Analysis of solar photovoltaic power system for health facility in Akwa Ibom State

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***Abstract*—Analysis of solar photovoltaic (PV) power system for health facility in AkwaIbom State is presented. The load demand profile of the facility is presented along with requisite mathematical expressions for the solar radiation and system components sizing. The system was simulated using PVSyst solar power simulation software. The simulation specification for the solar power system required a 5 days of autonomy and 5 % loss of load probability. The simulation results showed that the battery bank had 11800 Ah storage capacity at 48 V which amounts to 566kWh of stored energy. The PV array consists of 170 modules each with 200 watt rating which amounted to a total array power of 34 kWp. Also, the system annual energy production was 51518 kWh/year, with specific energy yield of 1515 kWh/kWp/year and performance ratio of 0.627 or 62.7 %. This means that about 37.3% of the energy produced per year was lost due to various system and PV module derating factors. Furthermore, the system has annual average loss of load probability (LOLP) of 0.17% and total of 15 hours annual loss of load duration (LOSD). The maximum LOLP occurred in February with a value of 0.74 % and LOLD of 5 hours. In all, the solar power system satisfied the maximum specified LOLP of 5 %.**

***Keywords*—Photovoltaic, Solar Power, Loss Of Load Probability, Loss Of Load Duration, Specific Energy Yield**

I. Introduction

Health facilities across Nigeria are mostly powered by standby fossil fuel electric generators [1,2,3,4,5,6]. This is because the electric power from the national grid is unreliable; in most cases the power is not available and when the power is available, in some cases, it is very poor in quality, such that it is not good enough to power some key equipment in the health facility [7,8,9]. However, as the cost of solar power continues to drop and the need for clean energy in health facility increases, some health facilities across Nigeria have begun to install solar powered systems to power some of their electrical appliances [10,11,12,13,14,15].

Accordingly, in this paper, the analysis of the solar photovoltaic (PV) power system for health facility in Uyo, Akwa Ibom State is presented. The study seeks to present requisite mathematical expressions that are used to select the key solar power systems, namely; the PV array and the battery bank. Furthermore, the study utilizes the popular PVSyst software [16,17,18] to simulate the standalone solar power system for the health facility based on the daily load demand profile and solar radiation data of at the health facility. Through the use of the e simulation software, key system performance parameters are generated with which the power system assessed. Particularly, the system energy yield, loss of load probability and loss of load duration are determined. These parameters are used to determine if the power system can satisfy the system daily load demand and for how long will it not be able to satisfy the load demand in a whole year. The reset of the paper presented that analytical expressions and simulation details used in the study.

II. Methodology

The health facility is Akwa Ibom state with a latitude and longitude of 5.029796, 7.942533 respectively. The daily load demand profile of the health facility is given in Table 1.

Table 1 The daily load demand profile of the health facility (Source : [19])

S/N	Appliance Description	Qty.	Rated Power (Watts)	Number of Hours Operated	Total Kwh per day
1	Blood bank Fridge	2	50	24	2.40
	Vaccine Fridge	2	80	12	1.92
2	Microscope	2	15	6	0.18
3	Operating Lamp	1	125	4	0.50
4	Syringe Pumps	2	600	1	1.20
5	Air conditioners	2	746	6	8.95
6	Lighting	56	100	12	67.20
7	Hematology Mixer	1	28	4	0.11
8	Incubators	2	400	7	5.60
9	Curing light	1	90	3	0.27
10	Microwave	1	700	3	2.10
11	Medical Centrifuge	1	578	3	1.73
12	Washing Machine	1	450	2	0.90
13	PC and Printer	2	120	6	1.44
14	TV	2	50	10	1.00
15	Drier	1	500	3	1.50
16	Ceiling Fan	6	100	8	4.80
17				Total Daily Energy Demand	99.41

There are three components of the solar radiation used in solar PV system sizing; they are; the Direct Horizontal Irradiance *(DHI)*, the Direct Normal Irradiance (*DNI*) and the Global Horizontal Irradiance (*GHI.* The effective radiation that is incident on the tiled plane of the PV module at any given time t is given in W/m^2as [20] ;

$$G_T = DHI * R_b + DHI * R_d + GHI * \rho * R_g \quad (1)$$

Where

$\rho$is the surrounding environment albedo factor.

*Rb*is the tilt factor for the beam component (DNI) of the solar radiation,

Rd is the tilt factor for the diffused component (DHI) of the solar radiation,

*Rg*is the tilt factor for the GHI of the solar radiation,

The cell temperature is (T_c) in °C is given as [20,21;

$$T_c = G_T\left(e^{(a_c+b_c*W_s)}\right) + T_a + \Delta T\left(\frac{G_T}{G_{ref}}\right) \quad (2)$$

where

$W_s$the wind speed (m/s),

$a_c$is the coefficient used to the upper limit for cell temperature . where$a_c = -3.56$ [21],

$b_C$is the coefficient that is used to determine the rate at which the PV temperature varies with wind speed.

$a_c$and $b_C$are empirically determined values, where $b_c = -.0750$[21],

G_{ref}isthe reference solar radiation at Standard Temperature Conditions (STC) .where G_{ref} =1,000 W/m^2.

$T_a$is the ambient temperature (°C),

$\Delta T$is the temperature difference between the cell and module's back surface, at $G_{ref}$where $\Delta T = 3$[21],

The power generated by the PV array is given as;

$$P_{PVA} = (P_{PVM})(N_{PVM})\left(\frac{G_T}{G_{ref}}\right)\left(1 + K_T\left(T_c - T_{ref}\right)\right)[1 - f_{loss}] \quad (3)$$

Where

$P_{PVM}$is the STC power rating of each module

$N_{PVM}$is the number of modules in the array

K_T is the temperature coefficient of power of the module

$T_{ref}$is the reference STC temperature

$f_{loss}$is the loss or de-rating factors associated with each module.

If $G_{T(t)}$is the effective hourly global radiation incident on the plane of the PV module, then the daily energy generated by the PV module per day, denoted as E_{PVD}, is given as [22];

$$E_{PVD} = \sum_{t=0}^{t=24}(P_{PVA}) = \sum_{t=0}^{t=24}\left((P_{PVM})(N_{PVM})\left(\frac{G_{T(t)}}{G_{ref}}\right)\left(1 + K_T\left(T_c - T_{ref}\right)\right)[1 - f_{loss}]\right) \quad (4)$$

$$E_{PVD} = (P_{PVM})(N_{PVM})\left[\sum_{t=0}^{t=24}\left(\left(\frac{G_{T(t)}}{G_{ref}}\right)\left(1 + K_T\left(T_c - T_{ref}\right)\right)[1 - f_{loss}]\right)\right] \quad (5)$$

For the study site, the hourly global solar radiation on optimally tilted plane of 8° is shown in Figure 1.

If the daily energy demand , denoted as is given along with P_{PVM}, then, then number os PV modules required, N_{PVM} is given as;

$$N_{PVM} = \frac{E_{PVD}}{(P_{PVM})\left[\sum_{t=0}^{t=24}\left(\left(\frac{G_{T(t)}}{G_{ref}}\right)\left(1+K_T\left(T_c-T_{ref}\right)\right)[1-f_{loss}]\right)\right]} \quad (6)$$

If the system voltage is V_{SYS}, the PV module voltage is V_{PV} , the number of PV module in series, N_{PVS} is given as

$$N_{PVS} = \frac{V_{SYS}}{V_{PV}} \quad (7)$$

The number of PV module in parallel, N_{PVP} is given as

$$N_{PVP} = \frac{N_{PVM}}{N_{PVP}} \quad (8)$$

The energy (E_{BAT}) in Wh to be stored in the battery bank is given as ;

$$E_{BAT} = \frac{(E_{PVD})N_{DA}}{(DOD)(\eta_B)(\eta_{inv})} \quad (9)$$

Where $N_{DA}$is the number of days of autonomy, $\eta_B$is the battery efficiency, η_{inv} is the inverter efficiency and DOD is the depth of discharge .

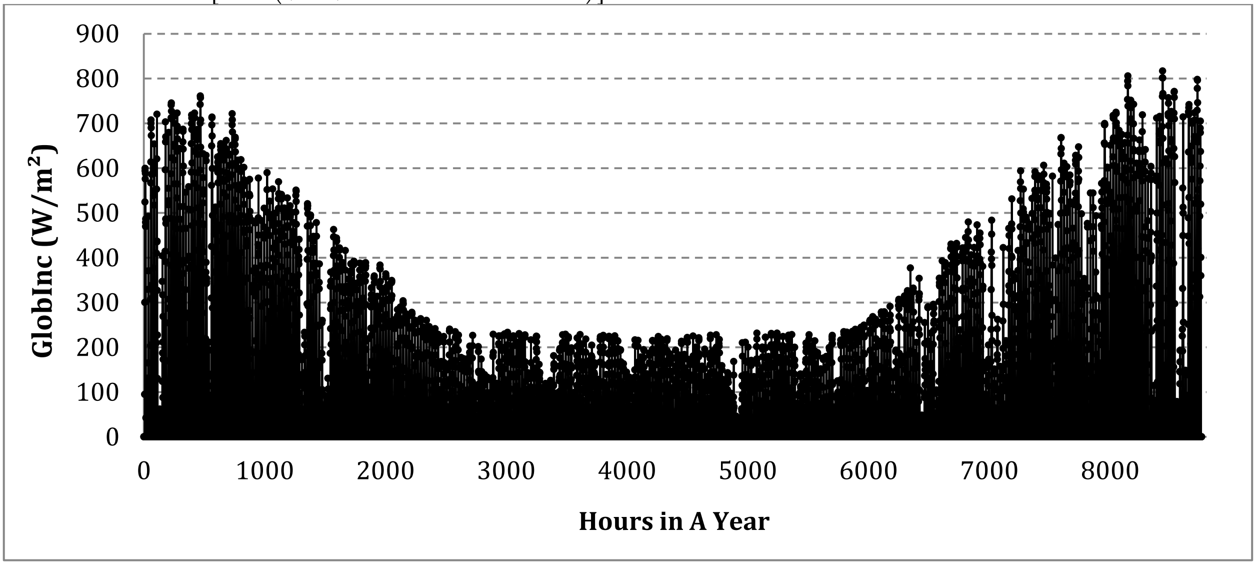

Figure 1: The hourly global solar radiation on optimally tilted plane of 8°

If the system voltage is V_{SYS}, the battery cell voltage is V_{CB} , the number of batteries in series, N_{BS} is given as [20,23]

$$N_{BS} = \frac{V_{SYS}}{V_{CB}} \quad (10)$$

If the battery cell capacity is Q_C , then the capacity of one string of battery in series in KWh, denoted as is Q_{string} is given as [20];

$$Q_{string} = \frac{N_{BS}(Q_C)(V_{CB})}{1000} \quad (11)$$

The battery capacity in ampere-hours, denoted as $B_C$is given as [23];

$$B_C = \frac{E_{BAT}}{V_{CB}} \quad (12)$$

The number of batteries $N_{BAT}$is given as [23]

$$N_{BAT} = \frac{B_C}{Q_C} \quad (13)$$

The number of batteries in parallel N_{BP} is given as;

$$N_{BP} = \frac{N_{BAT}}{N_{BS}} \quad (14)$$

III. Results and discussion

The PV power for the health facility is simulated using PVSyst .in the simulation, battery capacity is sized with 5 days of autonomy and maximum 5% loss of load probability. The LOLP, days of autonomy, selected PV and battery bank are shown in Figure 2. According to Figure 2, the battery bank has 11800 Ah storage capacity at 48 V which amounts to 566kWh of stored energy. The PV array consists of 170 modules each with 200 watt rating which amounted to a total STC array power of 34 kWp. The graph of the selected PV module efficiency versus temperature is shown in Figure 3. The graph shows that the efficiency of the cell at STC temperature of 25°C and solar radiation of 500W/m^2 is about 11% whereas at the same 500W/m^2 and cell temperature of 40°C the efficiency of the cell is about 10%. There is further drop in the efficiency of the cell as the cell temperature increases. This affects the energy yield of the solar power system.

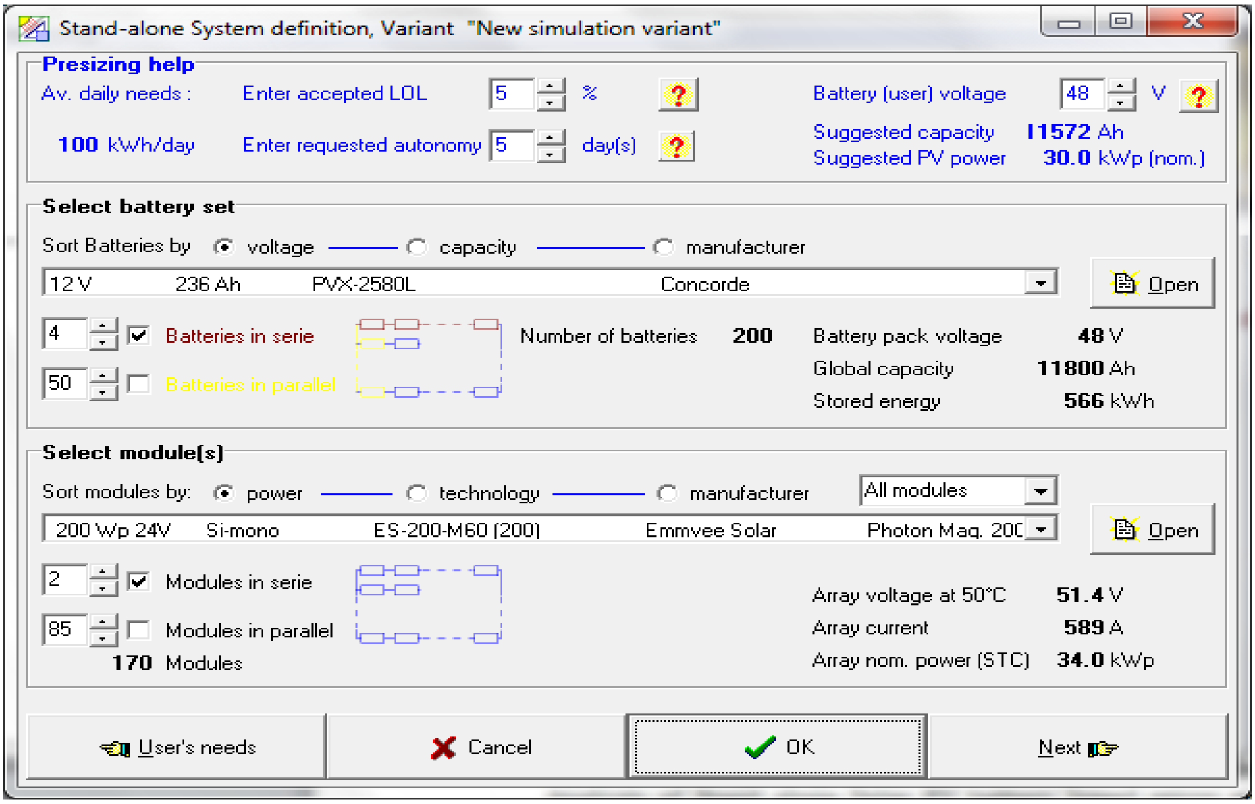

Figure 2; The LOLP, Days of Autonomy, Selected PV and Battery Bank

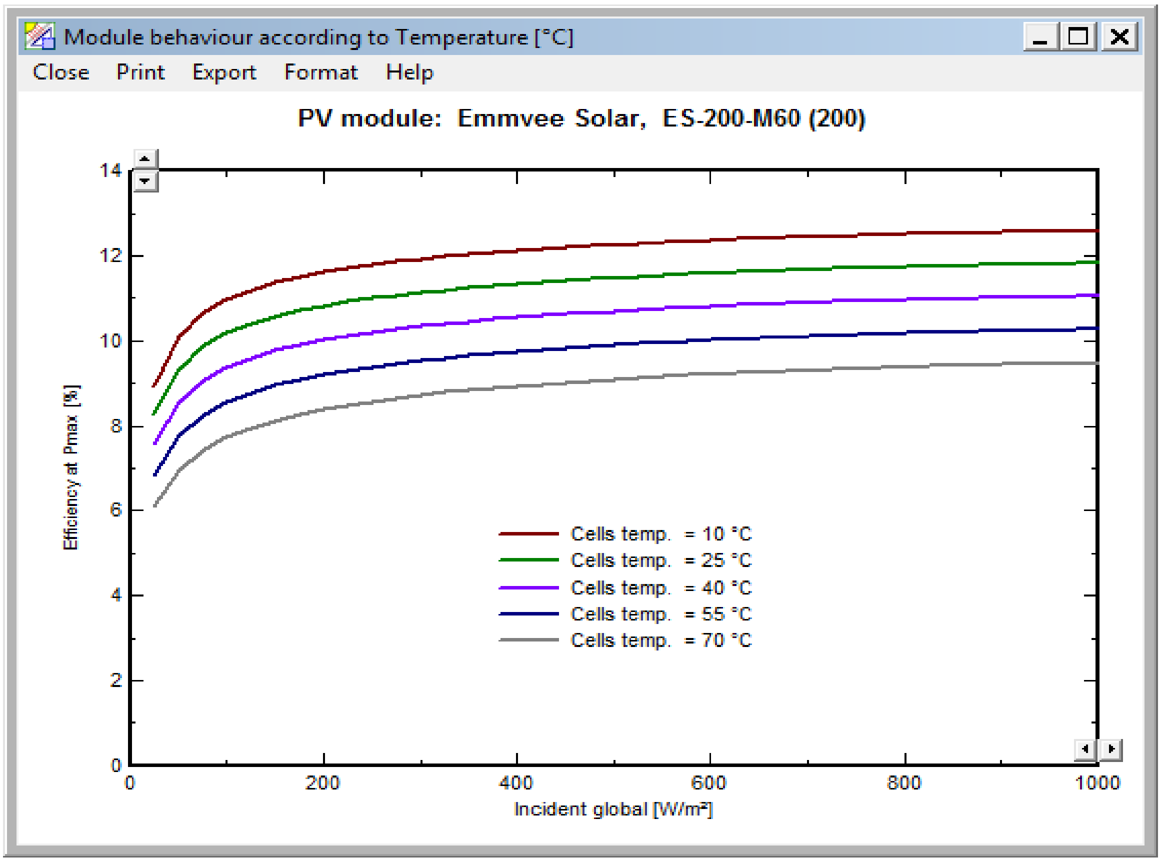

Figure 3 The graph of the selected PV module efficiency versus temperature

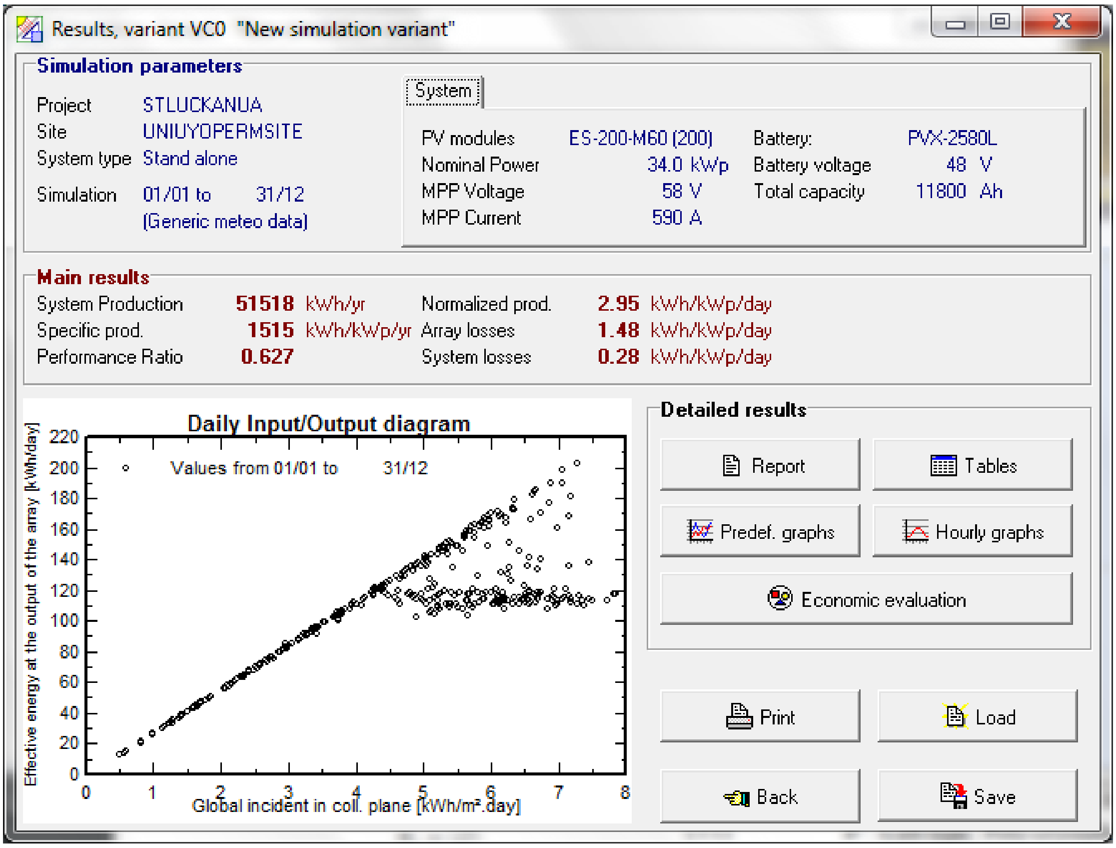

Figure 4 The main PVSyst result for the system

Table 2 The Energy use and loss of load table

Simulation variant : New simulation variant

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New simulation variant

Energy Use

	EArray kWh	E Load kWh	E User kWh	SolFrac	T LOL Hour	Pr LOL %
January	3645	3110	3108	0.999	2	0.27
February	3172	2809	2806	0.999	5	0.74
March	3446	3110	3108	0.999	3	0.40
April	3328	3010	3008	0.999	0	0.00
May	3382	3110	3108	0.999	1	0.13
June	3278	3010	3008	0.999	0	0.00
July	2966	3110	3109	1.000	0	0.00
August	3234	3110	3110	1.000	0	0.00
September	3278	3010	3010	1.000	0	0.00
October	3418	3110	3109	1.000	1	0.13
November	3428	3010	3007	0.999	2	0.28
December	3449	3110	3108	0.999	1	0.13
Year	40025	36620	36599	0.999	15	0.17

The PVSyst main result screenshot in Figure 4 shows that the system annual energy production is 51518 kWh/year, with specific energy yield of 1515 kWh/kWp/year and performance ratio of 0.627 or 62.7 %. This means that about 37.3% of the energy produced per year is lost due to various system and PV module derating factors.

Table 2 shows that the system has annual average loss of load probability (LOLP) of 0.17% and total of 15 hours annual loss of load duration (LOSD). This means that in a year with about 8760 hours , only in about 15 hours will the energy demand of the health facility not be satisfied. The maximum LOLP occurred in February with a value of 0.74 % and LOLD of 5 hours .In all, the solar power system satisfied the maximum specified LOLP of 5 %.

IV. Conclusion

Solar PV power system for a health facility in Uyo Akwa Ibom State is presented. The daily load demand of the health facility is determined along with the daily average solar radiation. The mathematical models for the determination of the key system components are presented and the system is simulated using PVSyst solar power system simulation software. The result showed that the solar power system will satisfy the stringent loss of load probability specified for health facility.

References

1. Osagie, I., Peter, I., Okougha, A. F., Umanah, I. I., Aitanke, F. O., &Fiyebo, S. A. B. (2016). Hazards Assessment Analyses of Fossil-fuel Generators: Holistic-study of Human Experiences and Perceptions in South-Southern Nigeria. *Journal of Sustainable Development Studies*, *9*(2).
2. Osueke, C. O., &Ezugwu, C. A. K. (2011). Study of Nigeria Energy resources and its consumption. *International Journal of Scientific & Engineering Research*, *2*(12), 121-130.
3. Oyedepo, S. O. (2013). Energy in perspective of sustainable development in Nigeria. *Sustainable Energy*, *1*(2), 14-25.
4. Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, *2*(1), 15.
5. Adair-Rohani, H., Zukor, K., Bonjour, S., Wilburn, S., Kuesel, A. C., Hebert, R., & Fletcher, E. R. (2013). Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability. *Global Health: Science and Practice*, *1*(2), 249-261.
6. Franco, A., Shaker, M., Kalubi, D., & Hostettler, S. (2017). A review of sustainable energy access and technologies for healthcare facilities in the Global South. *Sustainable Energy Technologies and Assessments*, *22*, 92-105.
7. Airoboman, A. E., Amaize, P., Ibhaze, A. E., & Ayo, O. (2016). Economic Implication of Power Outage in Nigeria: An Industrial Review. *International Journal of Applied Engineering Research*, *11*(7), 4930-4933.
8. Olaniyan, K., McLellan, B. C., Ogata, S., &Tezuka, T. (2018). Estimating Residential Electricity Consumption in Nigeria to Support Energy Transitions. *Sustainability*, *10*(5), 1440.
9. Ohajianya, A. C., Abumere, O. E., Owate, I. O., &Osarolube, E. (2014). Erratic Power Supply in Nigeria: Causes and Solutions. *International Journal of Engineering Science Invention*, *3*(7), 51-55.
10. Babatunde, E. (2007). Solar Energy, A Friendly Renewable Energy Option for Nigeria. *Solar Energy, A Friendly Renewable Energy option for Nigeria*, *1*(15).
11. Reid, G., & Wynn, G. (2015). The future of solar power in the United Kingdom. *Energies*, *8*(8), 7818-7832.
12. Timilsina, G. R., Kurdgelashvili, L., & Narbel, P. A. (2011). *A review of solar energy: markets, economics and policies*. The World Bank.
13. Franco, A., Shaker, M., Kalubi, D., & Hostettler, S. (2017). A review of sustainable energy access and technologies for healthcare facilities in the Global South. *Sustainable Energy Technologies and Assessments*, *22*, 92-105.
14. World Health Organization. (2014). *Access to modern energy services for health facilities in resource-constrained settings: a review of status, significance, challenges and measurement*. World Health Organization.
15. Owusu, P. A., &Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, *3*(1), 1167990.
16. Irwan, Y. M., Amelia, A. R., Irwanto, M., Leow, W. Z., Gomesh, N., &Safwati, I. (2015). Stand-alone photovoltaic (SAPV) system assessment using PVSYST software. *Energy Procedia*, *79*, 596-603.
17. Mermoud, A. (2012). Pvsyst: Software for the study and simulation of photovoltaic systems. *ISE, University of Geneva, www. pvsyst. com*.
18. Kandasamy, C. P., Prabu, P., &Niruba, K. (2013, December). Solar potential assessment using PVSYST software. In *Green Computing, Communication and Conservation of Energy (ICGCE), 2013 International Conference on* (pp. 667-672). IEEE.
19. Usman, R., & Barivure Sigalo, M. (2917) Analysis and Simulation of Electrical Load in

a Hospital Using Hybrid (Diesel/Solar) System as aBackUp. *Journal of Electronics and Communication Engineering Research Volume 3 ~ Issue 9 (2017) pp: 01-14*

20. Dash V., Rao, B. S. Sridhar, H. and Bharadwaj, M. D. (2018) Techno-Economic Analysis of Stand-alone Solar PV and Battery based Micro-grids in Karnataka. Technical paper of Center for Study of Science, Technology and Policy June, 2018 Available at:http://www.cstep.in/uploads/default/files/publications/stuff/CSTEP_report_Techno_Economic_Analysis_of_Stand_alone_Solar_PV_battery_based_micro_grids_in_Karnataka.pdf . Accessed on 12th January 2019.
21. King, D. L., Boyson, W. E., &Kratochvil, J. A. (2004). *Photovoltaic array performance model*. *Sandia Report No. 2004-3535*. Available at https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2004/043535.pdf. Accessed on 12th January 2019.
22. Omar, A. M., Hussin, M. Z., Shaari, S., &Sopian, K. (2014). Energy yield calculation of the grid connected photovoltaic power system. *Computer Applications in Environmental Sciences and Renewable Energy*, 162-167. Available at http://www.wseas.us/e-library/conferences/2014/Malaysia/RESEN/RESEN-24.pdf . Accessed on 12th January 2019.
23. Al-Shamani, A. N., Othman, M. Y. H., Mat, S., Ruslan, M. H., Abed, A. M., & Sopian, K. (2015). Design & sizing of stand-alone solar power systems a house Iraq. *Design & Sizing of Stand-alone Solar Power Systems A house Iraq Ali*, 145-150.