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Sizing and Optimization of a Livestock Shelters Solar Stand-Alone Power System

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ABSTRACT

The application of renewable energy system has become an important alternative in agricultural domain. This paper studies the Possibility of utilizing photovoltaic stand-alone systems to cover basic electricity needs of the livestock shelters located in Terny Beni Hdiel district of Tlemcen (Algeria). Data on solar radiation, sunshine duration has been recorded in Terny Beni Hdiel area. This photovoltaic system, which includes a PV, inverter, and a battery, was installed to supply energy to 5500W load, considering that the renewable energy resources of this site where the system was installed were 4509Wh/m2/day solar radiation yearly average speed. The National Renewable Energy Laboratory (NREL) optimization computer model for distributed power, “HOMER,” is used for the analysis of sizing and sensitivity, performed in order to obtain the most feasible configuration of a photovoltaic system.

General Terms

Photovoltaic System, Stand Alone, Livestock shelter,
Homer Software Tool

Keywords

Photovoltaic System, Stand Alone, Livestock shelter, Homer Software Tools, Sizing, Optimization, Terny Beni Hdiel.

1. INTRODUCTION

The uses of renewable resources have been charted specifically in many of the roadmaps of the developed countries. One of the most promising renewable technologies is photovoltaic (PV) technology. In recent years, photovoltaic (PV) energy is considered as an important type of renewable and clean resource of energy unlike conventional fossil fuels and their negative environmental impacts and high energy cost. . PV systems are popularly configured as: stand-alone, grid-connected, and hybrid systems. They are developing rapidly in the world, both in the developed and developing nations. Hence, Stand-alone PV systems operate reliably and are the best option for many remote applications around the world. However, Standalone photovoltaic (PV) systems are promising alternatives particularly in remote areas as an isolated small power producing units for the supply of electricity. There are a number of small isolated communities in the whole world without access to the electricity grid, like rural villages, island archipelagos and mountainous regions, where the establishment of main grid connections is impractical due to high cost of transmission lines [1].

Standalone photovoltaic (PV) systems offer an off-grid energy supply for various applications such as electrification of remote rural areas that are not connected to the main grid, telecommunication stations and agricultural sector**.** Moreover, there are a growing number of uses of PV for agricultural productive applications especially concerning livestock sector such as water pumping for cattle drinking , refrigeration for dairy and lighting for livestock. As well energy plays a crucial role in livestock farming. Where, energy is used for several applications; most importantly for lighting, heating, ventilation and cooling, and running electric motors for feed lines. Therefore, to electrify the previously mentioned farm equipments, that are used in remote area it is necessary to use a well designed stand-alone photovoltaic (PV) systems.

The potential for using clean energy technologies in remote desert agricultural areas is good given the abundant solar insolation in Terny-Beni Hdiel village and/or wind resources. But up to now, the use of renewable energy has been confined to demonstration projects where single renewable energy technologies were used. The present paper regards the description of a stand-alone photovoltaic for livestock shelter. The shelter was installed on Terny-Beni Hdiel in Tlemcen of Algeria to cover the basic electricity needs of the remote village. Basic electricity needs are defined as lighting, a fan and water pumping. Sizing a stand-alone PV system is an important part of its design since the equipment capital cost is a major component of the price of solar electricity. Over-sizing a stand-alone system has detrimental effects on the price of the generated power while under-sizing it reduces the supply reliability [2]. In order to size a stand-alone PV system the following must be known: solar radiation data for the particular location, load profile, expected supply reliability that is the percentage of time the system is capable of meeting the load requirements, and the related economics. The sizing procedure then recommends the array tilt angle, array size, and the battery capacity which are optimum for the application in terms of economy and reliability. The present paper regards the description of a stand-alone photovoltaic for livestock shelter. The shelter was installed on Terny-Beni Hdiel in Tlemcen of Algeria to cover the basic electricity needs of the remote village. Basic electricity needs are defined as lighting, a fan and water pumping. There are a several types of software for simulating standalone and hybrid PV System these can be found in [3]. These commercial software tools are named RETScreen, PV F-Chart, SolarDesignTool, INSEL, TRNSYS, NREL Solar Advisor Model, ESP-r 11.5, PVSYST 4.33, SolarPro, PV DesignPro-G, PVSOL Expert, and HOMER. In this paper, our attention moves towards the use of software Homer, because The HOMER software program is a very good optimization tool and it has been widely used by many researchers.This software provides direct optimization for all types of PV systems and performance emission and economic analysis for the designed system. However, the disadvantage of the HOMER software is that it is not able to predict the performance of the designed PV system. This paper investigates the life cycle cost analysis for the power system. Also, the optimal sizing and cost evaluation using HOMER software is presented. The proposed block diagram of the standalone PV system is shown in Fig.1. The main components of the system are namely the PV array, the MPPT controller, the battery, inverter and the load. The power flow begins when the solar radiation strikes the PV panels and directly converted to electrical energy and then transferred to the maximum power point tracking (MPPT) block in order to adjust the voltage (or current) of the PV array such that actual power approaches the optimum maximum power as possible [4]. Figure (**1**) shows the suggested block diagram of the household stand-alone PV system. Where, the function of the PV array is to convert the sunlight directly into DC electrical power and that of the battery is to store the excess power through using the battery.

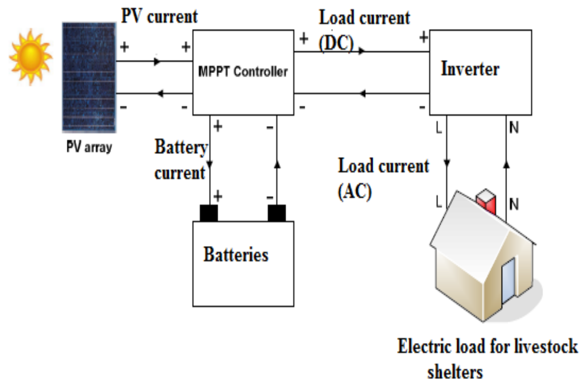


Fig 1: Diagram block of simplified stand-alone PV system

2. Design of the livestock shelters

The rural people of the Algerian semi arid area live mainly on diverse agricultural activities including farming livestock, which plays a major role in the socio-economy of the region. Livestock keeping is critical for many of the poor, often contributing to multiple livelihood objectives such as risk mitigation, wealth accumulation, food security and improved nutrition. In general, interventions aimed at reducing livestock mortality and improving animal nutrition and management would allow for greater use of renewable energy throughout the traditional agricultural system.

This study is concerned with designing a system with minimum total cost of unit of energy to be delivered, to get this various parameters on the system performance needed to be evaluated for optimal design. A sensitivity analysis of the solar power systems was performed using HOMER software package developed by the National Renewable Energy Laboratory (NREL), Colorado, United States was used, (http://www.nrel.gov/ homer) to evaluate the influence of different parameters on the system performance (*e.g.*, solar potential of the installation site, fuel price, number of PV panels, number of inverters, etc). HOMER is a complete set of software that performs sizing of components for both hybrid and standalone power systems that use renewable sources, and identifies the optimum technical and economical set of components able to comply with the desired demand of electric energy from the system, taking into account of other factors like capital cost, maintenance cost, fuel price and also the environmental constraints like the wind/solar potential of the location for the system. From this point of view, it is important to introduce a model for a livestock shelter powered by using photovoltaic system. Terny-Beni Hdiel was selected as the site under consideration. A livestock shelters in the The load analysis calculation is listed in Table 2.

Terny-Beni Hdiel village has been chosen as a case study to conduct the calculations of energy consumption. The livestock shelter comprises the following rooms:

* Block I: for the cattle
* Block II: for milking
* Block III: for storage
* Block IV it is a Barn
* A watering, and other devices used in this livestock unit.

Our analysis found that the total connected wattage is 320 W and the total average daily load is 5.5KWh.

3. STAND-ALONE PV SYSTEM SIZING

Estimation of the sizing parameters PV systems is very useful to conceive au optimal PV systems as well as conceiving an optimal and economic PV system. Several studies were elaborated on the performance of PV systems [5, 6] for an optimal sizing. The performance of a stand-alone PV system depends on the behavior of each component and on the solar radiation, size of PV-array and storage capacity.

3.1 Radiation Data for proposed area

The interest village is located at latitude, north 34°47’45’’, longitude, east 1°21’32’’E [7].

In order to design a cost-minimizing power supply system, we need to consider the available solar resources in the project area. Terny-Beni Hdiel area has very high potential of solar energy. Solar radiation data for this region were obtained from the automatic meteorology station. The annual average solar radiation is 4.92 kwh/m^2/day. The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions [8]. Data is Shawn in table 1.

3.2 Demand Load

In a remote rural village the demand for electricity is not so high as compared to urban areas. The basic energy requirements in such areas can be classified as domestic & agricultural .In the agricultural sector electricity is required for appliances like water pumping system, poultry lighting, and solar pumping for livestock watering. The proposed system is applied to livestock shelters of area 73m^2 with 25 livestock living in it. The load was obtained for livestock shelters in a rural village Terny Beni-Hdiel of Tlemcen (Ageria) and energy usage data was obtained from the electrical bills over a year; figure 3 shows the average monthly load profile, while figure 3 shows the seasonal profile for the load. Our analysis found that the total connected wattage is 730 W and the total average daily load is 5.5 kW h.

Table 1. Solar radiation and clearness index data for terny-Beni Hdiel

Month	Daily Radiation (KWh/m^2/day)	Clearness index
January	2.706	0.528
February	3.485	0.541
March	4.703	0.570
April	5.783	0.580
May	6.444	0.580
June	7.879	0.596
july	7.123	0.631
August	6.604	0.638
September	5.492	0.623
October	4.092	0.588
November	2.934	0.543
Décember	2.525	0.536

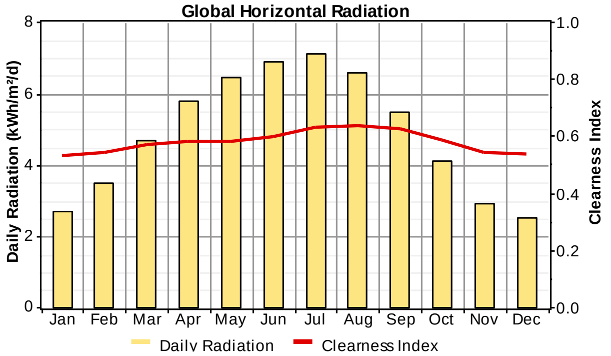


Fig 2: Terny-Beni Hdiel solar radiation and clearness index.

The load profile adopted in this research is that represented on figure 3. This hourly energy distribution is considered in the month of December. The load demand in the morning and late night hours are small. If it is considered component wise it is found that in the winter season the use of ceiling fan is minimum for this projected area. But in summer almost all the appliances gets the highest load demand. Here figure 3 explores the average hourly load profile in the month of December.

Table 2. Total electrical energy consumption per month

Electrical Load	Power (W)	N°.of Units	Power consumptions (KWh/day)
Lighting	20	4	0.08
Pump (DC)	300	1	0.3
Fan(DC)	60	2	0.12
Cooling (DC)	150	1	0.15
Other devices	200		0.2
Total energy use	**730**	**5.5 KWh**	

Figure 3 illustrates the hourly load profile; whereas the majority of the load occurs during the day time (8 am to 5 pm).

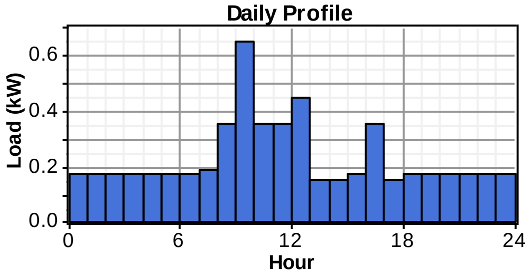


Fig 3: Hourly load variation in shelters for the days December 24,

3.3 Photovoltaic panels

Solar Energy is one type of the renewable resources, which can be converted easily and directly to the electrical energy by PV converters. BP Solar BP SX 150S PV module was selected for the proposed stand-alone PV system. The PV module is a multi-crystalline silicon type with nominal maximum power of 150W, each module contains 72 silicon cell connected in series. Table 2 shows its electrical specification [9].

Table3. Photovoltaic Module Electrical characteristics (BP Solar BP SX)

Characteristic	**Rating**
Maximum power (P_{max})	150W
Voltage at P_{max}	34.5V
Current at P_{max}	4.35A
Short-circuit current (I_{sc})	4.75A
Open-circuit voltage(V_{oc})	43.5V
Maximum system voltage	600V
Area	1.2m^2
Efficiency	15%

3.3.1 The PV peak power

The size of the PV array can be estimate as follow first the PV panel area is evaluated for on daily load energy requirements (El) [10]:

$$PV_{area}=\frac{E_L}{G_{av}\times\eta_{PV}\times TCF\times\eta_{out}} \qquad (1)$$

Where

G_{av} is an average solar energy input/day (kWh/m2/day)., average daily radiation of the month most unfavorable [kWh/m2/j]

In our case, the estimated energy needs E_L rise with 5,5kWh .

TCF is temperature correction factor

η_{pv} is PV efficiency,

η_{out} is battery efficiency (η_B) * inverter efficiency (η_{Inv})

The sizing of the photovoltaic generator carried out on the basis of an average solar energy input 4.62KWh/m^2/day.

TCF is a temperature correction factor, if the temperature is assumed to reach 60º C then the TCF will be = 0.8 [11].

In the evaluation procedure we need into account the efficiency of the system, where is a multiply of a PV module (12%) the battery (0.9) and the inverter efficiency (0.9).

$$PV_{area}=\frac{5.5}{2.525*0.765*0.8*0.12}=29.65\text{m}^2$$

The PV peak power, at peak solar insolation (PSI) of 1000 W/m2, is thus given by [11, 12]:

$$PV_{WP}=PV_{area}\times PSI\times\eta_{PV} \qquad (2)$$

Where,

PSI is the peak solar intensity at the earth's surface (1000 W/m^2),η_{pv}=12%, using the evaluated data this value is:

$$PV_{WPr}=29.65\times1000\times0.12=3558W_p=3.558KW_p\approx 4KWp$$

We choose the operating voltage as a function of the power of the photovoltaic field in watts. If the DC bus voltage is chosen to be V_{pv} =48 V.

3.3.2 Choice of the number of solar modules

For this application the number of the chose BP Solar BP SX 150S PV type modules wit 150Wp ($PV_{WP,module}$ =150)peak power for this given daily energy requirement can be established by the following equation:

$$N_{pv}=\frac{PV_{WP}}{PV_{WP,module}} \qquad (3)$$

$N_{PV}=3558/150=23.72\approx 24$

In this case 24 modules type BP Solar BP SX 150S PV are used to supply the application with the required energy.

3.3.3 Determination of the number of series-connected

The number of modules Ns to be connected in a series string is determined by V_n the nominal voltage of the module

$Ns = V_{pv}/V_n =48/24=2$

3.3.4 Determination Number of the module parallel-connected will be equal

The number of strings in parallel (NP) as given in Eq (4) is determined by dividing the designed array output PPVarray by the selected module output PModulemax. and the number of series modules NS.

$$N_p=\frac{PV_{array}}{N_S PV_{WP,module}} \qquad (4)$$

$$N_p=\frac{3558}{2\text{x}150}=11.86\approx 12$$

The series and parallel configuration of the resulted PV array can be adjusted according to the required DC bus voltage and current, respectively. If the DC bus voltage is chosen to be 48 V, then one module will be connected in series and 12 strings (each of 2 modules in series) will be connected in parallel.

3.4 The Storage Battery Capacity

Energy generated by the PV cells is accumulated and stored in batteries to be used as needed. The battery is capable of storing a certain amount of DC electricity at fixed round-trip energy efficiency with limits as to how quickly it can be charged or discharged without causing damage, and how much energy can cycle through it before it needs to be replaced. HOMER assumes that the properties of the battery remain constant throughout its lifetime, and they are not affected by external factors such as temperature. The chosen battery is Vision 6FM200D. Nominal space 12V ,200Ah , 2.4KWh. The storage capacity C can be calculated according to the following relation [13]. In this case the DOD = 80% was taken into account.

$$C=\frac{N_C\times E_L}{DOD\times\eta_{out}} \qquad (5)$$

Where:

η_{out} is battery efficiency (η_B) *inverter efficiency (η_{Inv}),

$\eta_{out}=0.85*0.9=0.765$

Nc is largest number of continuous cloudy days of the site

DOD is maximum permissible depth of discharge of the battery.

Where, N is a system autonomy day. In this present case N= 2 day.

$C=28758Wh/48=599.12Ah\approx 599Ah$

The largest number of continuous cloudy days N_C in the selected site is about 2 days. Thus, for a maximum depth of discharge for the battery *DOD* of 0.5 and battery efficiency 50%, the storage capacity using equation (5). Since, the selected DC bus voltage is 48 V, then the required ampere-hours of the battery =599 Ah. If a single battery of 12 V and 200 Ah is used, then 4 batteries are connected in series and 1strings of batteries are connected in parallel; to give an overall number of 3 batteries.

3.5 Power Converter

A converter is included in order to maintain the flow of energy between the AC and the DC bus. The conventional load is DC type, but generated power from diesel generator is AC type.

The size of the photovoltaic inverter is of vital importance for the energy yield. Its optimisation can result in improving the total energy usability of the photovoltaic generator and high availability is expected. A ration (ν) relating the inverter rated power $(P_{PV,INV,nom})$ and the photovoltaic peak power is used as a sizing criterion as follows:

$$P_{PV,INV,nom} = \nu \times P_{PV,Peak} \qquad (6)$$

The ratio is location dependent (i.e. based on the solar radiation intensity) and varies between 0.75 to 1.2 for locations of low and high radiation values respectively.

$$P_{PV,INV,nom} = 1.2 \times 3558 = 4.26KW$$

3.6 Controller sizing

The controller protects the batteries against deep discharge and it prevents them being overcharged. Thus, the life cycle of the battery is increased. To select the controller, The total current I_{PMax} needed can be calculated by dividing the peak powerPV by the DC- voltage of the system.

$$I_{max,Reg} = 1.2 \times N_p \times I_{p,max}$$

$$I_{pMax} = \frac{PV_{Wp}}{V_{PV}}$$

$$I_{pMax} = \frac{3558}{48} = 74.125A$$

$$I_{max,Reg} = 1067.4\,A$$

4. OPTIMUM PHOTOVOLTAIC SYSTEM

4.1 HOMER Simulation

In order to determine the energy production and the energy efficiency of stand- alone PV system, it was the modeling and the simulation of this system. It was used as specialized software for simulation of developed renewable sources named HOMER [14]. The details of various parameters such as solar and wind resource potential of the area, load profile of the livestock shelters and description of various component, i.e. size, number and cost of PV array, Battery, Converter, etc. in the proposed photovoltaic scheme have been collected from different resources. HOMER (Hybrid Optimization Model for Electric Renewables) is a computer model developed in 1992 by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micropower systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeler to compare many different design options based on their technical and economic merits.

Renewable power sources add further complexity because their power output may be intermittent, seasonal, and nondispatchable, and the availability of renewable resources may be uncertain. HOMER was designed to overcome these challenges. HOMER simulates and optimizes stand-alone and grid-connected power systems comprising any combination of PV arrays, wind turbines, run-of-river hydro power, biomass power, internal combustion engine generators, micro turbines, fuel cells, batteries, and hydrogen storage, serving both electric and thermal loads (by individual or district-heating systems).

The simulation considers a 1 year time-period using a minimum time-step of 1 minute. It performs sensitivity analyses which can help the analyst to do what-if analyses and to investigate the effects of uncertainty or changes in input variables. The objective of the optimization simulation is to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability [14], [15], [16] and [17].

4.2 DETAILS OF THE COMPONENTS

4.2.1 Equipment Considered

A stand-alone PV system consists of a renewable energy sources (solar energy, and wind turbine), batteries for energy storage and power inverter to maintain the flow of energy between the AC and DC sides. Figure 4 shows the proposed scheme as implemented in the HOMER simulation tool.

Different sizes for PV arrays are considered from 0,1,2,3 to 4 KW and the 1 to 30KW sizes are considered for the inverter. The proposed system consists of PV modules, batteries, and inverter. The optimization of the size of integrated energy system is very important, and leads to a good ratio between cost and performances.

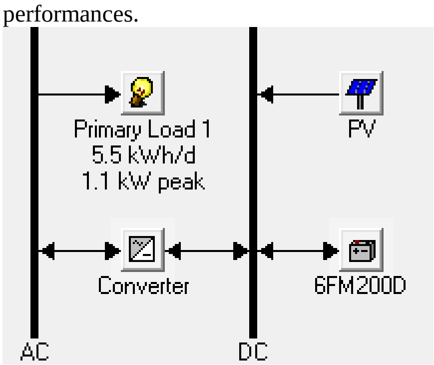


Fig 4: HOMER components of PV system

4.2.2 Economics

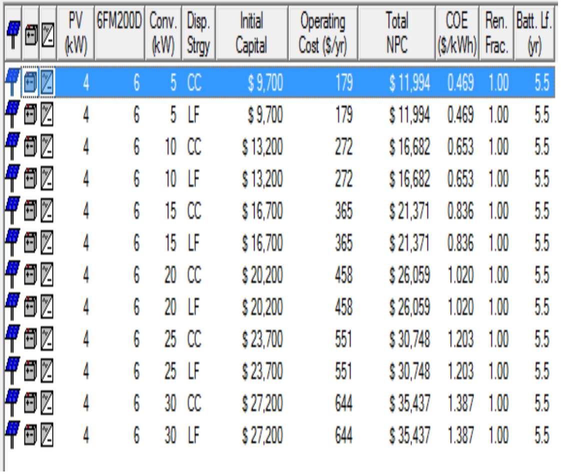
The advantage of HOMER offers is that it gives us the opportunity to design a cost-minimizing power system that provides a tailor-made power supply for the specific load demand. HOMER also minimizes the excess capacity problem mentioned above. Three types of cost data for each component were used in the analysis. These are capital cost, replacement cost, and operation & maintenance cost.

Table 4. Detail of the capital, replacement and O&M cost of various equipments employed in the proposed scheme.

Component detail	Capital cost ($)	Replacement cost ($)	O&M cost ($/yr)	Life time (year)
Solar PV system (1KW)	300	250	0	20
Battery	200	160	10	917KWh
Converter(1KW)	700	700	0	15

HOMER Software Performs Several Simulations In Order To Obtain the Optimal photovoltaic stand-alone System. Two sensitivity variables are considered in this system and they are solar irradiation, load, sensitivity analysis of the HOMER is shown in the overall winner which shows that the most cost that optimizes photovoltaic system is combination of the 4 kW PV, 5kW converter and 6 unit batteries. The optimal power system found by HOMER is a 4kw of PV, 1kw capacity generator, 6 batteries and an inverter of 5kw for an initial capital cost of $9.700 and NPC of $11.994. The optimization results are show in tableau 5.

Table 5: Optimization Results Of photovoltaic stand-alone System For livestock shelters.



PV (kW)	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
4	6	5	CC	$ 9,700	179	$ 11,994	0.469	1.00	5.5
4	6	5	LF	$ 9,700	179	$ 11,994	0.469	1.00	5.5
4	6	10	CC	$ 13,200	272	$ 16,682	0.653	1.00	5.5
4	6	10	LF	$ 13,200	272	$ 16,682	0.653	1.00	5.5
4	6	15	CC	$ 16,700	365	$ 21,371	0.836	1.00	5.5
4	6	15	LF	$ 16,700	365	$ 21,371	0.836	1.00	5.5
4	6	20	CC	$ 20,200	458	$ 26,059	1.020	1.00	5.5
4	6	20	LF	$ 20,200	458	$ 26,059	1.020	1.00	5.5
4	6	25	CC	$ 23,700	551	$ 30,748	1.203	1.00	5.5
4	6	25	LF	$ 23,700	551	$ 30,748	1.203	1.00	5.5
4	6	30	CC	$ 27,200	644	$ 35,437	1.387	1.00	5.5
4	6	30	LF	$ 27,200	644	$ 35,437	1.387	1.00	5.5

5. Simulation Result

Figure 5, 6, 7 and 8 represent hourly HOMER simulation results during the day of 26th December where the load peak appears. Note in Figure 5, the daily distribution of solar irradiation and photovoltaic power for the Day 26December. From Figure 5 we see that there is a perfect correlation between the incident solar radiation and photovoltaic power produced. *Figure 6* illustrates the DC power that can be produced by the PV generator. Figure 6 displays the power output that reached the batteries on a mostly clear day in December.

It can be seen, that the batteries is receive power as soon as it is started to be generated by the PV panels and it demonstrates that the power consumed by the load is very small compared to the power generated. On the other hand, the batteries are fully charged within few hours, because of the low power discharge, which is result in the huge capacity of the battery bank compared to the load consumption. However, it can be observed from the experimental curve in figure 7 that the batteries charging are continued until the end of the day to compensate battery self-discharging process.

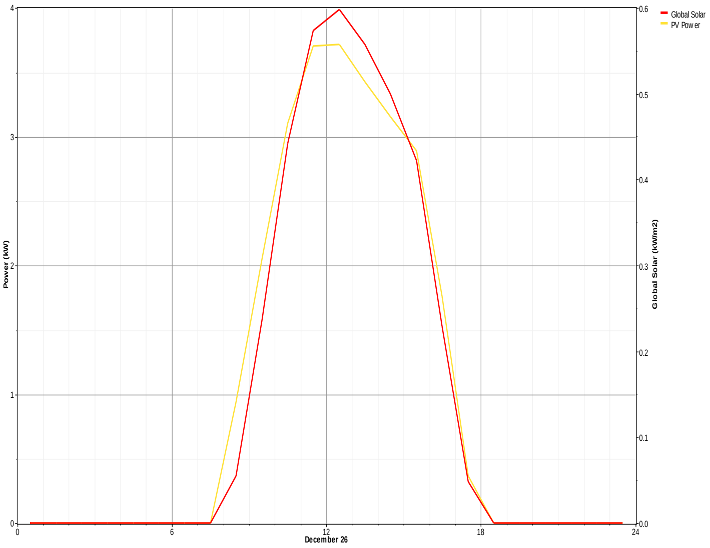


Fig5: Distribution of daily solar radiation and photovoltaic power

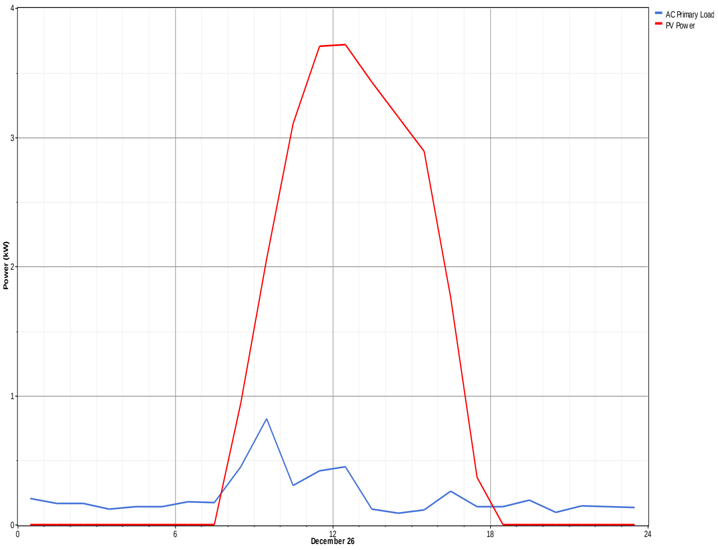


Fig 6: Load profile and photovoltaic power

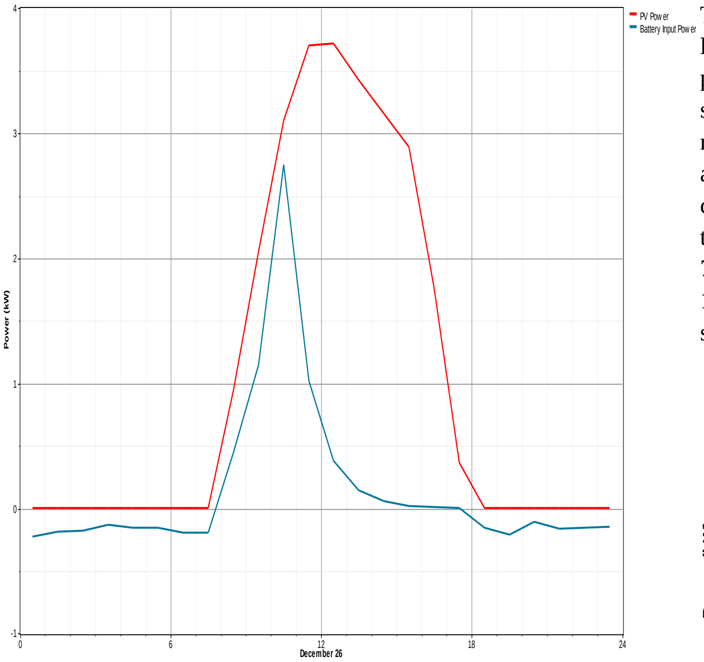


Fig 7: Power Output of the battery for the month of December, 26 th

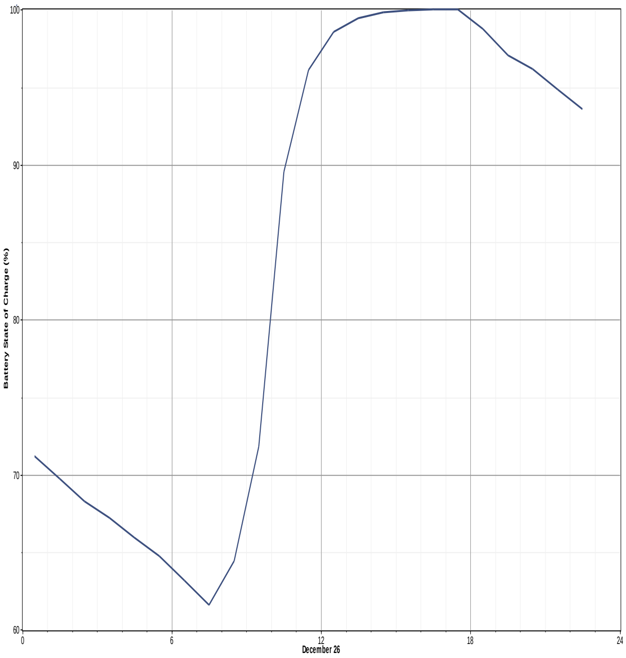


Fig 8: Evolution of the charging status of the battery

The performance of the PV system for a typical year in livestock shelters has been predicted. The monthly mean power contribution of PV systems to the photovoltaic power system remain almost the same with slight variation of maximum and minimum of 194.7kW and 173.8 kW in August and September, respectively, as shown in Figure 6, for this combination if we goes towards the electricity produced by that system then it is observed that PV array produce 7.213Kwh/Yr about 100% of total. And consumption is about 1.999Kwh/Yr so the 66.1% excess electricity is remaining shown in Figure9.

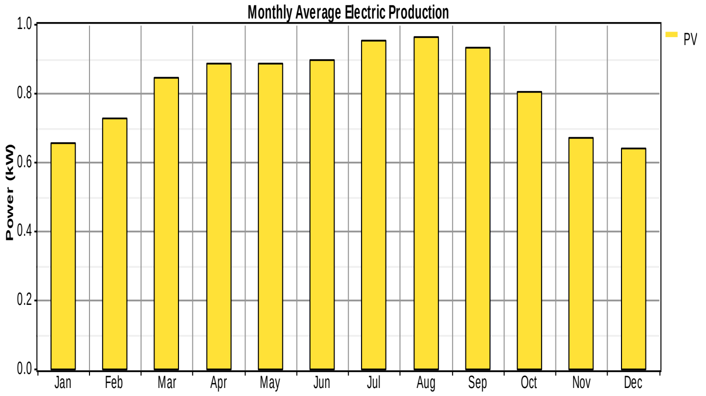


Fig 9: Power Output of the PV system for a typical year

The total costs of each component of the photovoltaic power systems, including mainly the photovoltaic panels, battery and power converter, are shown in Figure 10.

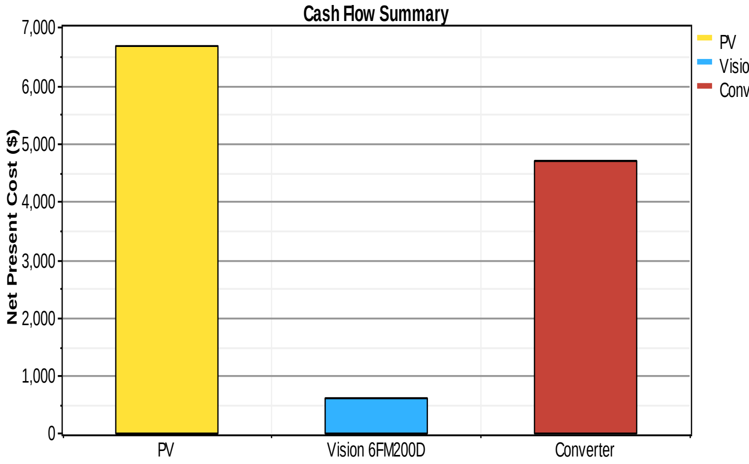


Fig10. Cost summery of different components

6. Conclusion

This paper studies the feasibility of utilizing the stand-alone photovoltaic systems proposed for livestock shelters located in Terny-Beni Hdiel village of Tlemcen (Algeria). Solar data such as solar radiation and sunshine duration has been recorded for area proposed.

In this study the performance of standalone PV systems for livestock shelters in Terny-Beni Hdiel village is processed in order to produce a comparative study between two methods namely numerical and HOMER used to size these systems. The simulation results illustrated that there is a considerable amount of the producible power is dissipated due to the over sized PV panels which can produce much more electricity than that could be stored in batteries bank.

Software HOMER program, including any modules and subprograms, data, and information are provided as a renewable energy source. HOMER, the micro-power optimization model, simplifies the task of evaluating designs of both off grid and grid-connected power systems for a variety of applications.

The simulation results give the information about the the way the system operates as well as how it produces energy. Using the HOMER software computer model, we determined that the most economic system for a remote livestock shelters having a daily load of 5.5 kWh which is composed of 4-kW PV modules, 6 batteries (200 Ah and 12 V), and a 5-kW inverter.

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