International Journal of Sustainable and Green Energy
2024; 13(1): 1-7
http://www.sciencepublishinggroup.com/j/ijsge
doi: 10.11648/j.ijrse.20241301.11
ISSN: 2575-2189 (Print); ISSN: 2575-1549 (Online)

Sizing and Simulation of a Photovoltaic Hybrid Energy System and Generator for the Electricity Supply of the Residence of the Governor of Mamou, Guinea

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To cite this article:
Ansoumane Sakouvogui, Nene Aissata Balde, Yacouba Camara, Saidou Barry, Elhadj Ousmane Camara et al. (2024).Sizing and Simulation of a Photovoltaic Hybrid Energy System and Generator for the Electricity Supply of the Residence of the Governor of Mamou, Guinea. *International Journal of Sustainable and Green Energy, 13*(1), 1-7. https://doi.org/10.11648/j.ijrse.20241301.11

Received: December 20, 2023; **Accepted**: January 2, 2024; **Published**: January 18, 2024

Abstract: The optimization sizing model of hybrid renewable energy systems is a model that applies to micro-energy and makes it possible to simplify the design and implementation of electrical energy projects in isolated areas of large distribution networks and can be interconnected. The objective of this work is the optimal sizing and simulation on HOMER (Hybrid Optimization Model for Electrical Renewable) software of a hybrid photovoltaic system and generator for the electricity supply of the residence of the governor of Mamou. The methodology followed to estimate the electrical loads of the residence, categorizing them in two ways (low consumers and high energy consumers). The field survey made it possible to know the average temperatures and average irradiations of the site. The dimensioning of the photovoltaic field was initially carried out using analytical formulas. The characteristics of the field elements were also determined. The choice of group was made on the basis of the total load of the residence. Finally, the HOMER software made it possible to carry out optimal sizing and simulation of certain parameters. The main results obtained relate to: the meteorological characteristics of the site (temperature and irradiation). The temperature varies from 23.10°C to 30.30°C with an average of 25.86°C. Irradiation varies from 4.68 kWh/m²d to 6.76 kWh/m²d from August to April with an average of 5.54 kWh/m2d. The elements of the hybrid system are: 20 panels of 260 Wp, for an installed power of 5200 Wp; 8220 Ah batteries, for an installed capacity of 1760 Ah; two (2) converters (Sunny boy and Sunny island) with a power of 84 kW each and a 10 kVA generator. The annual production of electrical energy of the entire hybrid system is thus 39.393 kWh. Including 18.113 kWh for the generator, i.e. 46%, and 21.28 kWh for the photovoltaic system, 54%. The investment cost of the system is estimated at 192420600 FG. The results obtained show that the use of renewable energy sources such as solar coupled with thermal remains the best optimal solution for providing electrical energy to isolated areas.

Keywords: Hybrid System, Photovoltaic, Generator, HOMER

1. Introduction

In Africa, access to electricity is a major problem which considerably slows down its development. It undoubted lyre mains the least electrified continent with 3% of global electricity consumption despite its population (15% of the world population) [1, 2]. In Guinea, the administrative regions in general, particularly that of Mamou, still have a low rate of access to electricity [3]. To solve this problem, the production of energy by combining two or more energy sources has become the appropriate solution today; This energy production system is essential due to its flexibility, its simplicity and the multiplicity of areas of activity where it plays an important role [4].

However, the study of sizing the coupling of a hybrid system (photovoltaic and generator) is always focused on the essential criteria which are: the solar deposit, the thermal deposit and the energy demand [5, 6]. Hybrid energy systems combine at least two complementary technologies. There are three types of configuration of Photovoltaic / Diesel hybrid systems which are: photovoltaic - diesel series; photovoltaic - switched diesel and photovoltaic - parallel diesel [7].

Guinea has enormous energy potential with an average annual sunshine estimated at 4.8 kWh/m² per day and the annual duration of sunshine varies from 2000 hours to 2700 hours, which favors the development of the solar energy system in these regions. With this significant potential, the rate of access to energy service in Guinea stiller mains below 20%, including less than 50% in urban areas and less than 5% in rural areas. Added to this are the very frequent problems of load shedding and power outages [8].

To solve this problem, the production of energy by combining two or more energy sources has become the appropriate solution today. This energy production system is very effective due to its flexibility, its simplicity and the multiplicity of areas of activity where it plays an important role [9].

This study is part of this perspective. Its main objective is to present a method of optimal sizing and simulation of the coupling of a photovoltaic system and a generator to supply electrical energy to the residence of the governor of Mamou.

2. Materials and Methods

2.1. Presentation of the Study Area

The prefecture of Mamou, capital of the Administrative Region of Mamou, is between 9°54’ and 11o10’ north latitude and 11°25’ and 12°26’ west longitude with an average altitude of 700m. It covers an area of 8400 km^2 with a population of 732117 inhabitants, i.e. an average density of 92 inhabitants per km^2 (according to the general population and housing census in 2014). The Governor's residence is located in the Almamya district, on an area of approximately 2000 m^2 [10]. The photo in Figure 1 shows the residence of the Governor of Mamou.

Figure 1.*Governor’sResidence.*

2.2. Materials

During this study, we used the following equipment: Multiple pliers, millimeter, insulating gloves, insulating mat, various screwdrivers, spirit level, drill, helmet, centimeter, saw, hammer, chisel.

2.3. Methodology

In general, there are two methods of sizing photovoltaic-hybrid systems, the manual method and the computer method. The manual method is based on the different powers of the receivers and their operating times. The differences of the photovoltaic system are carried out by empirical formulas [11].

2.3.1. Residence Charges

The summary of the various aspects of the residence are divided in to two groups: loads of low energy consumers (lamps, computers, printers, photocopiers, televisions, fan) and loads of large energy consumers (air conditioners and freezers) of the residence are given in table 1.

Table 1. *Charge of the residence of the Governor of Mamou.*

Designation	Quantity	P(W)	Ej(Wh)
Lamps	128	566	4260
Computers	8	520	3120
Print	1	110	330
Photocopiers	1	100	500
Televisions	8	480	3840
Fan	5	250	3000
Total 1		*2026*	*15050*
Air Conditioners	6	9000	10800
Freezers	3	2500	36000
Total 2		*11500*	*46800*
Totaux		13526	61850

2.3.2. Sizing of the PV Field

The sizing of the PV field is based on the supply of loads with low energy consumers. The daily energy is determined by relation 1 [12].

$$\mathrm{Ep} = \frac{\mathrm{Ej}}{\mathrm{K}} = \frac{15050}{0{,}65} = 23153{,}84\ \mathrm{Wh} \qquad (1)$$

Ej: Daily energy in Wh/d and K = 0.65: Efficiency coefficient;

The peak power of the photovoltaic plant is determined by relation 2.

$$\mathrm{Pc} = \frac{\mathrm{Ep}}{\mathrm{Ir}} = 4947{,}4\ \mathrm{Wc} \qquad (2)$$

Ir = 4.68 kWh/m^2.d: is the most favorable solar irradiation in the area, it is recorded in August.

The number of panels in the power station is determined by relation 3.

$$\mathrm{Cs} = \frac{\mathrm{Ej} \times \mathrm{Aut}}{\mathrm{D} \times \mathrm{U}} = \frac{15050 * 3}{48 * 0{,}7} = 343{,}75\mathrm{Ah} \qquad (3)$$

Pcu = 260 Wpis the unit peak power of the chosen panels. The photovoltaic field is thus composed of 20 panels, we thus have a total peak of 5200 Wp.

The capacity of the accumulators is determined by relation 4.

$$N_b = \frac{C_s}{C_u} = \frac{1343,75}{220} = 6,10 \quad (4)$$

Cs: Capacity of accumulators or batteries in (Ah); Aut = 3: Battery life; D = 0.5: Allowable discharge rate of lead-acid batteries; U = 48A: System voltage.

The number of bacteria is determined by relation 5.

$$I_{reg} = \frac{Pc}{U \times \eta_r} = \frac{5200}{48 \times 0,9} = 120.37 \text{ A} \quad (5)$$

Thus, the number of batteries in the system is 8. They will be connected as follows: series connection (Bs = Us/Up = 48/24 = 2), Us: System voltage and Up: Unit voltage of the panels.; parallel connection (Bp = Np/Bs = 8/2 = 4), NP: Number of panels and BS: Series connection.

The regulator provides interface between the module, the batteries and the loads, its sizing depends on the intensity and efficiency that it can support. This current is determined by relation 6 [13].

$$P_{ond} = \frac{P_C}{\eta_{ond}} = \frac{5200}{0,9} = 5777.7 \text{ W} \quad (6)$$

$\eta_r = 90\%$ is the efficiency of the regulator.

The number of panels connected in series and in parallel are calculated as follows: series connection (Bs = Us/Up = 2); parallel connection (Bp = Np/Bs = 10). We thus have 2 panels in series and 10 in parallel, for a total of 20 panels.

The choice of cables depends on their sections, their lengths and their physical properties. The cable section is calculated by formula 7 [14].

$$S = \frac{2 \times \rho \times L \times I}{\varepsilon \times U} \quad (7)$$

S: cable section in m^2, $\rho = 1.6.10^{-6}\Omega m$: resistivity in, ε = 0.02: voltage drop, U = 24 V: panel voltage.

The distance between the panels to the Sunny boy (regulator) being 2 m, the cable section calculated for a total current of 220 A is 25 mm^2. The distance between the Sunny island (regulator) and the batteries being 3m, the cable section calculated for a total current of 24 A is 50 mm^2. The surface area of a panel being 1.6m^2, the installation surface of the photovoltaic field is 32 m^2.

2.3.3. Choice of Diesel Generator

The generator will beused to power all the loads in the residence (lamps, computers, printers, photocopiers, televisions, air conditioners and freezers).

This total daily load of the group having been calculated, its power is that apparent (S) in Volt Ampere (VA) or in kilovolt Ampere (kVA). It miscalculated by relation 8 [15].

$$S = \frac{P}{\sqrt{3} \times \cos\rho} = \frac{13,526}{0.8 \times \sqrt{3}} = 9,762 \text{ kVA} \quad (8)$$

P =13526 W: Total power of the receivers in (W); Cosρ = 80%: Power factor which has the value (0.8). For a margin of safety taking in to account the additional loads of the residence we suggest the choice of a 10 kVA generator.

2.3.4. Optimal Sizing and Simulation with HOMER

As part of this work, the Hybrid Optimization Model For Electric Renewable (HOMER) software allowed us to perform optimal sizing and simulate certain parameters. It is a tool for the design and analysis of hybrid electricity production systems, generally composed of a generator, cogeneration system, wind turbine, photovoltaic system, hydraulic system, battery, fuel cell, biomass and many others [16-18].

The configuration of the hybrid PV and generator system through HOMER is shown in Figure 2.

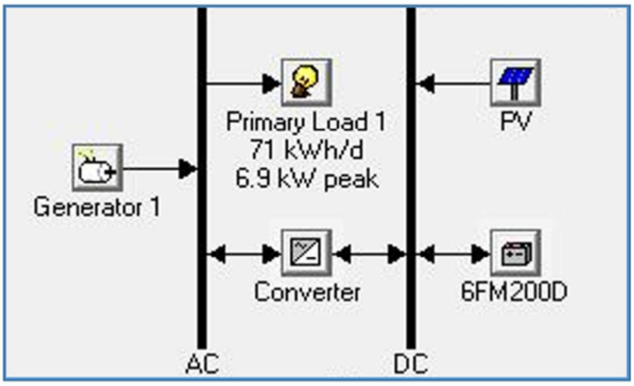

Figure 2. Configuration of the hybrid PV and generator system through HOMER.

3. Results and Discussions

3.1. Weather Characteristics

The results of the meteorological characteristics of the site relate to temperature and irradiation. They are shown in Figures 3 and 4.

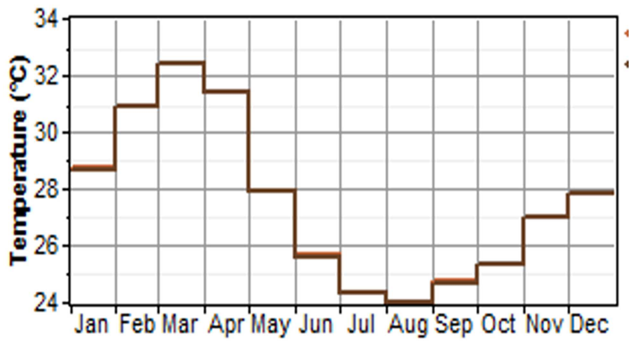

Figure 3. Temperature variation.

These curves show that variations in irradiation are a function of temperature. The temperature varies from 23.10°C to 30.30°C with an average of 25.86°C. The smallest values are recorded respectively, the least August (23.10°C), July (23.20°C) September (23.70°C) and October (23.90°C). The maximums are recorded respectively in the months of May (27.50°C), February (27.90°C), March (29.60°C) and April (30.30°C).

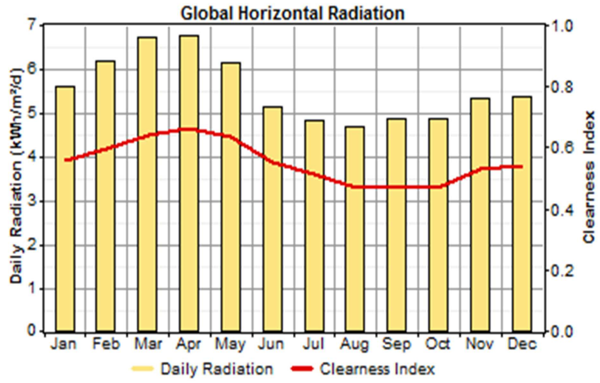

Figure 4. *Variation of irradiation.*

Irradiation also varies, from 4.68 kWh/m2d in August to 6.76 kWh/m^{2}d in April with an average of 5.54 kWh/m^{2}d. The most unfavorable value recorded in August was used for this study.

3.2. Analytical Sizing Results

The sizing results for powering low consumer loads (lamps, computers, printers, photocopiers and televisions) are shown in table 2.

Table 2. *Sizing results for powering low consumer loads.*

N°	Designation	Value	Unit
1	Daily energy	23153.84	Wh/j
2	Peak power	5200	Wc
3	Number of panels	20	-
5	Number of batteries	8	-
6	Inverter power	6000	W
7	Power of the generator group	10	kVA

3.3. Results of Optimal Sizing

The results of optimal sizing with HOMER of the Hybrid system are given in tables 3 and 4.

Table 3. *Possible results of system optimization.*

				PV (kW)	Label (kW)	6FM 2000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
				15	10	25	10	$ 7.093	371.252	$ 4.752.934	14.267	0.54	5.981	1.81
					10	25	10	$ 3.879	710.458	$ 9..085.913	27.273	0.00	11.535	3.496
				15	10		7	$5.414	1.296.289	$ 16.576.338	49.757	0.49	10.694	6.426
					10			$ 1.200	1.764.125	$ 22.552.640	67.696	0.00	14.576	8.759

After the simulation with the HOMER software on the basis of the specifications we obtain four (4) configurations, the first of which is the most suitable configuration. Table 4 gives the optimization results.

Table 4. *Optimal sizing result.*

Designation	Quantity	Unit power	Installed power	Output energy (kWh/year)
Champ PV	20	360 Wc	15 kW	21.280
Groupe diesel	1	10 kW	10 kW	18.113
Batteries	13	200 Ah	22.8 Ah	13.063
Convertisseur	1	10 kW	22.7 kW	19.898

These results give: 20 panels of 260 Wp, for an installed power of 5200 Wp; 8 220 Ah batteries, for an installed capacity of 1760 Ah; 2 converters (Sunny boy and Sunny island) with a power of 84 kW each and a 10 kVA generator.

3.4. Profile of Energy Production by Photovoltaic and the Generator

The energy production profiles by photovoltaic and the generator are given in Figures 5 and 6.

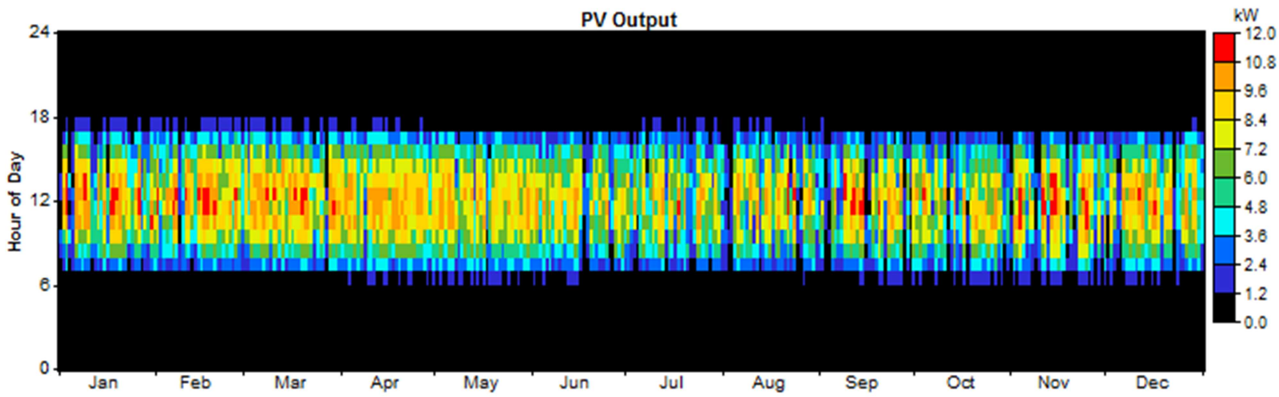

Figure 5. *Photovoltaic energy production profile.*

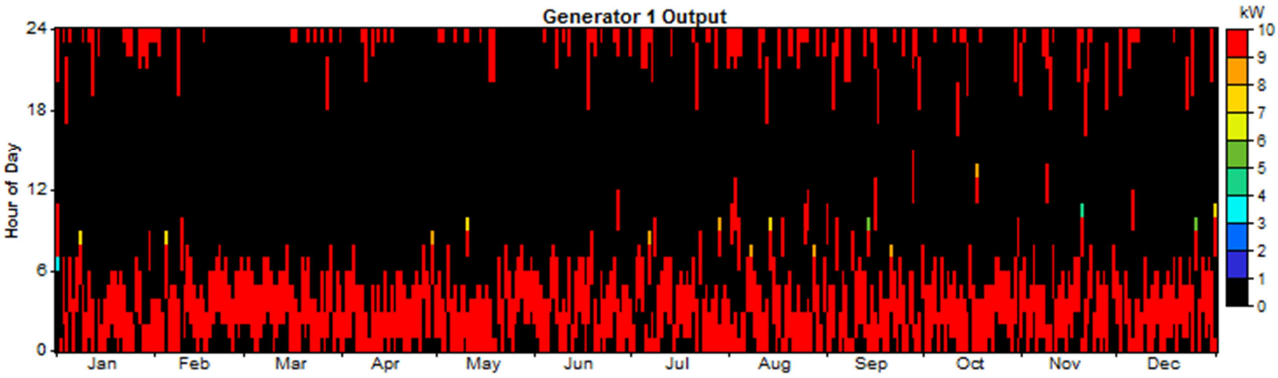

Figure 6. *Energy production profile by the generator.*

Figure 5 shows that the photovoltaic system produces energy every day between 6 a.m. and 6 p.m., with optimal production at 12 p.m. The black color shows the lack of electrical energy from 0 a.m. to 6 a.m. and from 6 p.m. to 24 p.m. During this period, the energy supply is ensured by the generator. From blue to red, the production of electrical energy increases. Optimal production (red color) is observed in the months of January to April and September to December. Figure 6 shows that optimal production of electrical energy is ensured by the generator from 0 a.m. to 6 a.m. and with low production from 6 a.m. to 12 p.m. and from 6 p.m. to 24 p.m.

3.5. Profile of Energy Accumulation by Batteries and Operation of Converters

The profiles of energy accumulation by the batteries and operation of the converters are given in Figures 7 and 8.

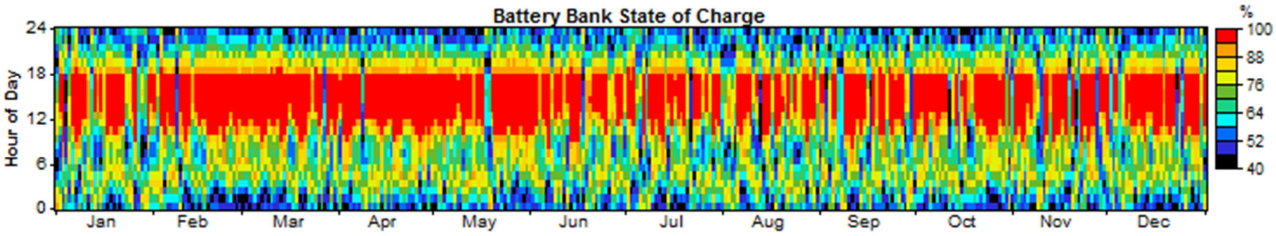

Figure 7. *Energy accumulation profile by batteries.*

Figure 7 shows thatbatterychargingis optimal between 12 and 6 p.m. This accumulated by the batteries ispotentiallyusedfrom 0 a.m. to 6 a.m. and from 7 p.m. to 24 p.m.

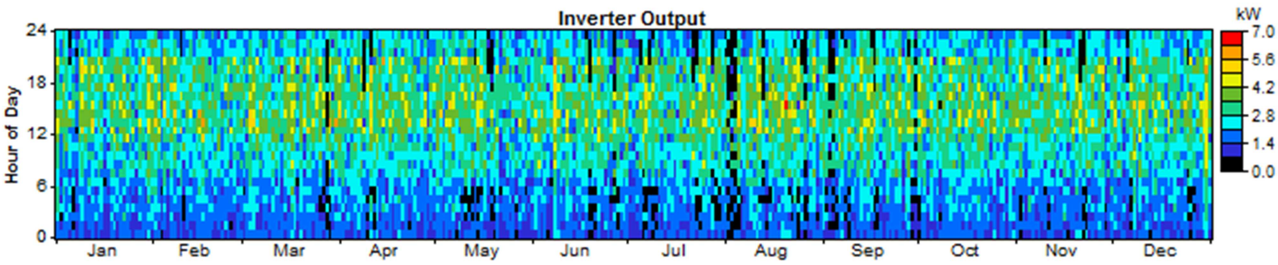

Figure 8. *Converter operating profile.*

Figure 8 shows that the potential converters operate from 11 a.m. to 7 p.m., characterized by colors from green to red. This period corresponds to the maximum energy production by the photovoltaic field

3.6. Annual Energy Production by the Hybrid System and Hourly Loads

The annualenergy production profile by the hybrid system and the hourlyloads of the Governor'sresidence are given in Figures 9 and 10.

Figure 9 shows the share of electrical energy production from each source, the black color for the generator, with an annual production of 18.113kWh or 46%. The yellow color for the photovoltaic system with an annual production of 21.280kWh or 54%.The annual production of the entire system is thus 39.393 kWh.

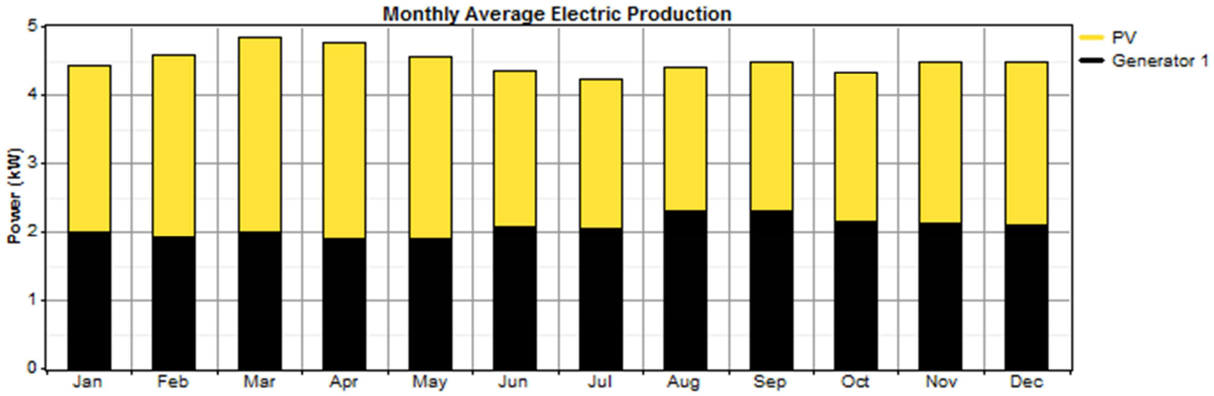

Figure 9. *Annualenergy production profile by the hybrid system.*

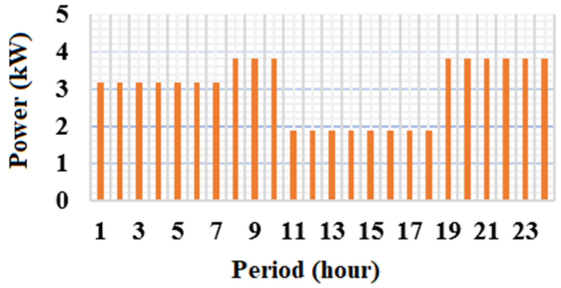

Figure 10. *Distribution of hourly charges for the Governor's residence.*

The diagrams in Figure 10 show the distribution of the hourly loads of the Governor's residence, from 24 p.m. to 7 a.m. the hourly loads remain relatively constant, i.e. (3.1807 kW) which corresponds to 25% of the daily loads; then from 7 a.m. to 10 a.m. and from 7 p.m. to midnight, the hourly loads are 3.8169 kW or 30% of the total daily loads, and finally from 11 a.m. to 6 p.m., the hourly loads are 1.9084 kW or 15% of daily loads.

3.7. Hybrid System Installation Diagram

The installation diagram of the hybrid system isgiven in Figure 11.

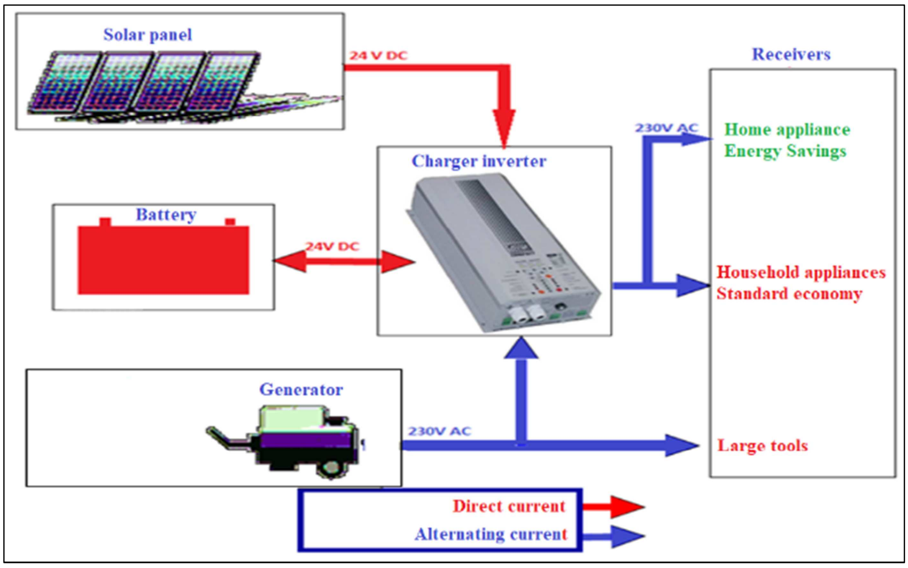

Figure 11. *Hybrid system installation diagram.*

4. Conclusion

As part of this work, the Hybrid Optimization Model For Electric Renewable (HOMER) software was used for the optimal sizing and simulation of a hybrid photovoltaic and generator system as part of the electrical energy supply of the residence of the governor of Mamou. This study made it possible to know the annual variation of the temperature and solar irradiation of the site.

The optimal sizing resulted in: 20 panels of 260 Wp, for an installed power of 5200 Wp; 8 220 Ah batteries, for an installed capacity of 1760 Ah; 2 power converters 84 kW each and a 15 kVA generator. The energy production profiles by photovoltaic system and generator are known. The different hourly loads are distributed between the two systems over time. The installation diagram of the hybrid system is produced. The results obtained show that the production of electrical energy by combining two or more energy sources remains today the adequate and effective solution to resolve the problems of very frequent load shed ding and power outages.

Conflicts of Interest

The Authors declare no competing interest.

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