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HYBRIDIZATION OF BIOMASS - SOLAR PV (PHOTOVOLTAIC) MICROGRID POWER SYSTEM POTENTIALS FOR KADUNA IN NIGERIA

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ABSTRACT

Using agricultural waste is a good source of biomass for generating energy. A model analysis for a hybrid biomas-solar PV microgrid was carried out in this study. The model analysis showed that it has potentials to generate electricity for Kadabo community in Kaduna state of Nigeria. The result from the data gathered showed that the maximum solar insolation is in the month of December, with a daily solar radiation of 6.51kwh/m2/day, and the minimum solar radiation was in August with a radiation of 4.45kwh/m2/day. An average of 5.64 kwh/m2/day solar radiation was obtained for the whole year. Also, the biomass gave an output of 30,000kW, indicating that the hybrid microgrid could be a reliable and sustainable means of electricity generation for the community.

Keywords: Microgrid, Electricity, Solar PV, Hybrid, Biomass, and Kaduna.

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1. INTRODUCTION

One of the major challenges for the remote dwellers in Nigeria and other Sub-Sahara African countries is access to power supply [1]. The Northern area of Nigeria have over 65% of the nation's population [2]. The people are faced with unreliable power, unimproved health services, high level of poverty, reduction in social development and economic activities [3] [4] [5]. Another challenge is that the traditional energy resources are fast depleting and so can no longer meet the power demands of everybody. In most cases the traditional resources also create health hazards to humans and pollute the environment. There is therefore need to bring in alternative energy source (renewable) such as solar, wind, and biomass, that can easily penetrate the remote sites and produce clean energy.

A microgrid is a small-scale energy system with interconnection between distributed energy sources and loads within a small location [6]. Microgrids can operate as grid connected or off-grid connected which enhances power reliability and consumers' comfort. Renewable or non-renewable sources can be incorporated into the micro-grid [7].

Solar power and biomass have shown some characteristics that they can be sources of clean power, and they are always available in nature. These have made them attractive in the power sector. However renewable energy sources all have their limitations, such as changes in weather factors. The weakness of one can be overcome by the strength of the other. Standalone solar based power systems, as seen by other researchers are always very expensive [8][9] hence the need for hybridization which will generate a better continuous power quality. This will in turn reduce the consumption of fossil fuel that produces CO2 which pollutes the environment [10][11][12]. Nigeria being a tropical region and Kaduna in the far North has high solar radiation intensity potentials that could be explored to generate electricity. The UN goal of making availability of sustainable energy for all throughout the globe of over a billion people in the developing world by 2030 under the initiative; Sustainable Energy for All (SE4All) is also a motivation for this work [13]. Biomass is becoming popular in other countries outside Nigeria. PV-biomass-wind hybrid system for rural areas of India was proposed in [14]. Also, PV-biomass hybrid based on waste was proposed by Rehman et al in Bangladesh [15]. Techno-economic analysis of hybrid PV-biomass energy system was presented for an off-grid site in Mozambique by Garrido *et al* [16].

Sara *et al* [17] also proposed a backup in a decentralized hybrid PV/wind/battery system in Kenya that would use biogas engine. The power system generation was made up of PV/wind/battery. The literature reviewed revealed that researchers have been working in this area though not in wide detail but it has not been implemented in the northern part of Nigeria, hence it is expedient to carry out this research that could be feasible for the Kadabo community in Nigeria that is without electricity.

Kaduna is also characterized with woody site which can enhance the usage of biomass renewable sources of energy. However, with the surplus of these resources, the area is having poor electricity supply. Hence the need for this study which seeks to look at the proper utilization of these potentials of the solar-biomass hybrid system to generate power for the Kaduna rural dwellers in Kadabo community.

The main goal of this study is to assess renewable resources available in Kadabo, Nigeria and choose the best to meet the electric supply of demand for the community using a hybrid biomass - Solar PV microgrid system [18].

2. STUDY AREA DESCRIPTION

Kadabo is community in Kaduna State of Nigeria, with about 1000 population. The major occupation of the people in the area is 70% farming. During the hot seasons the temperature can go as high as 42 degrees Celsius and during harmattan, it is as cold as 18^{o}C, hence the biomass can conveniently be used when no solar radiation is available. Kaduna is located at latitude 10.54°N and longitude 7.44°E. It is also located in the northern part of the country.

Electricity serves as the main source of lighting for the rural dwellers and other few household loads

2.1. Load profile

In the design the Kadabo community considered to have 200 houses with each estimated to have a family size of 7 members. The load demand in rural locations is usually simple and less because the households use more of electrical lighting appliances. The assumed load includes luminaires (CFLs, conventional fluorescent fitting), ceiling mounted fans, television set, GSM mobile phones and others. The estimated load is shown in Table 1

Table 1: Evaluated load profile for community

Load type	Quantity	Power (Watts)/Unit	Load in Watts	No of hours used per day	Power required in Watts hour/ day
Ceiling fan	3	50	150	9	1350
Television	1	50	50	5.5	275
Fluorescent light	4	40	160	12	1920
Computer	1	60	60	3	180
Lamps (CFL)	30	20	600	12	7200
Energy savings bulbs	4	20	80	12	960
table lamp	5	5	25	6	150
GSM phone	3	7	21	4	84
Total Demand (Wh/day)		252W	1146	63.5	72771

3. HYBRID BIOMASS - SOLAR PV (HBSPV)

In HBSPV, several renewable power generators are connected to the storage bank with converters to meet the demand for energy in the remote community. To develop an electric system with hybrid renewable energy sources for an area, the energy demand and the available energy sources in that particular area should be studied very well. In Kadabo, the load demand is more of lights and household appliances since the site is more of residential. Solar is chosen since it is in excess in Kadabo in the northern area of Nigeria. The biomass was also studied because of the advantages of the bushy area. The storage battery was used to store the excess power from the solar modules and also the biomass generator, to be used during autonomous days especially during solar intermittence. The inverter is connected to the storage battery, to covert DC to AC needed by the load. Figure 1 shows the HSBS configuration. This proposed system is most suitable for remote areas that are far from the grid and villages that are into farming especially in developing countries where access to the traditional grid is a problem.

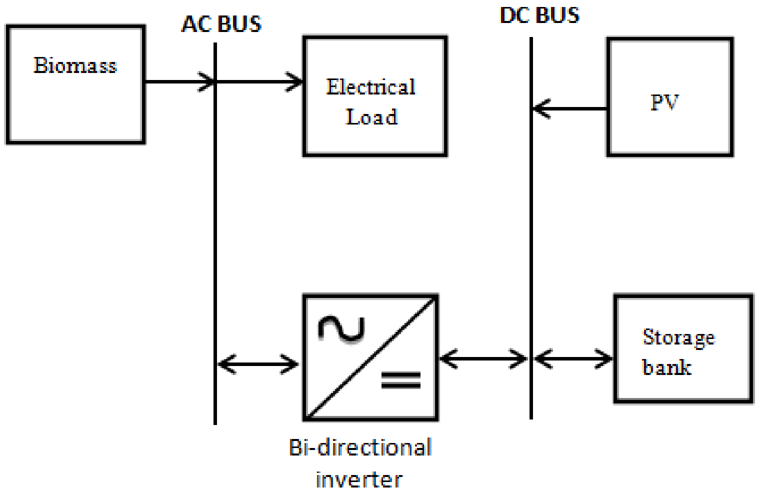

Figure 1: The proposed system model

3.1. Mathematical modeling of the Solar Photovoltaic system

To predict for the solar output power (DC) within a tropical location like Kadabo, the model will be similar to the one developed by [19]. Solar photovoltaic system requires the conversion of sunrays to electric power by using photovoltaic arrays. The solar radiation that strikes on the panel is usually measured in W/m^2 [20]. The model for the solar photovoltaic system is represented by equation (1),

$$P_{out} = \frac{G_i}{G_o} P_r D_f \tag{1}$$

Where

G_i = solar radiation (W/m^2)

G_o = solar radiation in standard condition ($1000W/m^2$)

P_r = maximum power point (W)

D_f = solar module panel derating factor

Pout = is hourly output power of PV cell

The temperature effect is not considered.

The maximum solar insolation for (Kaduna) is in the month of December, with a daily solar radiation of $6.51kWh/m^2/day$, and the minimum solar radiation was in August and radiation of $4.45kWh/m^2/day$. An average of $5.64\ kWh/m^2/day$ was obtained for whole of the year as shown in Table 2. NASA data sheet for the solar radiation data in Kaduna was used for the simulation [15].

Table 2: Data source of the solar system (NASA DATA)

Months	Irradiation ($KWh/m^2/day$)
January	5.76
February	6.06
March	6.32
April	6.30

Months	**Irradiation (KWh/m^2/day)**
May	5.94
June	5.40
July	4.85
August	4.45.
September	5.11
October	5.63
November	6.11
December	6.51
Annual Average	5.64

3.2. Mathematical modeling of the storage system

Renewable energy source variability can be compensated for by the use of storage system [21]. Hence it is usually placed between the renewable sources and the load. Stability of the system can also be monitored in terms of generation and the supply demand at any point.

The size of the battery storage was considered, and detailed calculation done, to support the energy demand when the power from the panel or biomass is not available.

The battery was used as back-up to supply electricity during the period of non-availability of power supply from the renewable energy sources. The battery system size (A-h) is given by equation (2), [22].

$$B_{size} = \frac{E_{load} \times Days_{off}}{DoD_{\max} \times \eta_b \times \eta_{inv}} \tag{2}$$

Where:

E_{load} is the load for the village that must be supplied with electricity

$Days_{off}$, is the numbers of days to run the battery system when the renewable energy sources are not available. (which is usually 3-5 days).

η_{inv}, is efficiency of the inverter efficiency = 92%,

η_b, is efficiency of the battery = 85%

DoD_{max} is the depth of discharge of the battery pack (usually 50-80% common for deep cycle batteries). This also depends on how you want to discharge the battery [17].

V_{batt} is the voltage of a single battery.

3.3. Bi-directional converter

This is a DC/AC and AC/DC converter, and it is always needed whenever there are DC and AC components in a system. The electric load is AC while the storage battery and the PV system generate DC output. The output of biomass generator is AC. The bidirectional converter connects the AC bus and the DC bus through which all the AC loads are fed.

The Size of the inverter depends on the demand of the load at peak periods, PL(t). the power rating of the inverter (P_{inv}) was gotten from the equation 3.

$$P_{inv} = \frac{P_L(t)}{\eta_{inv}} \tag{3}$$

Where η_{inv} = inverter efficiency[18].

3.4. Mathematical modeling of the biomass power system

The Biomass power plant works in a similar manner to a steam-fired turbine. The biomass feedstock input may not be fed directly to the combustor as they undergo some pre-processing such as size reduction, separation or drying. The availability of biomass feedstock is hugely dependent on location, climate and season and has properties in terms of the moisture content, heating value, transportation and handling and preparation [25] Biomass comes in various varieties, but for this research the forest residues will be used as the primary source.

The forest residue which includes stumps and waste from residential areas from the farmers and the villagers in the area is taken in this paper as source of biomass energy. The wood waste was used as biomass feedstock for this study [26].

Electricity output from the gasifier depends on the availability of the biomass materials and the operating hours of the generator daily. Mathematically, the power output generated annually by the biomass is expressed in equation 4 [27].

$$E_{BMGS} = (365 \times 24 \times capacity\ factor)\ \text{(Shakti Singh)}$$

Where:

$$P_{BMGS}\left[\frac{kwh}{year}\right] = \frac{Total\ \ biomass\ available\ \left(\frac{tons}{year}\right) x\ CV_{BM}\ x\ \eta_{BMG}\ \ x\ 1000}{365\ x\ 24\ x\ operating\ hours\ per\ day} \quad (4)$$

Where P_{BMGS} is the biomass rating from biomass generating system, the calorific value $CV_{BM,}$ is (4015 kcal), η_{BMG} is the biomass generator overall conversion efficiency from biomass (fuel wood) to electricity production (20%). Capacity factor was 50 8.

650 tones/day of biomass resource was used for simulation within the period from January to December which was constant in supply needed to run the generator. Figure 4 shows the daily biomass output.

Table 3: Hybrid components data for the proposed microgrid system.

Components	Parameter	Value	unit
Storage battery	Inverter efficiency, η_{inv},	92	%
	Battery efficiency, η_b ,	91.4	%
	Battery size, B_{size}	2,378,140	Ah
	Nominal voltage （V_{batt}）	12	V
	Load for the village, E_{load}	14,554,200	Watt hr
	Load for the village, DoD_{max}	60	%
	Numbers of days to run the battery system, $Days_{off}$	2	days
Biomass gasifier	output of biomass, P_{BMGS}	50	kW
	biomass calorific value, CV_{BM}	4015	kcal
	overall conversion efficiency of the biomass, η_{BMG}	21	%
PV	power at maximum power point, P_r	150	W
	Derating factor, D_f	85	%
Inverter	Rated power	297,960	W
	Inverter efficiency, η_{inv}	90	%

4. RESULTS AND DISCUSSIONS

The result showed that for a period of 24 hours load profile, the peak load was 12 kW as depicted in Figure 2. From figure 3, it could be seen that Kaduna State has abundant solar energy resource potentials throughout the year such that it could be tapped using Solar PV modules to generate electricity for the community. Figure 4 revealed that the initial use of the biomass output was very high but reduces with continued consumption with time, hence the need for a backup storage or an alternative energy source. Thus, a hybrid of solar PV and biomass would form a sustainable microgrid for power generation in Kadabo in Kaduna State.

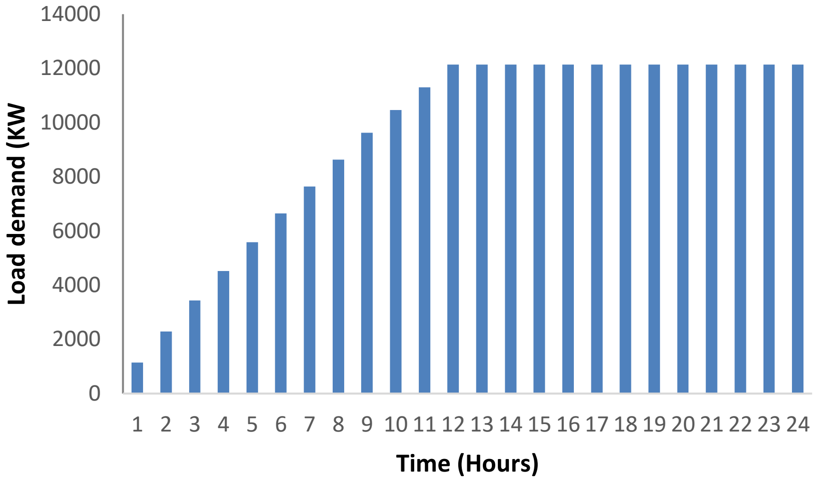

Figure 2: Hourly load profile

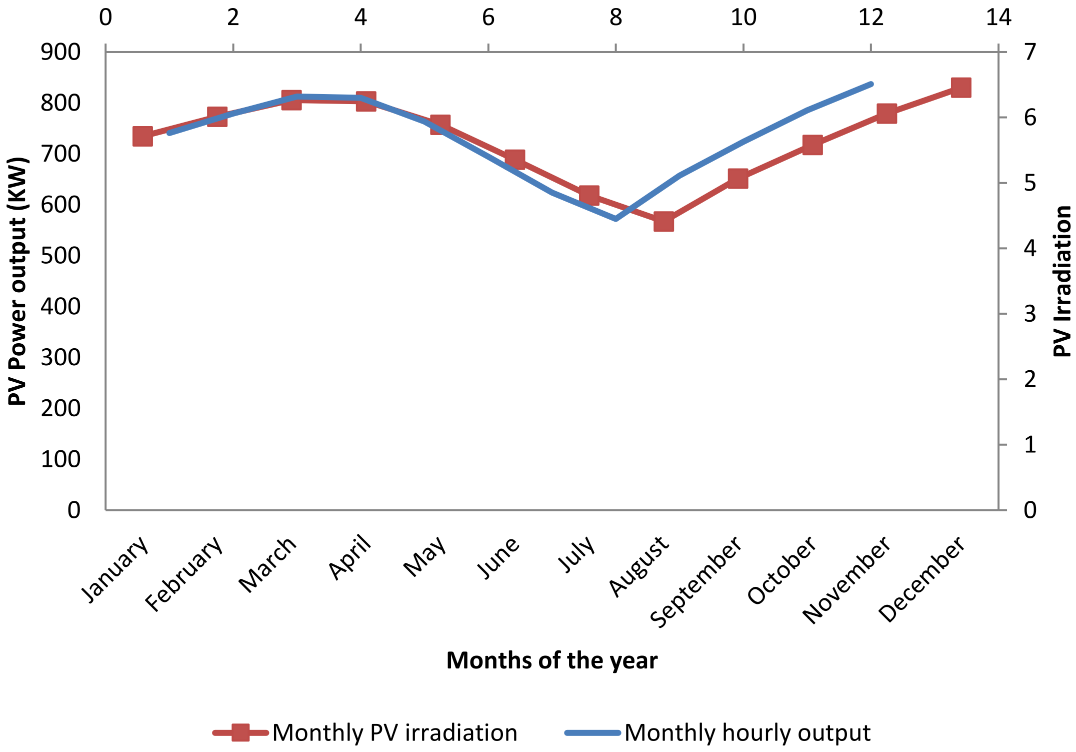

Figure 3: Solar irradiation and output available for Kaduna

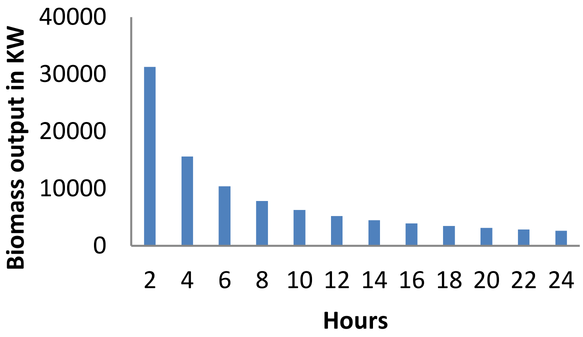

Figure 4: Daily biomass output

5. CONCLUSION

This research was carried out to determine the biomass - Solar PV potentials in Kadabo community in Kaduna State, Nigeria. To predict the power generation potentials of the biomass - Solar PV, a model with a storage bank was proposed for the evaluation. The study result showed that biomass - Solar PV can conveniently be used to generate electricity for the Kadabo community in Kaduna.

The high solar radiation and abundant wood residue with high-energy content in the area could be utilized in a biomass-solar PV hybrid microgrid for sustainable power generation. Further research will investigate hybridization of other renewable energy sources in the area under study

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