ASSESSMENTS OF HYBRID RENEWABLE ENERGY SYSTEM OPTIMAL CONFIGURATIONS FOR RURAL HEALTHCARE FACILITIES

Lanre Olatomiwa[1, 2,*] , Saad Mekhilef[1]

[1]Power Electronics and Renewable Energy Research Laboratory (PEARL), Department of Electrical Engineering, University of Malaya, Kuala Lumpur, Malaysia.
[2]Department of Electrical & Electronic Engineering, Federal University of Technology, PMB 65, Minna. Nigeria.

Abstract

In this paper, optimal configurations assessments of hybrid renewable system for rural healthcare facilities in three grid non-connected rural villages in Nigeria were conducted. These facilities contains an emergency room, consulting room, nurse/injection room, male ward, female ward, a labour room and a laboratory with average total daily energy consumption of 15.5kWh and 2.75kW peak demand. The assessment of configurations that optimally meet the daily load demand with zero loss of power supply probability (LPSP) was carried out using HOMER software, by considering three energy resources; solar photovoltaic (PV), wind and diesel with battery energy storage. The optimization results shows hybrid PV/wind/diesel/battery system as the most cost-effective configuration for powering the rural health facilities located in both Sokoto and Enugu, while hybrid PV/diesel/battery system is considered the best for Iseyin rural healthcare facility.

The overall results indicated that not only does the considered hybrid system configurations out-performed diesel-only scenario in terms of cost of energy production in all the three sites, but also exhibited better performance in the areas of quantity of energy production, fuel consumption and CO_2 reduction. It is therefore concluded that, inclusion of renewable energy resources, such as PV and wind in the design and implementation of power supply systems for the rural healthcare facilities in the selected sites will definitely enhance the quality of healthcare delivery.

Keywords—*hybrid energy system; rural healtcare; optimization; HOMER;* ***Nigeria***

1. Introduction

Reliability of electric power supply is considered vital in rural healthcare development, the lack of which has limited its efficient delivery in many poor rural communities, thereby putting human lives at risks [1]. Modern advances in the distribution of vaccines and other cold-chain dependent drugs, as well as global push for antiretroviral drugs (ARV) delivery have presented new demands for electricity in health centers where there is no or limited access to reliable power supply. Operators of rural health facilities in many developing nations are faced with many challenges such as; poor medical infrastructures, even where available, unreliable power supply has hindered its functionality. This has lead to ineffective healthcare delivery to the rural populace. For instance, an unreliable power supply can render cold-chain activities inoperable, also, a healthcare facility without means of illumination (lighting) can keep the patients arriving late night for medical attention waiting until the following morning before medical attention can be rendered.

In the recent past, Nigerian government have expended huge fund in its power sector reforms to ensure rural area electricity access. The development of the National Energy Policy which has the Renewable Energy Master Plan (REMP) is a key component is one such reforms, also, the establishment of the National Energy Master Plan in conjunction with United Nations Development Programme (UNDP), is another one as well as the implementation of numerous independent power projects (IPPs) [2]. Nevertheless, even with these reforms, accessibility of electricity by the rural communities has not improved due to several constraints, such as; inaccessible terrain, distance of rural communities to the grid center leading to high cost of connection into the national grid [2, 3] etc. However, considering the fact that improving rural access to electricity through grid extension does not seem promising at present due to its associated cost, it is thus imperative for a system of autonomous, off-grid power generation be established. A solution based on renewable energy (RE) resources and technologies, due to the vast deposit, and environmental friendliness would be a viable option; more so that rural locations have lower electricity demand.

Nigeria is endowed with vast renewable energy resources ranging from hydropower, wind, solar and biomass [4]. An overview of literatures on rural electrification proves that combination of these renewable energy sources (RES) is one of the most effective solutions to provide electricity to these rural areas. The methodology has proved to provide quality and reliable electricity for different applications in the many rural areas of the wolrd [5-9]. However, the two most commonly explored renewable energy are wind and solar. Therefore, this study aims to assess the potentials of wind and solar energy resources in three rural locations in Nigeria for healthcare applications. These locations were strategically selected from different climatic zones in the country with the aim that results of the analysis can be adopted to other rural villages having similar climatic condition as those considered in the study. Table1 contains the parameters of studied locations.

Corresponding Author: olatomiwa.l@futminna.edu.ng

Table 1. Study Site Characteristic and Dataset

S/N	Location	Climatic Zone	Latitude (°N)	Longitude (°E)	Altitude (meters)	Data period (Wind Speed)	Data period (Solar Radiation)
1	Iseyin	Tropical monsoon	7.96	3.60	330	(1983-2010)	(1990-2010)
2	Enugu	Humid	6.45	7.5	247	(1971-2007)	(1990-2007)
3	Sokoto	Tropical dry	11.83	13.15	353.8	(1976-2007)	(1977-2007)

Analysis of potentials of solar energy resources at the selected site based on certain key solar resources parameters, such as monthly and annual global solar radiation (GSR), beam radiation, diffuse radiation, as well as clearness index. The optimal tilt angle for south-facing solar collector orientation was also determined. Examination of wind energy potentials, on the other hand based on monthly mean daily wind speed data. Finally the conclusions on the suitability of each of the renewable sources and the best optimal configurations for rural healthcare applications in each of selected locations were drawn.

2. Description of Study Sites and Data Collection

The locations for renewable energy potential assessment in this study were selected from three geo-political zones in Nigeria characterized by different climatic condition. Iseyin in the West, Sokoto in the North and Enugu in the East. The meteorological data (wind speed and solar radiation) used in the analysis were obtained from Nigerian Metrological Agency (NIMET) [10]. Wind speed data were recorded daily at 10m height with a cup–generator anemometer at respective locations, while the daily solar radiations on a horizontal plane were measured with Gunn-Bellini radiometer [11]. Wind data ranges between 28 and 39 years, and solar radiation data ranges between 18-31years were use in the study (Table 1). These data were computed as an average of data for each month.

2.1 Solar Radiation

The power output of the PV array depends on the direct and diffuse solar radiation over a particular area. The insolation reaching the earth's surface hinge on the cloudiness or clearness of the sky, which in turn depends on the season of the year [12]. Characteristics and potential of solar energy at selected sites are analyzed based on mean monthly global solar radiation as well as the monthly clearness index. Other parameters explored in the analysis include the monthly mean daily diffuse and beam radiation, this is essential for efficient design and performance evaluation of solar energy applications. In this study, the period of solar data available for the analysis differs from one location to another as seen in Table 1. For all the sites considered, the available daily data were averaged to obtain the monthly mean and annual mean value. Table 2 shows monthly and annual average global solar radiation in the three sites.

2*.2. Wind Speed*

Comprehensive study of available long-term solar insolation data and wind regime in a particular location is essential in designing and predicting energy output of the respective energy conversion devices; the in-depth knowledge will help in determining their suitability for any particular applications. Generation of electrical energy from wind energy occurs, when wind blows through a wind turbine. The kinetic energy of the wind at rated wind speed is converted into mechanical power by turning the turbine blade, thus producing electricity through the shaft connected to the alternator [13]. In this study, we employed Weibull distribution function (WDF) in describing the monthly wind speed variation and seasonal changes occurring in the selected sites as well as for estimation of wind power density. Table 3 shows the monthly and annual average wind speed variation in the selected sites.

2.3 Rural Health Clinic Load Profile

The healthcare facility considered in this study is classify as a category 1 rural health clinic according to United States Agency for International Development (USAID) [14]. It consists of an emergency room, a doctor's consulting room, nurse/injection room, male ward, female ward, a delivery room, and a laboratory. The total number of bed space in the clinic is 10. In this facility, electricity is required for: (1) lighting for evening hour's operations to support limited surgical procedures (such as; suturing, cesarean section etc.) and lighting of surroundings. (2), Refrigerator for keeping cold chain vaccines, blood bank and other perishable medical supplies at required temperature. (3), Basic laboratory equipment including; centrifuge, microscope, incubator, hematology mixer, hand-held power aspirator etc. Other appliances that require electrical power includes; television, VCR, and fans.

However, these loads are not expected to operate simultaneously, because each has specific daily hours of operation. Figure 1 shows the hourly load profile of the clinic, where average energy consumption per day and the peak demand is found to be approximately 15.5kWh and 2.75kW respectively. Major load occurs during the daytime (6am to 6pm). Based on this variation, a day-to-day random variability of 5% and hour-to-hour random variability of 10% specified in HOMER, in order not to underestimate the peak load the proposed system can serve.

Table 2. *Monthly/annual average global solar radiation in the selected sites (kWh/m2/day)*

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Iseyin	4.66	5.07	5.29	4.93	4.72	4.26	3.36	2.94	3.77	4.43	5.15	4.92	4.46
Enugu	4.6	5.117	4.8	4.62	4.71	4.34	3.61	3.46	4.15	4.77	5.24	4.93	4.53
Sokoto	5.00	5.61	5.96	6.3	5.63	5.43	4.73	4.45	5.12	5.51	5.36	5.02	5.32

Table 3. *Monthly/annual average wind speed variation in the selected sites (m/s)*

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Iseyin	4.21	4.36	4.54	4.71	4.33	4.35	4.2	4.26	3.94	3.61	3.48	3.91	4.16
Enugu	5.62	5.66	6.3	6.22	5.35	5.21	5.48	5.44	4.85	4.56	4.12	4.95	5.31
Sokoto	8.95	8.63	7.35	7.59	8.70	9.03	7.94	6.23	5.81	6.02	7.50	7.86	7.63

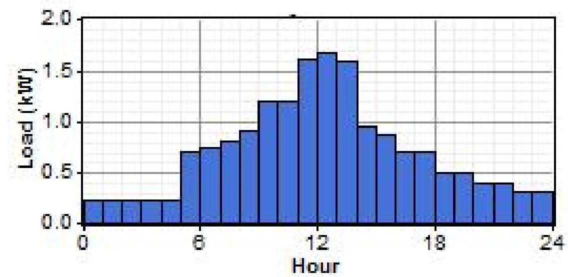

Figure 1. *Healthcare facility daily load Profile.*

3. Hybrid System Configuration

Fig. 4 shows a typical hybrid power system, which comprise of solar PV, wind, diesel generator and battery bank. The combination of solar PV, wind and diesel generator components enhances the output power of the system as well as compensates unpredictable variation in climatic condition. Converter was included to maintain the flow of energy between the system AC and DC bus, while the battery acts as a backup in ensuring uninterrupted power supply as well as to maintain desired power quality at specific load point [15]. In this system, the battery bank charges whenever the renewable energy output exceeds the load demand and discharges when the load exceeds the renewable power output. Combination of these energy resources in parallel with battery storage provides a smooth and uninterrupted power supply, hence makes the hybrid system reliable and efficient. Initial choice of the components size based on the site load profile presented in Figure 1. A brief description of the hybrid system components with their techno-economic details are summarized in Table 4.

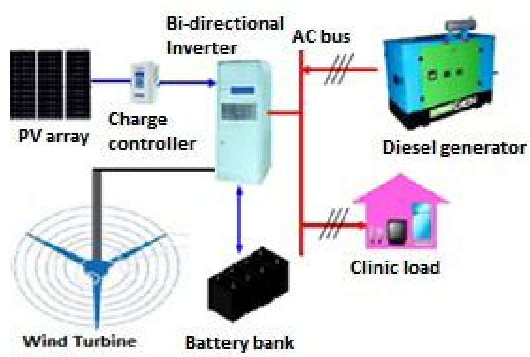

Figure 2. *PV/wind/diesel hybrid system configuration.*

4. System Modeling

Assessment of optimal system configurations is carried out by optimizing the objective function of total life cycle cost of the entire hybrid system represented by Figure 2. HOMER (Hybrid Optimization Model for Electric Renewable), a software developed by National Renewable Energy Laboratory, USA was employed to perform the optimization [16]. The software performs multiple iterations with ranges of input variables (sensitivity variables) to determine the effect the changes in input parameters may have on the system, and thereby search for best system configuration. In the optimization process, only the feasible system configurations as sorted according to lowest NPC are displayed in optimization result table.

PV arrays are model in HOMER as a device that generates DC voltage when exposed to solar irradiance, and the output power can be found from the relation [17];

$$P_{pv-out} = P_{pv-rated} \times f_{pv}\left(\frac{G}{G_{ref}}\right) \times [1 + K_T(T_c - T_{ref})] \quad (1)$$

where $P_{pv-rated}$ (kW) is the PV rated power at standard test condition (STC), f_{pv} is the PV derating factor (%), G is the global solar irradiance incident on the PV surface, G_{ref} is the radiation at STC (kW/m^2), T_{ref} is cell temperature at STC (T_{ref}=25^{o}C), K_T is the temperature coefficient of the PV module while T_c is cell temperature given by $T_c = T_{amb} + (0.0256G)$

On the other hand, wind energy conversion system (WECS) is modeled as rotational kinetic energy produced, when wind blows at the rated speeds over a wind turbine within a given area as represented by;

$$P_{WT} = \frac{1}{2}\rho A v^3 C_{pmax} \quad (2)$$

where P_{WT} output power of the wind turbine (kW), A is the swept area of wind turbine (m^2), ρ is air density (kg/m^3), v is the wind velocity (m/s) while C_{pmax} is the wind power coefficient, usually taken as 0.59 [18].

Table 4. *Summary of Technical and Economic Details of System Component*

PV array	
Capital cost	$3,200/kW
Replacement cost	$3000/kW
Sizes consideration	0, 1, 2, 3, 3.5, 4, 4.5 and 5 kW
Lifetime	25 years
De-rating factor	90%
Wind turbine	
Model	BWC WL.1
Rated capacity	1 kW
Initial cost per unit	$5,725
Replacement cost	$3650
Maintenance cost	$100/year
Units consideration	0, 1, 2, 3, 4 and 5 turbines
Lifetime	20 years
Battery	
Model	Trojan T-5
Rating	6V, 225 Ah, 1.35 kWh
Initial cost per unit	$174
Replacement cost	$174
Maintenance cost	$5/yr.
Units consideration	0, 8, 16, 24, and 32 units
Battery per string	8 batteries
Lifetime	5yr.
Converter	
Capital and replacement cost	$200/kW
Maintenance cost	$10/year
Sizes consideration	0, 1, 2, 3 and 4kW
Lifetime	10 years
Efficiency	90%
Diesel generator	
Rating	3 kW, 22.6 A
Maximum load ratio	10%
Initial cost per unit	$200/kW
Replacement cost	$200/kW
Operational cost	$0.05/hr
Lifetime	15,000 hours
System economic parameters	
Discount rate	8%
Inflation rate	2%
Diesel price	$1.1/L

Diesel generator is model based on its fuel consumption (F_G) pattern, which is proportional to its output power [17]:

$$F_G = B_G \times P_{G-rated} + A_G \times P_{G-out} \quad (3)$$

where $P_{G-rated}$ is the nominal power of the diesel generator, P_{G-out} is the output power, while A_G and B_G represents the coefficients of the fuel consumption curve as defined by the modeler (l/kWh).

The battery in this study is modelled as an energy storage device capable of storing certain amount of DC power at a fixed round trip efficiency during excess energy production from the renewable energy resources and discharging whenever the system energy resources are unavailable to meet the load demand. The battery storage capacity is given as [17]:

$$C_{Wh} = (E_L \times AD)/(\eta_{inv} \times \eta_{Batt} \times DOD) \quad (4)$$

where E_L is the average daily load energy (kWh/day), AD is the number of days of battery autonomy, DOD is battery depth of discharge, while η_{inv} and η_{Batt} represent inverter and battery efficiency respectively.

5. Economic Evaluation

Economic evaluation of the entire hybrid system is achieved by optimizing total life cycle cost of the system configurations. Total NPC is used to represent the system life-cycle cost, which is a composite of initial system component's capital cost, replacement cost, operation and maintenance cost as well as fuel cost where applicable over their useful lifetime, usually given as [17]:

$$C_{NPC} = \frac{C_{ann.tot}}{CRF\ (i,N)} \quad (5)$$

where $C_{ann.tot}$ is total annualized cost (\$/yr.), i annual interest rate, N is project life span (yr.), while $CRF\ (i,N)$ system capital recovery factor given as:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \quad (6)$$

On the other hand, the levelized cost of energy, which is average cost per kWh of energy produced by the hybrid system, is calculated as;

$$COE = \frac{C_{ann.tot}}{E_{loadseverd}} \quad (7)$$

where $E_{loadseverd}$ is actual electrical load serve by the hybrid system (kWh/yr.).

The flowchart of the entire simulation and optimization process is shown in Figure 3.

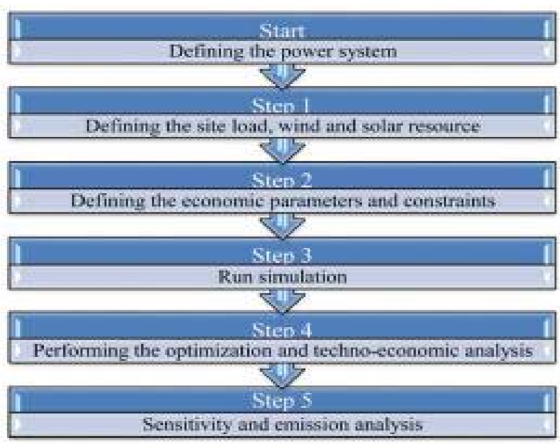

Figure 3. *System Optimization flowchart.*

6. Results and Discussion

The optimal configuration assessment for the selected rural sites, were carried out based on the collected data from each locations and system load profile in Figure 1. The feasibility of employing hybrid renewable energy system for powering rural health clinic is based on the availability of the energy resources in the selected sites and lifetime cost of the configurations. HOMER performed an hourly time series simulation for every possible system configuration on a yearly basis to evaluate operational characteristics such as; annual electricity production, annual load served, excess electricity, renewable fraction and so on. The renewable energy sources and diesel generator were evaluated to determine the feasibility of the system. HOMER searched for optimum system configuration and component sizes that meet the load requirement at the lowest net present cost (NPC) and then presents the results of the simulation in terms of optimal systems and sensitivity analysis.

The optimal results for Iseyin, Sokoto and Enugu sites are presented in Tables 5. From the table, it is observed, that the best configuration for both Sokoto and Enugu site is hybrid PV-wind-diesel-battery system, while PV-diesel-battery is considered optimal for Iseyin site. The obtained optimal configuration for Sokoto has the lowest NPC and COE of all the optimal configurations, this is because of high solar and wind resources availability in the site compare to the other sites (see Table 1 and 2).

Diesel only system is seen as worst configuration with highest NPC and COE, notwithstanding its low capital cost, this is as a result of high fuel and maintenance cost associated with the configuration. This has demonstrated that the configuration with lowest capital cost, may not necessary be configuration with lowest cost of energy. A diesel-battery configuration cost 45%, 52% and 96% more than the best optimal configuration in the entire Iseyin, Enugu and Maiduguri respectively. It is also noted that the COE of diesel alone system (without battery) is more than twice that of the optimal configuration in all the sites. The addition of renewable sources and batteries to the diesel system is considered a good investment in terms of fuel saving and emission reduction.

Table 6 shows the annual pollutant emission from the best optimal configurations and the existing conventional diesel-only system in each of the selected sites. This emission includes; carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbon (UHC), particulate matter (PM) sulfur dioxide (SO_2) and finally nitrogen oxide (NO_x). The conventional diesel based power generation configuration produces 9,551 kg/yr. of CO_2 in all the sites, while the optima hybrid renewable system configurations produced CO_2 1,247.1, 791.1 and 381.6kg/year in Iseyin, Enugu and Sokoto sites respectively. From this table, we observed that, a total of 87, 92 and 96 percent CO_2 emission could be averted; if a hybrid renewable, energy system configuration is adopted in Iseyin, Enugu and Sokoto sites respectively. The percentage reduction in pollutants emission is proportional to the rate of renewable energy penetration in the system. Hence, inclusion of renewable energy resources such as PV and wind in the hybrid system configuration will lead to more economically viable option in providing electricity to rural health centers. Moreover, the system will also help in abating the prevalent global warming, which occurred as a result of high rate of CO_2 emission into the environment.

***Table 5**: Comparison of various system configurations in the selected sites*

Site	System Configuration	Components size					Economics		
		PV (kW	Wind (kW)	Diesel (kW)	Batt. (unit)	Conv. (kW)	Initial capital ($)	Total NPC ($)	COE ($/kWh)
Iseyin	PV-Diesel-Battery	4.0	-	3	24	3	18,196	33,160	0.454
	PV-Wind-Diesel-Batt.	4.0	1	3	24	3	23,921	35,927	0.492
	Diesel-Battery	-	-	3	16	1	3,604	48,068	0.658
	Diesel alone	-	-	3	-	-	600	69,500	0.951
Enugu	PV- Wind-Diesel-Batt.	3.0	1	3	16	3	19,329	31,566	0.432
	PV-Diesel-Battery	4.0	-	3	24	3	18,196	32,986	0.451
	Diesel -Battery	-	-	3	16	1	3,604	48,068	0.658
	Diesel alone	-	-	3	-	-	600	69,500	0.951
Sokoto	PV- Wind-Diesel-Batt.	2	1	3	16	3	16,129	24,534	0.336
	PV-Diesel-Battery	3.5	-	3	24	3	16,596	38,746	0.393
	Diesel-Battery	-	-	3	16	1	3,604	48,068	0.658
	Diesel alone	-	-	3	-	-	600	69,500	0.951

Table 6. Pollutant Emission in optimal system configuration in the selected sites

	Best optimal configuration			Diesel alone
Pollutant emissions (kg/year)	Iseyin	Enugu	Sokoto	All sites
CO_2	1,247.1	791.1	381.64	9,551.6
CO	3.08	1.95	0.94	23.58
UHC	0.34	0.22	0.10	2.61
PM	0.23	0.15	0.07	1.78
SO_2	2,50	1.59	0.77	19.18
NO_x	27.47	17.42	8.41	210.38

6. Conclusion

In this paper, optimal configuration of hybrid renewable system for rural health clinic (RHC) application in three grid-unconnected rural villages in Nigeria is assessed. According to the results obtained for the selected sites, the following conclusion were drawn:

- The PV/wind/diesel/battery hybrid renewable system configuration is considered optimum for both Sokoto and Enugu RHC according to NPC, COE and RF calculation, while PV/diesel/battery for Iseyin RHC.
- The diesel only system provides the highest COE ($0.951/kWh), and emits 9,552kg of CO_2 per year in the entire site; this is huge and will have adverse effect on the environment as well as the health of patients in the rural health facilities. The wind system hybrid configuration is not considered best option in Iseyin site, due to the relatively low wind speed as compared with other sites. However, the simulation result shows it, still better than diesel-only configuration.
- The overall results indicated that not only does the hybrid system configurations perform better than diesel-only simulation with regards to the NPC for all three sites, but also displayed better performance in the categories such as electrical, fuel consumption and CO_2 reduction.
- The high solar irradiation levels in the country create an ideal environment for inclusion of renewable energy systems, such as PV and wind in the design and implementation of standalone power supply systems for rural clinic application to improve rural health delivery.

Acknowledgement

The authors appreciate the efforts of Ministry of Higher Education, Malaysia and Bright Spark Unit of University of Malaya for providing enabling environment and financial supports under the University Malaya Research Grant (UMRG) no: RP006E-13ICT and High Impart Research (HIR) grant no: UM.C/HIR/MOHE/ENG/24.

References

[1] NREL, "Renewable Energy for Rural Health Clinics, ," USSeptember 1998 1998.

[2] Ohunakin OS, Adaramola MS, Oyewola OM, Fagbenle RO. Solar energy applications and development in Nigeria: drivers and barriers. Renewable and Sustainable Energy Reviews 2014; 32(294-301.

[3] Sambo AS. Strategic Developments in Renewable Energy in Nigeria. . International Association for Energy Economics 2009; 15 – 9.

[4] Ohunakin OS. Energy utilization and renewable energy sources in Nigeria. Journal of Engineering and Applied Sciences 2010; 5(2): 171-7.

[5] Olatomiwa L, Mekhilef S, Huda A, "Optimal sizing of hybrid energy system for a remote telecom tower: A case study in Nigeria," in *IEEE Conference on Energy Conversion (CENCON).* 2014, pp. 243-7.

[6] Hiendro A, Kurnianto R, Rajagukguk M, Simanjuntak YM. Techno-economic analysis of photovoltaic/wind hybrid system for onshore/remote area in Indonesia. Energy 2013; 59(652-7.

[7] Olatomiwa L, Mekhilef S, Huda A, Ohunakin OS. Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. Renewable Energy 2015; 83(435-46.

[8] Olatomiwa L, Mekhilef S, Ohunakin OS. Hybrid renewable power supply for rural health clinics (RHC) in six geo-political zones of Nigeria. Sustainable Energy Technologies and Assessments 2016; 13(1-12.

[9] Dihrab SS, Sopian K. Electricity generation of hybrid PV/wind systems in Iraq. Renewable Energy 2010; 35(6): 1303-7.

[10] NIMET. (2014). *Nigerian Meteorological Agency* Available: htttp://www.nimet.gov.ng

[11] Olatomiwa L, Mekhilef S, Shamshirband S, Petkovic D. Potential of support vector regression for solar radiation prediction in Nigeria. Natural Hazards 2015; 77(2): 1055-68.

[12] Duffie JA, Beckman WA, *Solar engineering of thermal processes*: John Wiley & Sons, 2013.

[13] Lang Y, Zargari N, Kouro S, *Power conversion and control of wind energy systems* vol. 74: John Wiley & Sons, 2011.

[14] USAID. (2014, 05/04/2014). *Powering Health*. Available: http://www.poweringhealth.org/index.php

[15] Olatomiwa L, Mekhilef S, Huda A, Sanusi K. Techno-economic analysis of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: the way forward for rural development. Energy Science & Engineering 2015.

[16] NREL. (2009). *HOMER*. Available: http://www.homerenergy.com

[17] Lambert T, Gilman P, Lilienthal P. Micropower system modeling with HOMER. Integration of alternative sources of energy 2006; 1(1): 379-85.

[18] Shamshirband S, Petković D, Saboohi H, Anuar NB, Inayat I, Akib S*, et al.* Wind turbine power coefficient estimation by soft computing methodologies: comparative study. Energy Conversion and Management 2014; 81(520-6.