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# Sizing and Simulation of a Hybrid Hydroelectricity and Photovoltaic System with Storage for Supplying the Tamagaly District in Mamou, Guinea

Ansoumane Sakouvogui[1], Elhadj Ousmane Camara[2], Nènè Aïssata Balde[1] and Mamby Keita[1]

*1. Energy Department, Mamou Higher Institute of Technology, Mamou, BP 63, Guinea*

*2. Polytechnic School of Engineers, Kofi Annan University of Guinea, Ratoma, Conakry, BP 1367, Guinea*

**Abstract:** The present study is a contribution to the study of hybrid electric power conversion systems in rural areas. The approach adopted uses a methodology for analyzing the complementarity that exists between the two renewable energy potentials (solar and hydraulic) based on their daily, monthly and annual variations. The different analytical formulas for sizing a PV (photovoltaic) field and a small hydroelectric power station are recalled in this work. The HOMER software served as a tool for optimal sizing and simulation of the system. This work focuses on the analysis of the behavior and control of the performances of a hybrid system made up of two renewable energy sources, hydroelectricity/PV with a storage system and a converter. The main results obtained relate to: monitoring of the variation in temperature variation, solar irradiation of the site, as well as the flow of the watercourse. The profile of the village's annual charges is known. The annual production of electrical energy is 527.936 kWh/year. The hydroelectric plant will provide 155.316 kWh/year, or 29%, and for the PV field (372.620 kWh/year), or 71%. The monthly energy average is 43.995 kWh/month. The average daily consumption is 731 kWh/d with a maximum power of 163 kW. The completion of this project makes it possible to cover all electrical loads in the Tamagaly district, with an annual energy production of 206.783 kWh. This would make it possible to locally limit greenhouse gas emissions in the area.

**Key words:** Sizing, simulation, hybrid system, PV, hydroelectricity.

## 1. Introduction

The production of electrical energy from renewable energy sources has increasingly experienced considerable growth in recent years. This is due not only to environmental constraints, but also to the continued mastery of the different technologies used for the conversion of these sources into electricity [1].

Electric power demand in Africa was 621 TWh in 2012, and is expected to increase to around 1,258 TWh by 2030 and around 1,869 TWh by 2040. The sub-Saharan Africa region continues to face major energy crises. Despite its enormous energy potential, access to electricity eludes millions of people in this region. The rate of access to electricity in this Sub-Saharan region is very low compared to that of North Africa in both rural and urban areas [2].

According to the World Bank, in 2017 Africa had 603 million people without access to electricity and 602 million of them were in Sub-Saharan Africa. Nearly 80% of people without access to electrical energy in sub-Saharan Africa are in rural areas [1].

Sub-Saharan Africa has enormous untapped renewable energy resource potential, widely distributed across the region, which could be used to produce enough electricity to meet the continent's needs. The share of renewable energy sources in the production of electrical energy can increase by 50% by 2030.

Hydroelectricity is the electrical energy produced by a hydroelectric power station which exploits the potential energy of a watercourse (rivers, waterfalls,

**Corresponding author:** Ansoumane Sakouvogui, Ph.D., assistant professor, research field: energy-environment.

marine currents, etc.). It is one of the most mature forms of electricity production [3].

Hybrid hydro/PV power plants, whether or not associated with storage systems, are becoming more and more attractive, due to their low costs and the operational flexibility of hydroelectric power plants. Additionally, solar energy is highly available throughout the world. Several authors have focused their attention on the analysis of the complementarity between the two energy sources of the hydro-PV hybrid power plant [4].

The Republic of Guinea has great energy potential from various sources (biomass, hydroelectric, solar, wind and thermal), with 612,000 toe in biomass, 6,000 MW hydroelectric, an average solar irradiation of 4.8 kWh/(m$^2$ day) and an average wind speed varying between 2 and 4 m/s. The Tamagaly waterfall is located on the Karankawol River (three months of low water) and is 200 m from the village center. The energy needs and the proximity of the waterfall make this site one of the most important. Taking into account the rainfall variability during the different seasons (dry and rainy) in the area and with significant solar potential, we therefore proposed the supply of electrical energy to the district by a hybrid PV/hydroelectric system [5]. This study is part of this dynamic.

## 2. Materials and Method

### *2.1 Description of the Study Area*

Tamagaly is one of the seven (7) districts of the Konkouré sub-prefecture. It is located 9 km from Konkouré and 33 km from the urban commune of Mamou. It covers an area of 415 km$^2$ with a population of 6,500 inhabitants divided into 650 households in 2020. The main activities carried out in this area are commerce, agriculture and livestock. This district is crossed by the Mamou-Kindia national road and extends between 10°18′ north latitude and 12°18′ west longitude with an average altitude of 700 m. The district of Tamagaly, due to its geographical position, constitutes a stopover place for travelers. It has a middle school, a primary school, a Franco-Arab school, three boreholes, a health post, video clubs, an oil station and around a hundred shops [6].

This site has a waterfall on the Karankawol River (one of the tributaries of the Konkouré). The energy sources that power this area are solar panels and generators.

The geographical position of the Tamagaly site is presented in Fig. 1.

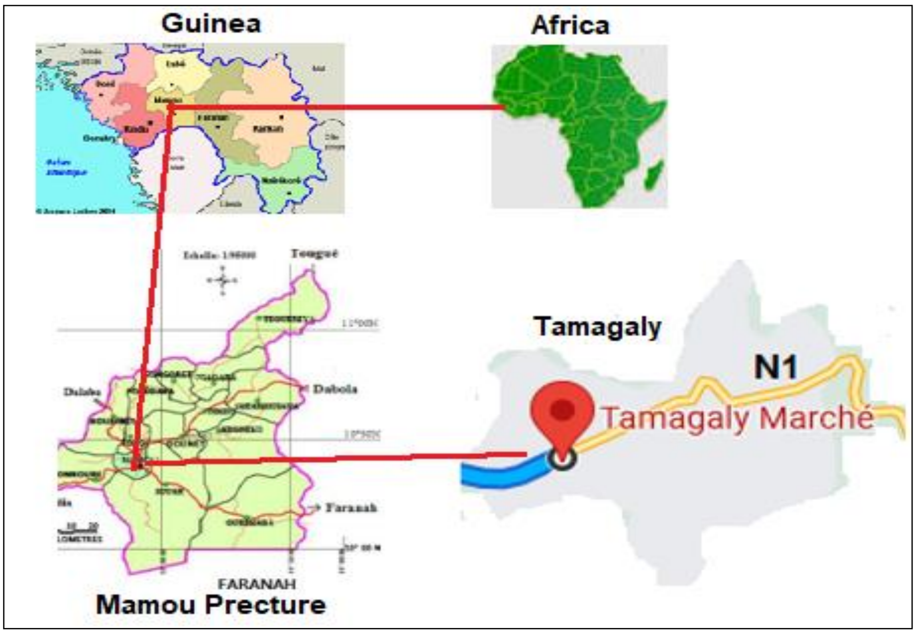


**Fig. 1 Geographical position of the site.**

*2.2 Work Equipment*

A number of materials and equipment were used as part of this research, namely: the telescope (level), a graduated ruler (target), a clinometer, a GPS (global positioning system), a tape measure, a stopwatch, a float, a calculator, the HOMER software.

*2.3 Method*

The methodology adopted for this research consisted of: research of meteorological parameters; the measurement of certain hydrological parameters, the use of analytical formulas for the sizing of the two systems and the simulation with the HOMER software [7].

The meteorological parameters of the site (solar irradiation, temperature and relative humidity) were obtained from the Mamou meteorological station and the National Meteorological Directorate. The hydrological parameters were provided on the one hand by the National Directorate of the Ministry of Energy, Hydraulics and Hydrocarbons and on the other hand, we took measurements on the site.

*2.4 Sizing of the PV (Photovoltaic) Field*

The aim of sizing the PV field is to determine the characteristics of the PV installation which are: daily energy, peak power, number of panels, battery storage capacity, converter and accessories [8]. Daily energy is calculated by Eq. (1).

$$E_j = E_p \times N_{re} \times \tau \quad (1)$$

$E_p$: Daily energy consumption; $N_{re}$: Number of receivers of the same nature; $\tau$ = 40%: Average electrification rate.

The peak power of the direct current PV field is calculated by Eq. (2).

$$P_c = \frac{E_d}{G \times K} \times \frac{1\ \text{kW}}{\text{m}^2} \quad (2)$$

$E_d$: Daily consumption in kWh/d; $G$ = 5.54 kWh/m$^2$/J: average annual solar irradiation of the site; $K$ = 0.6: average annual solar irradiation of the site.

The voltage of the PV field depends on the type of application, the PV power of the system and the availability of materials (modules and receiver). It is generally chosen according to the peak power of the system. For peak power less than 500 WC, 12 V is used; for a peak power between 500 WC and 2 kWp we use 24 V (DC) and for a peak power greater than 2 kWp we use 24 V [9].

The number of panels is calculated based on the characteristics of the chosen module and the peak power of the generator. It is calculated by Eq. (3).

$$N_{\boldsymbol{P}} = \frac{P_C}{P_U} \quad (3)$$

$N_P$: Number of panels; $P_C$: Peak power; $P_U$: Unit power of the chosen panel type.

The storage capacity of batteries is calculated using Eq. (4).

$$C_s = \frac{E_d \times d_{at}}{U_{ba} \times DOD_{\text{max}}} \quad (4)$$

$d_{at}$: Autonomy time in days; $DOD_{\text{max}}$: Maximum discharge degree in %; $U_{ba}$ = Unit voltage of the battery in volts. Thus, the numbers of series and parallel connection batteries are determined respectively by the formulas: $N_{bs} = U_s/U_b$ and $Nbp = C_s/C_b$, with, the system voltage ($U_s$); the voltage across the battery terminals ($U_b$); the number of batteries in parallel ($N_{pb}$); battery storage capacity ($C_s$) and nominal battery capacity ($C_b$).

The sizing of the charge regulator depends on its ability to adapt to the maximum input current coming from the panels and the output current leaving the regulator for the loads to be supplied. The sizing of an inverter is based on the sum of the maximum powers of each piece of equipment to be supplied, called active power, the output voltage of the solar panels in DC and the operating voltage of the receivers in AC are often powered at 230 V. Rated power of the inverter ($P_{\text{ond}}$) is calculated by Eq. (5).

$$P_{\text{ond}} = \frac{P_{\text{ch}} + P_{\text{loss}}}{\eta_{\text{ond}}} \quad (5)$$

$P_{\text{ch}}$: charging power; $\eta_{\text{ond}}$: efficiency of the inverter, $P_{\text{loss}}$: loss in the cables. The maximum power that can thus be delivered is $P_{\text{max}} = ks \times P_{\text{ond}}$, with $ks$: imposed safety coefficient, varying from 1.1 to 1.4 [9].

*2.5 Sizing of the Hydroelectric Power Station*

The main characteristic quantities of a hydroelectric power station are: the equipment flow, the height of the fall, the power of the development, and the electrical energy [10].

The equipment flow rate ($Q_{eq}$) is the maximum flow rate likely to be turbined by the power plant when all the turbines are operating together at full power. It is determined by Eq. (6).

$$Q_{eq} = Q_{di}\ Q_{re} \quad (6)$$

The average available flow is:

$$Q_{di} = S_m \times V_m \quad (7)$$

The reserved flow rate is determined by Eq. (8).

$$Q_{re} = t_r \times Q_{di} \quad (8)$$

$Q_{eq}$: Equipment flow rate in ($m^3/s$); $Q_{di}$: Average flow available in ($m^3/s$); $Q_{re}$: Reserved flow in ($m^3/s$); Wetted section in ($m^2$); $V_m = L_m/t_m$: Average speed in ($m^2/s$); $t_r$ = 10%: Reserved water rate.

The gross head ($H_b$) is the difference in altitude, expressed in meters (m), between the water level at the water intake (free surface level in average water) and the level of the water to the right of restitution. It is determined by Eq. (9) [11].

$$H_b = H_{am} - H_{av} \quad (9)$$

$H_b$: Gross fall height in (m); $H_{am}$: Altitude upstream; $H_{av}$: Altitude downstream.

Load losses or pressure losses represent the reduction in gross head as it flows through the pipes. They are of two types (singular and linear) [12].

Net head of fall ($H_n$) is the difference between the gross head of head ($H_b$) and the total sum of pressure losses ($\Sigma\Delta h$). We have:

$$H_n = H_b - \Sigma\Delta h \quad (10)$$

Hydraulic power is the power supplied to the turbine by the water that feeds it [13].

$$P_h = \rho \times g \times Q_{eq} \times H_b \quad (11)$$

$P_h$: Hydraulic power in W; $Q_{eq}$: Average flow in $m^3/s$; $H_b$: Gross fall height in (m); $g$: Acceleration of gravity in (N/kg) and $\rho$: density of water.

*2.6 System Simulation with HOMER*

HOMER energy simulation software is an effective tool for the design and analysis of hybrid energy production systems containing different components: wind turbine, PV, hydroelectricity, diesel, batteries, etc. [14, 15].

## 3. Results and Discussions

*3.1 Ambient Temperature*

The variation and DMAP of monthly average temperatures are given in Figs. 2 and 3.

The maximum monthly average temperature is 30.3 ℃ in April, while the minimum monthly average temperature is 23.1 ℃ in August, which makes an annual average of 25.9 ℃. The variation of average temperatures conforms to the evolution of solar irradiation, the months of January, February, March, April and May have the highest temperatures, they vary from 26.1 ℃ in January to 30.3 ℃ in April (Figs. 2 and 3). This temperature variation influences the energy production efficiency of PV panels.

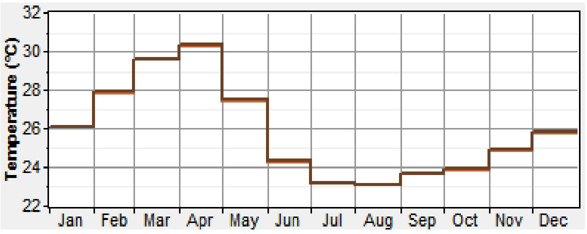


**Fig. 2 Annual ambient temperature profile of Tamagaly.**

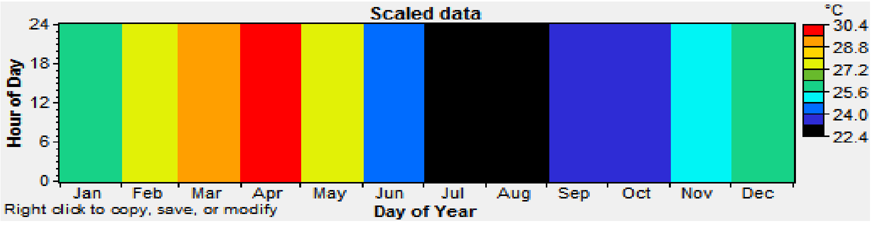


**Fig. 3 DMAP of Tamagaly ambient temperature.**

### *3.2 Solar Irradiation*

The variation of the annual horizontal global solar irradiation and the DMAP of Tamagaly are represented respectively by Figs. 4 and 5.

Figs. 3 and 4 shows that the overall horizontal irradiation in Tamagaly varies from 4.68 kWh/m$^2$/d to 6.76 kWh/m$^2$/d, recorded respectively in August and April, with an annual average of 5.54 kWh/m$^2$/day. The months of January, February, March, April and May remain the sunniest during the year. Throughout the year, illumination begins from 12:00 a.m. until 6:00 p.m., with the maximum observed at 12:00 p.m. (Fig. 6), this is due to the geographical position of the site.

### *3.3 River Flow*

The variation and DMAP of the flow of the Tamagaly waterfall are illustrated by Figs. 7 and 8.

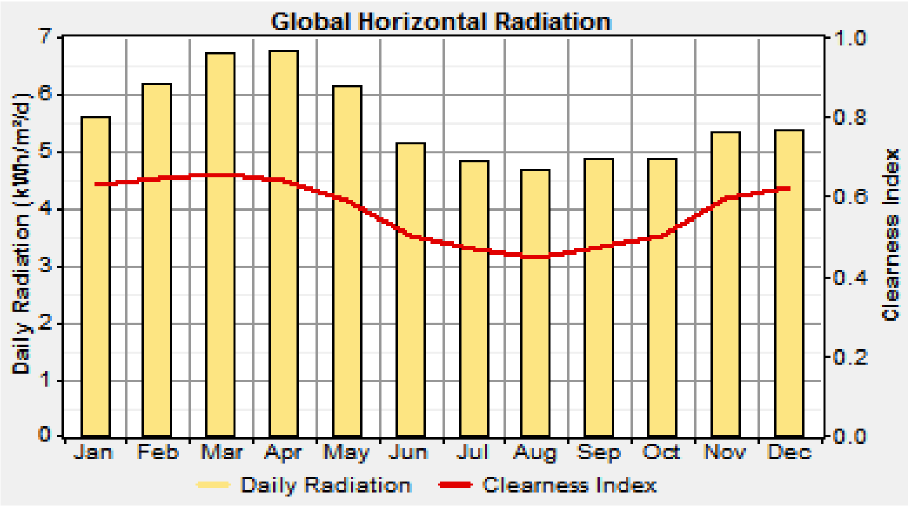


**Fig. 4 Annual horizontal global irradiation of Tamagaly.**

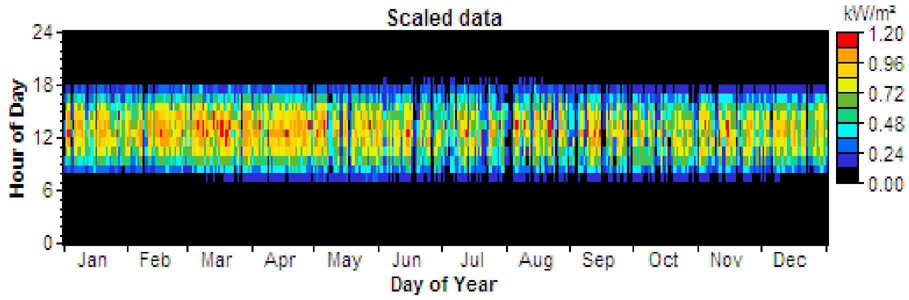


**Fig. 5 DMAP of illuminance in Tamagaly.**

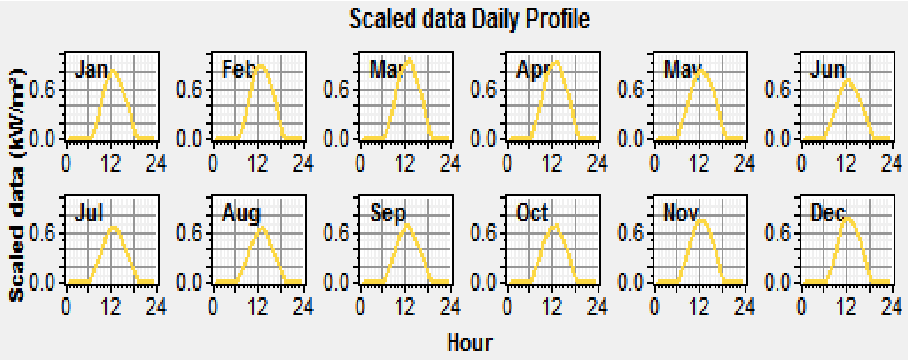


**Fig. 6 Variation of illuminance over the months for Tamagaly.**

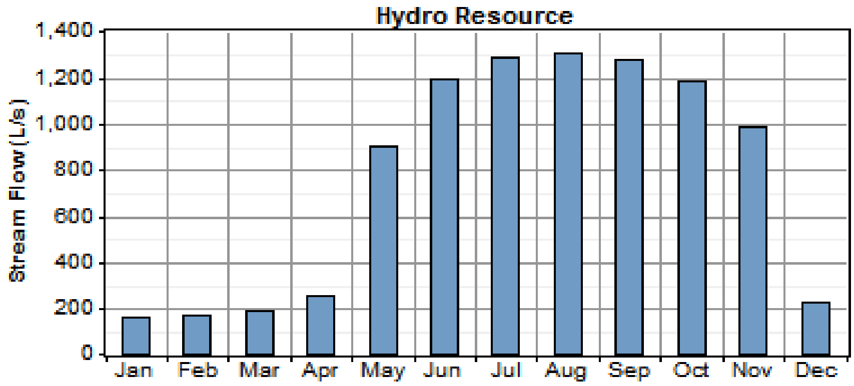


**Fig. 7 Annual flow profile of Karankawol-Tamagaly.**

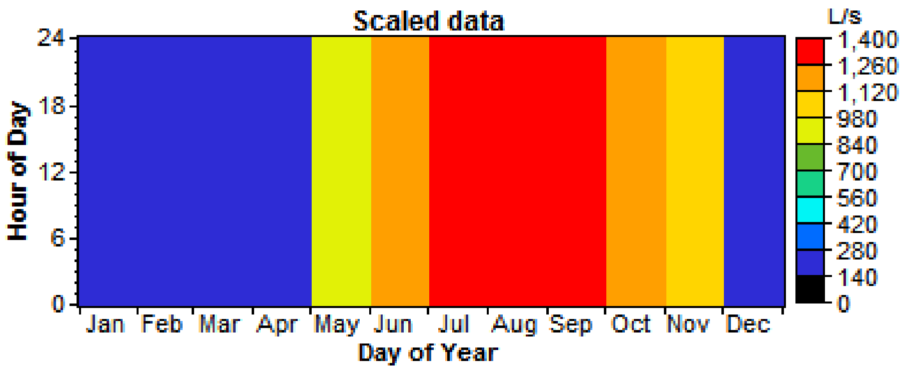


**Fig. 8 Flow DMAP.**

Figs. 7 and 8 show that the flow profile of the watercourse varies from 160 L/s to 1,300 L/s respectively in January and August, with an annual average of 765 L/s. The months of July, August and September have the highest flow rates during the year, so they remain the most favorable for the production of energy by the hydroelectric plant.

### 3.4 Annual Profile of Tamagaly Charges

The annual profile of site loads is given in Figs. 9 and 10.

These figures show massive use of energy throughout the year, this energy is especially maximum in the month of January and April and we see a drop in energy consumption in the month of September. The load represents a peak power of 163 kW in January.

### 3.5 Hybrid System Simulation Setup

The simulation setup results of the hybrid system are shown in Fig. 11. The architectural system is presented in Fig. 12. The hybrid system simulation configuration results (Fig. 11) show that the first variant in blue is the one that meets the optimal configuration of the hydroelectricity and PV hybrid system with energy storage batteries and converter (hydro/PV). The PV field has a peak power of 220 kWp, with an average daily energy of 1.021 kWh/d, or an annual production of 372.620 kWh/year.

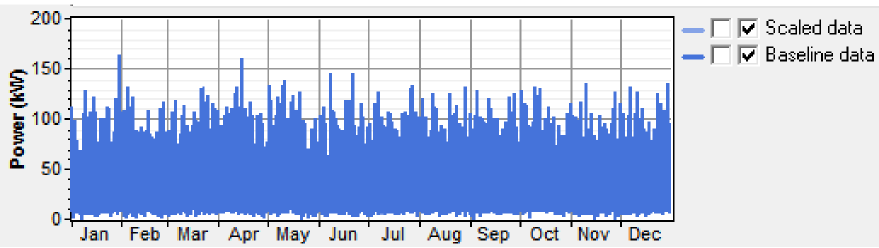


**Fig. 9 Annual profile of Tamagaly charges.**

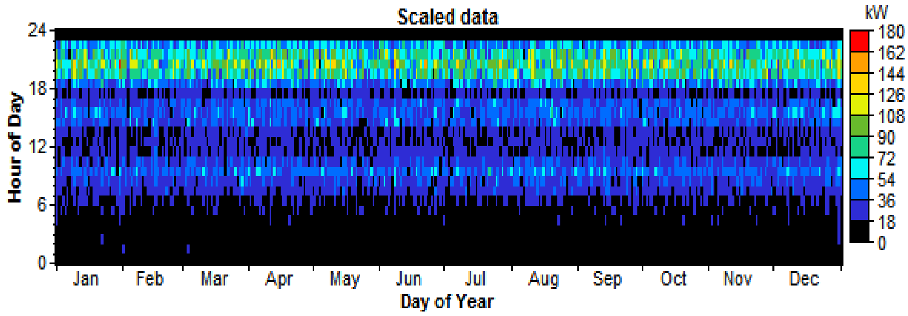


**Fig. 10 Site load profile DMAP.**

| | PV (kW) | Hydro (kW) | H1500 | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Batt. Lf. (yr) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 220 | 67.5 | 2400 | 150 | $ 928,950 | 27,870 | $ 1,333,023 | 0.345 | 1.00 | 20.0 |
| | 250 | | 2400 | 150 | $ 939,950 | 28,580 | $ 1,354,311 | 0.350 | 1.00 | 20.0 |

**Fig. 11 Hybrid system simulation setup.**

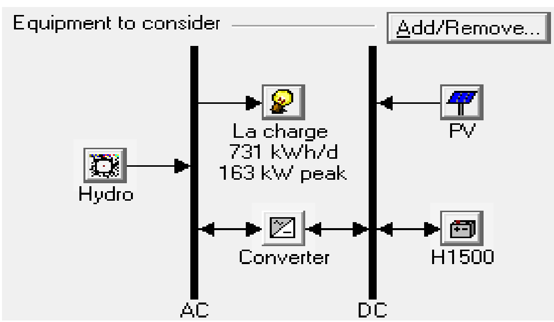


**Fig. 12 Architectural diagram of the system.**

which corresponds to a number of panels of 440, including 4 rows in series and 110 rows in parallel, for 48 V voltage bus. The number of storage batteries 2,400 of 2 V, type Hoppecke 12 OPzS, including 24 rows in series and 100 in parallel, the converter has a power of 150 kW. The hydroelectric power produced is 67.5 kW, with a hydraulic turbine (Banki Michel). The DMAPs in Figs. 13-15 respectively show the production profile of the PV field, the state of charge of the batteries and the hydroelectricity production of the site.

Energy production by the PV system starts from 7 a.m. to 6 p.m., with optimal production between 11 a.m. and 4 p.m. (Fig. 13). Battery charging is optimal during the months of June to October, this is due to the simultaneous production of energy by the two systems (Hydro/PV) during this period (Fig. 14). The DMAP in Fig. 15 shows that energy production by hydroelectric plant during the year takes place from June to October, which corresponds to the period of the rainy season. The annual distribution of loads and the average monthly energy production by each PV and hydroelectricity plant are illustrated in Fig. 16.

The average annual production by the two systems is respectively 372.620 kWh/year for the PV field, i.e. 71%, and 155.316 kWh/year for the hydroelectric plant, i.e. 29%. The total annual average production is therefore 527.936 kWh/year.

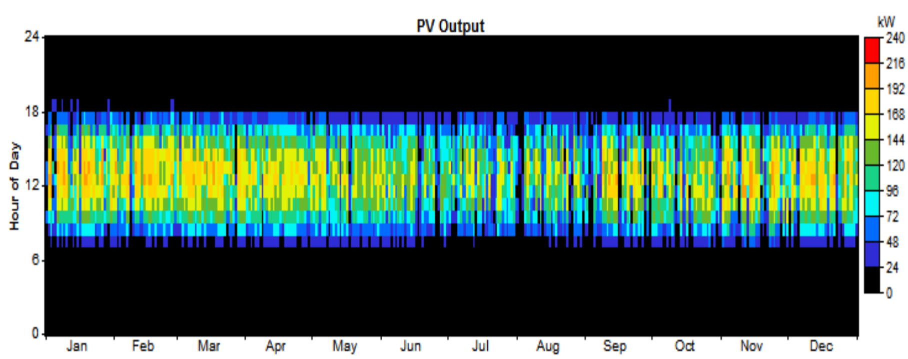


**Fig. 13 DMAP of PV field production.**

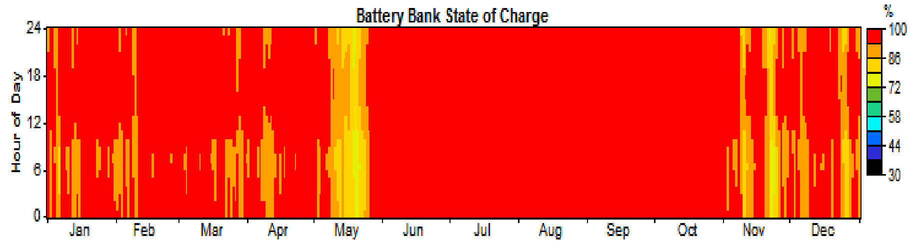


**Fig. 14 Battery state of charge DMAP.**

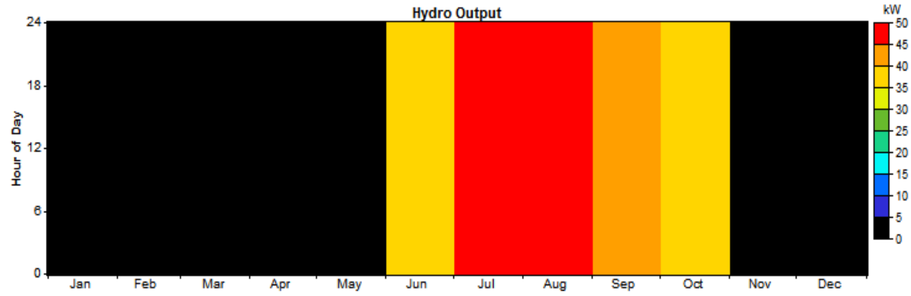


**Fig. 15 DMAP of hydroelectricity production.**

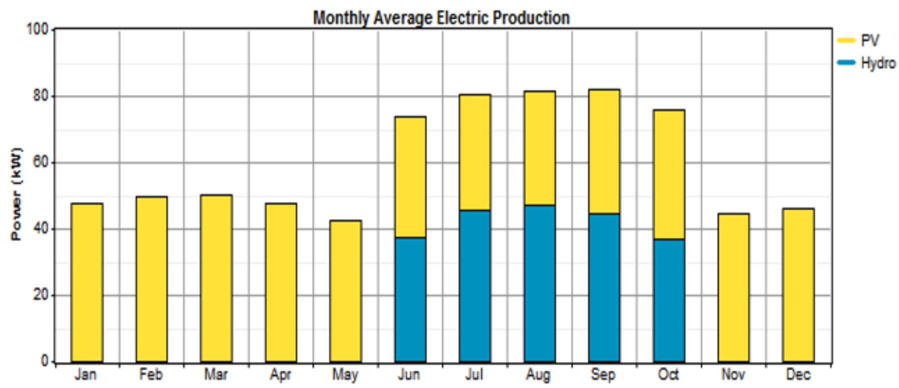


**Fig. 16 Monthly average distribution of energy produced.**

## 4. Conclusion

At the end of this study, we can conclude that the total annual production of electrical energy delivered by this system is 527.937 kWh/year. Hydroelectricity provides 155.316 kWh/year of this energy, or 29%, and for the PV field, 372.620 kWh/year, or 71%. The system delivers an average monthly electrical energy of 43.995 kWh/month. The consumption profile adopted is 731 kWh/d on average with a maximum power of 163 kW. The results show that the current charges of the village are largely covered, with an annual energy production surplus of 206.783 kWh/year. It emerges from this study that the combination of the two renewable energy sources (solar and hydraulic) is promising and advantageous for the supply of continuous electricity in the locality.

Also, this work shows that the combination of several renewable energy sources makes it possible to optimize the overall energy yield with the minimum cost option. This leads to a reduction in greenhouse gas emissions resulting from the misuse of non-renewable energy sources.

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