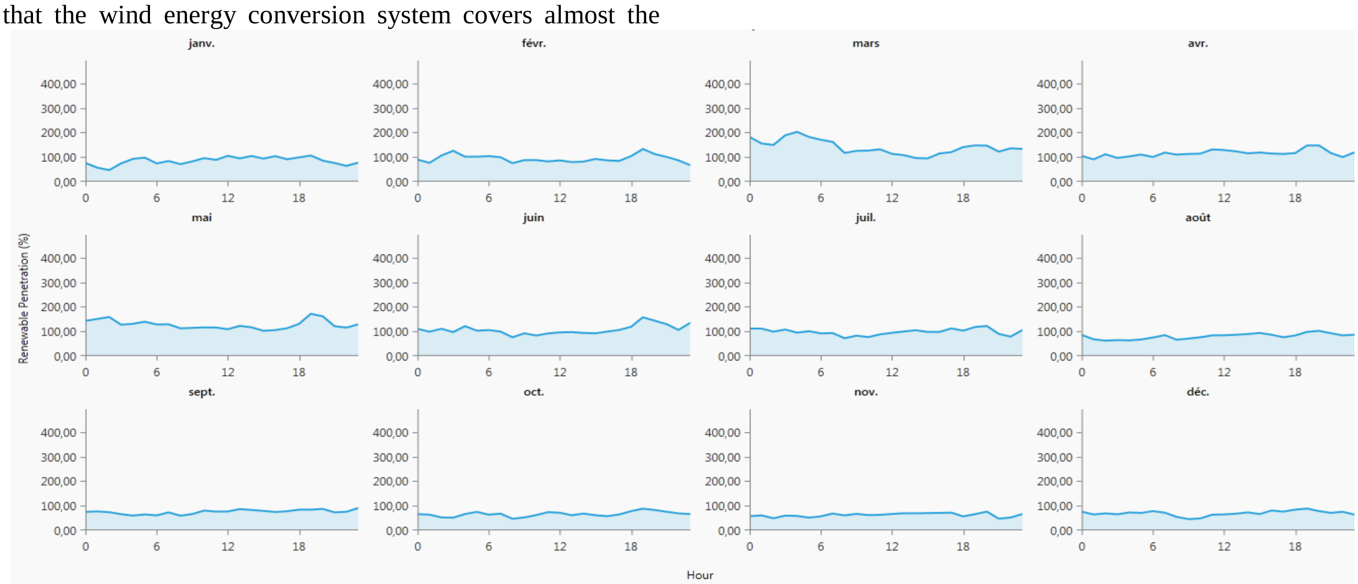

Fig. 10a. Rate of renewable energy penetration of wind turbine system.

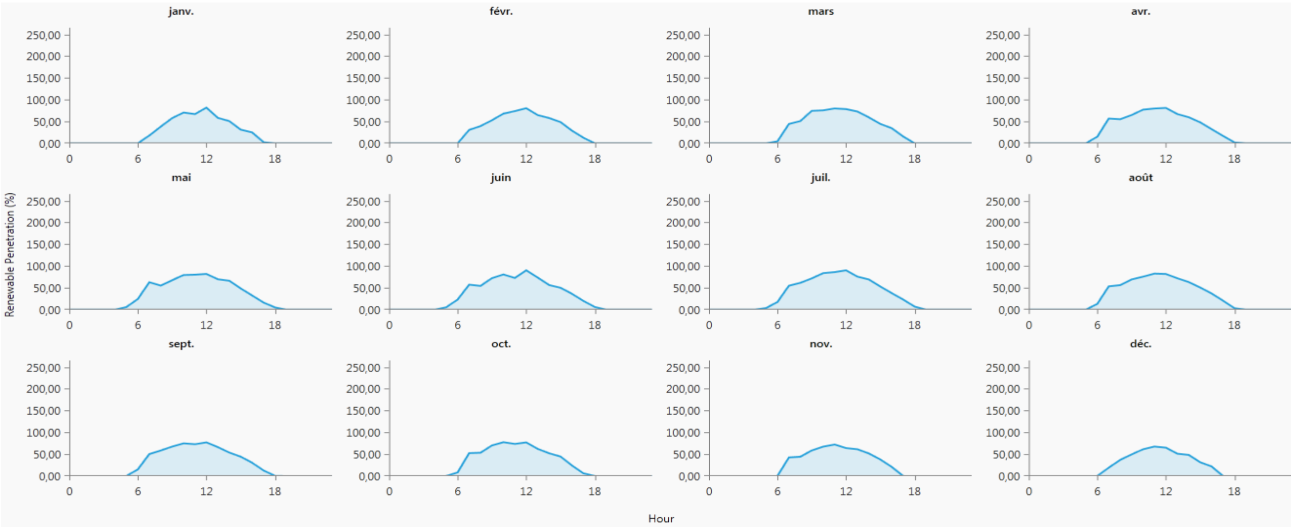

Fig. 10b. Rate of renewable energy penetration of photovoltaic system.

The difference between the energy produced by the conversion system and its participation to power the load has excess production to be injected into the grid to retrieve when needed. Indeed, **Fig.11a** and **Fig.11b** describes excess production in KW for each system. Indeed, the first system presents high production excess throughout the day in return the second system has no excess production.

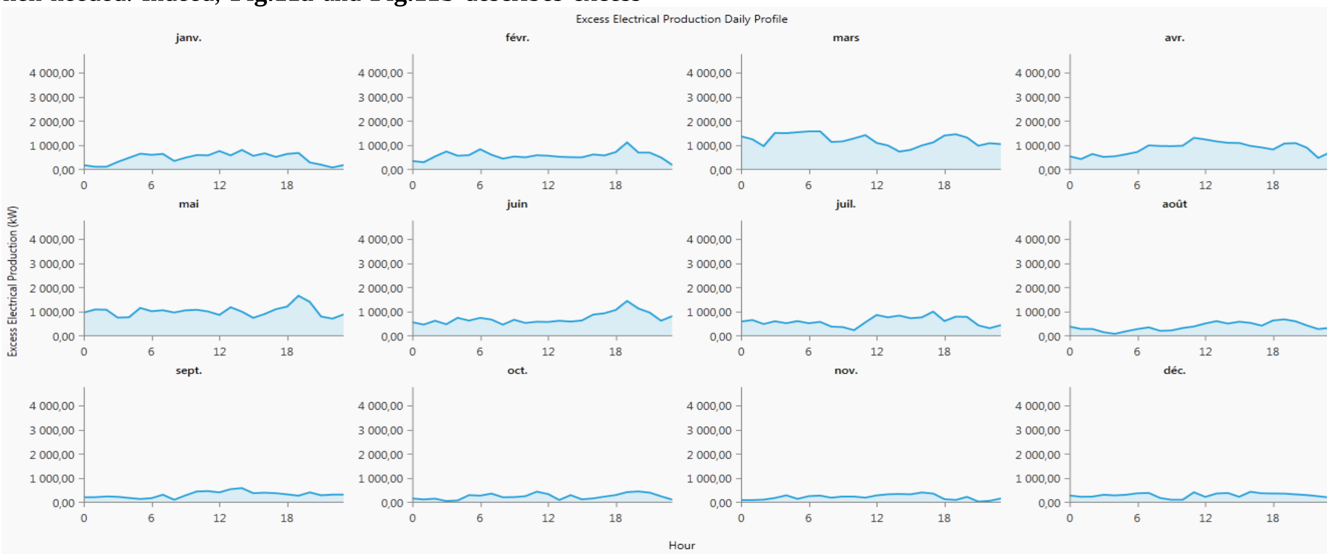

Fig. 11a. Rate of excess renewable electric of wind turbine system.

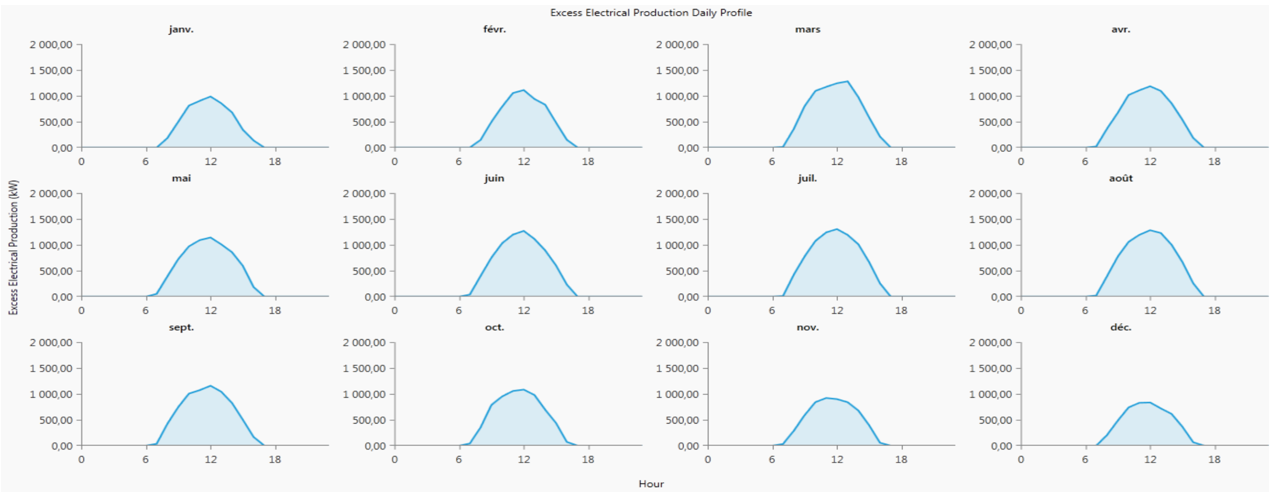

Fig. 11b. Rate of excess renewable electric of photovoltaic system.

Figure 12a, figure 12b, figure 13a and figure13b show the electric power exchange between the owner systems and the electric network.

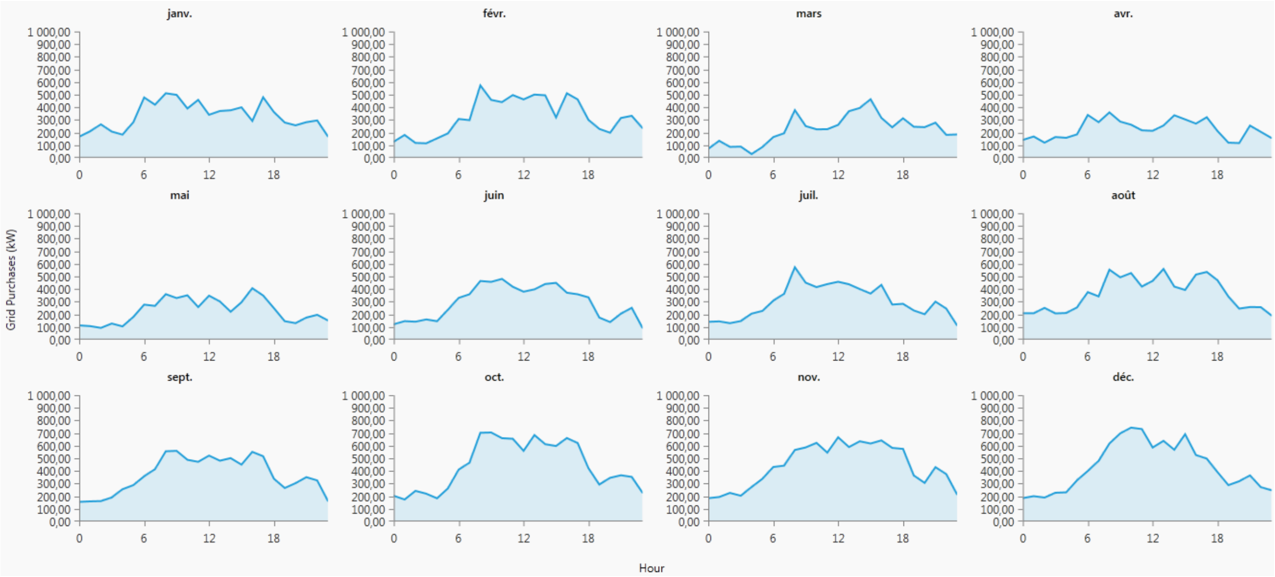

Fig. 12a. Rate of electric energy supplied by the network of wind turbine system.

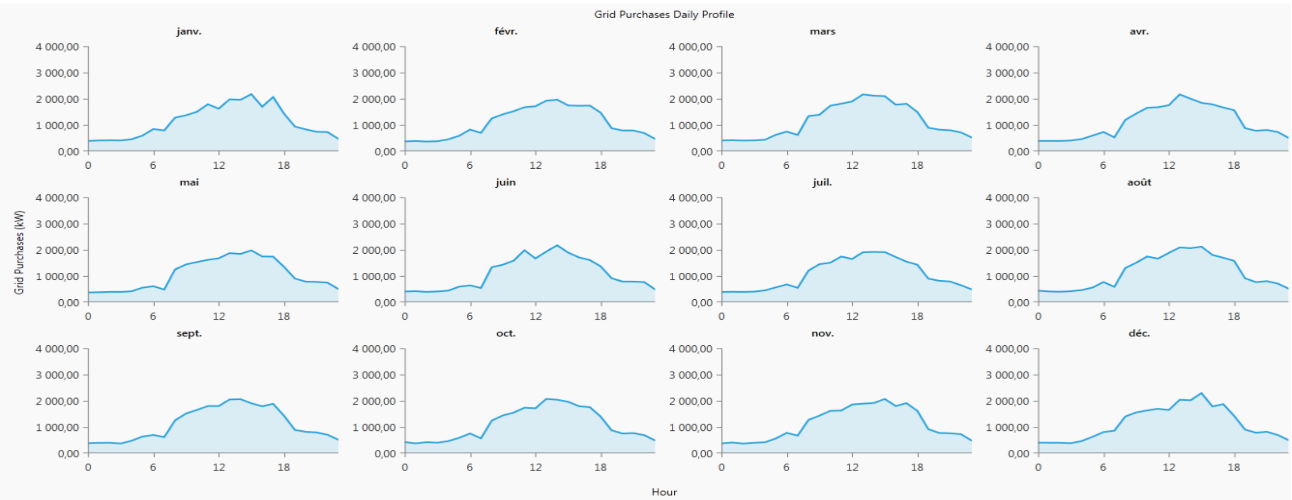

Fig. 12b. Rate of electric energy supplied by the network of photovoltaic system.

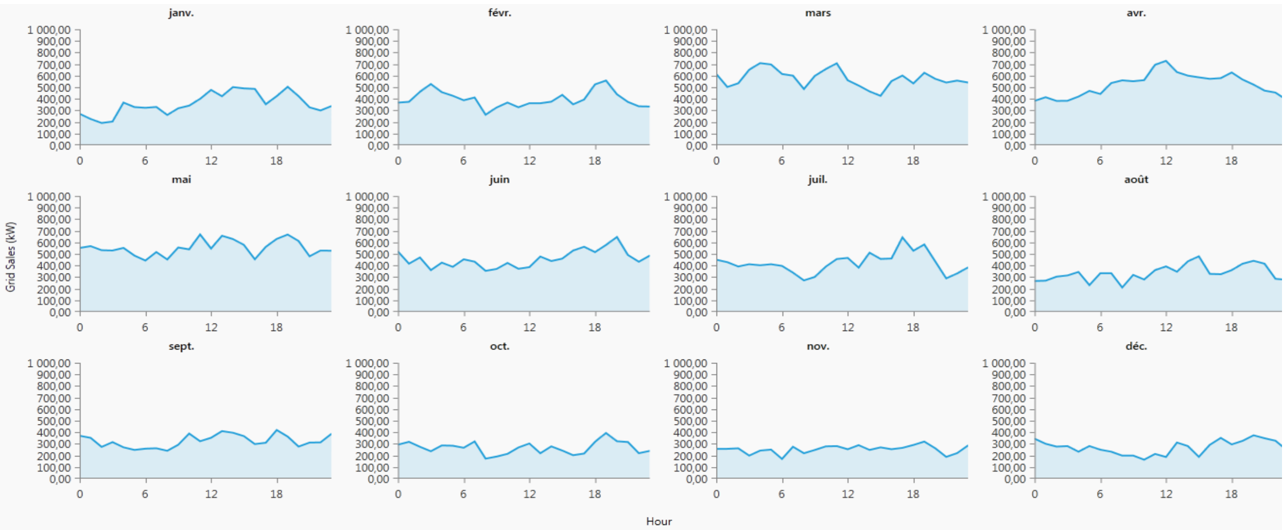

Fig. 13a. Rate of electric energy injected to the network of wind turbine system.

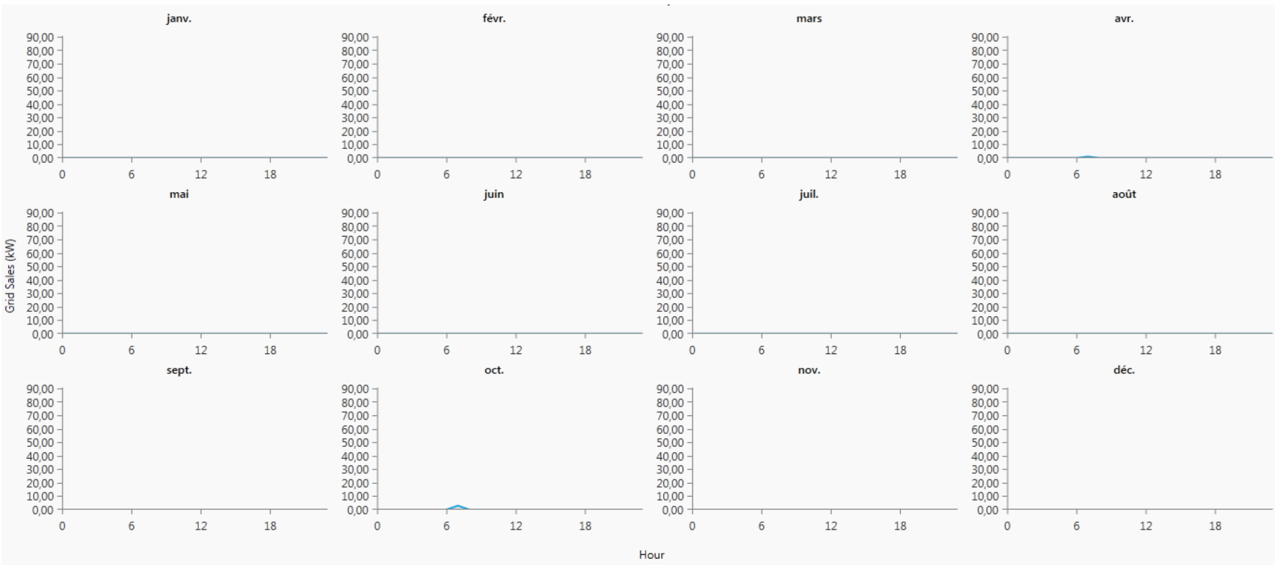

Fig. 13b. Rate of electric energy injected to the network of photovoltaic system.

In conclusion, based on the results, we notice that the wind energy conversion system is the most favourable system.

5.2. Economic aspect

Any conceptual study should be conducted in order to perform the best compromise between costs and electricity need satisfaction. Generally, renewable energy systems have a higher investment cost than conventional sources, while they enjoy a lower operation cost. Our study is based on the results from HOMER pro depending on the Net Present Cost parameter and it proceeds as follows:

- Cost Of Energy COE :

HOMER pro defines COE as the average cost per kWh of supplied electrical energy produced by the system and it takes into account all the considerations and all sources [20]. It divides the annualized cost of the energy produced by the total annual production. The COE is given by [24]:

$$COE = \frac{C_{ann_{tot}}}{E_{diffe} + E_{gidsales}} \tag{5}$$

$C_{ann_{tot}}$: Total annual Cost of the system (€ / year), it presents the total annual cost of each system component

E_{diffe} : The supplied deferred load (kWh / year)

$E_{gidsales}$: Total energy fed into the grid (kWh / year), so:

$$COE = \frac{C_{ann_{tot}}}{C_{utile_{produite}}} \tag{6}$$

- Net present cost [24] :

As already defined before, the NPC is the current net cost and is given by:

$$COE = \frac{C_{ann_{tot}}}{Fa(i_1, R_{proj})} \tag{7}$$

With F_a: update Factor

- Distribution of project costs:

To estimate the total cost of the project, the parameters listed below must be defined for each component of the system [21]:

- The initial capital
- The cost of operation and maintenance
- The replacement cost
- The lifetime

Thanks to all these data, we can also define the income cost (€) at the end of the project and express it as follows [24]:

$$C_R = C_{rep} * \left(\frac{R_{rem}}{R_{comp}}\right) \tag{8}$$

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \tag{9}$$

$$R_{rep} = R_{comp} - INT\left(\frac{R_{proj}}{R_{comp}}\right) \tag{10}$$

C_R : Income cost (€)

C_{rep} : Component Replacement Cost (€)

R_{rem}: Component life (year)

R_{comp} : Remaining life of the component after the end of the project (year)

R_{proj}: Project life (year)

R_{rep}: Duration of replacement cost

In our case, the cost of two installations wind turbine farm and Photovoltaic Park was issued by HOMER as the following tables:

Table 4. Allocation of net cost of a wind power system installation

Device	Capital (€)	Replacement (€)	maintenance (€)	Salvage (€)	Total (€)
GENERIC	5200000	1657796	517100	-934274	6440622
Electric network	0	0	-44308	0	-44308
System	5200000	1657796	472793	-934274	6396316

Table 5. Allocation of net cost of a photovoltaic power system installation

Device	Capital (€)	Replacement (€)	maintenance (€)	Salvage (€)	Total (€)
Flat plate PV	4000000	0	517100	0	4517100
Electric network	0	0	10303242	0	10303242
Converter	150000	63641	19391	-11978	221054
System	4150000	63641	10839734	-11978	15041389

As for the economic aspect of the two systems, we notice that the photovoltaic park has a very high installation costs as compared to the wind farm.

To get the proper power system to our site, Homer offers solutions with different combinations. From Table 4 and Table 5, we chose the first solution with an installation cost of € 6396316 and a unit cost 0,036 €. Our choice is based on the system that gives us the maximum renewable energy to minimize the intervention of the grid.

5.3. Environmental aspect

In order to provide a sustainable power plant, the Minimization of polluting gases emanating from the conventional part of the installation remains an important objective of this study. This is reached by the selection of a solution that resorts to the conventional source of energy the least.

Indeed, we studied the power exchanges in both directions: Either an exchange of power is delivered by the wind farm or solar park to the network in case of overproduction where the Intervention of power plants is avoided. An energy transfer is performed from the network to the load when needed to ensure continuity of service in the less windy and sunny times. In this case, we need the intervention of electric power plants that release quantities of greenhouse gases presented in Table 6:

Table 6. Quantity of pollutant gases for a wind energy conversion system connected to the network

Gas	Emission	Unit
Carbon dioxide	346524	Kg/ans
Carbon monoxide	0	Kg/ans
sulfur dioxide	1502	Kg/ans
Nitrogen dioxide	735	Kg/ans

Table 7. Quantity of pollutant gases for a photovoltaic energy conversion system connected to the network

Gas	Emission	Unit
Carbon dioxide	6142742	Kg/ans
Carbon monoxide	0	Kg/ans
sulfur dioxide	26632	Kg/ans
Nitrogen dioxide	13024	Kg/ans

Table 7 shows the amount of pollution gases released into the atmosphere for the two conversion systems for one year. Indeed, based on the energy aspect, the electricity network intervenes more frequently at the photovoltaic park system than the wind energy conversion system. Therefore, the consumption of fuel increases during the operation of the electricity grid to run the conventional plants which explains the release of a higher amount of pollutant gas.

6. Conclusion

In this article, we presented an energetic and economic feasibility study for two kinds of conversion system such as a wind farm and a photovoltaic park. These systems are connected to the grid for the supply of a village in the region of Sfax. The design of our system is based on meteorological parameters such as wind, temperature and solar irradiation then the load profile of the studied area. The design of such a conversion system is still needed to make more competitive integration of alternative energy sources in the energy balance of large production systems.

In this context, the wind energy conversion system connected to the grid has the most effective solution in our site as compared to the photovoltaic park from different perspectives namely energy, economic and environmental aspects.

Our choice is based on the following results:

- An energy contribution rate of 79%
- A unit cost of 0.036 € per KW / H
- Installation cost 6396316 €
- Less pollution gas emissions

We configured the system so as to produce energy using wind turbines connected to the grid. In the optimization process, Homer pro simulated several possibilities for design and sorted out the best results, according to the economic and energy parameters.

As conclusion, the modelling approach in HOMER pro aims at reducing the implementation cost and choosing the most appropriate architecture to the climatic condition of the site, so that our project can be realized. The simulations results showed that the production system is efficient despite several constraints.

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