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Design of a Hybrid PV/Wind/Diesel Generator Energy System for 120 Residential Apartments in Gusau

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Abstract **- Gusau, a city in zamfara state, Nigeria is faced with the challenge of inadequate power supply as electricity supply from the national grid is unstable and inadequate, besides majority of those in the remote areas are isolated from the grid. The location has a potential for renewable resources, to overcome this challenge of inadequate power supply, a hybrid electric power system which employs the use of battery storage, solar and wind energy system with a diesel generator as reserve to provide adequate power to 120 residential apartments in a settlement isolated from the grid is being designed. The solar and wind energy resources in the location were assessed; the data from the two renewable energy resources available in the location was collected for the year 2015 from the Nigerian meteorological Agency, NIMET alongside the geographical coordinates and other useful parameters as input to the HOMER software simulator for analysis. The load profile of the location was carried out, the sizing of the energy mix from PV, wind, battery and generator was made using the software. The result of the simulation shows a yearly electricity production of 168,545KWh/yr, the yearly AC primary load is 67160KWh/yr. And the excess electricity is 88581Kwh/yr, this accounts for 52.6% of the total electricity generated hence, the hybrid energy system has the potential to provide the micro-grid with adequate power with high penetration of renewable energy.**

Keywords— HOMER; NIMET; Radiation; apartment; reserve.

I. INTRODUCTION

The cost of energy and demand for electricity is both rising while the reserve for the sources is reduced e.g. fossil fuel globally is actually diminishing, and as such we are left with the idea that in years to come, the demand for electricity might exceed the supply of electricity from fossil fuel such that other sources of energy may be required, asides energy generation from fossil fuel gives rise to the emission of pollutants. As a result of the quest to cut down on pollution and prepare for the future energy demand requirement, the use of available renewable energy resources in every location for the provision of electricity is a necessity [1].

To enable us to meet the electrical load demand using renewable energy sources, a hybrid energy system is required, this will help us to employ the use of wind and solar resources to provide power and in the process overcome the challenge which energy generation from a single renewable energy source experiences [2].

Nigeria, popularly known as the giant of Africa, has a lot of mineral and renewable resources; daily average sunshine of 6.25 hours is experienced in the country, the period of sunshine hours varies from 3.5 hours in locations in the coast of the country to 9 hours towards the north end. As a result of the long duration of sunshine hours, the value of its annual average daily radiation ranges from 7.0 KW/m2/day at the north end to 3.5KWh/m2/d at the coastal area with annual average daily radiation of 5.25KWh/m2/d and as such a high amount of energy can be generated from the sun. Consequently, the potential for the use of renewable resources to provide alternative power supply is high provided the maximum use of the available renewable resources is adopted [3].

A. Description of research location and data

The major source of electric power in developing countries, for example Nigeria, is usually the national grid in which most cases have limitations, as some areas cannot have access to the grid due to the geographical location of the place like many areas in Gusau in Nigeria situated at Longitude: 6.77 Degrees East and Latitude: 12.17 Degrees North. Hence an independent and reliable source of power is essential, where the majority depend on fuel-based generators for power supply which is usually associated with heavy cost of maintenance and environmental pollution [4].

Gusau, the capital of Zamfara state was discovered to be one of the states in the country with a good potential for wind generated electricity and this is because the location experiences high temperature and long period of sunshine hours.

The data for the average sunshine hours alongside the minimum and maximum temperature in Gusau for the year 2015 were obtained from the Nigerian Meteorological Agency, NIMET as shown in fig 1 and 2 respectively.

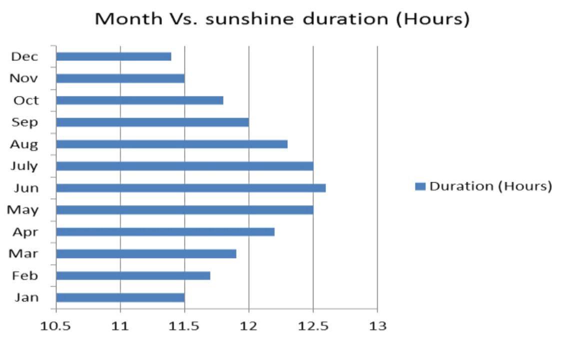

Fig. 1: Average Monthly Sunshine hours for Gusau in 2015.

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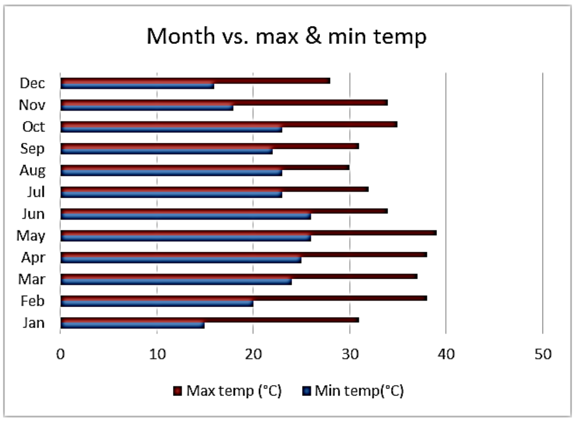

Fig. 2: Minimum & maximum temperature for Gusau in 2015.

From figure 1, it can be observed that the least of the sunshine hours are above 11 hours and the peak of the sunshine hours is slightly above 12.5 hours which implies there is an abundance of sunlight in the area. Conversely from figure 2, the peak of temperature in this location is around 38°C which puts the temperature of the location high. Other data obtained from NIMET include the monthly solar radiation for Gusau in the year 2015 as shown in table 1

Table 1: Monthly solar radiation in Gusau in the year, 2015

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly solar Radiation (Kwh/m2/day)	6.70	7.39	6.63	6.38	5.87	5.12	4.58	4.66	5.24	5.87	6.76	5.75

Unlike in Europe, wind resources are low in several areas of Nigeria but the distribution is appreciable in some part of the country, including the location of study as shown in fig. 3.
The areas in green in the figure are the areas in the country where there is a good potential for wind energy.

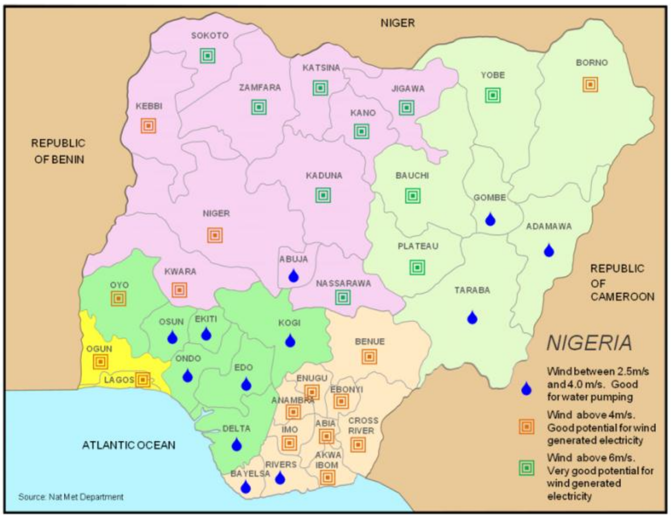

Fig. 3: wind energy potential in Gusau, Zamfara state and other states in Nigeria [5]

Wind speed and solar radiation data for the research location is used to estimate the electricity potential at the location. The wind speed data were obtained from a research in the past [6]. The solar energy resources and clearness index for Gusau in the year 2015 is as shown in fig 4, and table 2 shows the clearness index, daily solar radiation and wind speed values for each of the different months.

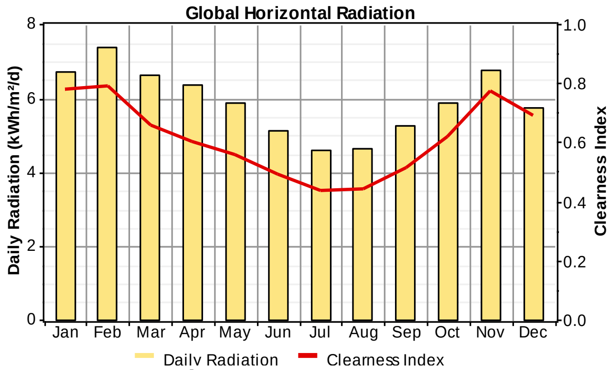

Fig. 4: Solar energy resources at Gusau in 2015

Table 2: Solar and wind resources at Gusau in 2015

Month	Clearness Index	Daily Radiation (kWh/m2/d)	Wind Speed (m/s)
January	0.780	6.700	7.500
February	0.791	7.390	7.000
March	0.655	6.630	7.000
April	0.605	6.380	7.100
May	0.556	5.870	7.200
June	0.490	5.120	7.000
July	0.438	4.580	5.900
August	0.444	4.660	5.000
September	0.513	5.240	4.000
October	0.616	5.870	3.600
November	0.775	6.760	5.000
December	0.692	5.750	7.400
Annual Average		5.94899	6.139

The month, which experiences the highest sunlight is February with a daily radiation of 7.390KWh/m2/d, on the other hand, July had a daily radiation of 4.580KWh/m2/d, which is the least, from the month of March to July, the daily radiation reduces progressively with the following differences: (0.25), (051), (0.75), and (0.54). During this period of reduction in daily radiation, energy from the wind energy system can be of tremendous support, besides during the nights, the energy stored in the battery alongside the wind energy can support the system.
Conversely, the daily radiation increases progressively from the month of August to November with the following differences: (0.08), (0.58), (0.63), (0.89), after which it reduces in December by (1.01) followed by another increase in January and February by (0.95) and (0.69) respectively. A plot of the wind speed, solar radiation, maximum, and minimum temperatures in Gusau is as shown in fig 5.

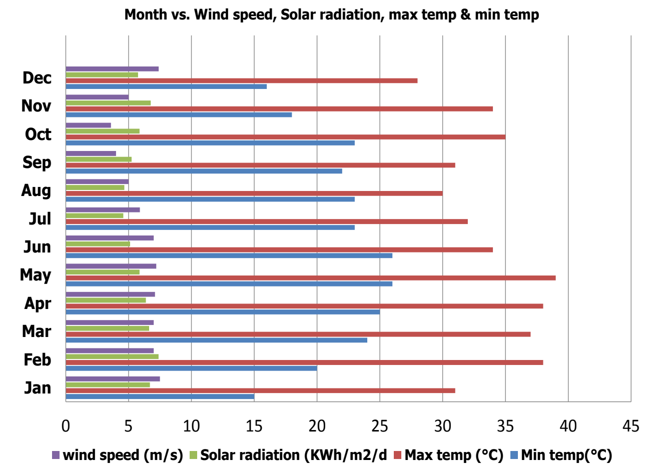

Fig. 5: Month Vs solar radiation, max & min temperature

The wind and solar energy resources in the location have the potential to provide adequate power supply to the community, but remains yet untapped and as a result the area is faced with inadequate power supply. Other reasons behind the challenge of inadequate supply in the area include:

- The power supply is majorly from fossil fuel, which is adequate and capital intensive
- Several people don't have electricity as they are being isolated from the grid
- The efficiency of the Photovoltaic module reduces at the peak of the sun for those who can afford it.

In most households in rural areas including Gusau, fuelwood appears to be the major source of energy for cooking, trees are being fell indiscriminately, since access to adequate electricity becomes more difficult, and people realized they can access fuelwood resources with ease, the use of fuelwood as an energy source became their choice, besides for lighting, kerosene appears to be in high demand [7].

In a research carried out in the past [8] There has been no proof to confirm that those who live in remote locations make use of electricity supply from the grid.

Solar and wind energy systems are still gaining awareness in the country as hydropower, energy from fossil fuel and fuelwood constitute the major source of energy consumed [9].

In order to find a solution to this lingering electricity crisis, the use of island mode of hybrid energy system is a necessity. The main essence of employing renewable energy to provide electricity to the affected areas is due to the fact that the use of renewable energy resources for power generation provides security of supply, it reduces the amount of pollutants, there is a power quality enhancement and in the process create some form of employment to those in the area [10].

The main contribution of this paper is to design a hybrid energy system to provide a stable and adequate power for a hundred and twenty residential buildings in the area with room for future expansion of the micro-grid.

II. METHOD

This project is specifically designed to provide electricity to people isolated from the grid and those who are connected to the grid but are dissatisfied with the use of electricity from the grid. A general description of this project is as shown in fig 6. The design requires energy majorly from renewable energy applications such as wind turbine and PV which requires battery storage, and a diesel generator as a reserve. The diesel generator is to serve in a situation where there is a failure of one of the sources or for the provision of reactive power to the micro-grid to help stabilize the voltage.

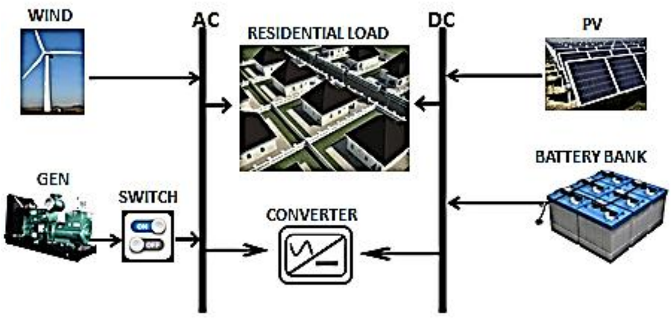

Fig. 6: Project description

The method involves the general assessment of the location to identify the gravity of the power failure challenge in the area, the unavailability of the electricity grid, the extent of environmental pollution being experienced as a result of constant use of diesel generator as a source of power supply. The load requirement of the selected location was also designed; the data from the available renewable energy resources in the area, coupled with the geographical information of the study location were also gathered. HOMER software simulator was adopted for use to enable an efficient and reliable analysis of the energy requirement of the site in question and a systematic procedure for the implementation of the simulator software was used.

The wind turbine and diesel generator are connected on the AC Busbar while the PV array, battery bank are all connected to the DC Busbar. With this arrangement in place energy storage can be achieved from any of the electrical sources with the help of the converter. The diesel generator is controlled with the help of the electrical switch as it serves as reserve and will be put to use in the event of total power failure. When both the Wind turbine and PV array is ON, the battery bank charges and stores energy for use when the load demand is more than supply.

A. Load estimation of one hundred twenty residential apartments.

The system load profile design for the location was carried out and represented as shown in fig 7 and table 3, it's a design for 120 residential apartments and as such a diversity factor of 0.4 was used in the design to aid the accurate determination of the total demand.

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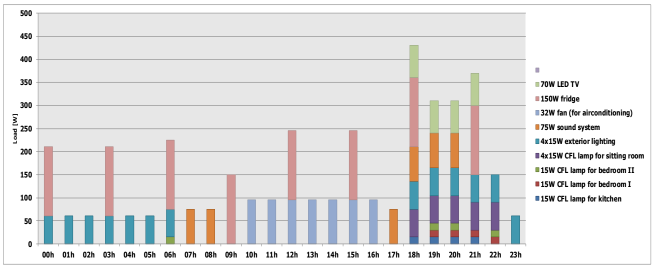

Fig. 7: System load profile

Table 3: System load requirement

HOURLY LOAD [W]	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h
15W CFL lamp for kitchen												
15W CFL lamp for bedroom I												
15W CFL lamp for bedroom II							15					
4x15W CFL lamp for sitting room												
4x15W exterior lighting	60	60	60	60	60	60	60					
75W sound system								75	75			
32W fan (for airconditioning)											96	96
150W fridge	150			150			150			150		
70W LED TV												
TOTAL [W]	210	60	60	210	60	60	225	75	75	150	96	96
Number of users	120											
TOTAL USERS [kW]	25.2	7.2	7.2	25.2	7.2	7.2	27	9	9	18	11.52	11.52
Demand factor	0.4											
TOTAL DEMAND [kW]	10.08	2.88	2.88	10.08	2.88	2.88	10.8	3.6	3.6	7.2	4.608	4.608

HOURLY LOAD [W]	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Energy [Wh]
15W CFL lamp for kitchen							15	15	15	15			60
15W CFL lamp for bedroom I								15	15	15	15		60
15W CFL lamp for bedroom II								15	15		15		60
4x15W CFL lamp for sitting room							60	60	60	60	60		300
4x15W exterior lighting							60	60	60	60	60	60	780
75W sound system						75	75	75	75				450
32W fan (for airconditioning)	96	96	96	96	96								672
150W fridge	150			150			150			150			1200
70W LED TV							70	70	70	70			280
													0
TOTAL [W]	246	96	96	246	96	75	430	310	310	370	150	60	3862 [Wh]
Number of users													
TOTAL USERS [kW]	29.52	11.52	11.52	29.52	11.52	9	51.6	37.2	37.2	44.4	18	7.2	463.44 [kWh]
Demand factor													
TOTAL DEMAND [kW]	11.81	4.608	4.608	11.81	4.608	3.6	20.64	14.88	14.88	17.76	7.2	2.88	185.38 [kWh]

Table 4 represents a diversity factor table for residential apartment as specified by French standards NFC14-100 but this is used for a residential apartment that does not require electrical heating and this is applicable to the majority of the states in Nigeria but in a situation where electrical heat-storage is required for space heating, then irrespective of the number of residential apartment involved, a factor of 0.8 is used.

Table 4: Diversity factor for residential apartments

Apartment factor (KS)	Diversity
2-4	1
5-9	0.78
10-14	0.63
15-19	0.53
20-24	0.49
25-29	0.46
30-34	0.44
35-39	0.42
40-49	0.41
50 and above	0.40

B. System load variations

The load demand for this design varies from time to time during the day, from 11 pm in the night to 6 am in the morning as shown in table 3, the load demand is low, this is because most of the electrical devices are OFF and only the exterior lights and fridge are ON and also during this period the least load is observed when the fridge is not consuming energy, though there is a slight increase experienced by 6 pm. The load demand between the hours of 7am and 5pm is still low owing to less use of electrical devices, but the moment the time is 6pm, the load demand is observed to be at its peak (20.64KW) as most devices are in use since most individuals would have returned back home either from work, school etc. The load remains high from 6pm to 9pm and begins to reduce since most people are preparing to go to sleep. The procedure used to implement the design using a HOMER software simulator is as shown in fig 8.

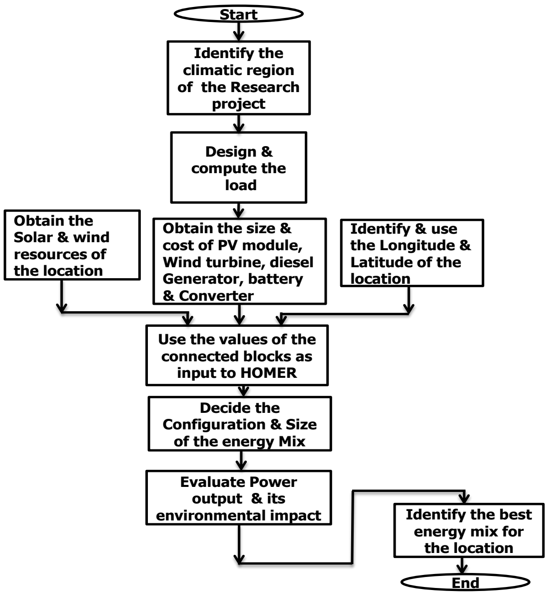

Fig. 8: Systematic procedure

III. RESULTS

The required inputs were fed into the HOMER software simulator using the systematic procedure in fig 8 to achieve the desired system configuration, several simulations were carried out to ensure a reliable and efficient system sizing and the results were obtained.

A. System configuration

The system configuration comprises of a wind turbine, PV array, diesel generator, battery bank, the converter, the load requirements, DC and AC buses for connection, several values of the different energy sources and devices were used as input to ensure that the best energy mix for the project under consideration is obtained. The system configuration is as shown in fig 9.

The simulated hybrid energy system is made of different sums of PV module of 250W up to 120KW but the range of PV sizes varies from 0KW – 120KW, 50KW diesel generator, 50KW wind turbine and a set of converters which range from 0KW – 80KW, the outcome of the simulation displays a number of the appropriate mix of the hybrid systems with the potential to cater for the required load demand. In this design, the peak load demand is 35KW and as such a diesel generator slightly higher than the peak load demand was selected to match the load demand and also provide an avenue for the storage of excess energy [11]

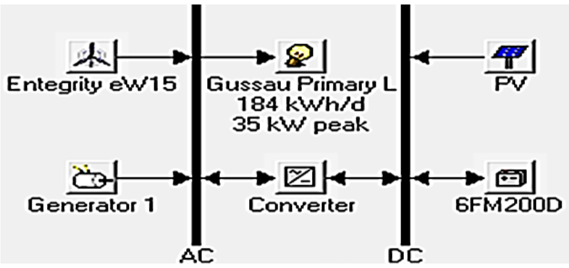

Fig. 9: System configuration

B. *Simulation results*

Among the numerous simulations carried out, a section of the simulation results for sensitivity values of 5KWh/m2/d and 5m/s was considered as shown in table 5

Table 5: Simulation result

Global Solar (kWh/m²/d) 5 Wind Speed (m/s) 5

Double click on a system below for simulation results.

PV (kW)	eW15	Label (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
45	1	50	540	55	$ 70,862	2,460	$ 102,314	0.119	0.97	1,623	101
40	1	50	480	46	$ 63,385	3,046	$ 102,324	0.119	0.95	2,433	150
60	1		720	44	$ 84,760	1,375	$ 102,333	0.119	1.00		
35	1	50	540	48	$ 57,891	3,477	$ 102,338	0.119	0.94	2,950	181
50	1	50	300	46	$ 74,265	2,197	$ 102,349	0.119	0.97	1,368	85
35	1	50	540	47	$ 57,798	3,487	$ 102,376	0.119	0.94	2,965	183
40	1	50	360	60	$ 63,727	3,023	$ 102,377	0.119	0.95	2,409	148
35	1	50	180	44	$ 54,640	3,734	$ 102,378	0.119	0.93	3,301	207
55	1	50	600	44	$ 82,640	1,545	$ 102,391	0.119	0.99	446	27
45	1	50	300	60	$ 69,407	2,582	$ 102,408	0.119	0.96	1,821	113
45	1	50	360	55	$ 69,422	2,581	$ 102,418	0.119	0.96	1,856	113
35	1	50	600	44	$ 58,000	3,475	$ 102,418	0.119	0.94	2,927	178
40	1	50	480	47	$ 63,478	3,050	$ 102,461	0.119	0.95	2,433	150
55	1		1140	50	$ 82,517	1,561	$ 102,474	0.119	1.00		
50	1	50	540	50	$ 76,557	2,028	$ 102,483	0.119	0.98	1,080	66
55	1	50	360	50	$ 81,277	1,659	$ 102,485	0.119	0.99	683	43
50	1	50	300	47	$ 74,358	2,200	$ 102,486	0.119	0.97	1,368	85
30	1	50	420	44	$ 50,400	4,075	$ 102,492	0.119	0.92	3,791	234
60	1		540	65	$ 85,272	1,348	$ 102,507	0.119	1.00		
55	1	50	720	44	$ 83,600	1,480	$ 102,519	0.119	0.99	297	18
35	1	50	360	65	$ 58,032	3,483	$ 102,551	0.119	0.94	2,984	184
40	1	50	600	55	$ 65,182	2,923	$ 102,553	0.119	0.95	2,185	134
55	1		1200	44	$ 82,440	1,573	$ 102,554	0.119	1.00		
30	1	50	420	50	$ 50,957	4,038	$ 102,575	0.119	0.92	3,725	230
60	1	50	480	44	$ 87,840	1,153	$ 102,585	0.119	1.00		0

Several system architectures were considered from the simulation result to help ascertain the architecture that allows for high penetration of renewable energy with room for future expansion of the micro-grid, and on that basis, the architecture is selected as shown in table 6

Table 6: System architecture

60KW PV, 50KW Wind turbine, 50KW Diesel Gen, 480 Vision 6FM200D battery, 44KW Inverter & Rectifier					
Production	KWh/yr	%	Consumption	KWh/yr	%
PV array	90,638	54	AC Primary load	67160	100
Wind turbine	77,907	46	Total	67160	100
Generator	0	0			
Total	168545	100	Excess Electricity	88581	52.6
			Unmet electrical load	0.00000226	0.0
			Capacity shortage	0.00	0.0
Quantity	Value				
Renewable fraction	1.00				

As shown in table 5 and 6, 100% energy generation is from renewable energy sources with the diesel generator serving as reserve to serve the system in the event of system failure.

The monthly average electricity production is as shown in fig 10

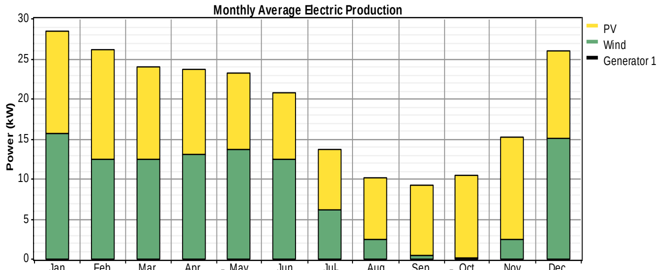

Fig. 10: Monthly average electricity production

From fig. 10, it can be observed that the peak period of electricity production is January, with December, January and February as the periods of abundant renewable energy resources, the electrical output reduces progressively from the month of February to September, after which it begins to rise gradually. The electrical energy generated is also stored in the solar energy battery bank, which also gives back the energy to the system and as a result of the energy stored by the battery system; the AC production achieves a big boost to enable it serve the AC primary load as shown in fig. 11.

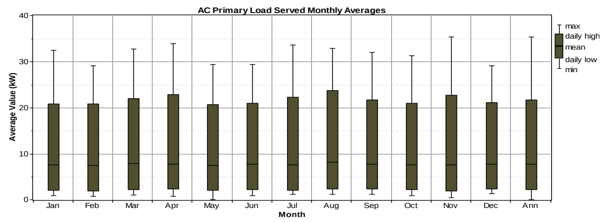

Fig. 11: AC primary load served monthly

The configuration of the battery bank is given in fig. 12, a total of 480 6FM200D batteries was implemented by the simulator software with 16 batteries in parallel in a string size of 30 for energy storage using a bus voltage of 360V. The minimum state of charge of the battery is slightly above 40%, the battery bank has a nominal capacity of 1,152 kW and autonomy of 90.2 hours, the battery bank gives out a total of 31,149 kWh/yr, with losses of about 7700KWh/yr and an expected life of 10years. The batteries monthly statistics show that in the month of January, February, March, April, May, June, July, November and December, the battery bank state of charge remains high and this is because there is enough energy produced by the mix that the battery does not need to be used up, but in the month of August, the state of charge of the battery drops and the least is obtained in September and that is the month when the least electricity production is obtained. In those months in which the energy generated is more than the load demand, the storage of the excess energy is done by the battery bank.

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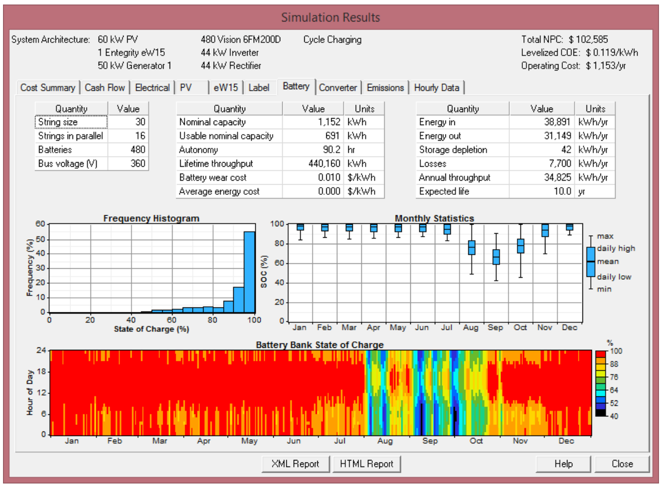

Fig. 12: Battery bank state of charge

Fig 10 shows the inclusion of a diesel generator in the energy mix, but with no output as show in table 6 and fig. 13

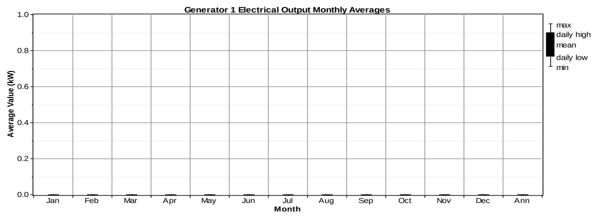

Fig. 13: Generator electrical output.

The monthly electricity output generated by the wind turbine and the PV array is as shown in fig. 14 and 15 respectively.

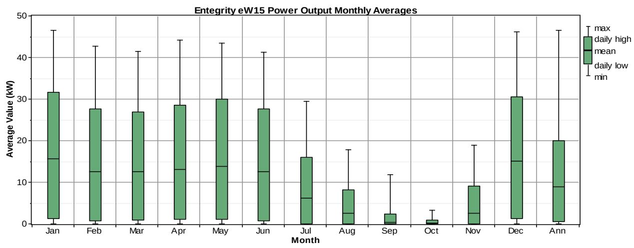

Fig. 14: wind turbine power output

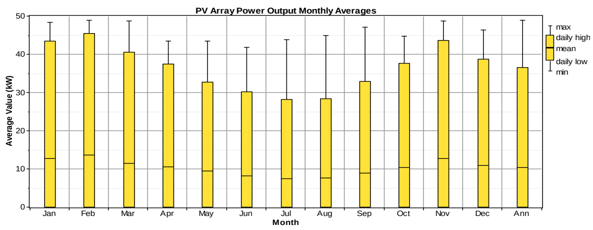

Fig. 15: PV array power output.

IV. CONCLUSION

From the Homer Software simulator output, the total yearly electricity production is 168,545KWh/yr., the yearly AC primary load consumption is 67160 KWh/yr. And the excess electricity is 88581Kwh/yr. The excess electricity accounts for 52.6% of the total electricity generated. Conversely, from table 3, it can be seen that the peak demand is 20.64 KW, and the AC primary served as shown in fig. 11 shows that the AC primary load for each month was met. Therefore, the hybrid energy system has the potential to provide the affected area with adequate power supply that is environmentally friendly (no emission of pollutants).

The next line of research in this work is the modelling of the hybrid PV/wind/diesel Gen energy system using MATLAB.

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