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RESEARCH ARTICLE

DESIGN AND PV-BIOGAS HYBRID MICRO-NETWORK OPTIMIZATION FOR ISOLATED ZONES TO ELECTRICAL GRID

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ABSTRACT

This paper deals the electrification problems in African rural localities particularly in Malian localities. One solution is to develop the renewable energy sources due to their enormous resource which is inexhaustible and their production mode which preserves environment. To increase the energy production and to manage the intermittent period of renewable resource, it will be interesting to combine divers renewable sources. In this hybridization of renewable energy sources context, the PV-Biomass hybrid system becomes very interesting compared to others hybrid energy systems, due to his high flexibility and low dependency to meteorological conditions. These properties place the PV-Biomass hybrid energy system as one of the bests systems in reliable and sustainable energy production for rural areas. In this study, we propose a PV-Biomass hybrid energy system with energy storage to produce 100% renewable energy and to preserve at the same time the environment. This hybrid system is studied under HOMER PRO software in order to identify the optimal configuration in terms of reliable energy production, sustainable and minimal cost over the hybrid system life cycle. The obtained results after simulation show that the optimal configuration is composed of a biogas generator of 100kW, a PV field of 160kWc and a battery park for reliable and sustainable energy production with a low cost over the life cycle of the hybrid energy system for Kolokani locality.

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INTRODUCTION

More than 80% of malian population live in rural areas, less than 15% of this population have access to electricity. These rural areas have an enormous potential which is partially exploited. Malian populations live generally in rural areas which are an annual average irradiation is estimated at 1900kWh/m^2. In these areas, the main activities are the agriculture and raising, which generate an enormous potential for the hybrid energy systems development, such as the PV-Biomass hybrid system. At to date, these rural areas use the diesel generators, electric battery, wood and charcoal for electrical energy needs. The use of this conventional energy sources has a great environmental impact and a high cost for poor energy quality. To increase the access rate to electricity of rural areas and preserve the environment, the challenge is to develop the hybrid renewable energy systems. Nowadays, several works are focused on the renewable energy production sources hybridization. In paper [(1)], authors study under HOMER a feasibility analysis of PV-Biogas hybrid energy system for rural electrification in Ghana. The obtained results are interesting, only the Ghana rural zones realities are different those in Mali. In addition, this study doesn't take into account the economic analysis of national grid extension compared to hybrid system design.

The carried works in [2] present the analysis results of experimental, economic and environmental study for PV-biogas hybrid system. This study does not focused on the optimization and national grid extension problem. Authors of [3] made a feasibility study and optimization analysis of standalone hybrid PV-Biogas for rural electrification in Pakistan by using HOMER software. As in [1], this study realities are not compatible with Malian realities and the national grid extension analysis is not take into account. In [4], authors use HOMER to analyze the hybrid PV-diesel-biogas system as an alternative solution to the unreliable electrical grid. This study is not applied in rural environment and it not interested to national grid extension problem. The realized works in [5] use HOMER to analyze PV/Biogas hybrid power system based on real load data for unelectrified rural area in Bangladesh. As in [1,3], this study realities are not compatible with Malian realities and the national grid extension analysis is not take into account Authors of [6, 7] develop a hybrid system PV-Biomass-Wind power for the sizing, optimization and the economic evaluation of the system for rural areas. However, they does not take into account of energy storage system which is important for the system reliability during intermittent periods. Authors of [8, 9, 10] made a comparison and study the viability of hybrid system compared to national electrical grid extension without take into account the storage system. In [11], authors developed a hybrid system purely renewable in durable development context, which is very vulnerable to climatic conditions because there is no energy storage system. In this study, we interest not only to sizing and optimization of hybrid system PV-Biomass, but also to energy storage system integration. This fact allows to ensure the service continuity during weather disturbances, generators failures and during periodic maintenance. This hybrid system PV-Biomass with energy storage is modeled and simulated under HOMER software in order to determine the optimal configuration and the minimum cost on life cycle of hybrid energy system for Kolokani rural area.

METHODOLOGY

Renewable energy hybrid system with energy storage: The hybrid system purely renewable with energy storage consist to combine two or more renewable sources with a storage system to store the generated energy surplus. This combination allows to exploit efficiently the each sources potentialities in order to manage slack periods of one or the other sources. The storage system allows to ensure the hybrid system reliability. The hybrid PV-Biomass energy system with energy storage became actually a durable and reliable energy production system for rural areas in general and specifically that of Mali. Kolokani's populations are essentially farmers, the daytime sunshine is about 8h with a peak between 5 and 6kWh [12].

PV-Biomass hybrid system modeling: The hybrid system is composed of PV field, a biogas generator, a battery park with high capacity, a bidirectional converter and load controller. The total power generated by the system is given as the follows:

$$P_{tot} = P_{Biogaz} + P_{solar} \quad (1)$$

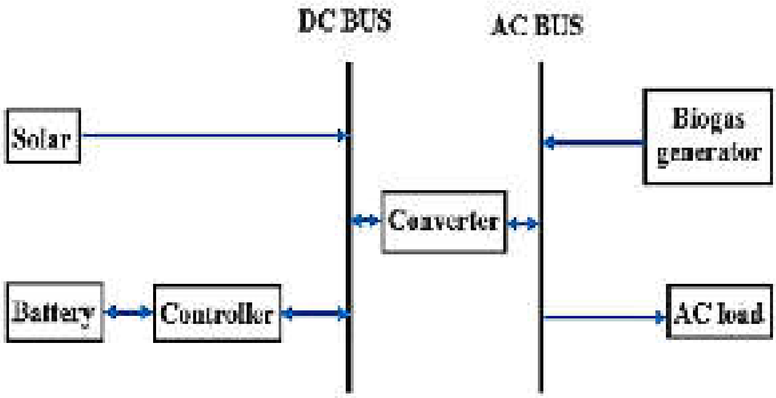

Figure 1. Diagram of hybrid PV- Biomass system

The biogas generator: The power produced by the biogas generator is given by:

$$P_{Biogas} = \eta_{gen} * B_0 \quad (2)$$

$$B_0 = D * Y \quad (3)$$

where η_{gen}, $D, Y\ et B_0$ are respectively the biogas generator efficiency, the waste quantity collected per day, the biogas quantity produced per waste kg and the biogas yield. This quantity is estimated at 40L/kg for cows' fresh waste [13]. The table 1 informs us on generated biogas quantity by the substrates. Table 1 Generated biogas quantity by the substrates

$$D = N * F * d \quad (4)$$

N : animal number ; d : waste quantity per animal and F : the collected waste fraction.

Table 1. Generated biogas quantity by the substrates

Resources	Produced Biogas(l/kg)
Farmed waste	40
Green plants and stems	100
Alimental wastes	160
Dry Plants	118

The digester volume is given by:

$$V_D = \frac{V_S}{0{,}9} \quad (5)$$

With $V_S = V_1 * T_R$ (6)

V_D ; V_S and T_R are respectively, the digester volume, the digestate volume and the substrate content.

The table 2 gives some substrate content values.

Table 2. Substrate content values

Fresh substrates	Substrates content
Cow waste	50
Chicken waste	20
Rice husk	33
Sugar cane bagasse	43

$$T_R = m_S * \rho \quad (7)$$

$$m_S = m_D * 2 \quad (8)$$

m_S : digestate mass ;ρ : digestate volume mass and m_D : substrate mass.

PV power: The PV power is given by the following relation.

$$P_{solar} = A * \eta_P * N_P * I \quad (9)$$

with, A is a solar panel area, N_P the panels number, I the average irradiation varies between 5 to 6 kWh for Kolokani and η_P the panel yield. This yield is about 15% for trading modules.

Optimization Technique: Sizing and optimization techniques are essentially based on, technological constraints, local and economic conditions in order to satisfy the energetic demand. The simulation software are focused on technical and economic performances to produce durable and reliable energy. Nowadays, it exists several simulation software such as HOMER, HOGA, HYBRID 2 and many others [14]. HOMER (Hybrid Optimization Model for Electric Renewable) developed by USA NREL (National Renewable Energy Laboratory), is a predilection software for hybrid renewable energy systems [15, 16]. It allows to perform three main actions, the simulation, the optimization and the sensitive economic analysis to determine the net cost on system life cycle by taking into account fluctuations.

The implantation site

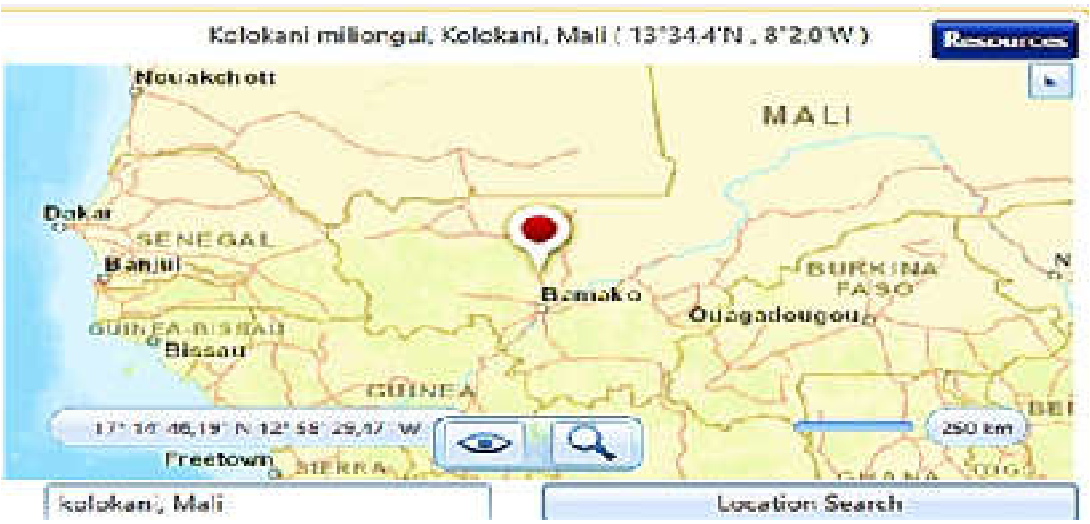

Figure 2. KOLOKANI map

The rural municipality of Kolokani is located at 120 km from Bamako on the road RN 3 and at more than 90 km from EDM sa electrical grid. The municipality area is around 1250 km^2 and its population is estimated at 57307 residents, distributed in 7164 family homes [17]. The access rate to electricity in this rural locality is less than 15%. In this locality, the agricultural production is estimated at 145000 tons of dry cereals, 30000 tons of peanuts, 10000 tons of cottons and a livestock composed of more than 6360 heads [18]. This resources generate more than 20 tons of bio gasification substrate per days, the day time sunshine is superior than 8h per day with 5,77kWh/m^2/j as average peak [19].

Figure 3. Radiation curve of KOLOKANI

Energetic needs: After a households investigation in 2019, the obtained data are registered in the tables 3 and 4.

Table 3 Domestic energy needs

Materials	Number	Power (W)	Load (kW)	Duration(H)	Total load (kWh)
Lamp	5375	15	80,59	8	644,76
fan	645	60	38,7	8	309,6
Radio	1075	20	21,5	12	258
TV	645	100	64,5	8	516
Computer	20	500	10	3	30
fridge	30	900	27	8	216
Pump	20	1500	30	3	90
Other	1075	10	10,75	4	43
Total					2107,36

Table 4. Community energy needs

Materials	number	Power(W)	Load(kW)	Duration (H)	Total load(kWh)
Street Lamps	50	55	2,75	10	27,5
Fan	20	60	1,2	4	4,8
School need	10	80	0,8	4	3,2
hospital need	2	800	1,6	8	12,8
Computer	10	600	6	4	24
Fluorescent tube	130	15	1,95	4	7,8
Mill	10	1500	15	4	60
Other	8	100	0,8	4	3,2
Total					143,3

RESULTS AND DISCUSSION

Simulation: The simulation under Homer software environment consists to identify the optimal configuration in terms of energy needs satisfaction and economic sizing. The hybrid PV-Biomass energy system diagram with energy storage system is shown as following.

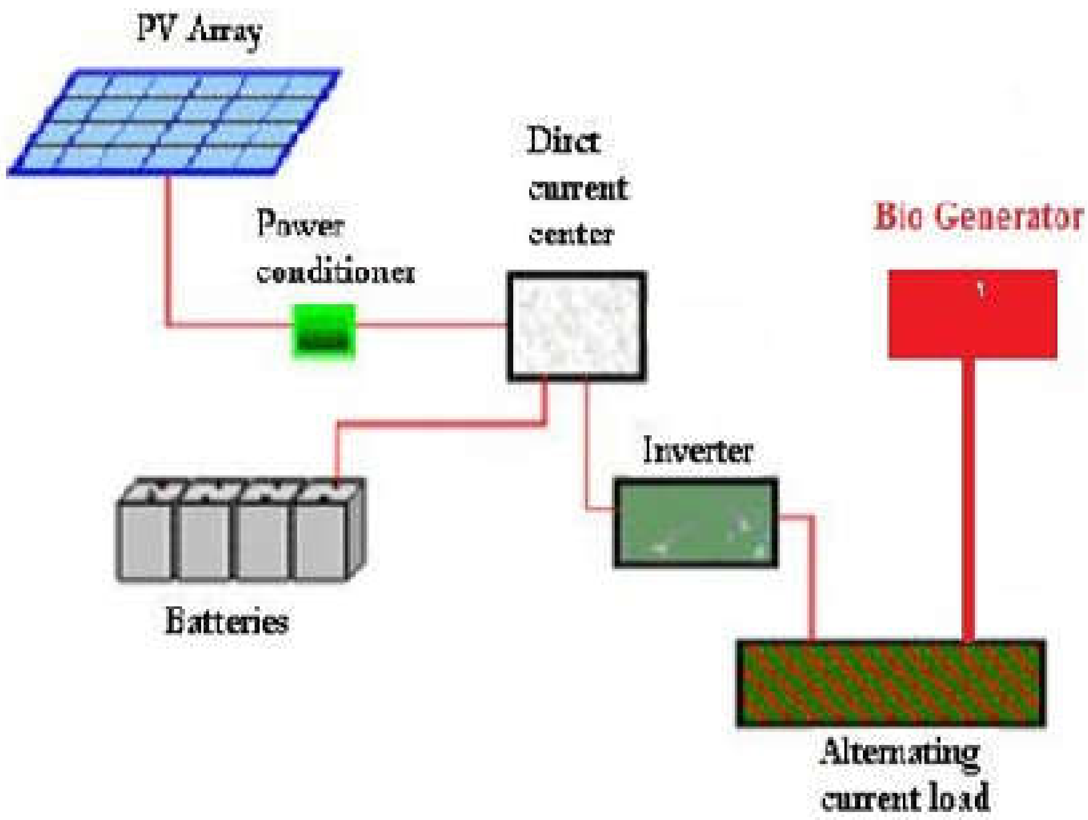

Figure 4. Hybrid PV-Biogas generator diagram for isolated site

For the simulation under Homer environment, the system have need of input quantities relative to the locality and available resources. After simulation, the obtained results analysis allow us to identify most optimal configurations. The following Figures show the electrical consumption profile of Kolokani rural area.

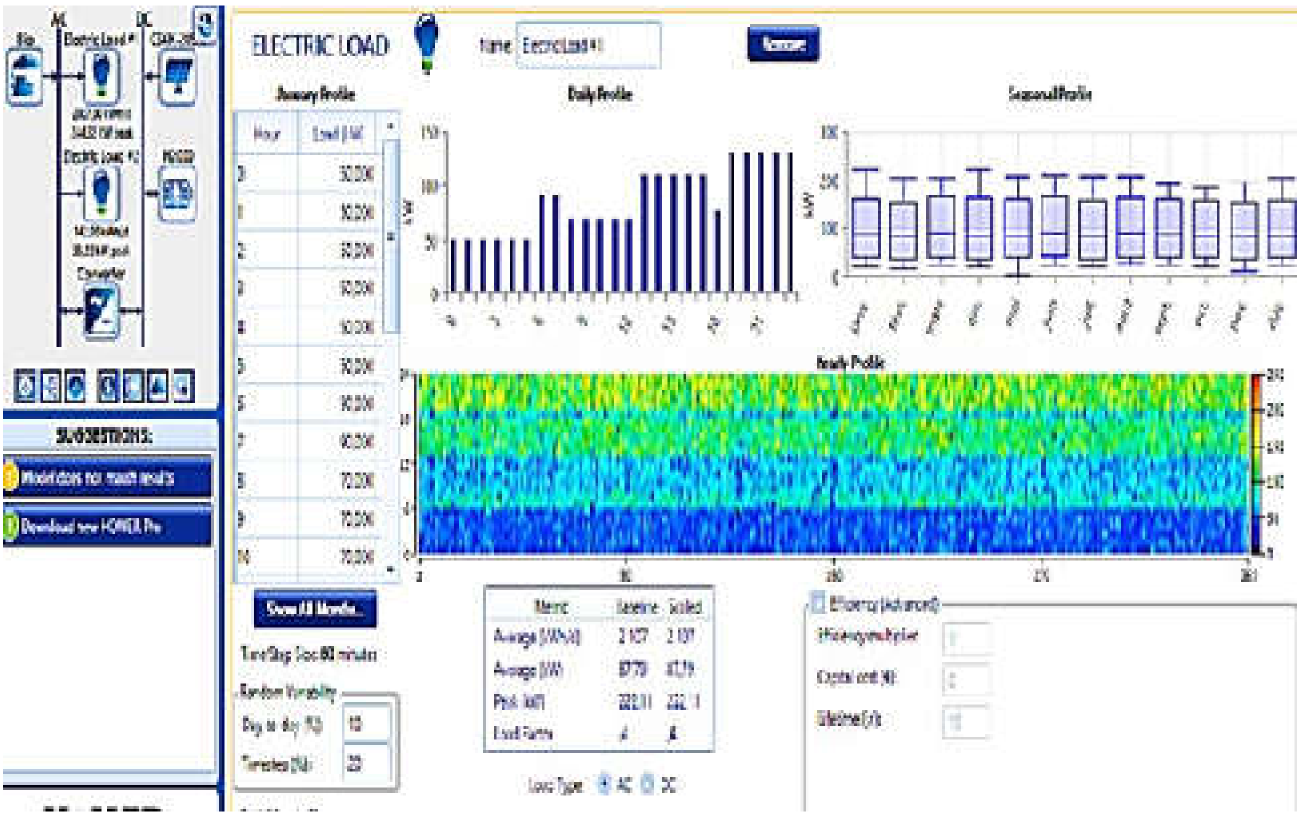

Figure 5. Kolokani load profile

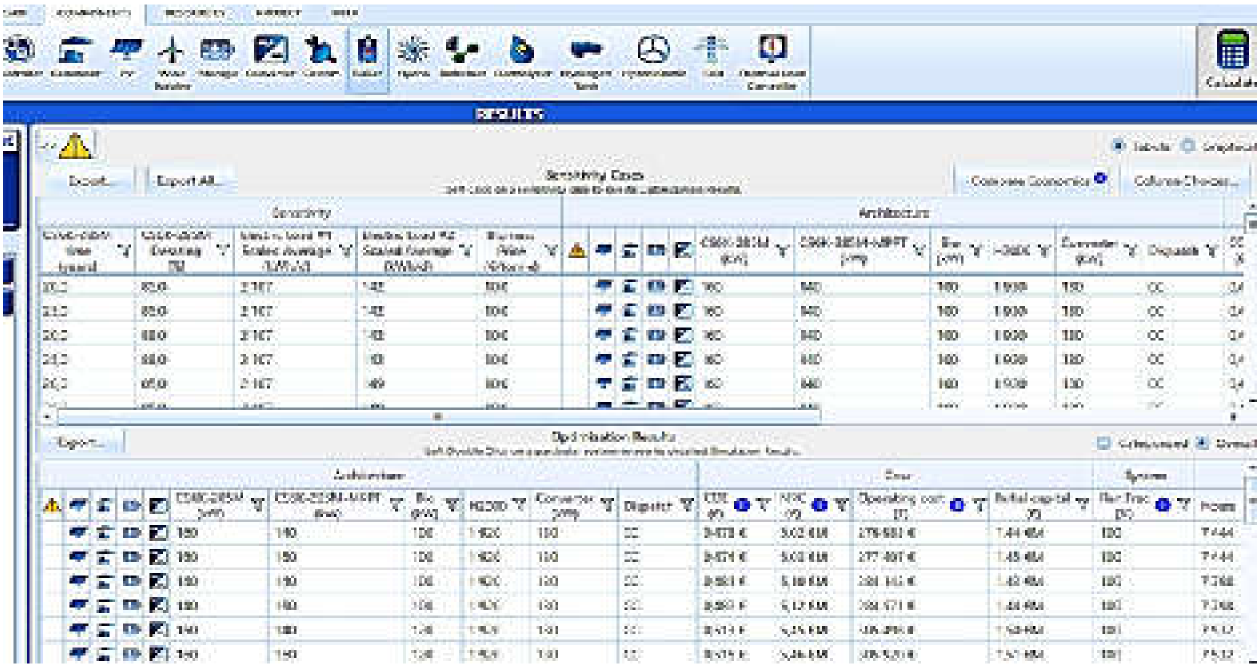

Figure 6. Optimization results

After simulation, we haveanalyzed the obtained results for Kolokani rural area allowed us to determine the optimal economic configuration. These obtained results are illustrated as follows:

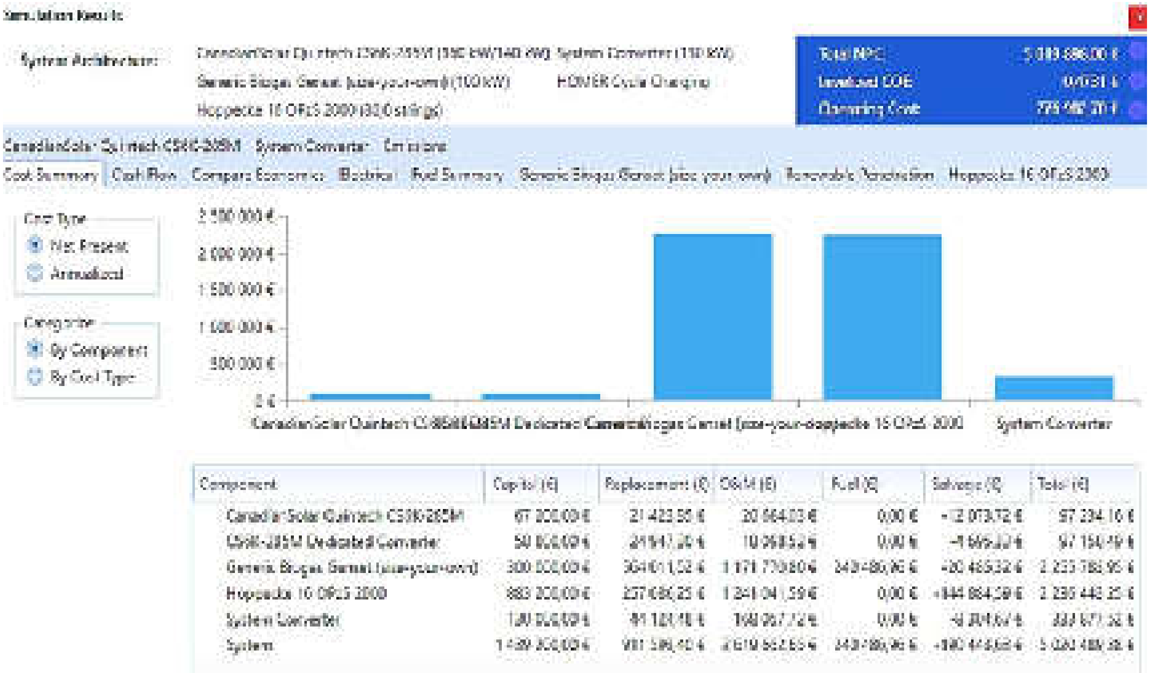

Figure 7. Economic analysis of hybrid PV-Biomass system

RESULTS AND DISCUSSION

The simulations under HOMER from solar resources and biomass potentialities for Kolokani rural municipality, allow to determine the different optimal combinations as follows:

The above table provides results and after analysis, the optimal combination is obtained with 944.000.000 FCFA as initial capital and 3.300.000.000FCFA as net cost on life cycle of hybrid energy system, this implies a kWh cost about 230FCFA, which is the lower cost in above table.This optimal combination also corresponds to the minimum time of bio-generator use (7444hrs/yr), consequently, it is the best in term of environmental consideration.

The below Figure shows the contribution of each source.

PV (KW)	Bio-generator (KW)	Battery	Conver-ter(KW)	Initial Capital (CFA)	Total NPC (CFA)	COE (CFA/KWh)	PV Fraction (%)	Bio-generator (hrs/yr)
160	100	1920	130	944.000.000	3.300.000.000	230	31.1	7444
140	100	1920	130	938.000.000	3.350.000.000	240	27.2	7798
160	120	2400	130	1.140.000.000	3.950.000.000	300	31.1	7526

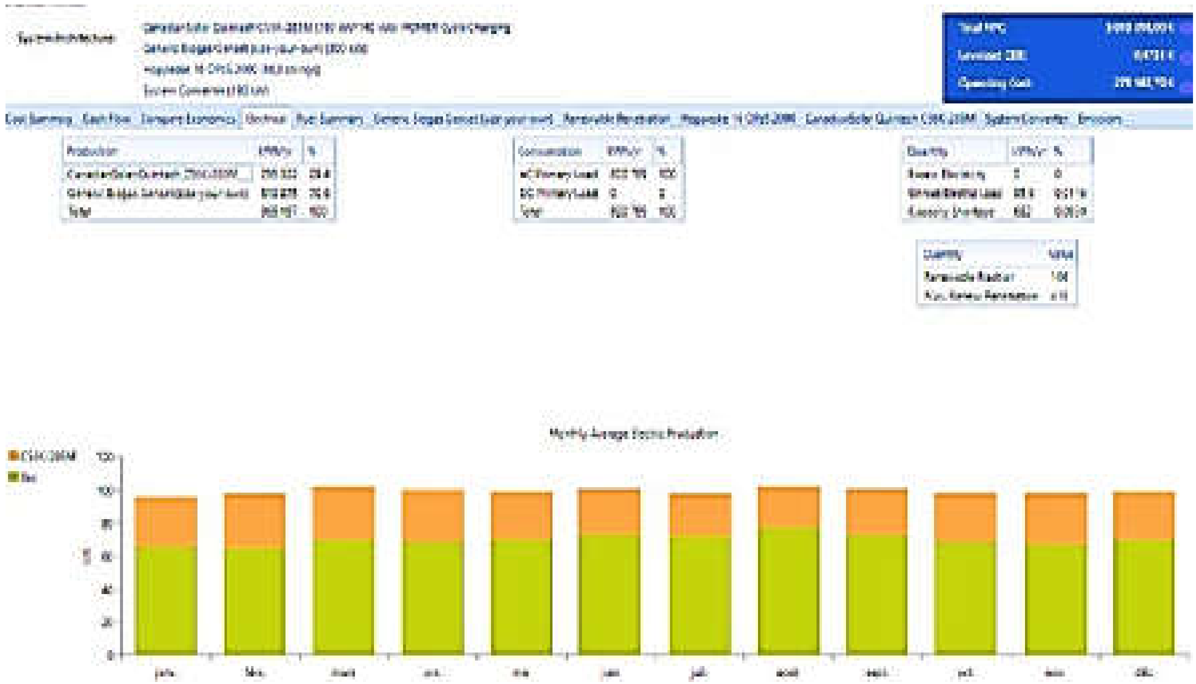

Figure 8. Sources Contribution

The Figure 9curves show the batteries charge state and the instantaneous power delivered by each source to satisfy the energy demand. We easily see that PV system allows to cover the energetic demand and during off-peak periods, the Bio-generator comes in backup.

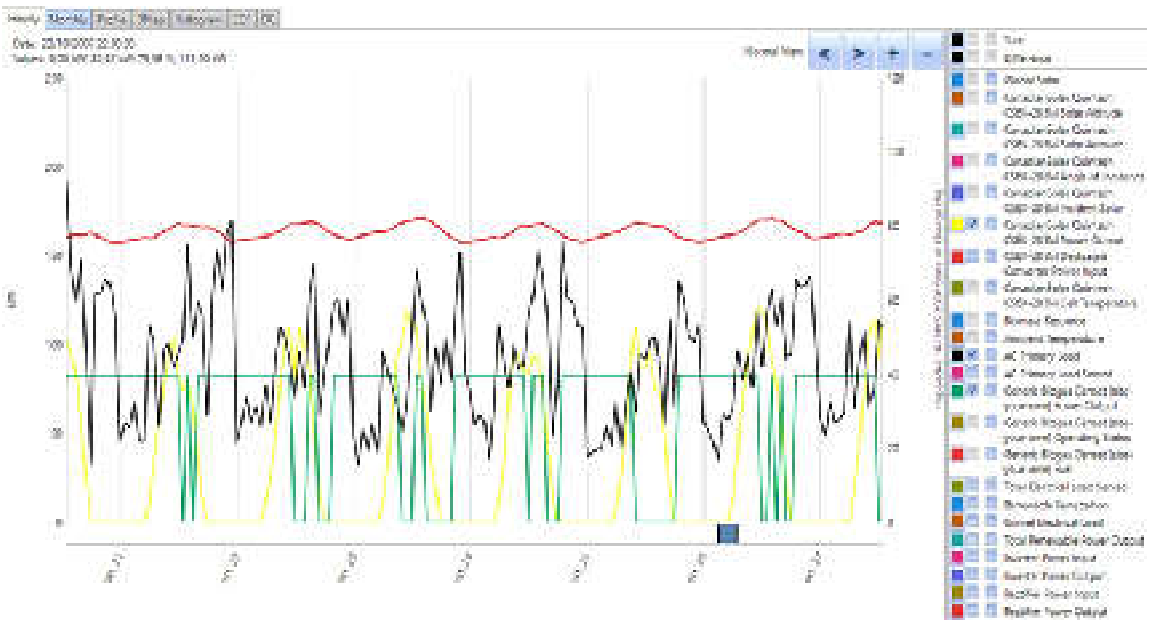

Figure 9. Sources behavior

-Yellow curve: delivered power by PV module.
-Green curve: delivered power by biogas generator.
-Black curve: power to be supplied for loads.
-Red: the batteries state charge.

Conclusion

In this paper, we have sized and optimized the performance of a hybrid PV-Biomass energy system with energy storage for Malian rural areas, particularly for Kolokani locality. This study offers a durable and reliable energy solution for isolated localities of national electric network and which know a real electrification problem. The simulation results under HOMER pro show that the energy demand of this locality is composed of biogas generator of 100kW, PV field of 160kWc and a battery park of 1920. In addition, the economic analysis reveals an initial capital of 944.000.000FCFA for achievement of this hybrid system. The same analysis shows that the national network extension up to Kolokani requires a cost about 1.500.000.000 FCFA without taking into account the non-environment quality of supplied energy. The system provides reliable energy and contributes to the environment preservation. For African rural areas which are generally characterized by the poverty, this study proves that the hybrid energy systems development is energetically and economically viable, because it allows to economize about 500.000.000FCFA comparatively to the national electric network extension.

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