RESEARCH

The Potential of a Mix of Renewable (PV/Wind) Energy System for an Information and Communication Technology (ICT) Centre in a Rural Environment

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Received 02 March 2013; revision received 02 July 2013; accepted 08 July 2013. Published online 30 December 2013 (www.ejee.cl). DOI 10.7770/ejee-V1N3-art490 . ISSN: 0719-269X.

ABSTRACT The design is presented of an optimized mix of renewable (PV/Wind) energy system for an Information and Communication Technology (ICT) Center in Rural environments in Kauru (Kaduna State), Northern Nigeria with a daily load of 24 kwh d^{-1}. Solar radiation and wind speed for the design of the system were obtained from the NASA Surface Meteorology and solar energy website at a location of 10° 39' N latitude and 8° 09' E longitude, with annual average solar radiation of 5.64 kWh $m^{-2}d^{-1}$ and annual average wind speed of 2.5 m s^{-1}. The patterns of load consumption by the ICT Centre were studied and suitably modeled for optimization using the National Renewable Energy Laboratory's Hybrid Optimization Model for Electric Renewables (HOMER) software. The proposed PV/Wind system was simulated using the model resulting in two different topologies: PV/Wind and PV only. From the simulation results, the PV/Wind system solution was considered to be the best energy option (solution) for the ICT Center. This optimization study indicates that energy requirements to provide electricity for an ICT center in Kauru with the least cost could be accomplished by a combination of 8 kW PV array, 1 unit 7.5 kW BWC Excel-R wind turbine, 1.5 kW inverter and 24 Hoppecke 24 OPzS 30000 batteries. The system configuration suggested also benefits from 33% excess electricity supply which allows for future ICT network expansion and power needs. This system also saves $6,341 for the project lifetime when compared with PV only system due to reduced number of battery unit. A detailed design and description of expected performance of the PV/Wind system are also presented.

KEYWORDS HOMER, ICT, Remote/Rural Area, Mix of Renewable Energy System, Energy Optimization, Simulation, Nigeria.

Introduction

Over several decades, rural electrification has been recognized as a powerful tool that increases the living standards in poor and remote communities [Pipattanasomporn, 2004]. Electricity Power supply has been acknowledged as a means of fighting poverty and illiteracy in developing economies like Nigeria, if we are to meet the Millennium Development Goals (MDGs) targets [Adejumobi et al., 2011]. In rural communities, Information and Communication Technologies (ICTs) centers have access to a variety of local data, including information about the district, up-to-date market prices of crops and livestock, weather reports and a village newspaper. E-government services are also provided, including access to a host of local government services, such as driving license applications, registration of births and deaths, application for income, caste and domicile certificates, and public complaints. ICT is a tool to facilitate e-service programmes, especially to those institutions such as banks, hospitals and schools in rural and unreached communities and has been expanding rapidly in the past several years in remote villages in Nigeria.

A primary barrier to Internet penetration in rural areas is the lack of the most important element for its functioning, which is electricity. In order for the Internet to be usable and sustained over the long term, reliable local power supply must be provided first. The irony of this situation is that Nigeria is endowed with very abundant renewable energy resources that remained unexplored and unexploited for alternative energy solutions for telecommunications particularly in the largely populated rural areas in the country [Ani and Nzeako, 2012a].

This paper focuses on the renewable energies (Solar-PV and Wind) to generate electricity, and each source is detailed below:

Solar Energy

Nigeria has an annual average daily sunshine of 6.25 hours, ranging between about 3.5 hours in the coastal areas and 9.0 hours at the far northern boundary [Bala et al., 2000]. Similarly, it has an annual average daily solar radiation of about 5.25 KWh $m^{-2}d^{-1}$, varying between about 3.5 KWh $m^{-2}d^{-1}$ at the coastal area and 7.0 KWh $m^{-2}d^{-1}$ at the northern boundary [Chendo, 2002]. Nigeria lies along the Equator, with abundant sunshine all the year round, receive about 4.851×10^{12} kWh of energy per day from the sun. This is equivalent to about 1.082 million tonnes of oil (mtoe) per day [Ani, 2013b]. This huge energy resource from the sun is available for about 26% of the day. Based on the land area of 924×10^{3} km^2 for the country and an average of 5.535 kWh $m^{-2}d^{-1}$, annually Nigeria has an average of 1.804×10^{15} kWh of incident solar energy [Chendo, 2002].

Wind Energy

Two principal wind currents affect Nigeria. The southwestern winds dominate the rainy season of the year, while north-eastern winds dominate the dry season. Depending on the shifts in the pressure belts in the Gulf of Guinea, these winds are interspersed respectively by the southeastern and the northwestern winds in different parts of the year [Ani and Nzeako, 2012a]. The wetter winds prevail for more than 70% of the period due to the strong influence of the Atlantic Ocean. Mean annual wind speed varies between 2 to 6 m s^{-1}. Speeds in dry season (November - March) are lower. In the wet season (April–October), daily average speed could rise to 15 m s^{-1}. Values of up to 25 m s^{-1} are sometimes experienced due to inducement by convective rainfall activities and relative diffusion. From meteorological centres in Nigeria and satellite-derived meteorology and solar energy parameters from National Aeronautics and Space Administration (NASA), the average daily wind which spreads across the country, at 50 m height above the earth, is within the range of 2.7 m s^{-1} in the central western parts to 5.4 m s^{-1} in the North East. Therefore, wind is a great promise for alternative renewable energy for the telecommunications industry in Nigeria [Ani and Nzeako, 2012a].

Review of the Hybrid PV/Wind system

Solar and wind energy systems are omnipresent, freely available, environmentally friendly, and they are considered as promising power generating sources due to their availability and topological advantages for local power generations. The mix of renewable energy system for this study included the PV generator, wind turbine generator and battery system. Battery storage increases the flexibility of system control and adds to overall system availability [Shaahid and El-

Hadidy, 2003; Shaahid and El-Hadidy, 2004]. Battery operation in a hybrid system, as opposed to a single-source application, may result in certain advantages with respect to battery lifetime optimization. This can be attributed to the fact that there is often more sophisticated control installed in a hybrid system due to the interaction of many components. This requires better regulation of components and will result in better treatment of the battery. Moreover, there are more energy sources available resulting in the battery not being utilized as high a degree as in single-source systems. Batteries are costly and can often be sized smaller in a hybrid system than in a single-source system [Ani and Nzeako, 2012b].

These energy systems have good prospects and many opportunities in hot climates. They are termed as one of the cost effective solutions to meet energy requirements of remote areas. The combination of various renewable sources simply makes sense in many scenarios. For instance, when solar and wind power production is used together, the reliability of the system is enhanced. During the same day, in many regions worldwide or in some periods of the year, there are different and opposite patterns in terms of wind and solar resources. These different patterns can make the hybrid systems the best option in electricity production [Ani, 2013a]. For example, a mix of energy sources can accommodate seasonal resource fluctuations, with solar PV collectors complementing wind power during the months with less wind. Where daily energy variations are concerned, solar energy has a production peak around noon, while wind power facilities can operate whenever the wind is blowing. Batteries add stability to the system by storing the energy for peak consumption when there is insufficient production from renewable sources (i.e., to offset lack of solar power during nighttime hours) [Ani, 2013a]. The use of different energy sources allows improving the system efficiency and reliability of the energy supple and reduces the energy storage requirements compared to systems comprising only one single renewable energy source. With the complementary characteristics between solar energy and wind energy for certain locations, the solar–wind power generation systems with storage banks offer a highly reliable source of power [Yang et al., 2007], which is suitable for electrical loads that need higher reliability [Giraud and Salameh, 2001]. A procedure is described in [Markvart, 1996], which determines the sizes of the PV array and wind turbine in a PV/wind energy system using the measured values of solar and wind energy at a given location. Celik [2002] presented a techno-economic analysis based on solar and wind biased months for autonomous PV/wind energy system. A new technique for the sizing of the PV array and battery storage for a stand-alone wind-photovoltaic system has been developed by [Bagul et al., 1996]. These authors observed that an optimum combination of the PV/wind energy system provides higher system performance than a single system, for the same system cost and battery storage capacity.

In tropical regions like Nigeria, PV and Wind are a good match, because wind speeds are lower in dry seasons when the sun is high and higher in the rainy season when the sunshine is rather low [Ani and Nzeako, 2012b].

The aim of this paper,,therefore, is to: (i) design an optimized PV/Wind energy system that will produce the desired power needs and show the potential of renewable energy in powering ICT Centers in Nigeria, (ii) to compare the optimized PV/Wind energy system with an optimized PV only system in terms of cost analysis and electricity generated. A detailed design and description of expected performance of the PV/Wind system are presented in this paper.

Energy Consumptions

The ICT load profile depends on multiple parameters such as the Router, Port fast Switch, Wireless Access Point, Server (plus accessories), RF (Radio Communication), Laptops (with security cables), VOIP Phones, Laser Printer, Lighting and Ceiling fans. Therefore it is important to outline an accurate power profile in order to dimension correctly the alternative energy components for the system. The only way to "outline an accurate power profile" is to answer the question: what are the times when the loads are used, and this

Table 1 Energy needed for a typical ICT Center in Rural environments.

Description of Item	Qty	Load (Watts per unit)	Total Load (Watts)	Daily Hour of actual Utilization (h)
Router	1	25	25	24
Port fast Switch	1	15	15	24
Wireless Access Point	2	12	24	24
Server (plus accessories)	1	150	150	24
RF (Radio Communication)	1	40	40	24
Laptops (with security cables)	10	40	400	24
VOIP Phones	2	20	40	8
Laser Printer	1	100	100	4
Lighting	4	15	60	24
Ceiling fans	4	60	240	24

will give us a baseline data on energy consumptions. From the acquired data, a profile of the ICT center was created and shown in Tables 1 and 2.

The daily average load variation is shown in Fig. 1 and Table 2; it is assumed that it is identical for every day of the year. The annual peak load of 1.1 kW was observed between 9:00 h and 13:00 h, with 24 kWh d^{-1} energy consumption.

Simulation and Optimization Software

The Hybrid Optimization Model for Electric Renewables (HOMER) is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone and distributed generation (DG) applications [NREL, 2005]. It has been developed by The National Renewable Energy Laboratory (NREL), United States (US) since 1993. It was developed specifically to meet the needs of the renewable energy industry system analysis and optimization [Lau et al., 2010].

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 and thermal loads and satisfies any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. In the optimization process, HOMER performs simulation on different system configurations to come out with the optimal selection. In the sensitivity analysis process, HOMER performs multiple optimizations under a range of inputs to account for uncertainty in the model inputs.

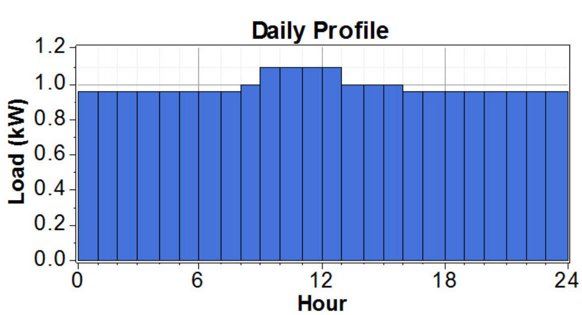

Figure 1 Daily average load variation for a typical ICT Center in Rural environments.

Table 2 The electrical load (Daily load demands) data for a typical ICT Center in Rural Environments.

Time (Hr)	Router (W)	Port fast Switch (W)	Wireless Access Point (W)	Server (W)	RF (W)	Laptops (W)	VOIP Phones (W)	Laser Printer (W)	Lighting (W)	Ceiling fans (W)	Total (W h^{-1})
00-01	25	15	24	150	40	400			60	240	954
01-02	25	15	24	150	40	400			60	240	954
02-03	25	15	24	150	40	400			60	240	954
03-04	25	15	24	150	40	400			60	240	954
04-05	25	15	24	150	40	400			60	240	954
05-06	25	15	24	150	40	400			60	240	954
06-07	25	15	24	150	40	400			60	240	954
07-08	25	15	24	150	40	400			60	240	954
08-09	25	15	24	150	40	400			60	240	954
09-10	25	15	24	150	40	400	40		60	240	994
10-11	25	15	24	150	40	400	40	100	60	240	1094
11-12	25	15	24	150	40	400	40	100	60	240	1094
12-13	25	15	24	150	40	400	40	100	60	240	1094
13-14	25	15	24	150	40	400	40	100	60	240	1094
14-15	25	15	24	150	40	400	40		60	240	994
15-16	25	15	24	150	40	400	40		60	240	994
16-17	25	15	24	150	40	400	40		60	240	994
17-18	25	15	24	150	40	400			60	240	954
18-19	25	15	24	150	40	400			60	240	954
19-20	25	15	24	150	40	400			60	240	954
20-21	25	15	24	150	40	400			60	240	954
21-22	25	15	24	150	40	400			60	240	954
22-23	25	15	24	150	40	400			60	240	954
23-00	25	15	24	150	40	400			60	240	954
Total	600	360	576	3600	960	9600	320	400	1440	5760	23616

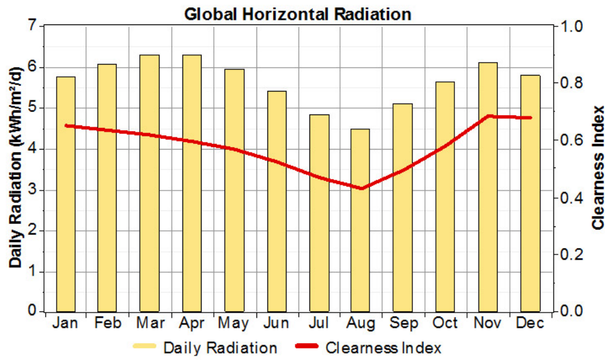

Figure 2a Average Solar (clearness index and radiation) profile for Kauru (Kaduna State).

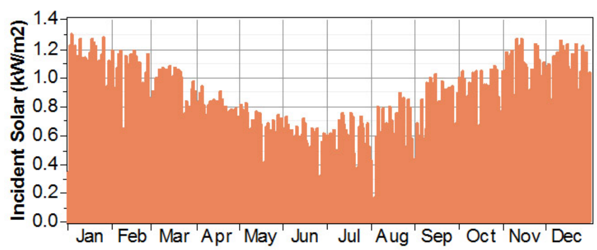

Figure 2b Daily Incident Solar for Kauru (Kaduna State).

Study area

The study area was kauru (Kaduna State) at a specific geographical location of 10° 39' N latitude and 8° 09' E longitude with annual average solar (clearness index and radiation) of 5.64 kWh m^{-2}d^{-1} and wind speed of 2.5 m s^{-1}. The data for solar and wind resources were obtained from the NASA Surface Meteorology and Solar Energy web site [NASA, 2012]. For this study, solar PV and wind technology were considered. Figs. 2a, 2b, 3a and 3c show the solar and wind resource profile for the location shown in Table 3.

In solar resource, March is the sunniest month of the year. During this month (March), the solar energy resource is 6.32 kWh m^{-2}d^{-1} while in August it is only 4.47 kWh m^{-2}d^{-1} as shown in Fig. 2 (a and b) and Table 3. Whereas in wind resource, September is the least windy month of the year while March, April and May are the windiest. Expected maximum wind speed is 2.8 ms^{-1} as shown in Fig. 3 (a and b) and Table 3.

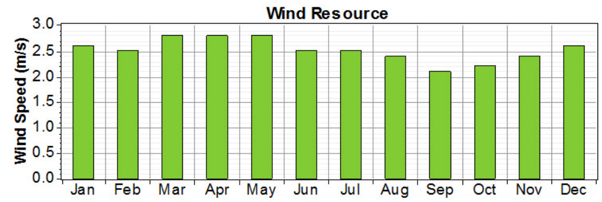

Figure 3a Average Wind Speed profile for Kauru (Kaduna State).

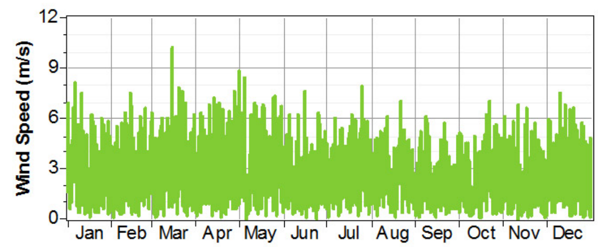

Figure 3b Daily Wind Speed for Kauru (Kaduna State)

Model Development

The following equations are based on the equations used by (Ani, in press; HOMER, 2012; Kamaruzzaman et al, 2008; Lambert, 2009) to derive the power supplied by renewable, battery charging and discharging.

PV Power:

$$P_{PV} = \eta_{PV} \cdot N_{PVP} \cdot N_{PVS} \cdot V_{PV} \cdot I_{PV} \qquad \text{Eq. (1)}$$

Wind Power:

$$P_{WT} = \eta_{WT} \cdot \eta_g \cdot 0.5 \cdot \rho_a \cdot C_P \cdot A \cdot V_r^3 \qquad \text{Eq. (2)}$$

Total Renewable Power:

$$P(t) = \sum_{PV=1}^{n_{PV}} P_{PV} + \sum_{WT=1}^{n_{WT}} P_{WT} \qquad \text{Eq. (3)}$$

Battery Discharging:

$$P_B(t) = P_B(t-1) \cdot (1-\sigma) - \left[\frac{P_{BR}(t)}{P_{BL}(t)}\right] \qquad \text{Eq. (4)}$$

Table 3 Wind and Solar Resources for Kauru - Kaduna State.

Month	**Clearness Index** (kWh $m^{-2}d^{-1}$)	**Average solar Radiation** (kWh $m^{-2}d^{-1}$)	**Average Wind Speed** (m s^{-1})
Jan	0.654	5.760	2.600
Feb	0.638	6.060	2.500
Mar	0.620	6.320	2.800
Apr	0.598	6.300	2.800
May	0.568	5.940	2.800
Jun	0.523	5.400	2.500
Jul	0.469	4.850	2.500
Aug	0.428	4.470	2.400
Sep	0.498	5.110	2.100
Oct	0.583	5.630	2.200
Nov	0.684	6.110	2.400
Dec	0.678	5.790	2.600
Scaled annual average		5.641	2.518

Battery Charging:

$$P_B(t) = P_B(t-1)\cdot(1-\sigma) + \left[P_{BR}(t) - P_{BL}(t)\right]\cdot \eta_{BB} \quad \text{Eq. (5)}$$

P_B : Battery energy at time interval
P_{BR} : Total energy generated
σ : Self discharge factor
P_{BL} : Load demand at time interval
η_{BB} : Battery charging efficiency

Where,
V_{PV} : Operating voltage of PV panels
N_{PVS} : Numbers of PV panels in series
η_g : Efficiency of the gravitational acceleration
P_{WT} : Wind turbine power output
η_{WT} : Efficiency of wind turbine
ρ_a : Density of air
C_P : Power coefficient of wind turbine
A : Wind turbine swept area
V_r^3 : Wind velocity
P_{PV} : PV power output
η_{PV} : Conversion efficiency of PV
N_{PVP} : Number of PV panels in parallel
N_{PVS} : Number of PV panels in series
I_{PV} : Operating current of PV panels

During the optimization procedure, the sizes of system components are decision variables.

Power Design

In order to design a power system for the ICT Center, it was necessary to obtain information about the particular location of the ICT Center, such as the resources available and the load profile that should be met by the system [Ani, 2013b]. The proposed mix of renewable energy system consists of a wind turbine and solar photovoltaic (PV) panels with batteries added as part of a backup and storage system. The proposed system is shown in Fig. 4.

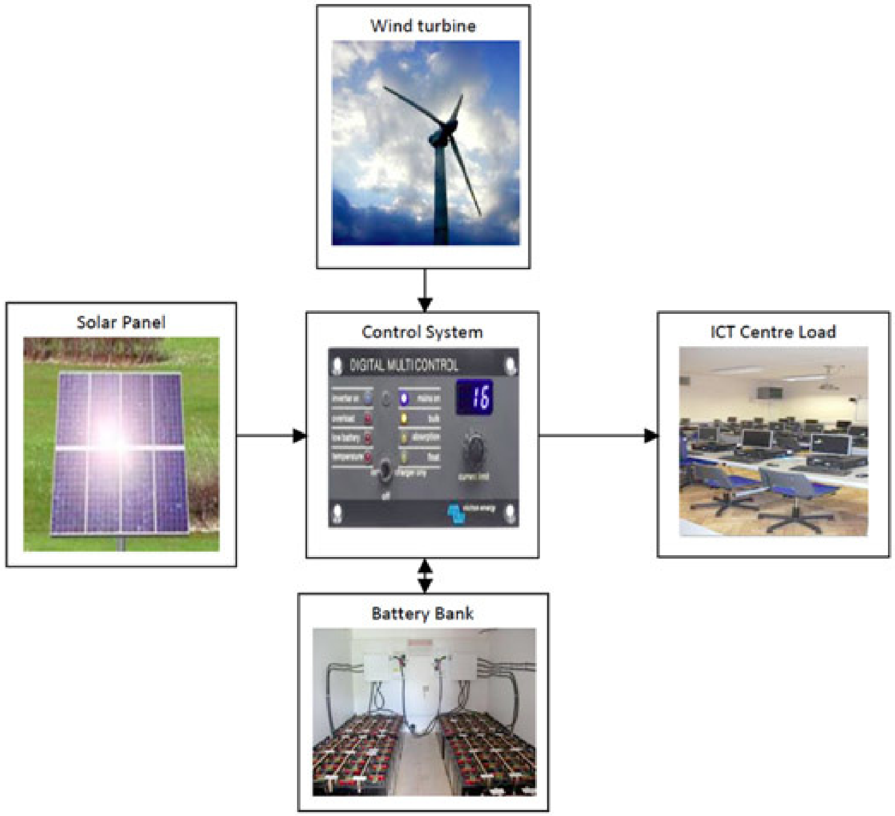

Figure 4 Architecture of the Proposed Stand-alone Hybrid System.

Mix of Renewable Energy System Components

Photovoltaic Module

The PV module has a derating factor of 80%. No tracking system is incorporated as part of the PV system design. The cost of PV module has been given in Table 4.

Wind turbine model

The number of BWC Excel-R 7.5 kW DC wind turbines considered for the simulation was one. The cost of the wind turbine has been given in Table 4.

Storage Battery

The variations of solar and wind energy generation do not match the time distribution of the demand. The storage battery chosen was Hoppecke 24 OPzS 30000. From the datasheet given by the HOMER software, the minimum state of charge of the battery is 30%. Its round trip efficiency is 86% [Battery Experts, 2012]. Batteries are considered as a major cost factor in small-scale stand-alone power systems.

Inverter

In the present case, the size of the inverter was 1.5 kW for simulation purposes. The inverter had an efficiency of 85%.

Constraints

Operating reserve is the safety margin that helps ensure reliability of the supply despite variability in electric load, solar power supply and the wind power supply. The operating reserve as a percentage of hourly load was 10%. Meanwhile, the operating reserve as a percentage of solar power output and wind power output was 25% and 50% respectively.

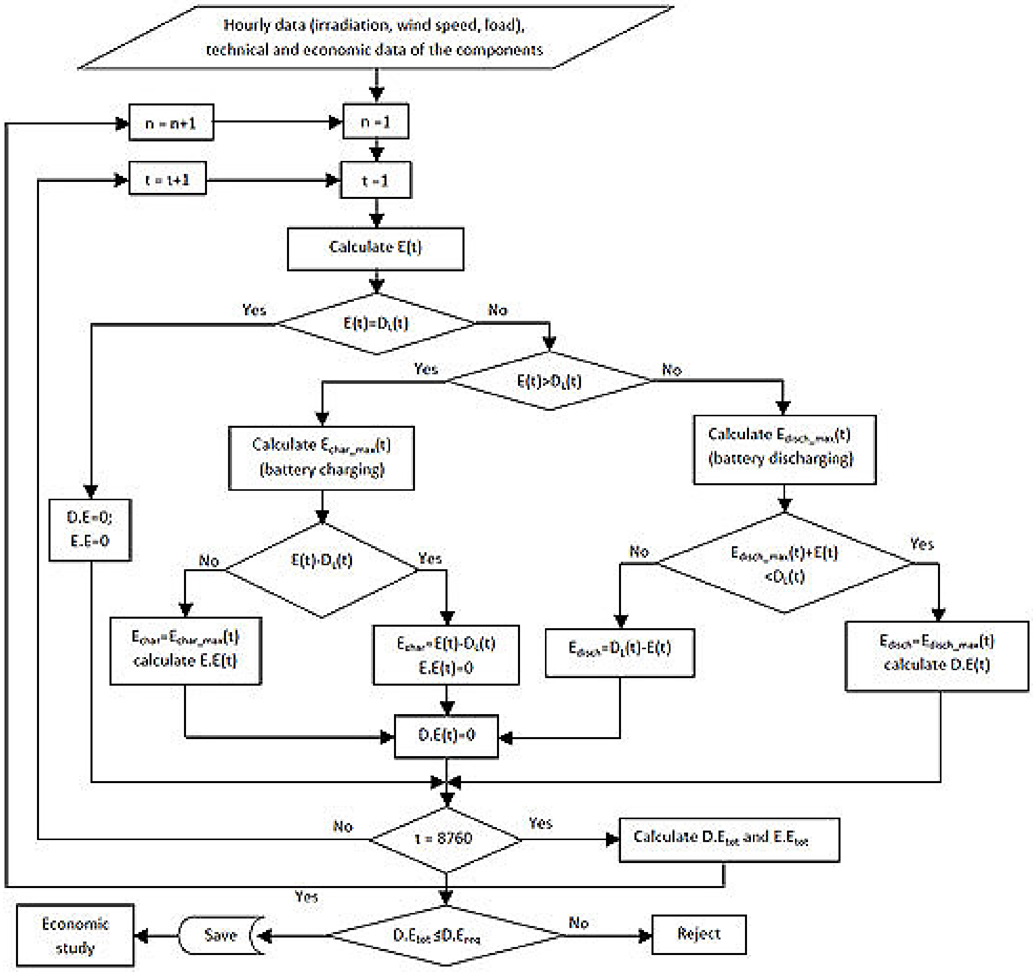

Figure 5 Optimization Chart of the hybrid PV-Wind system.

Control Strategies

The configuration of the stand-alone PV/Wind system is shown in Fig. 7. In the proposed PV/Wind energy system with batteries, the dispatch strategy was as follows: the battery charges if the mix of renewable energy is in excess after meeting the demand, and the battery discharges if the load exceeds the mix of renewable energy system.

The input parameters and system constraints as described above, were used to simulate hybrid systems and perform the optimization analysis.

Optimization Algorithm

The optimization algorithm of the hybrid system of renewable energy used by the HOMER Software in simulation is presented in Fig. 5. Inputs of the algorithm are the technical and economic data of all the components of the system [Souissi et al., 2010]. These data cover the climatic variation, the load and the constraints on the operation of the system. The inputs to the simulator (HOMER) are mentioned previously. For each combination n, the total power, E(t), generated by the PV generator and wind turbine at the hour t is calculated as follows:

$$E(t) = E_{PV}(t) + E_{WT}(t) \qquad \text{Eq. (6)}$$

During system operation of the PV/Wind system, different situations may appear:

The total energy generated by the PV and Wind generators can be greater than the load demand ($D_L(t)$). In this situation, the energy surplus is stored in the batteries (E_{char}) after calculation, as a preliminary, the maximum amount of energy that can be charged ($E_{char\_max}(t)$) in the battery bank. The excess of energy (E.E(t)), if it exists, is calculated for each hour.

The demand of the load can be greater than the total energy generated by the PV and Wind generators. In this case, the load must be covered by the energy stored in batteries (E_{disch}) after calculating, as a preliminary, the maximum amount of energy that can be discharged ($E_{disch\_max}(t)$) from the battery bank. The deficit of energy (D.E(t)), if there exists, is calculated for each hour.

The load demand can be equal to the total energy generated by the PV and Wind generator, the battery's capacity remains unchanged.

The total excess ($E.E_{tot}$) and deficit ($D.E_{tot}$) of energy that can occur during the year are calculated to decide the rejection or the save of the combination, by comparison between the total deficit and that required ($D.E_{req}$).

Finally, an economic study is done allowing a classification of the feasible combinations according to the total net present cost of the system.

Controller and Simulation for Validating Optimization Results

The method of validating the optimization algorithm result is using a virtual controller and simulating the control of the system over the year period and monitoring the times of loss of supply, and the power supplied by the PV panels, wind turbines and battery in relation to the power required by the load.

A sliding control was used for this, using the PV energy generation as the primary source of energy, wind energy generation as the secondary source and battery as the supplement and backup. The system move between different mode depending on the power needed by the load and the power able to be supplied by each of the sources. Fig. 6 outlines the flow between the different modes.

Initially, the power supplied by the PV panels and the wind turbines is calculated for each hour over the year and stored in matrices, so that power availability in each hour can be accessed easily. The control process then begins at hour 1. The first decision loop looks at the power that can be supplied by the PV panel in this hour and the power required by the load. If the power generated by the PV panel is sufficient to match the load, the system enters Mode 1. If the PV panel cannot provide sufficient energy to the load, the control looks at the total amount of energy that can be provided by the PV panel and the wind turbine together. If these together are sufficient to provide power to the load, the system enters Mode 2. If the combined energy supplied by the PV panels and the wind turbine is not sufficient to supply the load, the state of charge of the battery is considered. If the battery SOC is not at its minimum value, the system enters Mode 3. The detailed mode of operational control (sliding) is given below:

Mode 1

Mode 1 uses solely the energy generated by the PV panel to supply the load. When the system is in mode 1, at times, the energy available from the PV panel might be in excess of what is needed by the load and therefore the amount of energy supplied to the load must be matched to the load demand. This is called sliding control. As the wind turbines are connected to the system, but not used to supply the load in this mode, the energy generated by the wind turbine as well as any excess energy from the PV panels can be used to charge the battery.

During the charging of the battery, if the SOC of the battery is at its maximum possible SOC value, the excess power is sent to a dump load [Dump load is a device to which power flows when the system batteries are too full to accept more power], which can be defined according to the ICT's needs, charging of phones, etc. The flowchart inside the dotted line shown in Fig. 6 is the charging control circuit. If the SOC of the battery is less than the maximum SOC, the amount of excess power is checked. Battery-Experts [2012] advised not to use a charging current of more than 60A. The power is then checked to make sure that the current used to charge the battery will

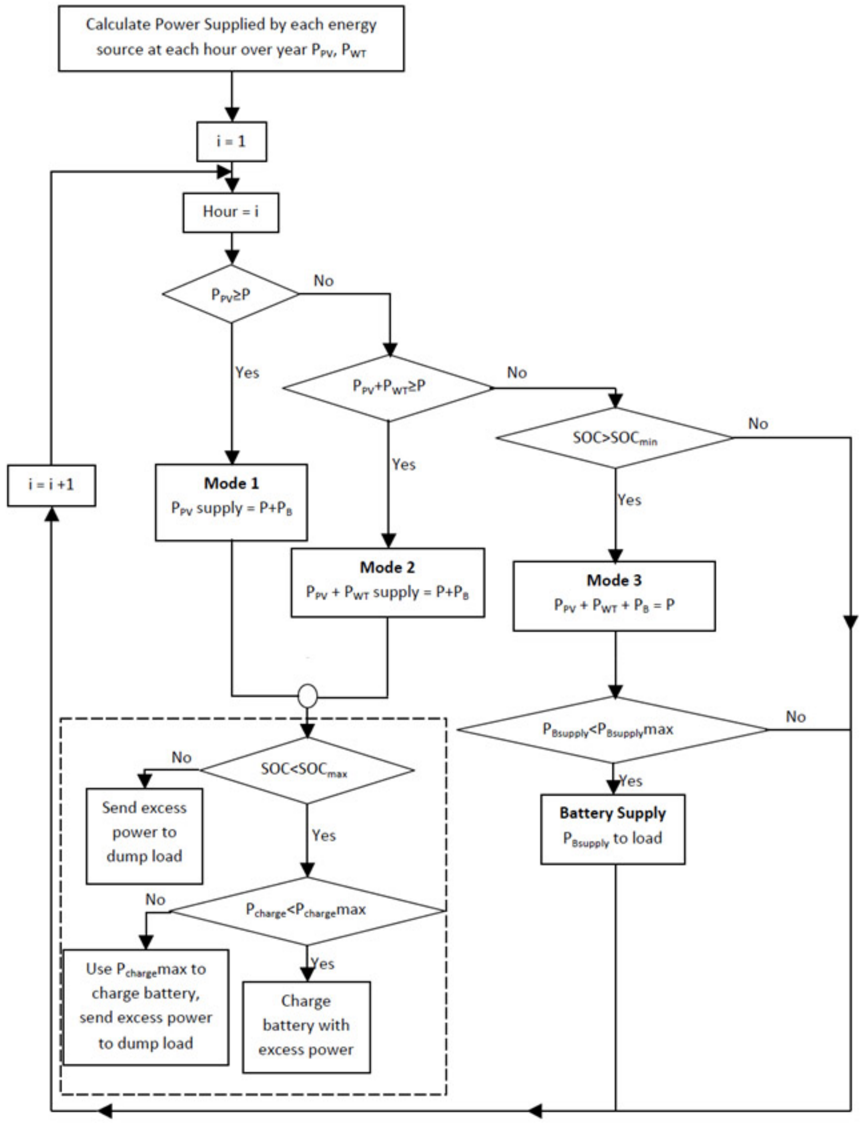

Figure 6 Flowchart of modes of control for Hybrid PV/Wind Energy System.

be less than 60A. If the excess power is less than this maximum charging power, the battery is charged with the full excess power. If the power is above that of maximum charging of the battery, the maximum battery charge power is used to charge the battery and the excess is used for the dump load.

Mode 2

Mode 2 uses the power of the PV panels plus the power of the wind turbine to supply the load. In Mode 2, if the energy available from the PV panel and the wind turbine combined is in excess of what is needed by the load, then the full power available from the PV panels is used to supply the load and the power from the wind turbine is supplied using the sliding control to match the power required by the load. The excess energy from the PV panels and the wind turbine can be used to charge the battery, as in Mode 1.

Mode 3

The system enters Mode 3 when the power generated by the PV panels and wind turbine is not sufficient to supply the load, but the SOC of the battery is greater than the minimum amount and therefore the

Table 4 Summary of initial system costs, Replacement costs and Operating & Maintenance costs

Item	Initial system costs	Replacement costs	Operating & maintenance costs
PV Modules	₦ 324/W ($2)	₦ 291.6/W ($1.8)	₦ 16,200/kW/yr ($100)
BWC Excel-R7.5kW Wind Turbine	₦ 2,916,000 ($18,000)	₦ 2,430,000 ($15,000)	₦ 16,200 ($100)
Hoppecke 24 OPzS 30000 Battery	₦ 185,490 ($1,145)	₦ 162,000 ($1,000)	₦ 16,200 ($100)
Inverter	₦ 324/W ($2)	₦ 324/W ($2)	₦ 0/kW/yr ($0)

battery is able to supply power to the load. The full power generated by the PV panels and wind turbine is supplied to the load. There is however a possibility that the amount of power required by the load is not able to be supplied by the battery. Manufacturers specify that the batteries should not supply more than 80A current, and therefore the amount of power needed to be supplied by the batteries must be checked before it can supply that amount. If the load power needed to be supplied by the batteries is below this maximum, the battery then supplies the load power. Otherwise, load cannot be supplied.

From this control simulation, the performance of the system is seen over the course of the year as well as which modes the system spends most time in, the power supplied by each of the energy sources and the power required by the load. This is useful to check how the system is being supplied and which source of energy is the most proficient in supplying the load.

System Economics

The capital costs of all system components including PV module, wind turbine, inverter, battery and balance of system prices are based on quotes from PV system suppliers in Nigeria [Solarshopnigeria, 2012]. They are likely to vary from the actual system quotes due to many market factors, and are therefore only indicative. The replacement costs of equipment are estimated to be 20% – 30% lower than the initial costs, but because decommissioning and installation costs need to be added, it was assumed that they are the same as the initial costs.

The PV array, wind turbine, Inverter and battery maintenance costs are estimates based on approximate time required and estimated wages for this work in a remote area of Nigeria. All initial costs including installation and commissioning, replacement costs and operating & maintenance costs are summarized in Table 4.

As HOMER calculates in US Dollar ($), all costs have been converted from Naira (₦) into USD ($) as shown in Table 4 using the equivalent as 1 US Dollar ($) equal to ₦162 of Nigerian currency (Exchange rate, *accessed on* 07/17/2012).

Configuration of Solar-Wind System Components

The design of a stand-alone PV/Wind system is site specific and depends on both the resources available and the load demand [Ani, 2012b]. A typical standalone solar/wind system consists of the PV array, wind turbine, battery bank, inverter, and other accessory devices and cables. The proposed energy system for the ICT Center consists of PV/Wind power as depicted in Fig. 7. The PV array and wind turbine work together to satisfy the load demand. When the energy sources (solar and wind energy) are abundant, the generated power, after satisfying the load demand, will be supplied to feed the battery until it's fully charged. On the contrary, when energy sources are poor, the

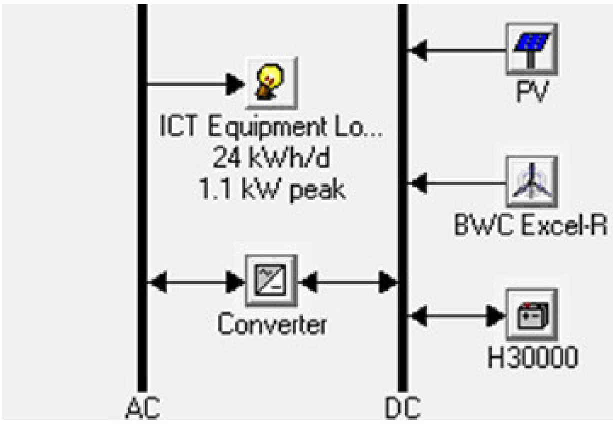

Figure 7 Network Architecture of the Proposed Stand-Alone Hybrid PV/Wind System.

battery will release energy to assist the PV array and wind turbine to cover the load requirements until the storage is depleted.

Simulation of the PV/wind hybrid schemes

The combined schemes were analyzed using simulation software called HOMER to predict the feasibility of the energy schemes in terms of the system's capital cost, replacement, operation and maintenance, as well as annual electricity energy production study. It simulated the system operation by making energy balance calculations for each of the 8760 h in a year. Further details are given in [Lambert et al., 2006]. For the simulation of the ICT center, the system components considered were PV arrays, wind turbine and battery. The inverter converts the direct current (DC) power produced to alternate current (AC) power which can conveniently power all electrical appliances that are being used at the ICT Center such as laptops, a laser printer, lighting, etc. The lifetime of the project was estimated at 20 years with a fixed annual interest rate of 6%. The simulation was performed with the assumption that the daily operation hour for the system was constant. The proposed renewable Hybrid PV/Wind system was simulated using the model which resulted in two different topologies:

The Hybrid PV/Wind system had the following system design: 8 kW PV array, 1 unit 7.5 kW BWC

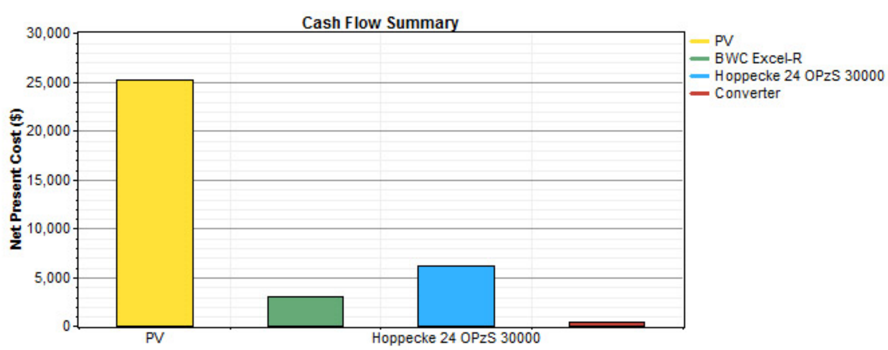

Figure 8 Net Present Cost of component of optimized PV/Wind hybrid system for ICT Center.

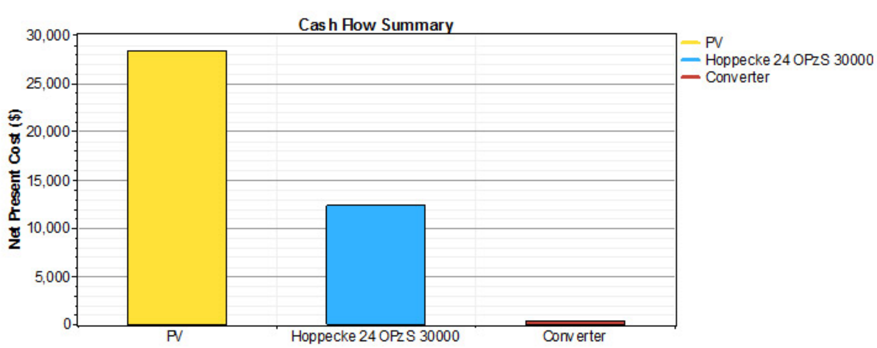

Figure 9 Net Present Cost of component of PV system for ICT Center.

Table 5 Cash Summary of Energy Components for ICT Center.

Component/Costs	Capital Cost($)		O&M Cost($)		Total NPC($)	
	PV/Wind-Battery System	PV-Battery System	PV/Wind-Battery System	PV-Battery System	PV/Wind-Battery System	PV-Battery System
PV	16,000	18,000	9,176	10,323	25,176	28,323
BWC Excel-R	1,800		1,147		2,947	
Hoppecke 24 OPzS 30000	5,040	10,080	1,101	2,202	6,141	12,282
Inverter	420	420	0	0	420	420
System	23,260	28,500	11,424	12,525	34,684	41,025

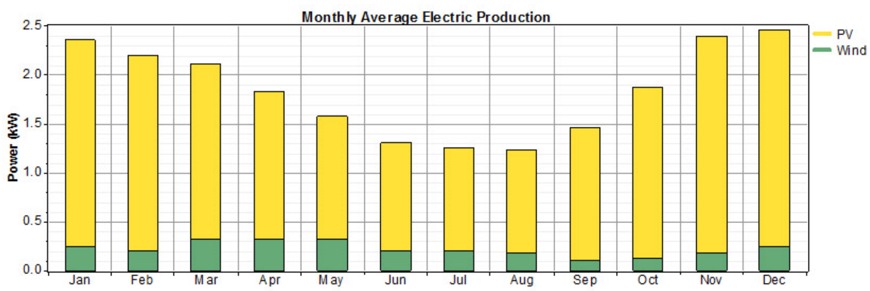

Figure 10 Electric production of PV/Wind hybrid system.

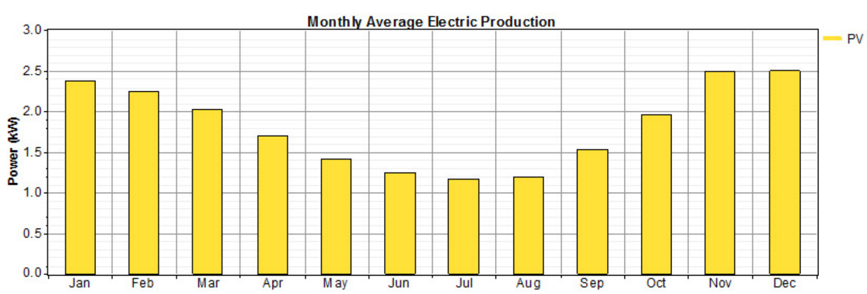

Figure 11 Electric production of PV only system.

Excel-R wind turbine, 1.5 kW inverter and 24 units Hoppecke 24 OPzS 30000 batteries.

The PV only system had the following system design: 9 kW PV array, 1.5 kW inverter and 48 units Hoppecke 24 OPzS 30000 batteries. These two different system designs were compared in terms of cost analysis and electricity generated.

Results and discussion

Cost analysis for the simulated hybrid PV/Wind scheme

The costs of the systems were estimated and analyzed by employing the HOMER simulation and the results obtained (Fig. 8 and 9) are summarized in Table 5. The cost analysis includes the initial cost, operation and maintenance (O&M) cost and the total Net Present Cost. The system's lifetime of 20 years was taken into consideration. The rate of interest or share char-

Table 6 Electricity Production, losses and Consumption of the ICT Center.

Electricity	PV/Wind system		PV system	
	kWh yr^{-1}	%	kWh yr^{-1}	%
Production				
PV array	14,196	88	15,970	100
Wind turbine	1,906	12		
Total	16,102	100	15,970	100
Losses				
Inverter	1,520		1,520	
Battery	717		811	
Total	2,237		2,331	
Consumption				
AC load	8,613	100	8,613	100
Total	8,613	100	8,613	100
Excess Electricity	5,252	33	5,026	31

ges were assumed 6% and the Total Net Present Cost of PV/Wind Hybrid system and PV only system were $34,684 and $41,025, respectively, with a difference of $6,341.

The simulated hybrid PV/Wind scheme analysis

The simulated results obtained from HOMER showed that in the PV/Wind Hybrid system, the PV arrays contributed most of the energy for the whole year in which it produced 14,196 kWh yr^{-1} (~88%) with a capacity factor of 20.3% followed by wind power that produced 1,906 kWh yr^{-1} (~12%) with a capacity factor of 2.90% which gives a total of 16,102 kWh yr^{-1} (100%) as shown in Table 6. In September, the wind electricity scheme was merely able to contribute minimum power, this is because unlike other periods there is no significant breese during this period as can be clearly seen in Fig. 10; whereas in PV only system, the PV arrays generate 15,970 kWh yr^{-1} (100%) alone with a capacity factor of 20.3% as shown in Table 6. In July, the solar electricity has the least minimum power generated; this is because unlike other periods there is always rainfall during this period as can be clearly seen in Fig. 11.

The total load of the ICT Center [(mainly consists of Router, Port fast Switch, Wireless Access Point, Server (plus accessories), RF (Radio Communication), Laptops (with security cables), VOIP Phones, Laser Printer, Lighting and Ceiling fans)] corresponding to a total AC primary load of 8,613 kWh yr^{-1}.

Therefore:

The annual electric energy production by PV/Wind Hybrid system and PV only system are 16,102 kWh yr^{-1} (100%) and 15,970 kWh yr^{-1} (100%), respectively, as shown in Table 6.

Total AC primary load: 8,613 kWh yr^{-1}.

Excess electricity

In PV/Wind Hybrid system, the excess electricity occurred in all the months except in the months of July and August, and some days in June and September but occurred most in March (as can be clearly seen in Fig. 12) when the energy generated by the solar

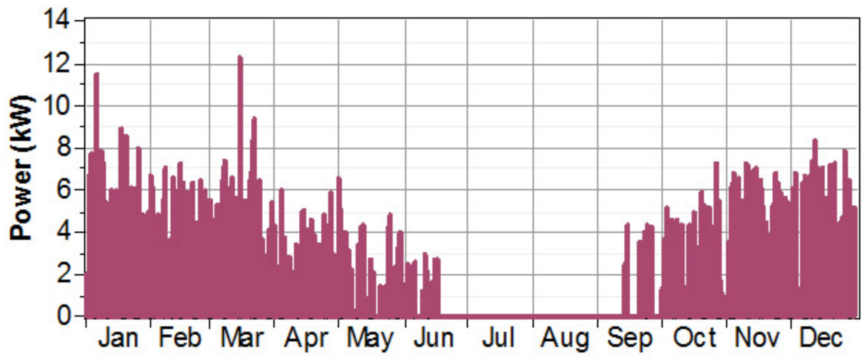

Figure 12 Excess Electricity generated by the Hybrid PV/Wind Energy System.

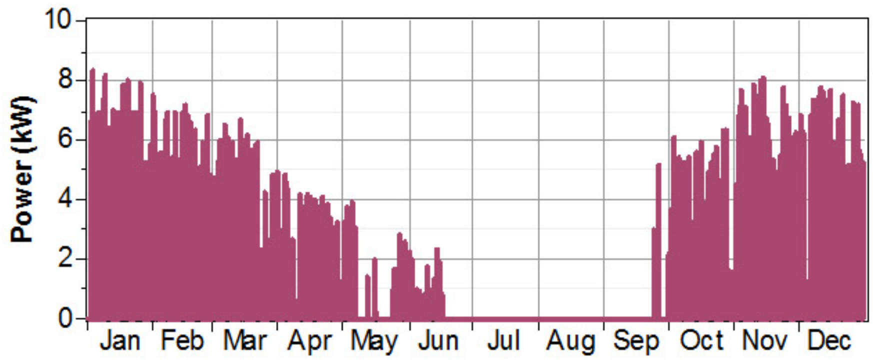

Figure 13 Excess Electricity generated by the PV Energy System.

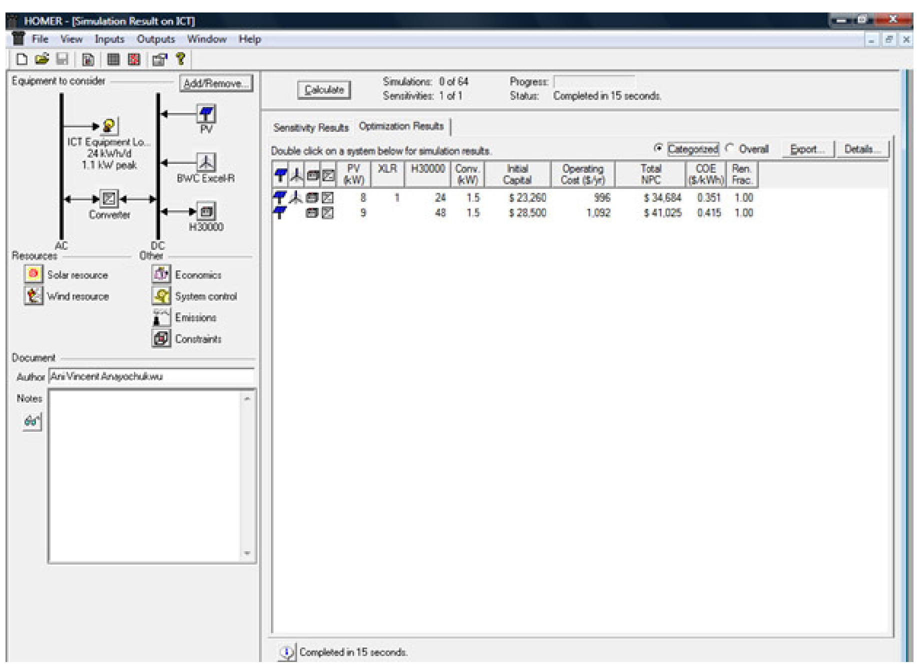

Figure 14 Overall optimization results of HOMER solutions.

and wind are at the highest (Table 3); while in PV only system, the excess electricity occurred in all the months except in the months of July and August, and some days in May, June and September as shown in Fig. 13.

Excess energy = Total energy Production – (Total losses + Total energy Consumption)

Excess energy from PV/Wind hybrid system = [16,102 - (2,237+8,613)] = 5,252 kWh yr^{-1}.

Excess energy from PV only system = [15,970 - (2,331+8,613)] = 5,026 kWh yr^{-1}.

The PV/Wind Hybrid system has excess electricity of about 5,252 kWh yr^{-1} (33%) power supply, while the PV only system has excess electricity of about 5,026 kWh yr^{-1} (31%). This excess electricity power supply is guaranteed in the location simulated in order to give room for future Center expansion. It can also be sold to nearby villages, factories, schools or facilities. The sale of this excess electricity will offer a promising approach for ICT facilities to finance operations and maintenance costs of the hybrid system.

In the energy system designed, 24 Hoppecke 24 OPzS 30000 batteries were used in Hybrid PV/Wind system, while in PV only system 48 Hoppecke 24 OPzS 30000 batteries were used as shown in Fig. 14. This shows that batteries are often sized smaller in a hybrid system than in a single-source system as claimed in [Ani and Nzeako, 2012b].

From the optimization results the best optimal energy system components (8 kW PV array, 1 unit 7.5 kW BWC Excel-R wind turbine, 1.5 kW inverter and 24 units Hoppecke 24 OPzS 30000 batteries) was determined for ICT Center located in a rural area of Kauru (Kaduna State) as shown in Fig. 14.

Conclusion

In this study, the proposed renewable Hybrid PV/Wind system was simulated using HOMER software which resulted in two different topologies. These two different configurations (PV/Wind system and PV only system) were compared in terms of cost analysis and electricity generated. From the optimization results the best optimal energy system components (8 kW PV array, 1 unit 7.5 kW BWC Excel-R wind turbine, 1.5 kW inverter and 24 units Hoppecke 24 OPzS 30000 batteries) was determined for ICT Center located in a rural area of Kauru (Kaduna State). This system saves $6,341 when compared with a PV-only system due to reduced number of battery units. The results also demonstrate that renewable hybrid systems have the potential of supplying electricity to ICT centres in a cost effective manner. Therefore, this study shows that there is a great promise for alternative renewable energy for power generation in Nigeria, if only the country could endeavour to explore and exploit these available resources.

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