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STUDY AND SIMULATION OF THE ENERGY PERFORMANCES OF A GRID-CONNECTED PV SYSTEM SUPPLYING A RESIDENTIAL HOUSE IN NORTH OF ALGERIA

I. Laib [*,1,2], A. Hamidat [3], M. Haddadi [1], N. Ramzan [2] and A.G. Olabi [2]

(1) Laboratory of Communication Devices and Photovoltaic Systems, Department of Electrical Engineering, National Polytechnic School, El-Harrach, Algeria

(2) Institute of Engineering and Energy Technologies, University of the West of Scotland, Paisley, UK

(3) Centre de Développement des Energies Renouvelables, CDER, Algeria

(*) E-mail: ismail.laib@g.enp.edu.dz

Abstract

Worldwide, building is one of the most consuming energy sectors which are contributing significantly to the greenhouse effect, climate change and negative environmental impact. In Algeria, building sector is responsible of about 42% of the final energy consumption, with about 35% in the residential houses and 6% in the tertiary. This consumption is still in expansion, due to mainly on an exceptional growth of population and urbanism. The main objective of this paper is to study and assess the contribution of the grid-connected photovoltaic system in the energy balance in the residential building. A case study is applied in the northern region of Algeria. The photovoltaic system supplies the house with electricity during the sunny days, and during the night or the cloudy days, the house is powered by grid. The calculation of energy performance is based on the optimization, rationalization and saving energy approach. This takes into account the energy profiles of residential homes, real data and meteorological conditions (ambient temperature and irradiance). The results show clearly that the use of saving energy and grid-connected photovoltaic system allows a reduction of energy demand and a positive annual electricity balance of the studied residential house. The PV system generated 67.6% of the overall energy used in the house. Only, 33.4% are purchased from the grid. An energy positive balance of 2 kWh/day is observed.

Keywords: Photovoltaic, Grid-connected, Energy performance, Energy balance, Bioclimatic housing, load profile, Energy Management.

1 INTRODUCTION

The energy available in nature is very necessary for everything. In the most ancient times, man has lived on energies of proximity such as wood for heating, and fire for lighting. The industrial revolution that occurred at the end of the 17th century was the main of energy revolution. Among the different energy carriers, electricity is the most important for human activities.

Electricity is produced mainly from fossil and fissile energies. Nowadays, as a result of economic crises, risks prices of fossil fuels, dangers of nuclear energy and climate change that endanger the existence of humanity. In this sense, there is a tendency to the new solutions for the production of electricity, namely renewable energies [1,2].

The use of mixed energy represents one of the solutions for sustainable energy that must be developed to increase the electrical production of renewable energies [3]. For example, solar energy is extraordinarily abundant since the irradiation that the sun sends to earth represents more than 10,000 times the current world primary energy consumption [4,5].

In Algeria, the energy consumption in building sector is one of the consuming energy sectors. So, it is responsible of 42% of the final energy consumption, with 35% in the residential building and 6% in the tertiary building [6]. The rate of energy consumption in the building sector is growing rapidly for several reasons: (a) low cost of conventional energy (Government-subsidized energy), (b) substantial increase of population and housing stock, (c) increase number of electrical equipment in each house,

(d) use of non-economic electrical equipment such as incandescent lamps and very cheap air conditioners, (e) absence of awareness and lack of culture on the energy saving [7,8].
The integration of photovoltaic system into the building can enable self-production of electricity. At the same time, the system can help the electricity-grid by injecting the extra photovoltaic electricity produced, especially during hot and sunny periods. Because, during these periods the electrical demand is the highest due to the use of air conditioning [9,10].
This will also help in reducing the climate and environmental impacts. However, for the feasibility of a PV system, there should be enough solar energy throughout the year. Algeria is one of many countries that has a high solar energy resource [11,12].
The techniques developed up till now, depending on the place of use and the power requirements; offer the possibility of combining several energies production systems [13]. The idea of embedded generation has the advantage of not only supplying electricity from renewable energy and the grid, but exporting the generated energy to the grid [14]. For example, the photovoltaic (PV) system can be used for a local grid in an urban environment to supply housing, and in the event of surplus energy, the excess energy can be injected into the grid.
To give voice to this study, a separate home with a 90-m2 floor area was selected in order to analyze the house energy performances in Mediterranean climate conditions. The experimental house was built as part of a European MED-ENEC program and scientific collaboration between Renewable Energy Centre (CDER, Algeria) and National Center for the Study and Integrated Research of Buildings (CNERIB, Algeria). The house is situated in the North of Algeria in a village named Souidania (Figure 1). The house contains seven parts specifically, two rooms, living room, kitchen, restroom, and corridor [15].

The height of the house is approximately 2.74 m. Its technical characteristics are as follow:
- Walls with stabilized earth blocks;
- PVC doubles glazed windows (4/6/4);
- Thermal insulation of external walls and floors;
- The house has a compact shape and is oriented along the E-W axis.

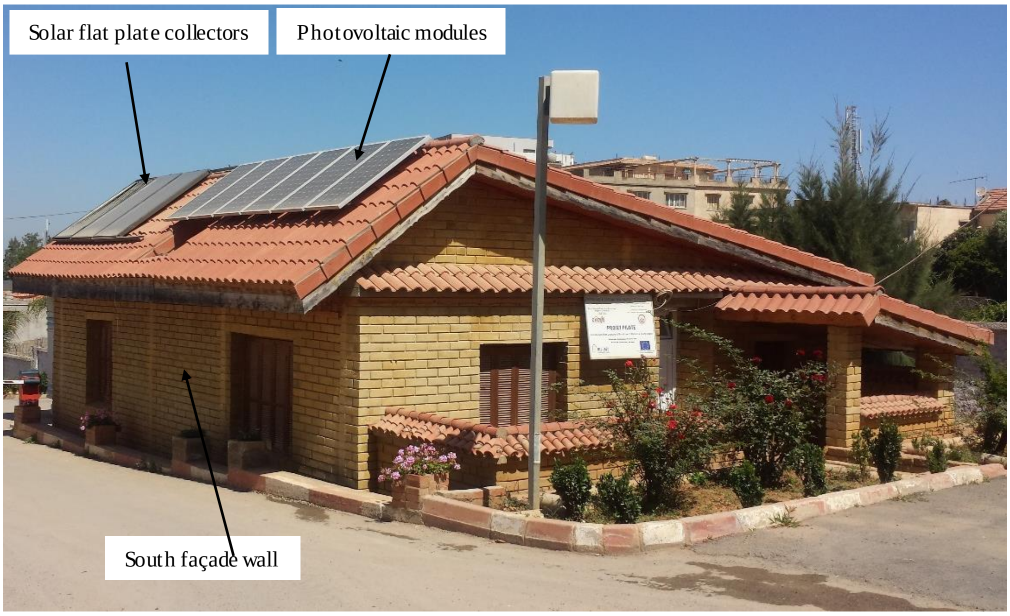


Figure1. The experimental bioclimatic house (Souidania, Algiers)

Today, solar energy and in particular photovoltaic systems are currently experiencing strong global growth (+ 16.9% of the photovoltaic power installed in the world in 2015 compared to 2014) and are

expected to represent a share of the future energy mix in the space of a few decades, various approaches exist to analyse installed solar PV world capacity [16] and share of grid-connected PV system [17].
Figure 2 Shows the evolution of photovoltaic power installed at the global level expresses a strong growth of the market since the beginning of the decade. It is also possible to distinguish in Figure 3(a) and 3(b) several configurations of Photovoltaic systems currently in use, grid-connected PV systems (On-grid) and stand-alone Photovoltaic systems (Off-grid) are used when the grid distribution is non-existent or when the cost of connection to this grid are prohibitive [18,19].
The installation capacity for off-grid cannot be compared to the grid-connected, as the rapid development of grid-connected PV eliminates the off-grid as clearly shows Figure 3. In most European countries, used off-grid remains a very small sector, mainly for remote sites and communication devices that deliver electricity for specific uses. Some hardly accessible places for example mountains. are equipped with photovoltaic generators as an alternative energy resource. in another hand, the off-grid systems with back-up (either diesel generators or chemical batteries) represent an alternative energy resource. This tendency is specific to countries that have enough solar resource throughout the year to make a PV system viable [20,21,22].
There are two types of structures of a photovoltaic system connected to the grid: centralized and decentralized. Centralized **(**Production/Sale) is a system with direct connection to the grid, the energy produced is injected directly into the grid. In this type of application, all the energy produced is destined to be sold to the electricity distributor at a preferential rate.
Decentralized (Production/Consumption/Sale):
The surplus energy produced by the PV system in the house is sold to the grid and to meet excess demand, when the consumption exceeds the production, the energy is provided by the Grid. It is therefore necessary to count separately the kWh injected and those taken from the grid, which requires installing two unidirectional (electronic) counters.
To support the development of the sector, the purchase price of the kWh produced by a photovoltaic installation is higher than the price charged by the electricity companies for the sale of electricity to their customers. Therefore, it is necessary to count separately the injected kWh and those taken from the grid, which requires installing two unidirectional (electronic) counters. In the event of a shutdown of the distribution of electricity coming from the grid (breakdown, work of the electricity company), the inverter does not deliver any current on the internal circuit nor on the grid [23]. For example, the new German tariffs for the purchase of photovoltaic energy go in this direction, an increase of 5€-cts/kWh of photovoltaic energy consumed on the site has been put in place (if the panels are integrated into the building) in January 2010 [24].

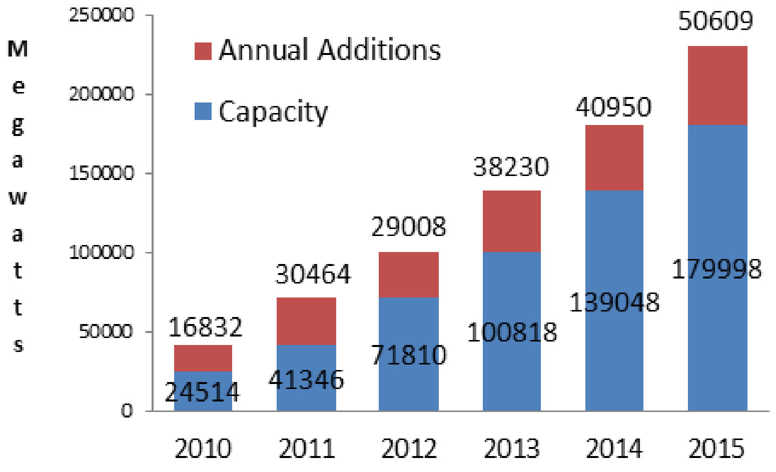


Figure 2. Solar PV global Capacity and Annual Additions, 2010-2015

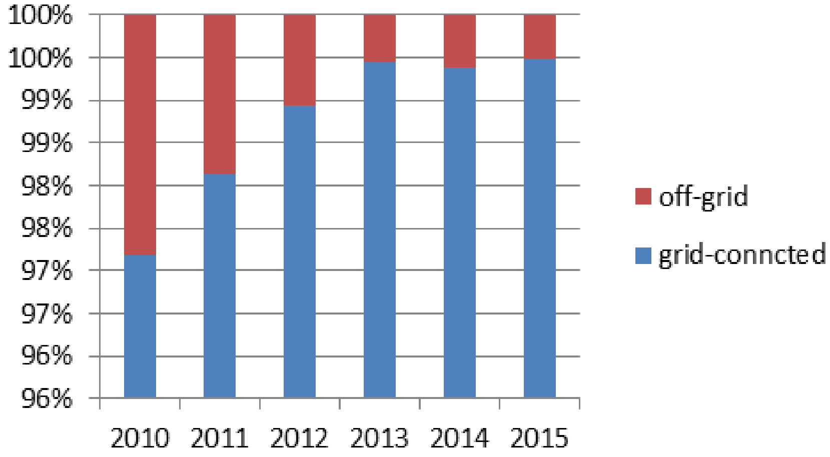


Figure 3(a). Share of grid-connected and off-grid in world, 2010-2015

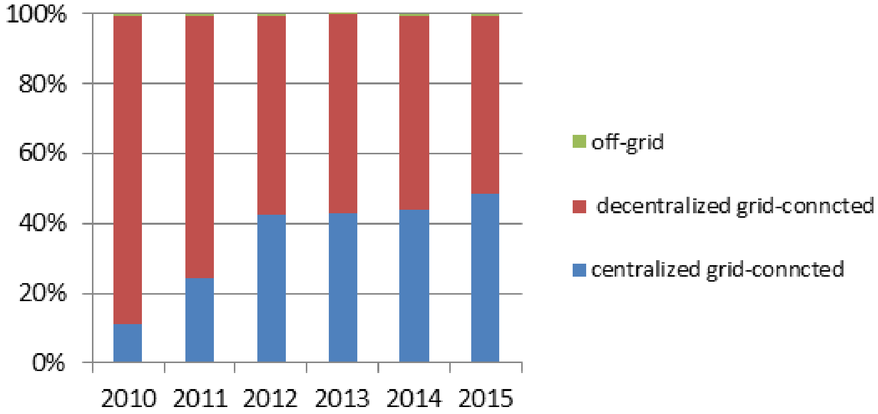


Figure 3(b). share of off-grid and centralized/decentralized grid-connected PV in world, 2010-2015

2 DESCRIPTION OF THE SYSTEM

Photovoltaic power systems connected to the grid may change in size depending on the demand, but they have the same components, figure 4 shows grid-connected photovoltaic systems are integrated into the building [23,25].

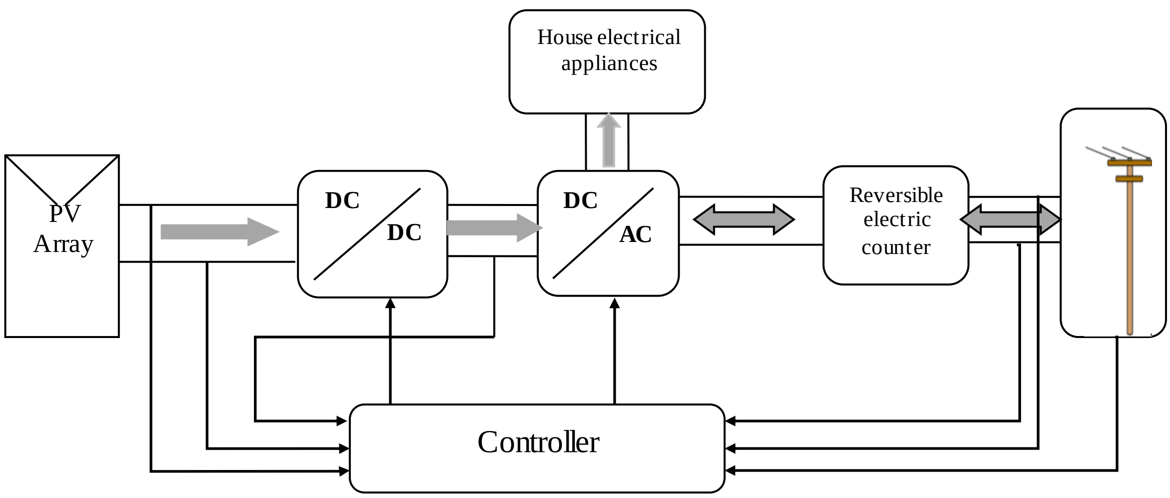


Figure 4. Block diagram of the grid connected photovoltaic system

The photovoltaic panels supply a DC voltage bus through a converter designed to carry out the DC-AC conversion and to ensure that the PV generator is always operate at its optimum point of operation

(MPPT: Maximum Power Point Tracking). Since the electrical characteristics of the photovoltaic panels are related to weather conditions, this converter improves the overall system's profitability. The grid can permanently accept the energy that is produced by the photovoltaic panels, allowing a relatively rapid return on investment. Therefore, there is no production shedding in this type of system. Indeed, the grid whose mission is to permanently ensure the match between production and electricity consumption.

2.1 Improved performance

For a well-planned PV installation, the power of the inverter must be adapted to the connected photovoltaic generator [26]. In order to perform this operation, the power ratio acts as a reference value. It defines the interface of the two systems based on the ratio between the maximum input power of the inverter and the peak power of the PV generator.

- ✓ If maximum efficiency is to be achieved; the configuration must have a power ratio of about 110%.
- ✓ If on the other hand, it is a configuration with an optimized profitability that is sought; the improvement of the profitability or the reduction the duration of damping. Also, it depends on the sunshine; the operating efficiency at a partial load of the " Inverter and the level of purchase rates.
- ✓ If the orientation of the PV generator deviates from ideal values (e.g. on a PV facade), this must be taken into account by considerably reducing the dimensioning of the inverter.

In Figure 5 is shown that this system contains 6 PV modules mono-crystalline arranged in series. The whole module area is 7.66 m². The power conditioning device is a range of supervisor and inverter (SMA 1200). This inverter guarantees the supervision and the safety of the grid furthermore the conversion DC/AC with a power of 1.2kVA.

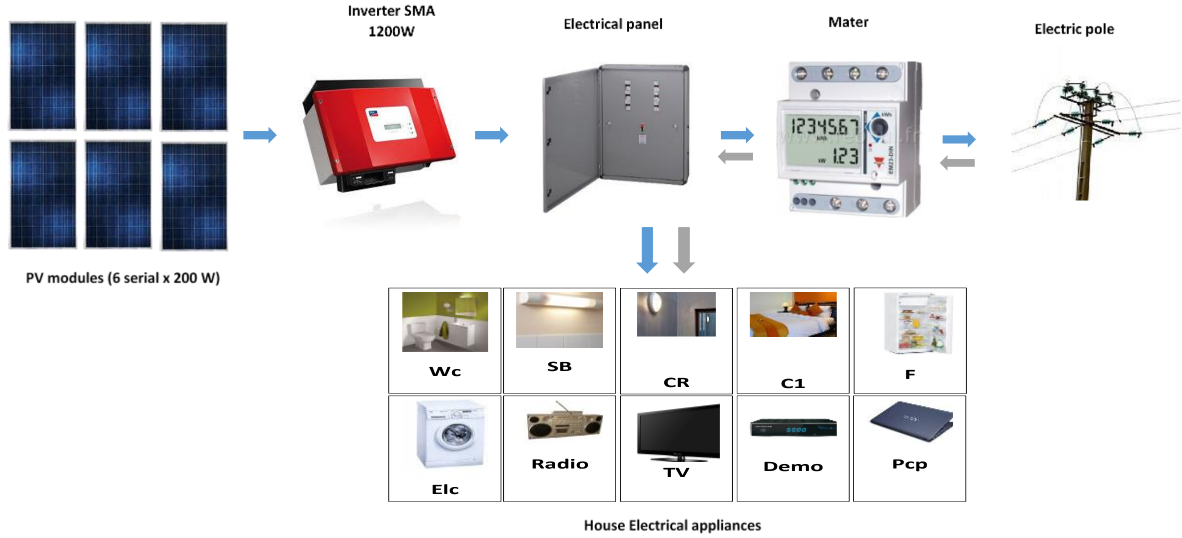


Figure 5. The general scheme of the proposed grid-connected PV system

The nominal productivity of this inverter is 92.1%. The photovoltaic array connected to the electric grid. During the daytime electricity is supplied by the photovoltaic system and during the night or absence of the sun, the electrical power is supplied from the electricity grid and in the event of surplus energy, the extra energy injected into the grid. Together with the house meter for calculates the energy production and consumption. All electrical appliances in the house is served by both the PV system and grid's power, the arrangement of the grid-connected the PV system.

3 MODELLING OF THE SYSTEM

3.1 Photovoltaic generator

The mathematical modelling of the equivalent circuit of a solar cell is idealized by a junction diode PN by an I_{ph} current source, a series resistor R_s, which models the joule losses, a parallel resistor R_{sh}, which represents the internal losses [27]. There are numerous mathematical models but the only difference is between the mathematical measures and the amount of parameters elaborated in the calculation of the voltage and current of the photovoltaic module. In this study, two diodes were modelled. A supplementary diode is positioned in parallel with the circuit of the simple model of a diode Figure 6. This diode is included to provide a much more accurate I-V characteristic curve [28]. Equation (1) is shown the ratio between the output current I and the output voltage V at the terminals of the load resistor R_c [29].

$$I = I_{ph} - I_{sat1}\left(\exp\left(\frac{V + R_s I}{n_1 V_{th}}\right) - 1\right) - I_{sat2}\left(\exp\left(\frac{V + R_s I}{n_2 V_{th}}\right) - 1\right) - \frac{V + R_s I}{R_{sh}} \qquad (1)$$

Where:

R_s is series resistor, R_{sh} is shunt resistor, I_{ph} is photo-current, V_{th} is thermal voltage of the diode, I_{sat1} and I_{sat2} are saturation current of the diode D_1 and D_2, n_1 and n_2 are ideality factors of the diode D_1 and D_2.

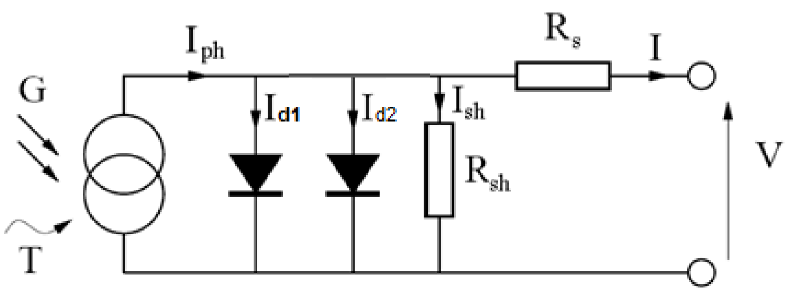


Figure 6. Equivalent circuit of a solar cell, model of two diodes

3.2 Inverter

In this section, an empirical model was introduced by SANDIA Laboratories (Sandia National Laboratories), the model was valid to all commercial inverters employed in PV systems. It is a simple model which allows calculating with precision the output power (P_{ac}) according to the input power (P_{dc}) of the inverter. This will be used model the dynamic behaviour of single-phase inverter (SMA1200) connected to the grid. The model requires an adjustment of the performance parameters (coefficients) under real conditions.

The equations below describe the model of the inverter developed by the SANDIA laboratories. The DC voltage (V_{dc}) and DC power (P_{dc}) are considered as independent variables to calculate the output power of the inverter (P_{ac}) [30].

Parameters with index "o" are constant values which are defined in reference conditions or nominal operation. The C_0, C_1, C_2 and C_3 are constant coefficients of the inverter model. The relationship between P_{ac} as a function of V_{dc} and P_{dc} is given by the following equation (2).

$$P_{ac} = \left[\frac{P_{ac0}}{A-B} - C\cdot(A-B)\right]\cdot(P_{dc}-B) + C\cdot(P_{dc}-B)^2 \qquad (2)$$

Where:

$$A = P_{dco} \times [1 + C_1 \times (V_{dc} - V_{dco})] \qquad (3)$$
$$B = P_{so} \times [1 + C_2 \times (V_{dc} - V_{dco})] \qquad (4)$$
$$C = C_o \times [1 + C_3 \times (V_{dc} - V_{dco})] \qquad (5)$$

The following table shows the SMA1200 Performance Parameter values, which are provided by the SANDIA database (Table 1).

The accuracy of the model depends on the accuracy of the performance parameters of the PV inverter model. These parameters can be obtained from the manufacturer's data sheets by considering the default values of the coefficients or test databases carried out in recognized international laboratories.

The self-consumption of the inverters used was determined by previous experimental measurements by a power analyzer. In the remainder of our approach, the performance parameter Pso is considered constant and equal to 3.5W.

Table 1. Performance Parameters of SMA1200

Performance settings	Default setting	Laboratory SANDIA	Units
P_{aco}	1200	1200	W
P_{dco}	1320	1320	W
P_{so}	400	400	W
V_{dco}	15	3.5	V
C_0	0	-1.44e-8	W-1
C_1	0	1.385	V-1
C_2	0	-0.00284	V-1
C_3	0	1.074	V-1

3.3 Consumption profile

The maximum power required and the daily energy consumed by the dwelling must be determined in order to realize the dimensioning of the electrification infrastructure. We estimated the mean hourly load curve of the habitat to be electrified. The consumption profile adopted in this study corresponds to the load profile generally encountered in suburban regions [31,32,33].

We chose a house equipped with all the appliances to provide comfort to the occupants. The characteristics of this house are:

- Number of rooms: Three (3) rooms, corridor, courtyard.
- Lighting: Rooms, kitchen, toilet, bathroom, courtyard and corridor.
- Appliances: Refrigerator, TV, Radio, computer, laptop, Washing machine, Air Conditioner, and Fan.

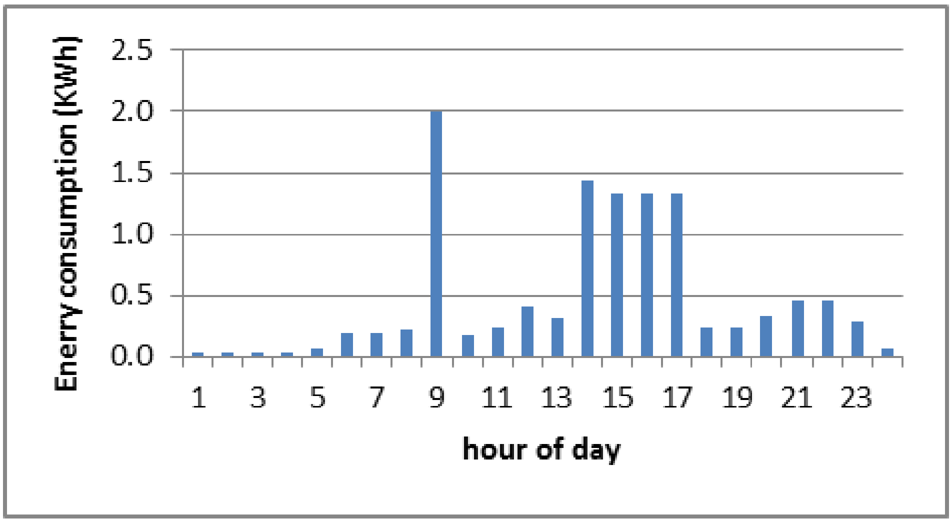


Figure 7. Daily load profile developed

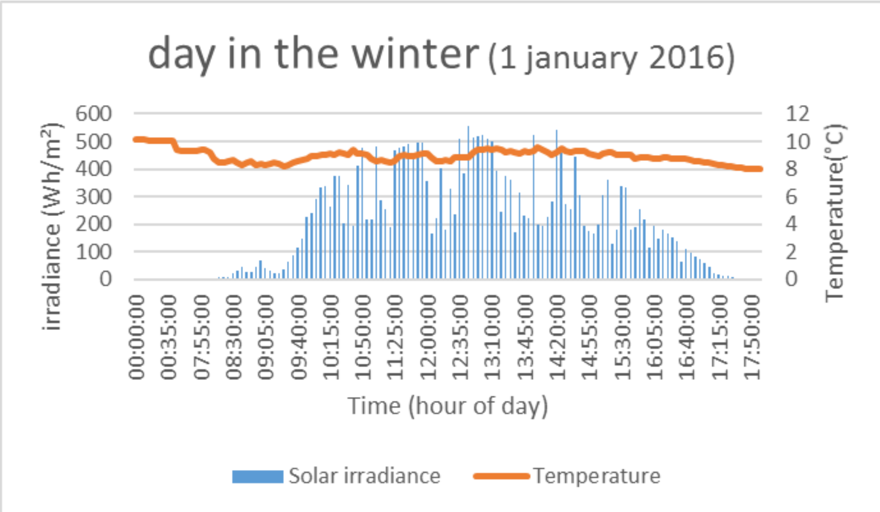
We considered one consumption profiles for the winter and summer period. The number of hours of use of the equipment is determined according to the consumption Figure 7.

4 SIMULATION AND RESULTS

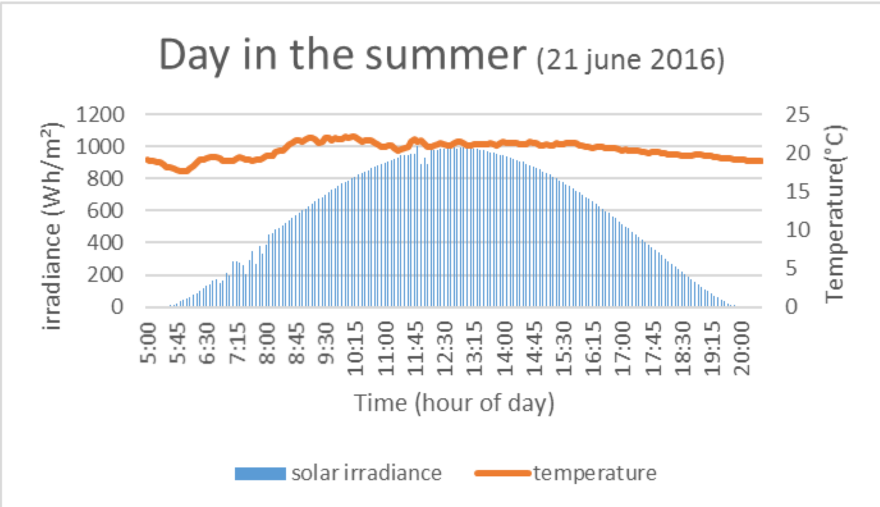
4.1 Simulation of electrical performances

An elaborated Matlab-Simulink model was developed and the effect of different subsystem of a grid-connected PV system was analysed. In the stimulating, the capacity for the PV array and Inverter considered in the model was 1.2 KWp. this simulation was performed with a real daily profile of data input from Algeria site, exactly in Suidania town, (the temperature, irradiance and the developed load profile). On the other hand, in the modelling, the demand side management was also considered.

The disparity in solar irradiance and temperature between winter solstice and summer is remarkable. (Figure 8-a and 8-b), shows the evolution of the outdoor air temperature and the solar radiation during one day in January and one day in June, (January is one of the coldest months and June is one of the hottest months of the year in Algeria). It can be noticed that noticed that winter days are less sunny than summer days, which influence really the proper functioning of the PV system (decrease in yield with low irradiances). Based on the model and the irradiance data the optimum angle of inclination at a given load of the PV array was found to be 35°. Figure 9 shows the PV proportion in the electrical balance as a function of the angle of inclination.



(a)



(b)

Figure 8. Evolution of the outdoor temperature and solar radiation during (a) the winter period and (b) the summer period

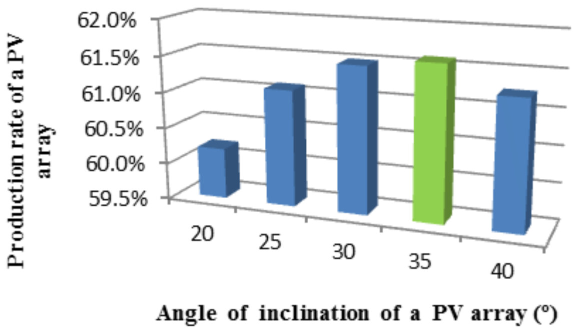


Figure 9. PV proportion in the electrical balance as a function of the angle of inclination

4.2 Daily Energy

The daily electrical simulation results for the 1.2 kWp PV system from two different days (One day was in summer and the author one was in winter) see Figure 10 and 11. The following results are: the produced energy from PV, load power energy, the purchased energy, and the PV electricity exported to the grid for each hour during the day. We can notice that the PV system continues in generating the electricity on winter days (for example cloudy days), but not as much as on a summer day.
Figure 10 shows that in the summer day, the PV- electricity which is generated before 8 O'clock in the morning cannot meet the energy consumption that is needed, because the sun's irradiance was not sufficient. The PV energy begins to increase from 8 O'clock to 18 O'clock. Therefore, when the power is produced from the sun, it can effortlessly meet the need of the house's energy required. The extra energy generated by the PV system, connected to the home will be injected to the grid. After 19 O'clock the PV does not any energy thus, all the energy is bought from the grid. Figure 11 presents the production of the electricity in winter day where the power produced by the PV system could not encounter the energy consumption required between 9 O'clock to 18 O'clock. During the winter period especially when it is cloudy, the energy consumption is utterly purchased from the grid.
The daily electrical simulations result for a 1.2 kWp PV system are given in Fig 12(a) and 12(b). The total daily electricity consumption in the house from both PV system and the grid is load_ac = 6439 Wh/day; The total daily Wh imported from the grid per (summer and winter day) which arises when the PV gives less power connected to the house electricity demand "Grid purchases" is Purchases grid for summer 2593Wh/day and 4054 Wh/day in winter; The total daily Wh produced by PV array for summer is 8483Wh/day and 3911Wh/day in winter, that happens when the PV produces extra energy connected to the house electricity demand ''grid sales'' is Injected_grid for summer 4636 Wh/day and 1525 Wh/day in winter.

4.2.1 Daily Energy Production

In winter, the daily rate of energy produced by the PV array was 49% of the total electric power produced in the house and daily energy imported by the grid was 51%. But in summer, daily rate of electricity produced by the PV array building was 67.6% and daily energy imported by the grid was 33.4%.

4.2.2 Daily Energy consumption

In winter, the daily rate of electricity consumed by loads was 81% of the electric power consumption in the house and daily rate of electricity injected into a grid (sold to the grid) was 19%. But in summer, the daily rate of electricity consumed by loads 58% and daily rate of electricity injected into a grid was 42%.

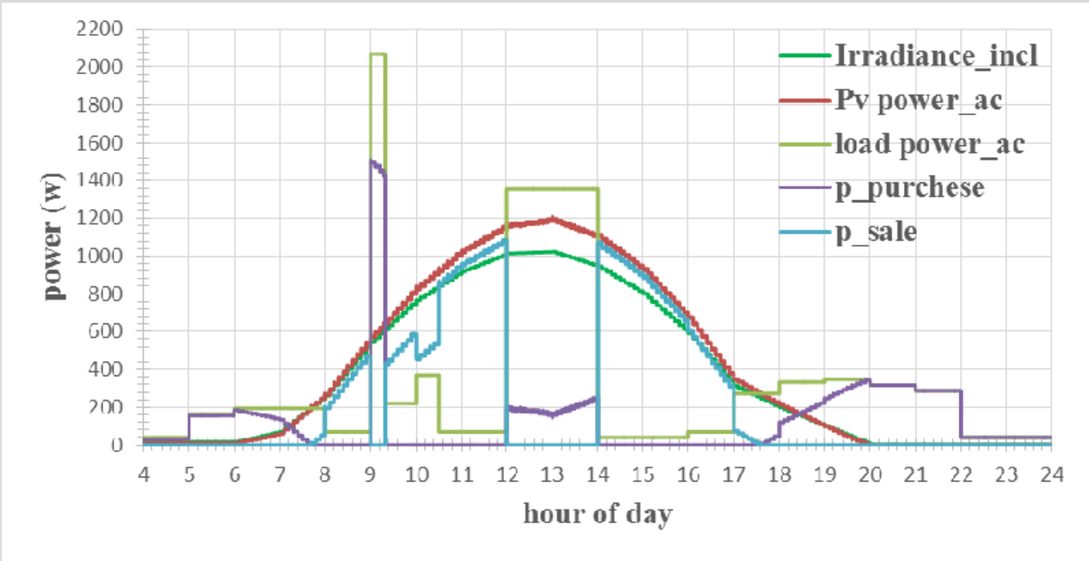


Figure 10. Matlab results for hourly electrical simulation of day in the summer

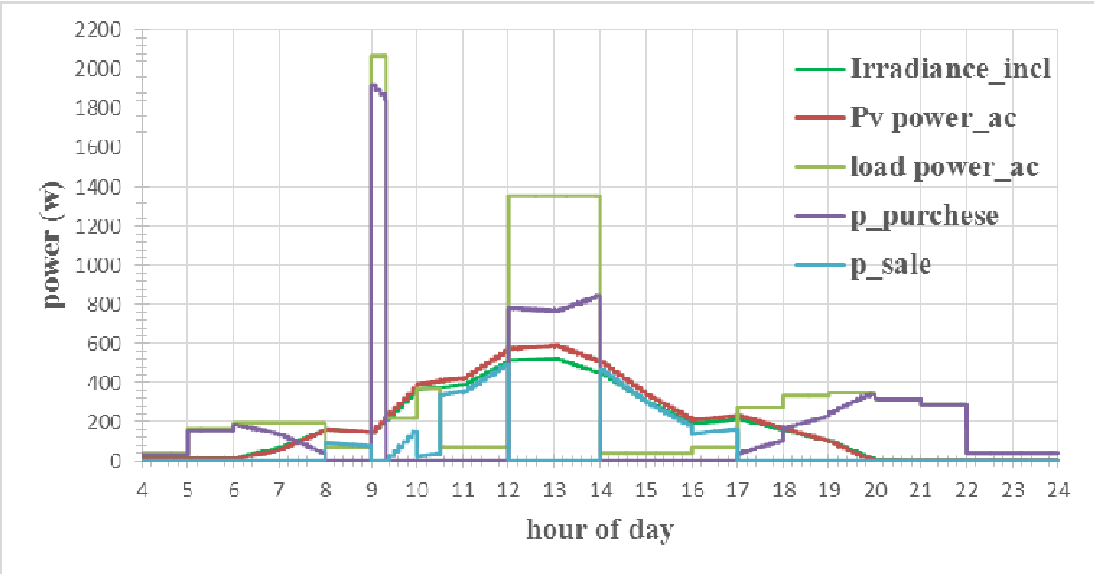


Figure 11. Matlab results for hourly electrical simulation of day in the winter

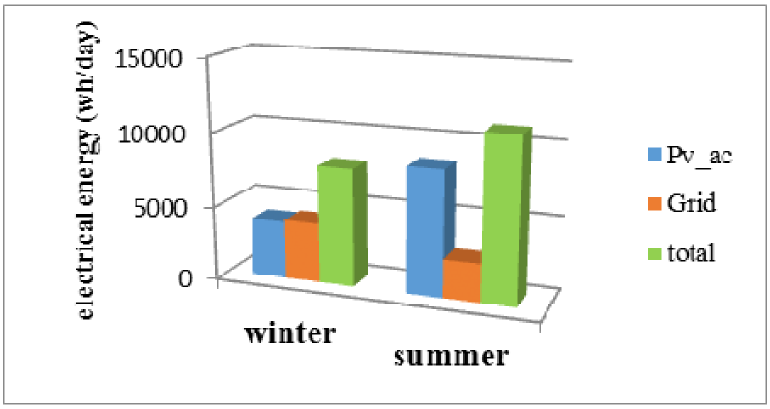


Fig 12(a) Daily electric power production

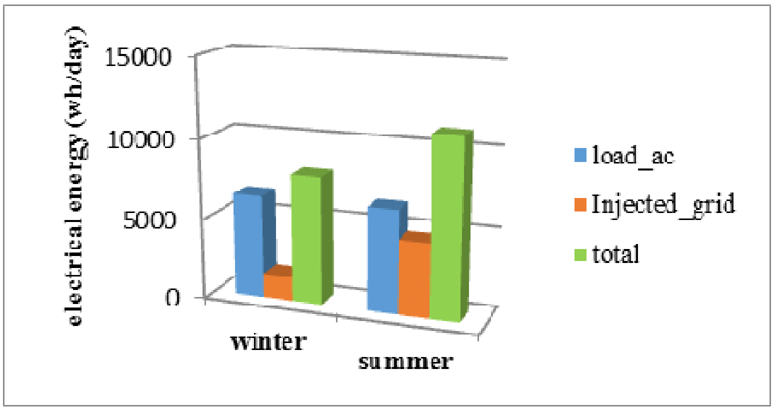


Fig 12(b) Daily electric power consumption

4.3 Monthly Energy

The monthly average of the electrical simulation results for grid-connected PV system is shown in Fig.13. The maximal production of the PV system is 8,2 kWh/day in August and the minimal production is 3,5 kWh/day in December. However, the monthly average electricity imported from the grid is very important in winter (4,1 kWh/day in December) and minimal in summer (2,5kWh/day in August). In Fig. 13, "power_purchases" is the monthly energy imported from the grid and "power_sale" denotes the monthly energy exported from the grid. In addition, we have calculated the net energy gain by subtracting the energy exported to the grid from the energy imported from the grid. We can note that the monthly net energy gain is positive during the summer, since the monthly electricity fed to the grid is higher than the electricity purchased from the grid. However, during the winter season, the monthly net energy gain is negative. This mean that the electricity fed to the grid is lower than the electricity purchased from grid.

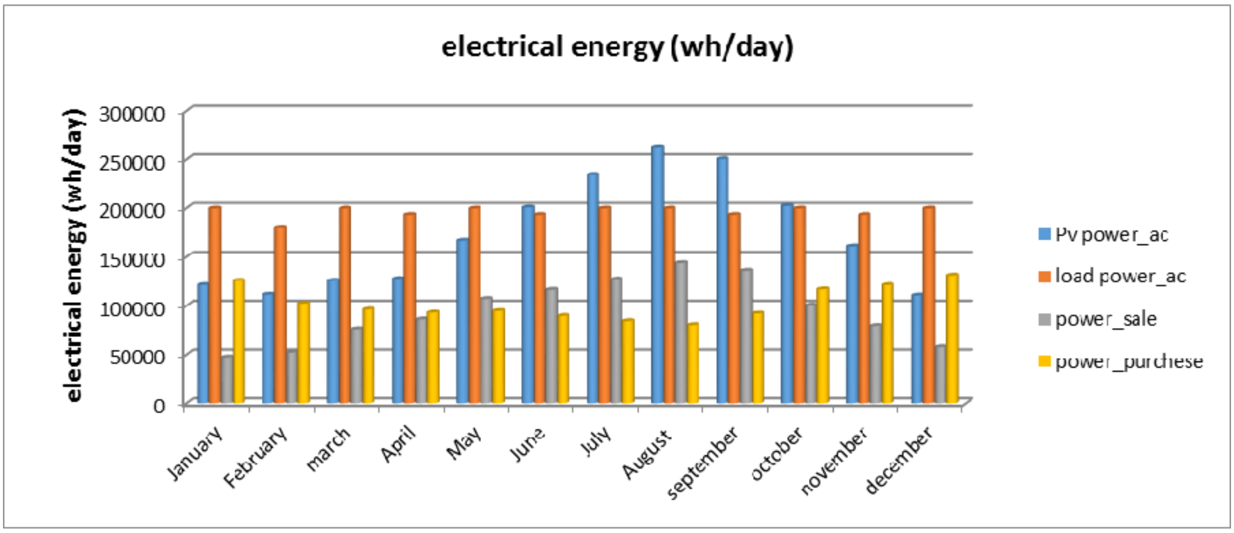


Fig.13: The monthly average electrical simulation results for grid-connected PV system.

4.4 Annual Energy

The annual electrical simulations result for a 1.2 kWp PV system are given in Fig.14. The total electricity consumption in the house from all sources ''load_ac'', supplied in parallel from the inverter and the grid is 2350 kWh and the total annual kWh exported to the grid per annum which occurs when the PV inverter generates excess electricity relative to the house electricity demand ''grid sales'' is 1130 kWh. The total annual kWh imported from the grid per annum which occurs when the PV inverter generates less electricity relative to the house electricity demand "Grid purchases" is 1227 kWh and the total annual kWh produced by the PV system "PV array" is 2075 kWh. The PV system produced the equivalent of 88% of the total electricity consumed in the house. The annual electricity purchased from the grid represents 12% of the total electricity consumption in the house.

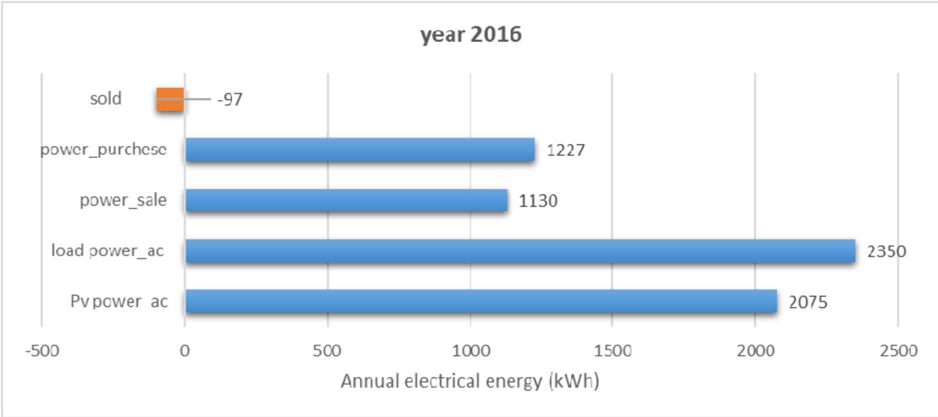


Fig.14: The Annual average electrical simulation results for grid-connected PV system

5 CONCLUSION

The study reveals that the grid-connected PV system might completely meet the energy needed for that house where we can still utilize the grid as a storage of electricity during night time when solar is energy is off.

The results of simulation of electrical performances are very effective and efficient. The daily energy balance on a summer day shows that photovoltaic produced more than the energy required for the house. Regarding the excess energy, it was exported to the grid for the storage. However, it was found that for a winter day, photovoltaic production is not sufficient to meet all of the demand. Nevertheless, in order to compensate the needed energy, we purchased from the provided grid.

The PV system generated the equal of 67.6% of the overall energy used in the house. The daily energy taken from the grid shows around 33.4% of the global energy utilized in the house, and the energy injected into the electricity grid is greater than the energy purchased from the grid. A positive balance of 2 kWh/day was observed. The integration of renewable energy sources in the house has shown to provide positive impact to the both the environment and to meet excess energy demands.

In addition to that, among the advantages of the system, we can find that it has no electrochemical storage and the benefits stresses on the less control and preventive maintenance of the system where also the cost can be reduced.

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