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(RESEARCH ARTICLE)

Dimensioning of a hybrid photovoltaic-electricity grid installation: Case of the computer rooms of the IST of Mamou, Guinea

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Abstract

The objective of this research is to propose a technical and economically viable solution to efficiently and sustainably power the computer rooms of the Higher Institute of Technology of Mamou using a hybrid photovoltaic-electric grid installation. This research will contribute to optimizing the use of solar energy and reducing electricity consumption from the grid, while improving the resilience and sustainability of IT installations. During this research, we used two (2) sizing methods, namely: the manual method based on empirical formulas and the method using HOMER software. These two methods led to several results, the main ones being:

Concerning photovoltaic solar: one hundred and ninety-two (192) 500WC panels for an installed power of 96,000 WC; one hundred and forty-four (144) 200 Ah batteries for an installed capacity of 28,800 Ah; two converters (Sunny boy and Sunny Island) with a power of 107 kW each and the EDG electrical network of 29,604 kWh/year: The annual production of electrical energy of the entire hybrid system is 171,665 kWh, of which 29,604 kWh for the electrical network supplied by the Garafiri hydroelectric power plant (75 MW) for a voltage level of 110kV/30kV, or 13%. According to our analyses, this research shows that the use of renewable energy sources such as photovoltaic solar energy coupled with the electrical network via a hydroelectric power plant remains the best optimal solution for providing clean and less polluting energy to an isolated site in general and that of Guinea in particular, whose hydroelectric potential is estimated at 6000 MW and very considerable solar irradiation

Keywords: Hybrid system; Solar Photovoltaic; Electricity Network; Hydroelectricity; Environment; IST; Guinea

1. Introduction

The production of energy based on renewable sources, in particular wind and sun, represents an interesting alternative to overcome the problems due to the excessive use of conventional energy sources. However, the performance of a system based on a single renewable source is limited because of the latter's dependence on climatic conditions and various political, economic, etc. issues. In addition, fluctuations in the load, on an annual or daily scale, are not necessarily correlated with the availability of energy resources. In order to overcome these difficulties of use, the use of hybrid energy production systems seems to be a promising solution [1, 2].

These systems are the result of either the combination of complementary renewable sources or the association of renewable and conventional sources with or without the addition of a storage device [3].

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Currently, the contemporary world is seeking to get rid of polluting energies and rely on renewable energies. These forms of non-polluting energies constitute an adequate solution to reduce greenhouse gases. Renewable energy has become an indispensable form of energy due to its flexibility, ease of use and the multiplicity of areas of activity where it is called upon to play a role. We can count on renewable energy not only because it has a high-performance technology that generates electricity from an inexhaustible and clean source but also because it is an industry in its maturity [4],[5],[6]. Renewable energy sources represent an attractive option for community electrification of remote or isolated rural areas [7], [8]. On the other hand, renewable energy production systems face difficulties in acceptance due to high investment costs and variable availability as a whole during energy production. Seasonal variations pose a problem of energy fluctuations throughout the annual climate cycle [9].

It seems unthinkable to solve the problem of electricity production only through a single form of energy, which is why we are interested in the hybrid system (Photovoltaic-Electricity Grid) because of their intense development in recent years. In a grid-connected hybrid photovoltaic system installation, the power conditioning device is an inverter which represents the most delicate key element of the installation. Inverters are no longer limited to transforming the direct power (DC) generated by the photovoltaic modules into alternating power in the form of sinusoidal voltage and desired frequency (230 V/400V – 50Hz), but they also exploit the power delivered [10],[11],[12].

Since energy production is a challenge for human societies, it is with this in mind that we proposed to work on the research topic entitled: Sizing of a hybrid photovoltaic-Electricity Grid installation. Case of the computer rooms of the IST of Mamou.

2. Material and methods

The Prefecture of Mamou, capital of the administrative region of Mamou is located 270 km from Conakry, it covers an area of 8000 km2 with a population of 318,981 inhabitants according to the general census of the population and housing in 2014. It is located between 9°54' and 11°10' of north latitude and 11°25' and 12°26' of west longitude, with an average altitude of 700 m. It is characterized by the alternation of two (2) seasons: a dry season which extends from November to April and a rainy season from May to October. The most unfavorable sunshine in Mamou is recorded in August with an average annual temperature of 25°c and an irradiation of 4.68 Kwh/m2/d. It is bordered to the north by the prefectures of Dalaba and Tougué, to the south by the Republic of Sierra Leone, to the east by the prefectures of Dabola and Faranah and to the west by the prefecture of Kindia. Its climate is of the Foutanian type.

2.1. Tools

To carry out this study, we used the meteorological data of the prefecture of Mamou. Its data are recorded in Table 1.

Table 1 Meteorological data for Mamou prefecture, Guinea

Month	Solar irradiation (KWh/m^2/j)	Air temperatures (°c)
January	5,59	26,1
February	6,17	27,9
March	6,71	29,6
April	6,76	30,3
Mai	6,16	27,5
Jun	5,15	24,3
Jully	4,83	23,2
August	4,68	23,1
September	4,87	23,7
October	4,88	23,9
November	5,35	24,9
December	5,38	25,8
Annual average	5,54	25,9

2.2. Estimation of daily building needs

To collect these needs, we conducted a field survey for data collection. These data are recorded in Table 2.

Table 2 Summary of total departmental expenses

Location	Designation	Nature of the current	Qty	Pu(w)	Times(h)	Pt(w)	Ej(Wh/J)
Desk	Lamp	AC	5	36	8	180	1440
	Printer	AC	2	60	2	120	240
	Air conditioner	AC	1	930	8	930	7440
	Computer	AC	2	200	8	400	3200
	Toilet	AC	1	7	3	7	21
	Fan	AC	1	45	6	45	270
Room 1	Computer	AC	50	200	7	10000	70000
	Air conditioner	AC	3	2500	7	7500	52500
	Lamp	AC	6	36	7	216	1512
	Video projector	AC	1	130	7	130	910
Room 2	Computer	AC	50	200	7	10000	70000
	Air conditioner	AC	3	2500	7	7500	52500
	Lamp	AC	9	36	7	324	2268
	Video projector	AC	1	130	7	130	910
Room 3	Computer	AC	50	200	7	10000	70000
	Air conditioner	AC	3	2500	7	7500	52500
	Lampe	AC	9	36	7	324	2268
	Video projector	AC	1	130	7	130	910
Room 4	Computer	AC	50	200	7	10000	70000
	Air conditioner	AC	3	2500	7	7500	52500
	Video projector	AC	1	290	7	290	2030
	Lamp	AC	6	36	7	216	1512
Terrace	Lamp	AC	8	7	8	56	448
Exteriors	Energy saving lamps	AC	12	7	12	84	1008
TOTAL 1						73582	516387
Other charges: 5% of total 1						77261,1	542 206,35

Given the existence of the MT/BT distribution network, we have planned to supply high-consumption devices via the electricity network. Thus, the table below contains the loads of low-consumption devices. The data in this table and the irradiation for the month of August serve as basic data for assessing the solar potential of the site.

Table 3 Loads to be supplied by the photovoltaic system

Location	Designation	Nature of the current	Qty	Pu(w)	Times(h)	Pt(w)	Ej(Wh/J)
Desk	Lamp	AC	5	36	8	180	1440
	Printer	AC	2	60	2	120	240
	Computer	AC	2	200	8	400	3200
	Toilet	AC	1	7	3	7	21
	Ventilateur	AC	1	45	6	45	270
Rome 1	Computer	AC	50	200	7	10000	70000
	Lamp	AC	6	36	7	216	1512
	Video projector	AC	1	130	7	130	910
Rome 2	Computer	AC	50	200	7	10000	70000
	Lamp	AC	9	36	7	324	2268
	Video projector	AC	1	130	7	130	910
Rome 3	Computer	AC	50	200	7	10000	70000
	Lamp	AC	9	36	7	324	2268
	Video projector	AC	1	130	7	130	910
Rome 4	Computer	AC	50	200	7	10000	70000
	Video projector	AC	1	290	7	290	2030
	Lamp	AC	6	36	7	216	1512
Terrace	Lamp	AC	8	7	8	56	448
Exteriors	Energy saving lamps	AC	12	7	12	84	1008
TOTAL 1						42652	298947
Other charges: 5% of total 1						44784,6	313894,35

3. Methods

For the case of this research, we used two methods namely: the manual method and the software method.

3.1. Manual method

The manual method consists of estimating the energy needs of the site in order to find the number of panels, the type of regulator, the capacity of the accumulators, the power of the inverters and the section of the cables. To do this, we have started the following steps for dimensioning by the manual method:

Calculation of peak power

Peak power is determined by the following relationship:

$$\text{Pc} = \frac{Ej}{Ir \times K} \qquad (1)$$

Or :

Ej : daily energy (313 894,35 Wh/J) ;

Ir : solar irradiation (4,68W/m^2)

K : system efficiency coefficient taken equal to 0,7.

Number of panels

The number of panels required for the system to operate is determined by the following relationship:

$$Np = \frac{Pc}{Pcu} \quad (2)$$

Or :

P_{CU}= 500 WC is the unit peak power of the panels we have chosen.

Panel connection mode

The actual power greater than 1000 watts, the system voltage is equal to 48V.

Series connection of the panels

The number of panels for a series connection is determined by the ratio of the system voltage to the unit voltage of the panels. It is determined by the relationship:

$$Bs = \frac{Us}{Up} \quad (3)$$

US : series system voltage ;

UP : unit voltage of the panels in volts.

Parallel connection of the panels

The number of panels for a parallel connection is determined by the ratio between the total number of panels and the number of panels connected in series. It is determined by the relationship:

$$Bp = \frac{Np}{Bs} \quad (4)$$

Or :

Np : Total number of panels ;

Bs : Number of panels connected in series.

Installed peak power

The installed peak power is the overall power that the photovoltaic system installation can provide. It is determined by the relationship:

$$Pci = P_{mod} \times N_{mod} \quad (5)$$

Or :

Pci : Installed peak power ;

Pmod : Unit power of a module (500 Wc) ;

Nmod : Number of modules.

3.1.1. Regulator selection

The regulator provides the interface between the module, the batteries and the use. Its choice depends on the intensity and efficiency it can support. This current is determined by the relationship:

$$Ireg = \frac{Pc}{Us \times \eta_{reg}} \quad (6)$$

Or :

η_{reg} = 90% is the efficiency of the regulator.

Capacity of accumulators

The capacity of the accumulators is determined by the following relationship:

$$\mathrm{Cs} = \frac{\mathrm{Ej} \times \mathrm{Aut}}{\mathrm{D} \times \mathrm{U}} \quad (7)$$

Or :

Cs : Capacity of accumulators in (Ah) ;

Aut : Battery life, taken equal to 3 days ;

D : Maximum permissible discharge of lead batteries, taken equal to 0.7;

U : System voltage, equal to 48 V.

Number of batteries

The number of batteries to be chosen for the entire installation is determined by the following relationship:

$$\mathbf{Nb} = \frac{\mathrm{Cs}}{\mathrm{Cu}} \quad (8)$$

Or :

Cu : Unit capacity of batteries, taken equal to 200Ah.

Battery connection mode

Series connection of batteries

The determination of the number of batteries for the series connection of the solar installation is expressed by the relation:

$$\mathrm{B_s} = \frac{\mathrm{U_s}}{\mathrm{U_b}} \quad (9)$$

Parallel connection of batteries

The determination of the number of batteries for the parallel connection of the solar installation is expressed by the relation:

$$Bp = \frac{Nb}{Bs} \quad (10)$$

Inverter power

The power of an inverter is determined based on the devices powered and its efficiency. It is calculated by the following relationship:

$$P_{ond} = \frac{P_{ci}}{\eta_{ond}} \quad (11)$$

Or :

P_{ond} : Inverter power;

η_{ond}: Inverter efficiency, taken equal to 90%.

Cable selection

To limit voltage drops, cables must be sized. The maximum voltage drops for 48 V between the different components are as follows:

From the panel to the regulator (0.8%), from the regulator to the inverter (0.8%), from the regulator to the batteries (0.6%) and from the regulator to the receivers (0.8%).

$$\frac{\mathbf{\Delta U}}{\mathbf{Ucc}} = \mathbf{2}\%$$

So, for the different components we have :

From the panel to the regulator (Ucc= 48V) : ΔU = Ucc × 2% = 0,02 × 48 = 0,96 ;

From regulator to batteries (Ucc= 24V) : ΔU= Ucc × 2% = 0,02 × 24 = 0,48 ;

From batteries to inverter (Ucc = 24V) : ΔU = Ucc × 2% = 0,02 × 48 = 0,96.

The section of the conductors is determined by the following relation :

$$\mathbf{S} = \frac{\mathbf{2 \times \rho \times L \times I}}{\mathbf{\Delta U \times U}} \quad (12)$$

With $$\mathbf{I} = \frac{\mathbf{P_{cu}}}{\mathbf{U_p}} \quad (13)$$

Or :

S : cable section in (mm^2) ;

ρ : Resistivity in (Ωm) : Conductive copper used ;

I : Intensity in (A) ;

ε : voltage drop in (%) ;

L : Length in (m) ;

U : Panel voltage in (V).

Section of cables connecting the panels to the Sonny Boy

$$I = \frac{P_{cu}}{U_p} = \frac{500}{24} = 20{,}83$$

The current between the panels and the Sonny Boy is 20,83A

$$S = \frac{2 \times 1{,}7 \times 10^{-8} \times 15 \times 20{,}83}{0{,}02 \times 48} = 11{,}06\ mm^2$$

According to the standards NFC 15-100 we take a section of 16 mm^2

Section of the cables connecting Sonny Boy to Sonny Island

With a length (L) of 2 meters :

$$Pct = N_p \times P_u \qquad (14)$$

Pct=192× 500 =96 000 Wc

$$I = \frac{Pct}{U} = \frac{96000}{220} = 436{,}36\ A$$

$$S = \frac{2 \times 1{,}7 \times 2 \times 10^{-8} \times 436{,}36}{0{,}02 \times 48} = 30{,}9\ mm^2$$

According to the standards NFC 15-100 we take a section of 35 mm^2.

Section of cables connecting Sonny Island to the batteries

$$\boldsymbol{S = \frac{2 \times 1{,}7.10^{-8} \times 2 \times 436{,}36}{0{,}02 \times 48} = 30{,}9\ mm^2}$$

According to the standards NFC 15-100 we take a section of 35 mm^2 which is the standard value closest to the calculated one.

Thus the admissible cable sections retained for the realization of this installation are the following:

Cables connecting the panels to the Sonny Boy with a section of 16 mm2;

Cables connecting the Sonny Boy to the Sonny Island with a section of 35 mm2;

Cables connecting the Sonny Island to the batteries with a section of 35 mm2.

Calculation of the surface area of the panels

The surface area of a panel (Sp) is equal to 1.8 m^2, from which the total surface area (ST) of the panels for the entire system is calculated by the following relation:

$$S_T = S_P \times N_P \qquad (15)$$

Thus, the total area for the installation of the solar field is 347 m^2.

4. Software method

This method consists of using computer tools such as: HOMER, RET screen-international, SOMES, HYBRID2, etc., for the modeling and simulation of hybrid systems (PV-Network, PV-Diesel, PV-Wind among others). All these softwares aim to optimize hybrid systems, but their optimization strategies are different. As part of this work, we used HOMER for sizing which is a software that takes into account certain parameters in relation to others.

4.1. Presentation of the HOMER software interface

HOMER (Hydrides Optimisation Model For Electric Renewables) software is a software for distributed renewable energy systems such as: solar photovoltaic, wind turbines, batteries, hydraulic systems, combined heat and power, biomass, etc. The interface of this HOMER software is shown in Figure 1.

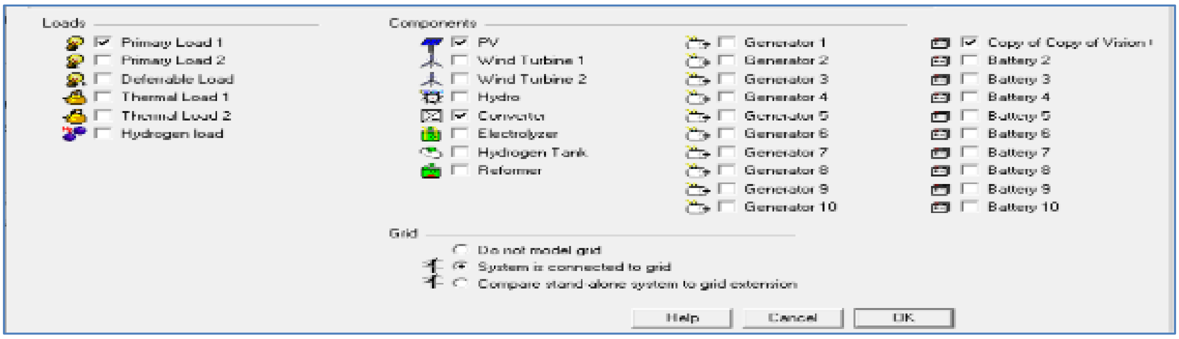

Figure 1 HOMER software interface

4.2. Simulation using HOMER software

From the data in Table 1 that we considered as input data for our simulation through the HOMER software, the configuration below represented by Figure 2 was obtained.

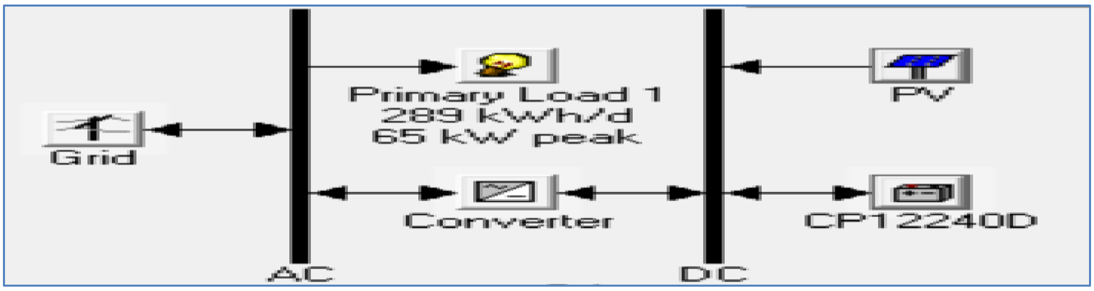

Figure 2 Hybrid system configuration diagram

After the simulation under the HOMER software from the basic input data of the specifications, we obtained two configurations of which the first configuration remains the most suitable. Thus table 4 gives the optimization results.

Table 4 Hybrid system optimization configuration

PV (kW)	CP12240D	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
96	144	107	1000	$ 0	364	$ 4,649	0.003	0.83
	144	107	1000	$ 0	10,554	$ 134,912	0.100	0.00

5. Results and discussion

The results of the sizing by the manual method and that by the HOMER software of the Hybrid system are given in tables 5 and 6.

Table 5 Results of manual sizing

Designation	Quantity	Unit power	Installed power
PV field	192	500 Wc	96000 Wc
Batteries	142	200 Ah	28400 Ah
Sunny boy	1	106,730Kw	106,730Kw
Sunny Island	1	106,730Kw	106,730Kw

Table 6 Results of sizing by HOMER software

Designation	Quantity	Unit power	Installed power	Output energy (KWH/year)
PV field	192	500 Wc	96000Wc	142,061
Batteries	144	200 Ah	28800 Ah	93
Converter	2	107 Kw	214 Kw	127,894
EDG Network				29,604

These results demonstrate that the two methods (manual and software) complement each other.

As part of this study, we retain:

- One hundred and ninety-two (192) 500Wc panels for an installed power of 96,000Wc;
- One hundred and forty-four (144) 200 Ah batteries, for an installed capacity of 28,800 Ah; Two (2) converters (Sunny boy and Sunny Island) with a power of 107 kW each.
- The advantage of the HOMER software is that it presents the photovoltaic energy production profiles and the EDG network, the charge of the accumulators, the converters, the hourly distribution of the loads and the average monthly distribution of the energy produced.

The production profiles are presented as follows:

- Photovoltaic energy production profile

Figure 3 shows that the photovoltaic system produces energy every day between 6 am and 6 pm with optimum production at 12 noon. The black color shows the lack of electrical energy from 0 am to 6 am and from 6 pm to midnight. During this period the energy supply is provided by the batteries. From blue to red color show that the production of electrical energy increases. The optimum production (red color is observed in the months of January to March and November to December).

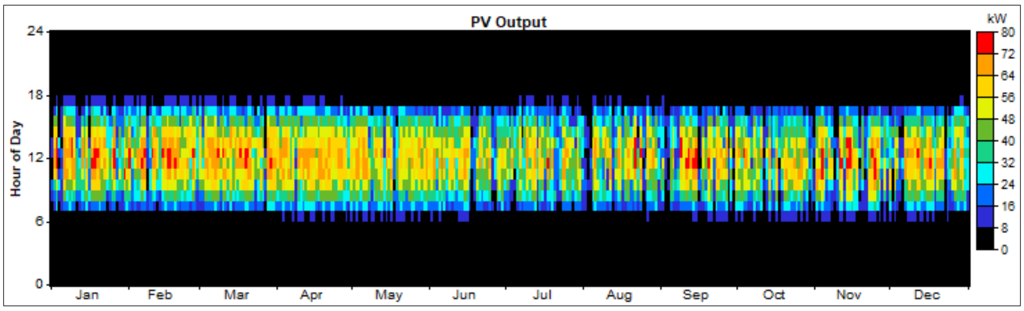

Figure 3 Photovoltaic energy production profile

- Battery energy accumulation profile

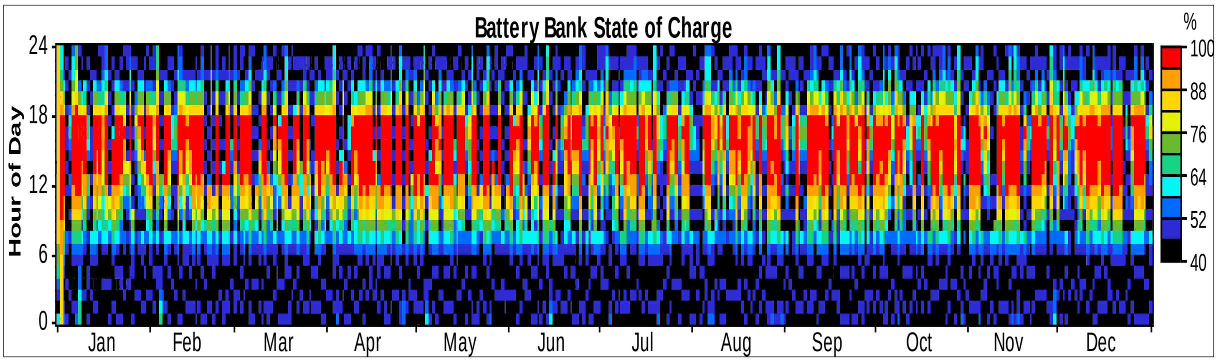

Figure 4 Battery energy accumulation profile

Figure 4 shows that the battery charge is optimal between 12:00 and 18:00. This energy accumulated by the batteries is potentially used from 24:00 to 6:00 and from 19:00 to 24:00. This proves to us that during the day the panels can take the charges and during the night the charges return to the accumulators.

- Operating profile of converters

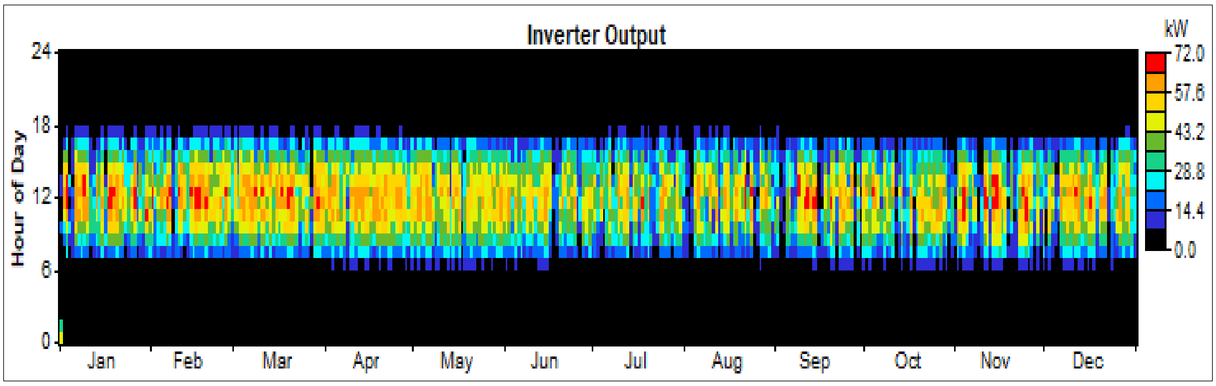

Figure 5 Operating profile of converters

Figure 5 shows that the converters potentially operate from 08:00 to 15:00, characterized by colors from green to yellow. This period corresponds to the maximum energy production by the photovoltaic field for our study area which corresponds to a hot and humid tropical climate.
Annual energy production profile by the hybrid system

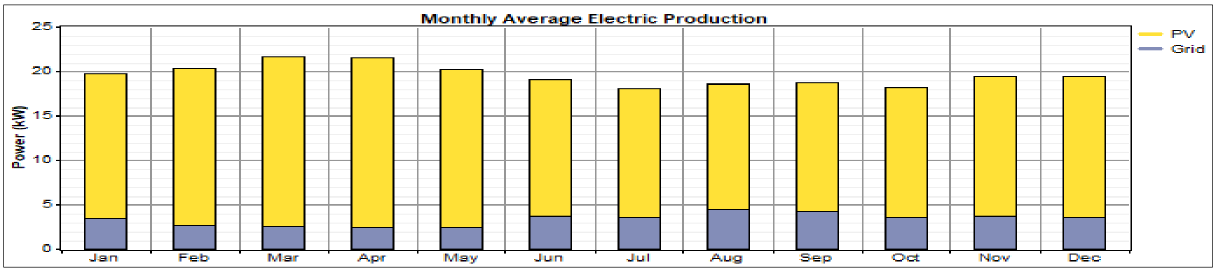

Figure 6 Annual energy production profile by the hybrid system

Figure 6 shows the share of electrical energy production of each source, the blue color for the Electricité de Guinée (EDG) network, with an annual production of 29,604 kWh or 13%.

While the yellow color indicates the photovoltaic system with an annual production of 142,061 kWh or 87%. The annual production of the entire system is 171,665 kWh or 100%.

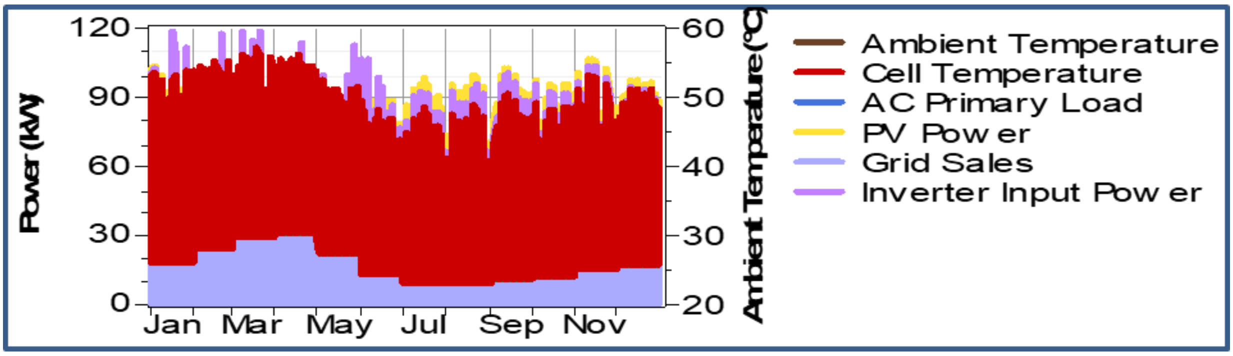

Figure 7 Annual system load

This figure illustrates the annual energy variation as a function of ambient temperature, PV cell temperature, primary energy, PV system power, grid power and input power. From this figure, we see that cell temperature is an influencing factor of the annual system load.

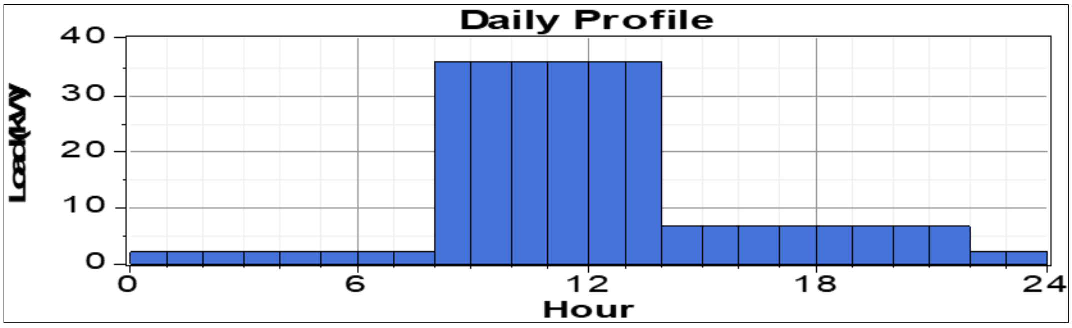

Figure 8 Distribution of hourly system loads

This figure shows the distribution of the hourly loads of the system. In this figure, we see that from 00:00 to 08:00 and from 22:00 to 24:00 the hourly load is 2.24 kW or 5% of the daily load, from 14:00 to 22:00 the hourly load is 6.73 kW or 15% of the daily load, from 08:00 to 14:00 the hourly load is 35.9 kW or 80% of the daily load. This shows that the loads are high from 8:00 to 14:00 for our system and this is justified by the fact that the courses are held in the computer rooms at these times.

6. Conclusion

This research has highlighted the importance of using a hybrid system to supply electrical energy to isolated areas. During this research, we sizing the system using two methods from which some results were obtained, the main ones being:

- Daily energy for the site: 542,206.35Wh/day; including 313,894.35Wh/d for the photovoltaic system and 228,312Wh/d for the network;
- The total power is: 95,816.35 Watt peak;
- One hundred and ninety-two (192) 500Wc panels for an installed power of 96,000Wc;
- One hundred and forty-two (142) 200 Ah batteries, for an installed capacity of 28,400 Ah by the manual method and one hundred and forty-four (144) 200 Ah batteries for an installed capacity of 28,800 Ah;
- Two (2) converters (Sunny boy and Sunny Island) with a power of 106.665 kW each by the manual method and 107 Kw by the computer method.
- These results show that the two methods (manual and computer) complement each other.

The annual electrical energy production of the entire hybrid system is 171.665 KWh/year; of which 29.604 KWh/year or 13% for the network and 142.061 KWh/year or 87% for the photovoltaic system

Compliance with ethical standards

Acknowledgments

We thank all those who contributed to the development of this research article, and we acknowledge their gratitude here.

Disclosure of conflict of interest

We inform you that there is no conflict of interest in relation to this work, which was collective and unanimously submitted for publication.

Statement of ethical approval

"This research work does not contain any studies carried out on animal/human subjects by any of the authors."

Statement of informed consent

This research does not involve information about a person, it is a work that consists of improving the electricity supply of the computer rooms of the Mamou Institute.

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