

Analysis of Autonomous Hybrid Wind/Photovoltaic Renewable Energy System with Load Variation

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Abstract - Hybrid energy system is the integration of wind, solar, hydro, biomass, into one system. Over the years, electricity generation in Nigeria has depended solely on burning of cheap fuels contributing to damage to the environment. Solar energy system through direct conversion of solar irradiance into electricity can be used as electrical power source for homes and remote areas to meet its daily energy requirement. In this project, detailed design of a hybrid photovoltaic system and wind turbine system for uninterrupted power supply for a residential building in a typical urban area is presented. Accomplishment of the process depends in a variety of factors such as geographical location, weather condition, solar irradiance, and load consumption, using the software called HOMER. The project outlines in details the procedures for specifying each components of the hybrid power system and as a case study, a residence in Port Harcourt Nigeria having latitude of 4.46N and a longitude of 7.01E with typical energy consumption is selected. An average AC load of 47.97kWh/day was considered. The capacity of the PV module was 23kW, the wind turbine was 3kW, system converter of 5.94kW, and 1kWh lead acid battery was also used.

Keywords: HOMER, Hybrid system, PV module, Wind turbine Nigeria, Optimization.

I. Introduction

Hybrid renewable energy systems are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products, and due to changing fluctuations in produced power. Economic aspects of these technologies are sufficiently promising to include them in developing power generation capacity for developing countries. Hybrid systems can be considered as a reasonable solution, capable to support systems that cover the energy demands of both stand alone and grid connected consumers. Commonly, it consists of a mixture of two or more energy sources used jointly to provide increased system efficiency as well as greater balance in energy supply system (Younsi *et al* 2016).

Due to the contradiction between gradual growth of the global energy demand and diminishing fossil fuel resources, renewable energy such as solar energy, wind energy, bioenergy, and hydropower might become a new manner in which we produce energy for sustainable development. Photovoltaic system and wind energy systems are the most promising candidates of the future energy technologies, and it has been widely noticed that hybrid connected photovoltaic and wind energy markets have grown (Kandil *et al* 2016).

Renewable energy produces zero or a very little amount of waste products such as carbon dioxide or other chemical pollutants, so it has minimal impact on the environment. Among all the renewable energy resources, the solar and wind energies have the great potential as a power generating energy source, because of their many advantage like zero emission of pollutant gases, low cost, inexhaustible sources and easy availability of these energy sources. But these systems have some disadvantages also like dependency on weather conditions. One of the major disadvantages with renewable energy is that it is difficult to generate the quantities of electricity that are as large as those produced by traditional fossil fuel generators. So we need to reduce the amount of energy we use or simply find alternated source of energy. The best solution to our energy problems may be to have a balance of many different power sources. Another disadvantage of renewable energy sources is the dependency of supply like sun light or wind etc. Renewable energy often depends on the weather condition for its source of power input. For example a hydro generator depends on rain to fill dams to supply flowing water. A wind turbine depends on wind to turn the blades to run the turbine, and a solar cell depends on the position and intensity of sun.

There is continues demand in electricity as civilization increases. The energy generated or power generated depends on the energy demand. There are many sources of energy which are

- Oil
- Coal
- Natural gas

- Nuclear energy
- Renewable energy
- Other energy

The best form of alternative conventional energy is renewable energy, which are continuously replenish and never exhausted Renewable energy come either directly (from sunlight or wind) or indirectly. Renewable energy is replenished naturally and are never exhaustible Autonomous power generation is utilized by many communities and remote areas that have no access to grid electricity. In other to combined two or more renewable into such system and to prevent fluctuation in the power generated which is caused by weather condition, additional energy storage is used, such as battery bank, and other storage devices (shivaram 2014).

The wind and solar energy are freely available and environmental friendly. One common disadvantage of these resources, is their unpredictable behavior, in addition, the variation of these sources may not match the time distribution demand, the wind energy systems may not be technically viable at all sites because of low wind speeds and being more unpredictable than solar energy. To solve this problem, Wind and Photovoltaic systems are used as hybrid power generation beside the energy storage systems such as super capacitor and battery bank. In these cases, the storage system should supply and deliver demanded power to improve power quality (Traore *et al* 2016).

Photovoltaic system is a solar power technology to convert energy directly from sunlight into electricity. Solar cells or photovoltaic cells are the devices to produce direct current (DC) electricity from the sun’s rays. Component of hybrid system include converters, inverters, batteries photovoltaic module etc.

Converters are electronics circuit that convert alternating current signal to direct current signal with the use of rectifier circuit which is made up of diodes.

Inverters are solid state devices that convert direct current to alternating current. Load is defined as anything that consumes electrical power to perform a task, also used in describing a power to be taking from a power source. Also a load is used to describe current in a line. Some common Nigerian household loads are: alternating current units, refrigerators, television, microwave ovens, lights, fans, pressing iron, computers, electrical heater, etc.

Wind power system is the conversion of wind energy into more useful forms, usually to generate electricity by using wind turbines. A wind turbine is a machine for converting the

kinetic energy in wind first into mechanical energy then to electricity by a generator.

It is true that there are many literatures on the hybrid energy systems. Most literatures that worked on hybrid energy systems include the work by Dagdougui *el tal*, (2016), Farahat *el tal* (2012) Pachori *el tal*, (2011) Nayeripour and Hoseintabar (2010), Zelalem (2013), Rehman, (2010), Khatib, (2100) and Obuah and Alalibo, (2017). The limitation of the above literatures is that diesel generator which is not friendly to the environment was used. The aim of this study is to analyze effectively the economic and technical performance of an autonomous hybrid renewable energy system, consisting of photovoltaic system and wind energy system with load variation.

II. The hybrid system model

The proposed hybrid system consists of PV module, wind turbine, a converter, and a battery to store electricity as shown in Figure 1. The optimization of the system aims to generate energy satisfying the demands in real time (electrical demand) thus taking into account the available renewable energy resources in each time interval. Either energy produced by the wind turbine or the energy produced by the PV module can be directly used to satisfy a part of the electrical demand for domestic used. The electricity surplus from wind turbine and the PV module can be sent to the storage battery. The battery storage system can receive electrical energy from PV module and wind turbine. The hybrid power developed is a combination of the PV module power and the generator power driven by the wind turbine. Domestic load is used; the load used.

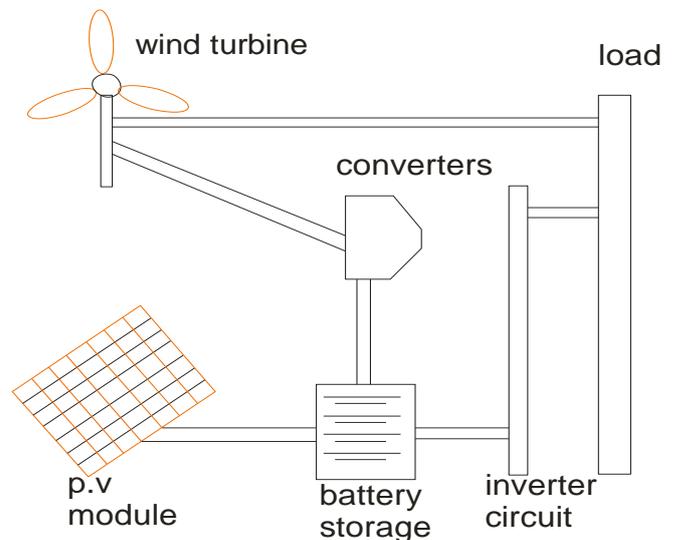


Figure 1: The hybrid system model

TABLE 1
Load profile for the month of January to March

January		February		March	
Hours	Load (kw)	Hours	Load(kw)	Hours	Load(kw)
0	3.150	0	3.150	0	3.150
1	3.150	1	3.150	1	3.100
2	3.152	2	3.152	2	3.152
3	3.155	3	3.155	3	3.155
4	3.238	4	3.238	4	3.238
5	3.903	5	2.000	5	3.903
6	2.603	6	2.145	6	2.603
7	0.270	7	0.259	7	0.270
8	0.150	8	0.150	8	0.150
9	0.150	9	0.150	9	0.150
10	0.300	10	0.145	10	0.300
11	0.550	11	0.030	11	0.550
12	0.693	12	0.715	12	0.693
13	0.690	13	0.690	13	0.690
14	0.600	14	1.000	14	0.600
15	0.680	15	0.415	15	0.680
16	0.923	16	0.920	16	0.923
17	1.500	17	1.400	17	1.500
18	2.183	18	2.100	18	2.183
19	3.034	19	3.011	19	3.034
20	3.523	20	3.523	20	3.523
21	3.542	21	3.542	21	3.542
22	3.160	22	3.160	22	3.160
23	3.155	23	3.155	23	3.155

The system load used is a domestic load which varies with time; and is located at Port Harcourt. The system load profile construction is necessary for system component sizing. The system load configuration was done according to the various months. The entire load are AC; hence inverter was needed to accurately size the hybrid system, accurate load assessment was done bearing in mind losses. The raining season when the solar isolation availability is least and the dry season when the load demand is high were also considered. Table 1 to 3 shows the load variation of the hybrid system.

TABLE 2
Load profile for the month of April to June

April		May		June	
Hours	Load (kw)	Hours	Load(kw)	Hours	Load(kw)
0	3.150	0	3.150	0	3.150
1	3.150	1	3.150	1	3.100
2	3.150	2	3.152	2	3.152
3	3.155	3	3.155	3	3.155
4	3.255	4	3.238	4	3.238
5	3.903	5	2.000	5	3.903
6	2.603	6	2.145	6	2.603
7	0.270	7	0.259	7	0.270
8	0.150	8	0.150	8	0.150
9	0.150	9	0.150	9	0.150
10	0.300	10	0.145	10	0.300
11	0.550	11	0.030	11	0.550
12	0.693	12	0.715	12	0.693
13	0.690	13	0.690	13	0.700
14	0.600	14	1.200	14	0.600
15	0.960	15	0.415	15	0.680
16	0.923	16	0.920	16	0.923
17	1.500	17	1.400	17	1.500
18	2.183	18	2.100	18	2.183

19	3.034	19	3.011	19	3.034
20	3.523	20	3.523	20	3.523
21	3.542	21	3.542	21	3.542
22	3.160	22	3.160	22	3.160
23	3.155	23	3.155	23	3.155

TABLE 3
Load profile for the month of July to September

July		August		September	
Hours	Load (kw)	Hours	Load(kw)	Hours	Load(kw)
0	3.150	0	3.150	0	3.150
1	3.150	1	3.150	1	3.100
2	3.152	2	3.152	2	3.152
3	3.155	3	3.155	3	3.155
4	3.238	4	3.238	4	3.238
5	3.903	5	2.000	5	3.903
6	2.603	6	2.145	6	2.603
7	0.270	7	0.259	7	0.270
8	0.150	8	0.150	8	0.150
9	0.150	9	0.150	9	0.150
10	0.300	10	0.145	10	0.300
11	0.550	11	0.030	11	0.550
12	0.693	12	0.715	12	0.693
13	0.690	13	0.690	13	0.780
14	0.600	14	1.000	14	0.610
15	0.680	15	0.415	15	0.690
16	0.923	16	0.920	16	0.923
17	1.500	17	1.400	17	1.500
18	2.183	18	2.100	18	2.183
19	3.034	19	3.011	19	3.034
20	3.523	20	3.523	20	3.523
21	3.542	21	3.542	21	3.558
22	3.160	22	3.160	22	3.160
23	3.155	23	3.155	23	3.155

TABLE 4
Load profile for the month of October to December

October		November		December	
Hours	Load (kw)	Hours	Load(kw)	Hours	Load(kw)
0	3.150	0	3.150	0	3.150
1	3.150	1	3.150	1	3.100
2	3.152	2	3.152	2	3.152
3	3.155	3	3.155	3	3.155
4	3.238	4	3.238	4	3.238
5	3.903	5	2.000	5	3.903
6	2.603	6	2.145	6	2.603
7	0.270	7	0.259	7	0.270
8	0.150	8	0.150	8	0.150
9	0.150	9	0.150	9	0.150
10	0.300	10	0.145	10	0.300
11	0.550	11	0.030	11	0.550
12	0.693	12	0.715	12	0.693
13	0.690	13	0.690	13	0.690
14	0.600	14	1.000	14	0.600
15	0.680	15	0.415	15	0.680
16	0.923	16	0.920	16	0.923
17	1.500	17	1.400	17	1.500
18	2.183	18	2.100	18	2.183
19	3.034	19	3.011	19	3.034
20	3.523	20	3.523	20	3.523
21	3.542	21	3.542	21	3.542
22	3.160	22	3.160	22	3.160
23	3.155	23	3.155	23	3.155

III. Relevant Equations

The power output from the wind turbine unit can be expressed as a function of the wind speed power coefficient and air density.

Let m = mass of air

V = speed at which the air travel

The wind energy is converted into mechanical energy as:

Wind energy = kinetic energy of moving air

$$\text{Wind energy} = K.E = \frac{1}{2} mV^2 \quad (1)$$

Where,

$$m = \rho \times V = \rho \times v$$

And ρ is density of air, V is volume of air

But the volume of air, $V = Q$

Q = area through which air passes \times velocity of air.

Therefore

$$\text{Wind energy} = \frac{1}{2} \rho A v V^2 \quad (2a)$$

$$P_M = \frac{1}{2} \rho A V^3 \quad (2b)$$

The aerodynamic power on the rotor of the wind turbine is given by the following equation:

The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the “power coefficient” and is defined as C_p 0.59. So, equation (2b)

$$P_M = \frac{1}{2} \rho \pi A V^3 C_p \quad (3)$$

Where, A is the cross sectional area of the rotor in m^2

$$A = \pi R^2$$

$$P_M = \frac{1}{2} \rho \pi R^2 V^3 C_p \quad (4)$$

ρ is the density of the air, ρ equals 1.22 Kg/m^3 , R is the length of the blade (m), V is the wind speed (m/s).

The power generated by the PV panels is given by Equation (5).

$$P_{PV-OUT} = P_{R-PV} * \left(\frac{G}{G_{ref}}\right) * [1 + K_T(T_C - T_{ref})] \quad (5)$$

where P_{PV-out} is the output power generated from the PV panel, P_{R-PV} is the PV rated power at reference conditions, G is solar radiation (W/m^2), G_{ref} is solar radiation at reference conditions ($G_{ref} = 1000 \text{ W/m}^2$), T_{ref} is the cell temperature at reference conditions ($T_{ref} = 25^\circ\text{C}$), K_T is temperature coefficient of the PV panel [$K_T = - 3.7 \times 10^{-3} (1/^\circ\text{C})$] for mono and poly crystalline silicon.

The cell temperature T_c is calculated as:

$$T_C = T_{amb} + (0.0256 * G) \quad (6)$$

Where, T_{amb} is the ambient temperature in $^\circ\text{C}$. The rated power P_{R-PV} can be calculated using the equation

$$P_{R-PV} = (E_L * S_L) / \eta_R * \eta_V * (PSH) \quad (7)$$

where E_L is daily load energy, S_L is stacking factor considered to compensate for resistive and PV-temperature losses, η_R , η_V are efficiencies of solar charging regulator and bidirectional inverter respectively, and PSH is the peak sun shine hours (numerically equals to daily average of solar radiation at the specified location).

The storage capacity of the battery (CWh) is calculated using Equation (8)

$$C_{Wh} = (E_L * AD) / \eta_V * \eta_B * DOD \quad (8)$$

Where, DOD is allowable depth of discharge of the battery, AD is number of autonomy days, and η_B is battery efficiency.

The total NPC is given as (9)

$$NPC = \frac{C_{ann,tot}}{CRF(i, T_p)} \quad (9)$$

Where,

$C_{ann,tot}$ is the total annualized cost ($\$/\text{year}$), i is the annual real interest rate (%), T_p is the project lifetime (year), and CRF is the capital recovery factor, which is given by (10).

$$CRF(i, n) = \frac{i(1+i)^n}{i(1+i)^n - 1} \quad (10)$$

IV. System Input Data for Simulation

This chapter shows the results obtained using the selected optimization tools, HOMER. HOMER answers a wide range of questions about the design of small power systems. For this

project, the question that HOMER would help to answer is: 'Is it cost-effective to add photovoltaic system and wind turbine?' The answer to this question will be based on net present value (NPC). HOMER will also size the optimal system considering the electricity generation capacity.

With this tool, the system's components' cost includes all costs associated with the components' subsystem like: mounting hardware, wiring, as detailed in each section of components input. Cost is classified as capital, replacement and operation and maintenance (O&M). HOMER performs its technical and economic calculation based on these variables.

Capital cost is the initial cost from purchasing and installation of each system component. Replacement cost is the cost of changing components after their lifetime; and it is relevant only if the project lifetime exceeds the components' lifetime. Operations and maintenance cost is the cost expected when the system components are in use. An example is cleaning of the PV array, checking of the firmness of PV array on the mounting hardware, maintenance of the wind turbine.

The electrical system load used is an AC load. The electrical daily profile has a peak average load of 3.155kW. This is illustrated in Figure 2. The seasonal load profile was obtained as shown in Figure 3.

V. Component Sizing

For optimum calculation, in the sizing table, sizes to consider starts from zero. Starting from zero tells HOMER to model various configurations.

Having obtained the system load, further effort was made to perform the PV sizing. To make a good PV array sizing, the temperature of the systems location as well as the solar global irradiation need to be obtained. Figure 4 shows the average location temperature while Figure 5 shows the solar global irradiation in kilo Watt hour per minutes square per day (kWh/m²/day).

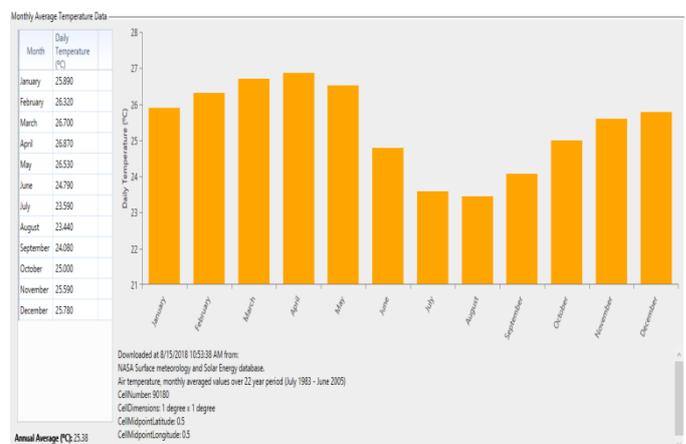


Figure 4: Average monthly temperature of Port Harcourt

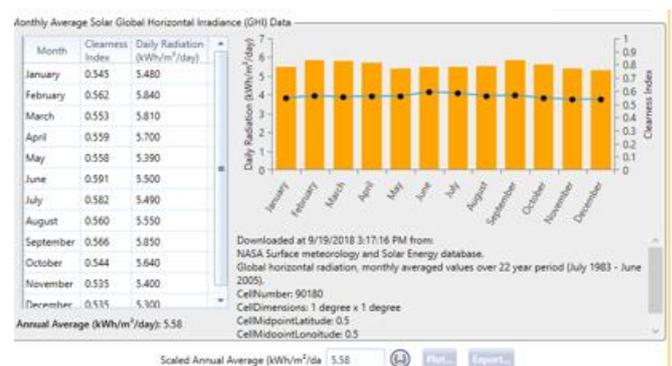


Figure 5: Average solar global irradiation in Port Harcourt



Figure 2: Daily load profiles in hourly basis

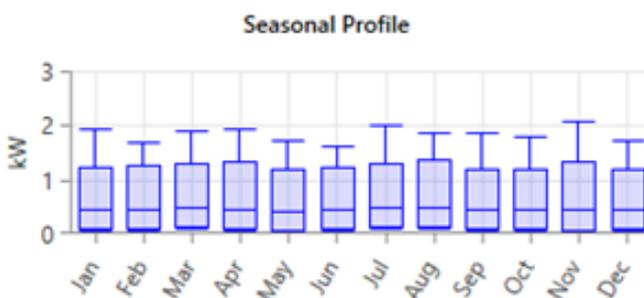


Figure 3: Daily load profiles in seasonal profile

The PV cost input is shown in Figure 6. For 1kW PV system obtained, the capital cost is \$3000.00 and the replacement cost is \$3000.00. The replacement cost is expected to be less than the capital cost as PV array prices falls yearly; the maintenance cost for a year is \$10.00. This includes the cost of cleaning the PV array, which could be done two or three times a year. The total lifetime expectancy is 25 years; the PV energy is transmitted to a DC electrical bus.

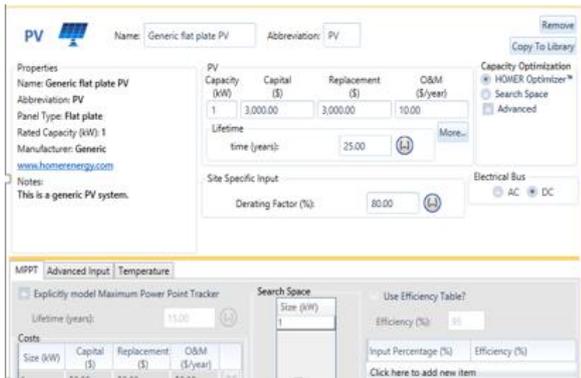


Figure 6: PV size and cost input

Based on load size inputs, the capital cost for 1kW wind turbine system is \$18000 and the replacement cost is \$18000, the expected lifetime of the wind turbine is 20 years the wind turbine input is shown below in Figure 7. Compared to solar PV cost input, it can be seen that the capital cost of the wind turbine is lower than that of the PV. However, O&M cost is higher.

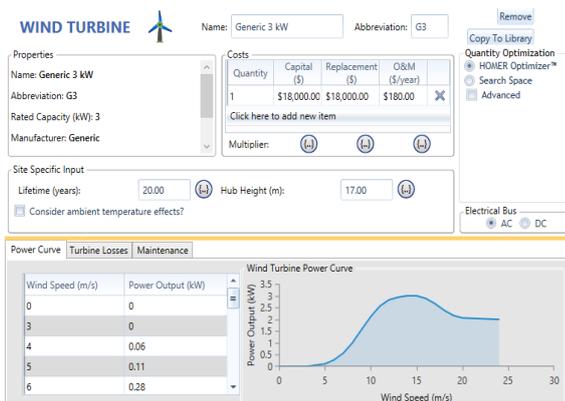


Figure 7: Wind turbine size and cost input

The wind resource data was obtained from homer as shown in Figure 8. The wind resource contained the average wind speed for each month. The average annual wind speed is 4.2m/s.



Figure 8: Wind energy resource monthly data

The converter does not have any operation and maintenance cost the capital cost. For 1kW converter, the purchasing cost is \$300. This is also same for replacement

cost. The converter has an efficiency of 95% and an expected lifetime of 15 years.

The storage to be used for the hybrid model is a lead acid battery. Compared to other storage devices like flywheel, the battery efficiency is high. This is because batteries do not have rotating which bring wearing out of components parts. The selected battery has a replacement cost of \$300 and a capital cost of \$300, including the operation and maintenance cost of \$10. The expected lifetime is 10 years. The battery nominal voltage is 12V and its capacity ratio is 0.403.

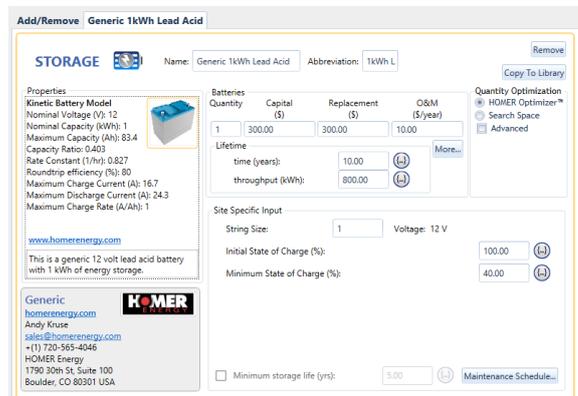


Figure 9: System battery size and input

VI. Simulation Results Obtained

The result of the hybrid wind/PV system by component is shown in Figure 8. Based on net present cost, the total system cost is \$227,917.10. The cost of the wind turbine for 25 years of operation is \$22,831.45. The battery storage has a cost of \$130,815.37. The PV module has a total cost of \$21,875.54. The cost of the system converter is \$2,394.75. The converter does not have O&M cost, it also does not have fuel cost. The battery has the highest cost compared to the other components, while the wind turbine has the highest salvage cost compared to the other components. The system architecture is shown in Figure 10 for the load of 6.25kW peak load or 48.33kW/h/day.

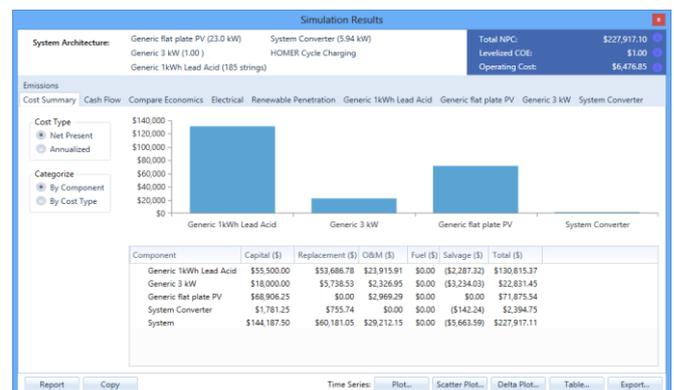


Figure 10: cost summary for the Wind/PV system

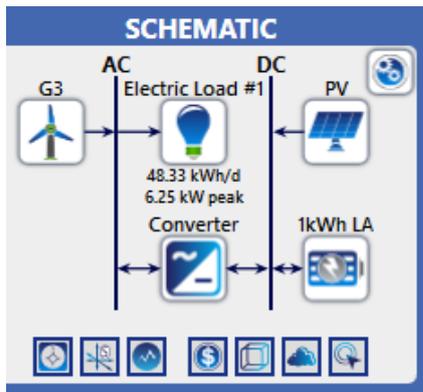


Figure 11: System architecture

Based on the load, the generic PV module alone will produce a total power of 39901kWh/year. The total AC load consumption is 17628kWh/year. The excess electricity produced is 17551kWh/year. The capacity shortage is 17.5kWh/year. The PV has the highest priority, producing a total of 3740797.10kWh/year. This is illustrated in Figure 12.

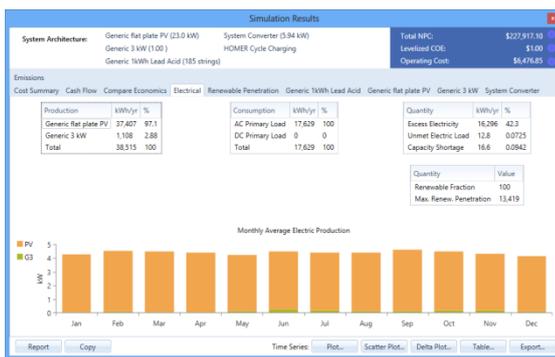


Figure 12: Electrical production for the PV/Wind system

As shown in Figure 13, the storage for the PV/Wind system is a lead acid battery. The battery has autonomy of 56hour. This means it can supply power to the load for 56hour without receiving power from the input PV module. The total energy entering the battery is 18678kWh/year. The total energy released by the battery is 14974kWh/year. The total losses are 3739kWh/year.



Figure 13: Storage for the Wind/PV system

The converter has a rating of 5.94kW, the converter acts as an inverter and as a rectifier. The total inverter hour of operation is 8,375hrs/year. The total energy entering the converter is 17587kWh/year. Also the energy released by the converter is 16708kWh/year. The total loss incurred is 879kWh/year.

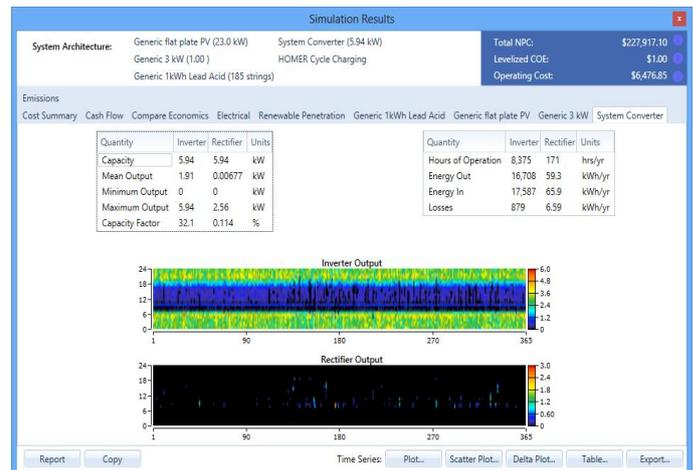


Figure 14: System converter for Wind/PV system

VII. Conclusion

A study and analysis of a hybrid wind/PV renewable energy system has been carried out in this paper. The hybrid Wind/PV system comprises of a 3kW wind turbine, 23kW of PV energy penetration, in addition to a 5.94kW inverter and rectifier. The PV system demonstrated to be optimal when compared to a PV/Wind system. The hybrid system was designed for an average load of 47.79kW/day supposed to be used for a residential building in Port Harcourt. The system can also be applicable to other domestic buildings with similar load profile. It is also profitable to any other applications where noise is tolerable. More so, any country with similar economic and climatic condition like the location of study can benefit from the system. Optimal combination of components was achieved by HOMER software. The numerical models developed using the HOMER software package proves to be an efficient and flexible tool for optimum sizing of hybrid power systems based on renewable sources. In the future work of this study, uncertainty factors such as change in fuel price and solar radiation need to be taken into account in calculating system reliability indexes.

REFERENCES

[1] Dagdougui H, Minciardi R, Ouammi A, Robba M and Sacile R. (2010). Modelling and control of a hybrid renewable energy system to supply demand of a green-building, *Genova, Italy*.

- [2] Farahat S, Yazdanpanah M. A and Barakati S. M. (2012) Modeling and Sizing Optimization of Standalone Hybrid Renewable Energy Systems, *International Conference on Mechanical, Nanotechnology and Cryogenics Engineering*, Kuala Lumpur.
- [3] Kandil M, Saeeda M, Hassan M and El-Saadawi. (2016) Economic analysis of a grid-connected, hybrid renewable system supplying CIT, *Center at Mansoura university-Egypt*.
- [4] Nayeripour M and Hoseintabar M. (2011) A Comprehensive Dynamic Modelling of Grid Connected Hybrid Renewable Power Generation and Storage System, *International Journal of Modeling and Optimization*, India.
- [5] Obuah E. C. and Alalibo T. J., (2017). Techno-Economic Analysis of Hybrid Photovoltaic/Diesel Energy System for Oil and Gas Industries in Nigeria," *International Journal of Science and Research*, July 2017, 6(7), Pages 346 – 351.
- [6] Pachori A, Suhane P and Scholar P.G, (2016) Design and modeling of standalone hybrid power system with Matlab/simulink, *International Journal of Scientific Research and Management Studies*, Bhopal, India.
- [7] Rehman S. A. (2010). Study of a Solar PV-Diesel-Battery Hybrid Power System for a Remotely Located Population near Rafha, Saudi Arabia," *Energy*, 35(12) Pages 4986-4995.
- [8] Younsi S, Jraidi M, Najib H and Cherif A. (2016), Modelling and control of hybrid renewable energy system connected to AC grid Higher Institute of technological studies Chargaui, *Tunis, Tunisia*.
- [9] Traore A, Taylor A, Zohdy M. A and PengF. Z.(2017) Modelling and Simulation of a Hybrid Energy Storage System for Residential Grid-Tied Solar Microgrid Systems, Rochester.
- [10] Zelalem G. (2013). Technical and Economic Assessment of solar PV/diesel Hybrid Power System for Rural School Electrification in Ethiopia, *International journal of renewable energy research*, 3(3).

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