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SIMULATION AND OPTIMIZATION OF PHOTOVOLTAIC/BIOMASS STAND-ALONE HYBRID POWER GENERATING SYSTEM FOR MAKURDI USING HOMER SOFTWARE

Iortyer, H. A*, Achirgbenda, V. T, Abaka J.U
* Department of Mechanical Engineering, University of Agriculture, Makurdi, Benue State, Nigeria
Energy Commission of Nigeria, Abuja, Nigeria

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ABSTRACT
The simulation and optimization of a hybrid photovoltaic/biomass stand-alone system for a residential building in Makurdi was carried out using HOMER software model 2.81. The lifetime of the project is 25 years and a real interest rate of 6% per annum was assumed. The average hourly electrical load demand/consumption data for a three bedroom residential building in Makurdi was measured for a week using digital Owl metre model CM199 and the values inputted into HOMER in order to simulate the power consumption for a twelve month (12) period. The solar resource data with an annual average insolation of 4.48kWh/m2/d for Makurdi location was obtained from the NASA Langley Research Centre website in order to calculate daily radiation and monthly average values of clearness index. The sizes of the different components were determined to make sure their sizes suit the load demand. The optimal system obtained from the simulation is the configuration consisting of 2kW PV array, 1kW biomass generator, 1kW converter and 12 LP16trojan. Its NPC is $20,184 with initial capital requirement of $8,990, annual operation cost of $873. The system has a yearly excess electricity of 3.36 kWh/yr (0.074%) and unmet load of 0.256 kWh/yr (0.0063%). The results obtained show that the PV/biomass hybrid system is technically and economically feasible for the location of choice.

INTRODUCTION
With about 1.3 billion people in the world (or about 1 in 5) without access to electricity in 2010, the challenge of providing reliable and cost-effective services remains one of the major global challenges facing the world in this century. Although grid extension still remains the preferred mode of rural electrification, extension of the central electricity grid to geographically remote and sparsely populated rural areas can either be financially unviable or practically infeasible. Off-grid options can be helpful in such cases [1]. Back-up power supply for areas where there is hardly a steady power supply from the grid with the use of renewable energy sources have become more cost-effective when compared to the use of diesel generators and a convenient option when compared to grid [2]. Moreover, the efforts in using renewable energies have often focused on single technologies. For example, Solar Home Systems (SHS), solar photovoltaic systems and micro-hydropower have been widely used, but such options are often from a variety of resources. Reliance on a single technology generally results in an over-sizing of the system, thereby increasing the initial costs. A hybrid system design can overcome the intermittent nature of renewable energy sources (RES), the over-sizing issue and enhance reliability of supply. Yet, hybrid systems have received limited attention due to their increased complexity and hardly any work has considered the issue of reliable supply of electricity in a rural context [3].

Nigeria is bedeviled with perennial power failure which has been the bane of our industrial development. This constant power outage has driven households and businesses in search of solutions. One of the easiest ways out is the use of diesel generators but this too has its own disadvantages of high cost of fuel and environmental pollution. Therefore, there are many renewable energy sources that can be implemented in hybrid systems like solar, wind, hydro, geothermal, biomass etc. It is economical to use hybrid systems consisting of solar and biomass once the biomass supply is available throughout the year especially for areas where there is a non-steady power supply from the grid, rural and remote areas. This research, therefor, seeks to simulate and optimize a hybrid photovoltaic/biomass stand-alone system for a residential building in Makurdi in order to determine its technical and economic feasibility for such a location.

MATERIALS AND METHODS

Materials/Equipments

The following were used for the simulation: HOMER software model 2.81, Owl metre model CM199 , Solar resource (hourly average solar radiation) for at least one year, Electricity Load consumption pattern for a middle income family in Makurdi, Market price and technical specification of all the components required to build the hybrid system.

Methods

Description of the Hybrid Systems

A PV-Biomass gasifier power system is a combination of a photovoltaic array integrated with a biomass gasifier generator serving as a backup. Because in most of the remote and non-electrified sites, extension of utility grid lines experiences a number of problems such as high capital investment, high lead time, low load factor, poor voltage regulation and frequent power supply interruptions, standalone solar photovoltaic systems and biomass systems have been acknowledged as the most suitable technologies for electricity generation in such locations. As a result, a PV-Biomass gasifier power system was selected as the best option for areas of Makurdi not connected to the grid or areas with low power as a best solution to electrification where extension of national grid is not a cost effective option. Schematic of the hybrid system as shown in figure 1 consists of a PV array, a biomass generator, a charge controller and a DC/AC converter. In the design and sizing of the system, itwas considered as an autonomous system..

Determination of Hourly Electricity Consumption Pattern

The electrical load consumption of a three bedroom bungalow in Makurdi was measured for a week and the values inputted into HOMER in order to simulate the power consumption for a twelve month (12) period. The electrical consumption data was measured by clipping the sensor of the Owl metre component to the live cable carrying electricity to the household. It uses a current transformer sensing technology to detect and monitor a tiny magnetic field around it and transfer the information to the sender box which in turn passes the information to the monitor where the consumption is read.

Determination of Solar Radiation

Average monthly insolation values for the period of one year for Makurdi location (latitude 7.43^0 N and longitude 8.32^0 E) were obtained from NASA website (www.nasasse.com.) and inputted into the HOMER software in order to calculate daily radiation and monthly average values of clearness index.

Average Biomass Availability Resource

Sensitivity values of 2, 6, 8, 10 and 12 were inputted into HOMER search space for biomass resource and 8 tons were considered to give the best result for such a hybrid system. A monthly average value of Eight (8) tons of biomass resource was used for the simulation which was fed into the gasifier to produce the fuel to run the biomass generator.

Specifications and Prices of the Components of the Hybrid System

The following are the components that were used for the system configuration and their prices were obtained from local and international dealers:

- Cost of biomass generator, replacement cost, operation and maintenance cost.
- Cost of PV panels, replacement cost, operation and maintenance cost.
- Cost of converter (inverter and rectifier).
- Cost of battery, replacement cost, operation and maintenance cost.

The system components and their prices were obtained from informal market survey conducted locally and websites of retailers of these components.

Economic model with HOMER

The feasibility is studied through the modeling of economic and environmental characters of a PV-biomass gasifier hybrid system with storages and converters. For economic aspect, the net present cost (NPC) and cost of energy (COE) of the system is calculated. In this study, total NPC and COE have been considered as performance

metrics to evaluate and compare different systems. These were calculated during the simulation by HOMER. The total NPC of a system is the present value of all the costs that it incurs over its lifetime minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, operational and maintenance costs, fuel costs, emissions penalties, and the costs of buying power from the grid [4]. On the other hand, COE is the average cost per KWh of electricity. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production. The NPC is a more trustworthy number than the COE, therefore in this analysis NPC has been taken as the primary metric. The lower the NPC and COE are, the better is the hybrid model output[4].
The NPC is calculated by

$$\mathrm{NPC}(\$) = \frac{\mathrm{TAC}}{\mathrm{CRF}} \quad (1)$$

Where: TAC is the total annualized cost. CRF is the capital recovery factor.

$$\mathrm{CRF}(\$) = \frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}}-1} \quad (3)$$

Where *N* is the number of years and *i* is the annual real interest rate (%). COE, in $/KWh, is the average cost per capita of useful electricity produced by the system. It can be calculated by:

$$\mathrm{COE}(\$) = \frac{C_{\mathrm{ann,tot}}}{\mathrm{E}} \quad (4)$$

Where C*ann,tot* is the annual total cost, $. *E* is the total electricity consumption, KWh/Year.

Inputs to HOMER
In summary, the inputs to HOMER are as listed below:

Ac primary load: Data source: synthetic**;** Scaled annual average: 0.200, 0.400, 0.600, 0.800, 1.000, and 11.300 kWh/d**;** Daily noise: 15% **;** Hourly noise: 20%

PV
PV cost: size:1kW. capital:$2300. Replacement cost: $2000. Operation and maintenance cost:$0. Sizes to consider: 0, 1, 2, 10 kW. Output current: DC. Lifetime: 25years. Derating factor: 90%. Slope: 48%. Azimuth: 0%. Ground reflectance: 20%. Tracking system: no tracking.

Biomass generator
Costs: size: 1kW. Capital: $1000. Replacement cost: $900. Operation and maintenance cost: $0.20. Sizes to consider: 0 1, 2, 10 KW. Description: biomass generator. Type: AC. Life time: 15000 hours. Minimum load ratio: 30%. Sensitivity values: biomass capital multiplier; 1, 0.9, 0.8, 0.7, 0.6. Biomass resource: 8 tonness. Lower heating value of biomass fuel: 5.5 MJ/kg. Density of biomass fuel: 0.72kg/m^3

Battery
Battery type: TrojanL16P
Costs: size: 1. Capital $220. Replacement cost: $220. Operation and maintenance cost: 4.00$/yr.
Quantities to consider: 0, 6, 12, 18, 24, 30. Batteries string per size: 1 (6V bus). Initial state of charge: 1005. Nominal capacity: 6V, 360Ah, 216kWh. Life throughput: 1075kWh.

Converter
Costs: size: 1. Capital: $750. Replacement cost: $750. Operation and maintenance cost: 04/yr.
Sizes to consider: 0, 1, 2, 10 kW. Inverter life time: 15years. Inverter efficiency: 90%. Rectifier efficiency: 85%. Capacity of rectifier relative to inverter: 100%.

Economics
Annual real interest: 6%. Project lifetime: 25 years. System fixed capital cost: $0. System fixed O & M: $0. Capital shortage penalty: 0 $kW/hr.
Figure 1 shows the schematic of the hybrid system after the inputs.

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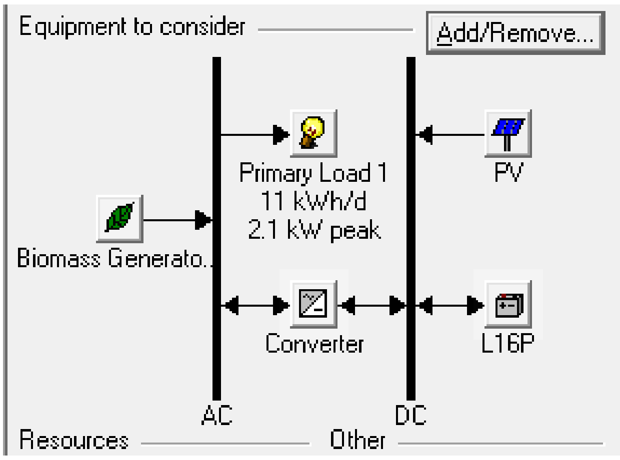

Figure 1. Schematic of the hybrid system.

SYSTEM ANALYSIS

System cost analysis

The simulation process serves two purposes. First, it determines whether the system is feasible. HOMER considers the system to be feasible if it can adequately serve the electric load and satisfy any other constraints imposed by the user [8]. Second, it estimates the life-cycle cost of the system which is the total cost of installing and operating the system over its lifetime [8]. In the optimizing process, HOMER simulates every system configuration. Table 1 presents the HOMER simulation results. It shows that the greatest optimal result is achieved when the system is composed of 2-kW PV modules, 12 batteries, and a 3-kW inverter, and the least optimal result is when only the generator is used. The initial cost, NPC, and electricity cost for this system is $ 8,990, $ 20,184 and $ 0.382/kWh, respectively.

Table 1: comparison of the optimized hybrid options for the simulation.

Options	PV (KW)	BIOMASS GENERATOR (KW)	L16P	CONVERTER (KW)	INITIAL CAPITAL	OPERATING COST $/YR	TOTAL NPC $	COE ($/KWh
PV/BIOMASS/BATTERY/CONERTER	2	1	12	1	8,990	873	20,184	0.382
BIOMASS/BATTERY/CONVERTER		1	12	1	4,390	1,659	25,593	0.485
PV/BATTERY/CONVERTER	10		18	2	28,460	477	34,558	0.655
BIOMASS		2			2,000	4,500	59,530	1.129

Energy production analysis

From the simulation results of the most optimal system shown in table 1, it can be noticed that the capacity shortage is 2.36kWh/yr (0.0571% and the load that the system was unable to serve was 0.259kWh/yr (0.0063%). This is as a result of the fact that the demand in the months of April and July exceeds the supply. By default, HOMER considers infeasible any system that experiences unmet load but since the percentage is so small, HOMER considers the system feasible and displays it among the results. Figures 5 - 7 show the contribution of the PV and biomass generator components individually and in combination for each month of the year. The energy production is high during August and low in January mostly because of the high and low contribution of the biomass generator.

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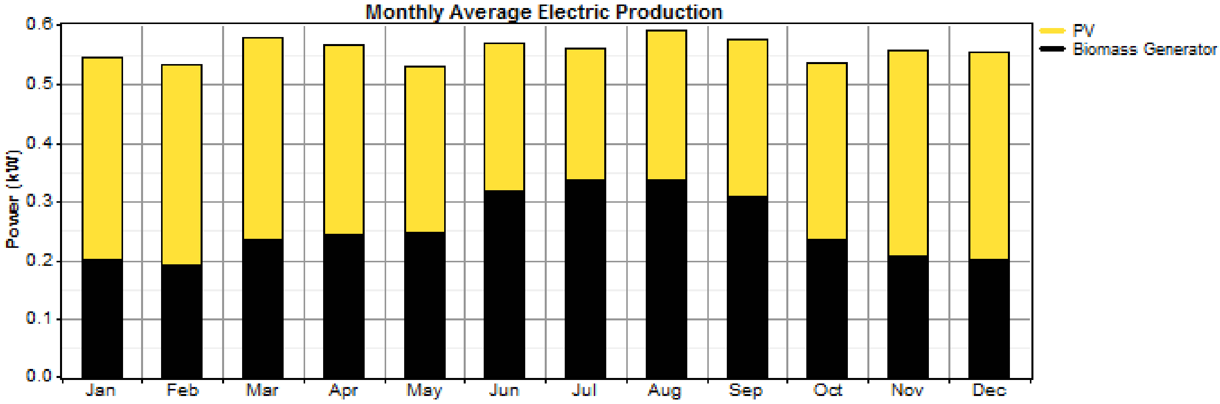

Figure 5. Monthly average electric production.

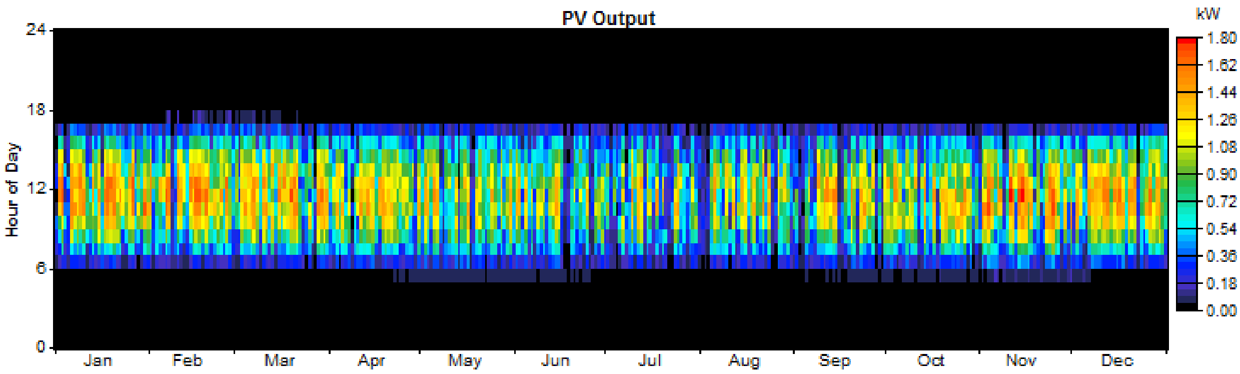

Figure 6. PV output

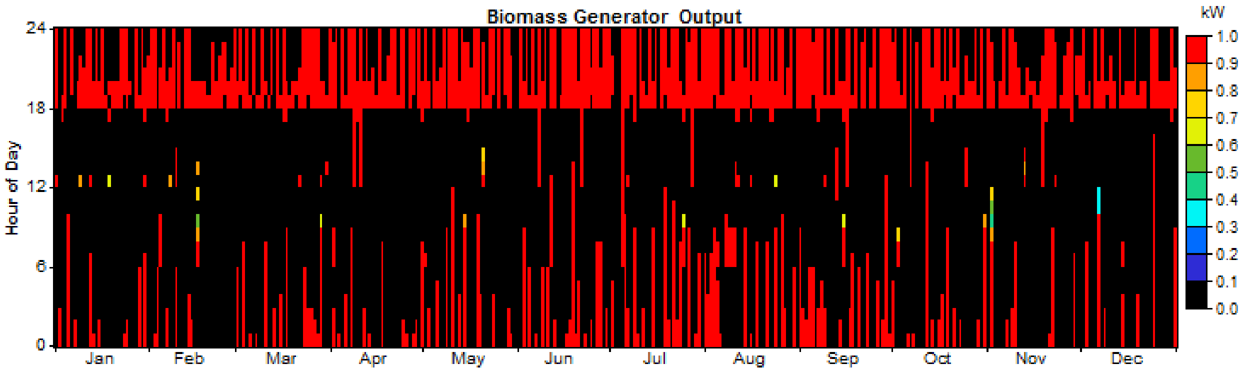

Figure 7. Biomass generator output.

Cash flow summary

Figure 8 shows the cash flow summary of the hybrid system. It shows that most of the cost is required for operating the biomass generator. However, the capital cost of the PV is high but it needs no operation and maintenance cost. Therefore, renewable energy sources require less operation and maintenance expenditure which is one of their most useful features.

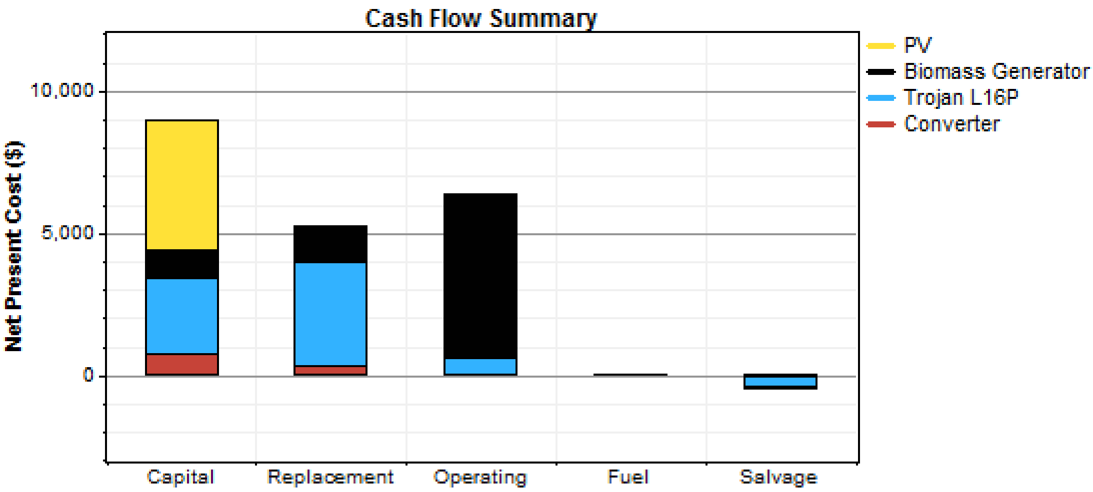

Figure 8. Cash flow summary

sensitivity analysis

Figure 9 shows that if the PV capital multiplier and the biomass capital multiplier are both set at 1, with a primary load of 0.4KWh/d and biomass price of 0.2$/t, the optimal system will be biomass/battery with an NPC of $5,089. But as the primary load increases regardless of the biomass price, the optimal system type is PV/biomass/battery. The NPC at this point depends on the price of the biomass which can increase from $ 17,849 at biomass price of 0.2$/t to $ 21,938 at a biomass price of 40$/t.

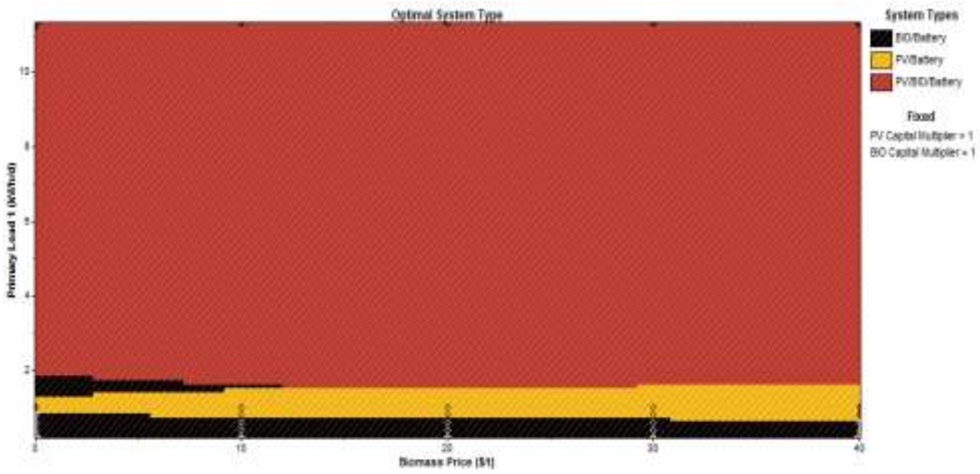

FIGURE 9: Sensitivity of Optimal System with Primary load Vs Biomass Price at PV Capital Multiplier and Biomass Capital Multiplier of 1.

Figure 10 shows that if the PV capital multiplier and the biomass capital multiplier are both set at 0.6 and 1 respectively with a primary load of 0.4kWh/d and biomass price of 0.2$/t, the optimal system will be PV/battery with an NPC of $5,006. But as the primary load increases regardless of the biomass price, the optimal system type is PV/biomass/battery. The NPC at this point depends on the price of the biomass which can increase from $ 13,627 at biomass price of 0.2$/t to $ 20,093 at a biomass price of 40$/t.

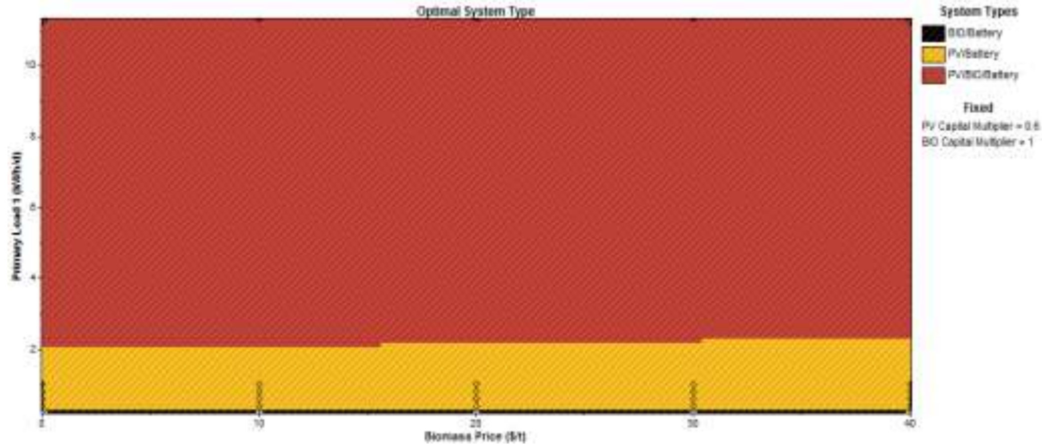

FIGURE 10: Sensitivity for Optimal System with Primary load Vs Biomass Price at PV Capital Multiplier of 0.6 and Biomass Capital Multiplier of 1

Figure 11 shows that if the PV capital multiplier and the biomass capital multiplier are both set at 1 and 0.6 with a primary load of 0.4KWh/d and biomass price of 0.2$/t, the optimal system will be biomass/battery with an NPC of $4,689. But as the primary load increases regardless of the biomass price, the optimal system type is PV/biomass/battery. The NPC at this point depends on the price of the biomass which can increase from $ 14,685 at biomass price of 0.2$/t to $ 21,538 at a biomass price of 40$/t.

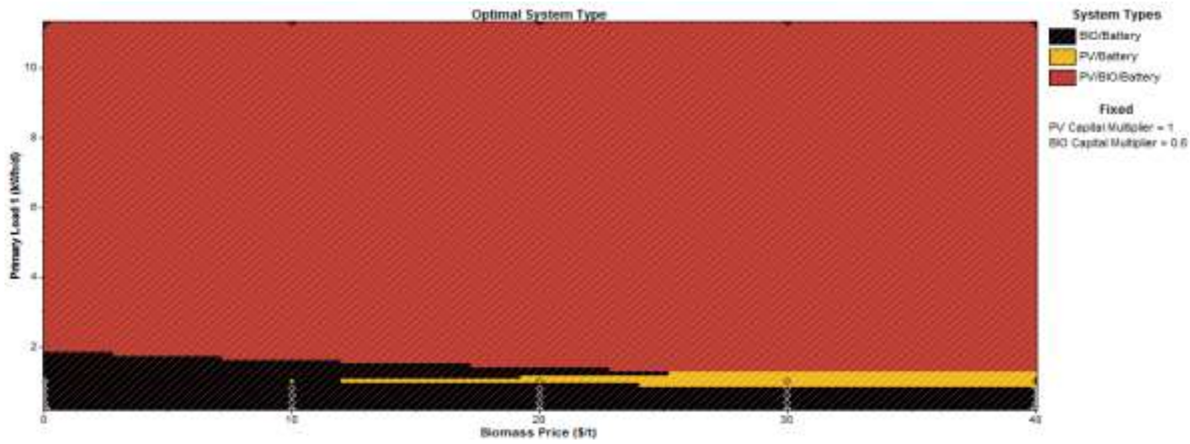

FIGURE 11: Sensitivity for Optimal System with Primary load Vs Biomass Price at PV Capital Multiplier of 1 and Biomass Capital Multiplier of 0.6.

It can be deduced that at a load of 11.300kWh/d and a biomass 0.000$/t, the net present cost (NPC) and the cost of energy (COE) decrease from $20,148 to $17,908 and 0.382$/kWh to 0.340$/kWh respectively. This is due to the PV capital multiplier and the biomass capital multiplier decrease from 1 to 0.6. Furthermore, as the price of biomass increases to 10$/t at the same load. The NPC and COE decrease from $20,577 to $18,337 and 0.390$/kWh to 0.348$/kWh respectively as PV capital multiplier and biomass capital multiplier decease from 1 to 0.6. Furthermore, for a load of 0.200kWh/d and a biomass price of 0.000$/t, the NPC and COE decreases from $4,768 to $4,368 and 5.110$/kWh to 4.681$/kWh respectively due to a PV capital multiplier and biomass capital multiplier decreasing from 1 to 0.6.

It can be concluded that at a given biomass price and a given load, the NPC and COE depend on the PV capital multiplier and the biomass capital multiplier. An increase of the PV capital multiplier and biomass capital multiplier results to an increase of NPC and COE. But as the load increases from 0.200kwh/d to 11.300kwh/d the

NPC increases while the COE decreases. The decease of COE is as a result of the increase of the total electrical load to be served by the system.

CONCLUSION

The conclusions are summarized as follows:

- Simulation results showed clearly that hybridizing PV array and biomass generator makes a technically and economically efficient power generating system for residential consumption over photovoltaic/fuel cell/biomass hybrid system. The PV/biomass hybrid system reduces the high capital cost associated with PV panels and also reduces the high fuel, operation and maintenance costs associated with the biomass generator. The operation hours of the biomass generator are drastically reduced as a result of high contribution of the PV array to power generation in the chosen location.
- The net present cost of 2kW PV, 1kW biomass generator, 12 Trojan L16P and 1kW converter is $20,148, initial capital cost of $ 8,990 and an annual operating cost of $873/yr.
- It can, therefore, be concluded that the PV/Biomass system is technically and economically feasible for a three bedroom flat that is not connected to the national grid as a standalone power supply unit in the design location of Makurdi.

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