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Sizing and analysis of a standalone photovoltaics system for a three-bedroom residence in Nigeria

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ABSTRACT

The intermittency of electricity supply from conventional sources, increase in fuel prices and constant emission of greenhouse gases by non-renewable energy sources are major challenges faced by energy users. Energy from reneweable sources have advantages over the traditional (non-renewable) sources of energy. This paper presents the sizing and analysis of a standalone photovoltaic (PV) system for a 3-bedroom residence situated at Obollo-Nsukka (6.876°N, 7.403°E, 389 m) in Nigeria. The energy requirements of such a residence are 8.14 kWh/day and analysis have shown that the cost of constructing the PV system is ₦2,838,040 Nigeria naira (NGN). The cost of maintaining such a system within a lifetime of 20 years is between 159,328 NGN/year to 1,895,918 NGN/year. Comparing the levelized cost of energy (LCOE) of enugu electricity distribution company (EEDC) which is 66.5 NGN/kWh to the LCOE of the standalone PV system which is between 102,124 NGN/kWh to 419 NGN/kWh it was found out that the cost of electricity from the PV system is more than that of the conventional grid. The PV system provides feasible solution to the intermittency issues of the conventional grid in Nigeria. Hence, this technology only technically viable for residential electrification purposes in Nigeria.

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1. INTRODUCTION

The limited availability of electricity, increasing fuel prices and environmental effects of conventional energy sources has led to an increased awareness of renewable energy sources in the world today. Amongst these sources, photovoltaic (PV) technology is adaptable and flexible enough to be used to create off-grid electrical systems, making it perfect for isolated locations, vacation homes, and other places where grid connections are inaccessible [1]. Research has been carried out in different areas of the world to confirm the feasibility of off-grid PV systems as a viable energy source. The research conducted by [2], [3] shows that the unit cost of electricity produced using off-grid PV systems is lower than the unit cost of electricity charged in conventional electric supplies for residential areas in Pakistan. Oton *et al.* [4] explored load analysis and system design to assess the feasibility of implementing a stand-alone solar PV system for the school's electricity needs by focusing on Uyo High School in Nigeria. Adesanya and Schelly [5] assesses the economic viability of solar PV-DG hybrid systems among Nigerian private companies using the levelized cost of energy (LCOE) by using different load factors in HOMER pro.

Many studies carried out accesses the applications of solar power system, solar system components optimization, efficiency enhancement techniques, environmental and economic benefits and challenges associated with solar power systems. Ferrara *et al.* [6] outline the utilization of solar energy for small-scale concentrated solar power (CSP) implying the utilization of solar heat for electricity generation. The studies in [7]–[9] explores the application of solar power systems for rural electrification, water desalination and smart grid integration respectively. Ibrahim *et al.* [10] presents an optimization method for sizing a PV system using numerical algorithm. Salam *et al.* [11] developed an optimization simulation model using HOMER software which allows for the identification of the best result optimization, ensuring the system is optimized for maximum energy efficiency. Kumar [12] provides detailed discussions on selected simulation tools such as PV Watts, PV geographical information system (PVGIS), PV-Online, PV*SOL, PVsyst, and system advisor model (SAM), the study offers valuable insights into the capabilities, simulation procedures, and data requirements of each tool. Viveros *et al.* [13] presents a stochastic simulation model for sizing a standalone PV system to supply a dairy's power demand. The study demonstrates a substantial reduction in installed peak power and battery storage capacity (Bsc), indicating the potential for cost-effective PV system design in the dairy industry. Sun *et al.* [14] evaluates the potential performance of bifacial PV on a global basis. The study generates empirical design guidelines for bifacial solar modules, providing a framework for quickly evaluating location-specific performance. Haverkort *et al.* [15] highlights recent progress in nanophotonic engineering to enhance the open-circuit voltage (Voc) of nanowire solar cells, a critical factor in improving solar cell efficiency.

Another research focused on maximum power point tracking (MPPT) techniques based on fuzzy logic control (FLC) for microgrid standalone PV systems using a MATLAB-Simscape-based model for simulating a PV generator. This offers a valuable tool for researchers and engineers to analyse and optimize the behaviour of PV systems [16], [17]. The minimization of energy generation cost and enhanced battery life is achieved using the particle swarm optimization method [18]. Adhikari *et al.* [19] focuses on the design, control, and performance evaluation of a low power solar-PV energy generating system by assessing the system's performance under diverse conditions. Rajput and Sudhakar [20] presents experimental data that study the electrical performances of PV panels under the effect of deposited dust particles. Ajan and Kumar [21] used MATLAB/Simulink for modelling and performance analysis of both on-grid and off-grid PV systems. Ahmad *et al.* [22] provides a comprehensive overview of various MPPT techniques suitable for both full-sun and partial shading conditions, addressing a critical challenge in real-world PV systems. Satpathy *et al.* [23] investigates three widely used interconnection topologies (series-parallel, bridge-linked, and total cross tied) to identify an optimal configuration that can mitigate the effects of shading patterns on SPV arrays.

Baharwani *et al.* [24] highlights the significance of life-cycle analysis in evaluating the environmental profile of energy technologies, including PV systems. It acknowledges that while PV systems have no emissions during their operational phase, emissions do occur during the manufacturing and installation stages, contributing to the system's life cycle impact. The challenges of grid connectivity in the North East region of India is the studiedby exploring the feasibility of implementing hybrid renewable energy systems to address the power shortage faced by a large population in rural areas on a daily basis [25]. Peng *et al.* [26] focused on the life cycle assessment (LCA) of these PV systems, which involves evaluating their impact from production, to disposal. Arcos-Vargas *et al.* [27] focused on analysing the economic and environmental aspects of installing PV facilities for residential electricity users without storage and never feeding electricity into the utility network. Choi [28] explores the concept of floating PV systems and compares their generation efficiency with traditional land-based PV systems. An insights into the implications of PV technology and the benefits it brings in terms of generating energy, creating job opportunities and promoting prosperity [29].

An alternative solution that utilizes the centrifugal fans in building air conditioning and mechanical ventilation (ACMV) systems to dynamically compensate for the fluctuating solar generation due to the intermittent nature of solar PV has been proposed in [30]. Pal and Bhattacharjee [31] proposed a MATLAB/Simulink-based model for a standalone PV system to meet the energy requirements of a small rural community. Desmukh *et al.* [32] presents a bidirectional controller with DC-DC converters, which plays a crucial role in raising PV voltage, interfacing with battery backup, and optimizing energy flow in the standalone solar power system. Satpute *et al.* [33] analysed an 11.58 KW solar PV-based standalone system model using MATLAB/Simulink under various shunt faults and short circuit conditions providing valuable insights into the system's behaviour under fault conditions.

Bhattacharjee *et al.* [34] focuses on multiport converters, which are essential components for efficient integration of solar energy and batteries in a reliable and steady manner. The study reviews various multiport converter topologies, comparing their architectures, features, efficiency, and other specifications. Shafiullah *et al.* [35] reviews and discusses various technical challenges, such as power quality, stability, and fault ride-through capability, that arise during the grid integration of solar PV systems. Amongst the studies reviewed, valuable insights have been provided into various methodologies, technologies, and factors that influence the design of solar systems in residential settings. However, a notable gap in the literature has been identified regarding the lack of studies that specifically focus on Nigerian residential buildings as a case study. This paper examines the intricacies and barriers facing this region faces in implementing sustainable solar energy solutions for a three-bedroom residential building.

2. DESIGN AND ANALYSIS

The design of the PV system starts with the solar resource assessment. For this paper, the site intended for the system is (6°52'34.8"N 7°24'10.7"E) Nsukka, Nigeria. The solar resource assessment was carried out using the PVGIS. PVGIS is a free online tool developed by the european commission joint research centre (JRC) with the aim to provide data and information related to solar energy potential and PV system performance for various locations around the world. In this paper, the PVGIS feature of interest is the ‘solar radiation data’ which helps access the solar energy potential of a specified region. PVGIS provides the solar radiation data for different time periods (daily, monthly, and yearly) and different components of the radiation (direct, diffuse and global).

2.1. Energy demand estimation

The selected year is 2020 (for the location 6.876°N, 7.403°E) which is the most recent available data in all the solar radiation databases in PVGIS. From the monthly global horizontal irradiation and average temperature from the month of January to December 2020, the results from PVGIS are average daily global horizontal irradiation (Havg) is approximately 5.297 $kWhm^{-2}d^{-1}$ with yearly average temperature of 26.7 °C.

The energy requirements for the intended solar system design are to supply electricity per day. This process involves specifying the loads present in the building, their wattage and the amount of time they are to be used in a day. As illustrated in Table 1 the average daily load requirements (L) of a 3-bedroom residence in Nigeria is 8.14 kWh/d.

Table 1. Load requirements calculation

Appliance	Quantity	Power (W)	Total power (W)	Daily use (h)	Energy (Wh/d)
Bulbs (Indoor)	14	12	168	5	840
Bulbs (Outdoor)	6	15	90	12	1,080
TV	2	70	140	6	840
Fan	5	70	350	8	2,800
Fridge	1	100	100	24	2,400
DSTV	1	30	30	6	180
Total			878		8,140

3. SYSTEM ANALYSIS

The essential components of a standalone PV system such as the PV array, battery, charge controller and inverter are sized in this section. The next step in designing the system is to design a model of the system illustrating the connections between the various components of the system. The feasible block diagram model of the off-grid solar system for a 3-bedroom residence for this study is illustrated in Figure 1.

3.1. Sizing of PV array

To size the PV array, the required PV array area A_{PV} and the peak PV power $P_{P(PV)}$ are to be calculated. The calculations can be done with the (1)-(3);

$$A_{PV} = \frac{L}{Havg \times \eta_{pv} \times \eta_B \times \eta_I \times T_{CF}} \quad (1)$$

$$P_{P(PV)} = A_{pv} \times I_P \times \eta_{pv} \quad (2)$$

$$T_{CF} = 1 + (\propto \times (T_C - T_{STC})) \quad (3)$$

where;
L = required electric load in kWh/d; H_{avg} = average daily global horizontal irradiation in $kWhm^{-2}d^{-1}$; η_{PV} = efficiency of PV panel; η_B = efficiency of battery; η_I = efficiency of inverter; T_{CF} = temperature correction factor; I_p = peak solar irradiation; L = 8.14 $kWhd^{-1}$; H_{avg} = 5.297 $kWhm^{-2}d^{-1}$; I_P = 1,000 Wm^{-2}. Assuming, a temperature coefficient ($\propto$) of -0.5%/°C, standard test condition temperature (T_{STC}) of 25℃ and cell temperature (T_C) of 60℃, η_{PV} = 15%; η_B = 85% and η_I = 90%. The T_{CF} is 0.825; A_{PV} is 16.23 m^2 and $P_{P(PV)}$ = 2434.5 Wp. Considering the calculated maximum power of the required PV array (2434.5 Wp), the

"340 W_P EraSolar module (ESPSC340)" has been adopted for this study [36]. A total of 8 such modules are required to give the total maximum power of 2,720 watts which can reliably supply the necessary energy demand of the 3-bedroom residence.

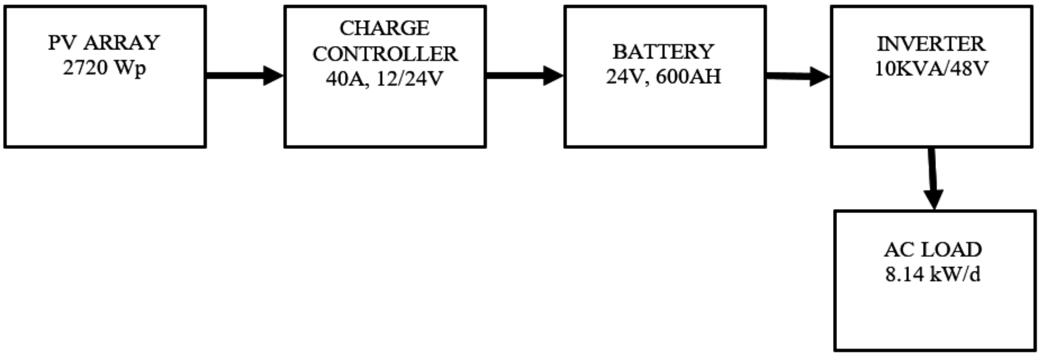

Figure 1. The block diagram model of off-grid solar system for a 3-bedroom residence

3.2. Sizing of battery

The Bsc can be calculated using the (4);

$$\text{Bsc} = \frac{Nccd \times L}{\eta_B \times \eta_I \times Dd} \quad (4)$$

where: Nccd is the number of continuous cloudy days; and Dd is the depth of discharge. Assuming; Nccd = 1; and Dd = 80%; Bsc is calculated to be 13300.65 Wh. For a DC bus voltage of 24 V, the required battery capacity is calculated to be 554.19 Ah. The battery selected for this study is "Forgo inverter deep cycle battery 12 V/200 Ah" [37]. A total of 6 such batteries will be required to meet the need of the PV system (24 V bus and 554.19 Ah capacity).

3.3. Sizing of charge controller

The required charge controller must be able to carry the short circuit current of the PV array. The short circuit current of the selected PV module is 9.45 A. Hence, the selected charge controller should be able to withstand 4×9.45 A which gives 37.8 A. The selected charge controller for this study is the "Epever 40 A 12/24 V MPPT solar charge controller" [38].

3.4. Sizing of inverter

The inverter rating should be capable of delivering the total energy requirements of the load instantaneously. For our study, the total load power is 878 W. By dividing the required load power by 0.8 (the nominal power factor) we would get the inverter's minimum kVA rating. Hence, the inverter should at least be 1.1 kVA. The selected inverter for this study is the "Felicity 10,000 kVA/48 V inverter" [39].

4. RESULTS AND DISCUSSION

The performance analysis of the systems is shown in Table 2 and Figure 2 respectively. The Figure 2(a) shows the normalized energy production in kWh while Figure 2(b) shows the performance ratio of the solar panels. This shows the potential of solar energy in Nigeria, seeing that there is more than enough energy to carter for the load requirements. It informs energy users on how well the installed system performs with regards to the generation of electricity to meet specified energy needs, its losses and battery performance. The solar fraction (SF) of 99.3% indicates that almost all the user's electrical needs are met using energy from the sun. The time fraction of 1.1 % indicates that for 0.011 of the period 20 years the system will not be all to fulfill the user's needs.

Table 2. Performance analysis results

System production	Results
Useful energy from solar	2949.66 kWh/year
Available solar energy	4227.73 kWh/year
Excess (unused) energy	1151.61 kWh/year
Performance ratio (PR)	56.95%
Solar fraction (SF)	99.28%
Loss of load	
Time fraction	1.1%
Missing energy	21.44 kWh/year
Battery aging (State of wear {SOW})	
Cycles SOW	84.4%
Static SOW	91.7%
Battery lifetime	6.4 years

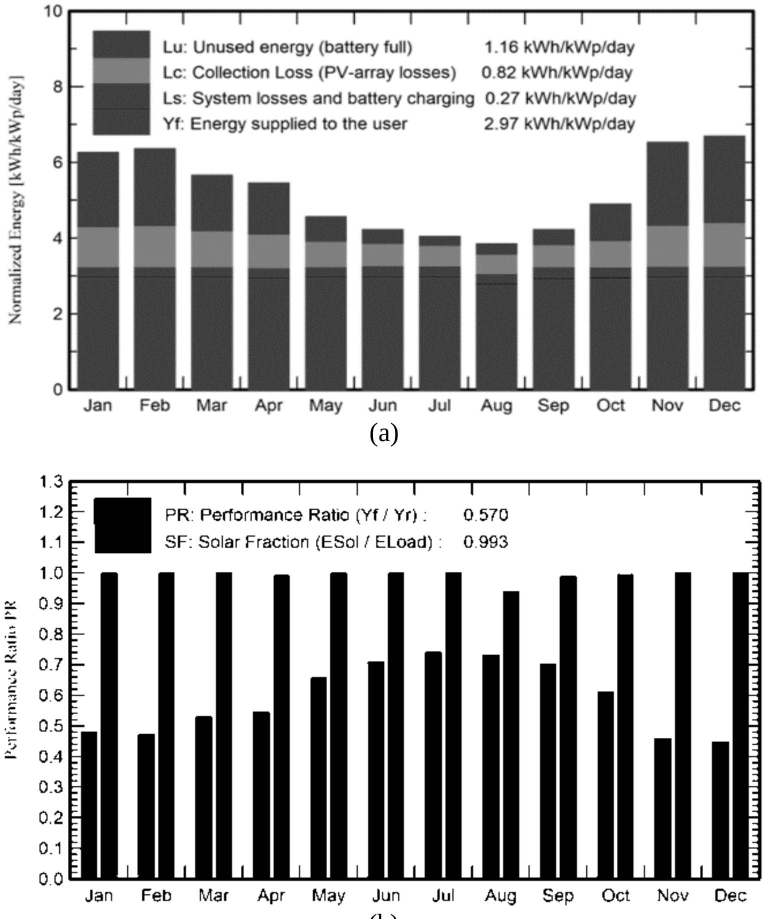

Figure 2. The performance analysis of a solar system with comparison in (a) normalized energy production in kWh and (b) performance ratio of the system

4.1. Economic impacts of solar systems installation

The economic analysis and implications of this research is geared towards calculating the investment cost (installation and maintenance costs), energy cost (from PV system), comparison between the retail rate by distribution companies and energy cost, and the return on investment (ROI). This was achieved by defining the variables inputted in the PVsyst software for the analysis. In the location for this project, the distribution company in charge is the enugu electricity distribution company (EEDC). The retail rate of EEDC as at July, 2023 is 66.47 NGN/kWh as shown in Table 3. Hence, the retail rate to be used for this analysis is 66.5 NGN/kWh. The lifespan of a PV module is typically 20-30 years. Hence the lifetime of the project is taken as 20 years. The battery lifespan was given in the performance analysis as 6.4 years, hence it is taken for the financial analysis that the lifetime of the battery is 5 years. The finstallation costs and maintenance costs used for the analysis are surmised in Table 4. The installation cost is assumed to be 10% of the total PV modules cost. The yearly operation costs refer to the amount of money it will take to keep the system operational throughout its lifetime (i.e., 20 years). This comprises of the salaries to the technicians performing maintenance checks on the system year after year and the amount of money it will take to change the battery system after a period of 5 years (i.e., the lifespan of the battery. The battery replacement cost is gotten from the installation costs and the salaries are assumed to be 2% of the total PV modules cost per year. The yearly operation costs are outlined in Table 5.

Table 3. Financial parameters of PV systems

Retail rate	Project lifetime	Start year	Battery lifetime	Finance source
66.5 NGN/kWh	20 years	2024	5 years	Personal Svaings

Table 4. Installation costs for PV systems

Description	Unit price (NGN)	Quantity	Total (NGN)
PV modules	118,300	8	946,400
Batteries	117,000	6	702,000
Controllers	145,000	1	145,000
Other (Inverter)	950,000	1	950,000
Installation cost	Approx. 10% of PV cost	1	94,640
Total			2,838,040

Table 5. Yearly operating costs of PV systems

Description	Cumulative cost (NGN)	Duration (year)	Yearly cost (NGN/year)
Salaries	378,560	20	18,928
Battery replacement	702,000	5	140,400
Total	3,186,560	20	159,328

4.2. Financial analysis of the 3-bedroom solar PV design

To account for the variation in yearly prices of goods, the financial analysis is carried out in two cases. Case A assumes there is no change in market prices within the 20-year lifetime period of the project. Case B uses the inflation and discount rates of Nigeria. The results of these cases are surmised in the Table 6.

The total installation costs cases A and B which is 2,838,040 NGN. The operating cost (operational expenditure OPEX) is susceptible to yearly change of market prices yearly hence it is different for cases A and B. The cost for case A is 159,328 NGN/year which for a 20-year period connotes a total of 3,186,560 NGN. The cost for case B is 1,895,917.75 NGN/year which for the system's lifetime connotes a total of 37,918,355 NGN. From this it can be seen that the components that requires the most capital for the system is the battery (as the operating costs is mostly comprised of the battery changing costs). It can also be established that the prices of goods are greatly affected by the state of the economy. This is a risk a potential investor in solar power systems should be aware of.

The LCOE takes into consideration the economic forces (i.e., future cash flow) by applying the discount rate. The (5) used by PVsyst to calculate the LCOE is;

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (5)$$

where:
I_t = investment and expenditures for the year (t), M_t = operational and maintenance expenditures for the year (t), E_t = electricity production for the year (t), r = discount rate that could be earned in alternative investments. n = lifetime of the system. The used energy cost for case A is 102,124 NGN/kWh while that of case B is 418.875 NGN/kWh. The tariff rate is the same for cases A and B which is 66.5 NGN/kWh. The payback period is the duration time required to recover the initial investment in the system with the system's lifetime. The payback period is unprofitable indicating that one wouldn't recover his/her initial investment within the project's lifetime as shown in Table 6. The recovered amount for the year is calculated by; Recovered amount for the year (t) = Net balance of year (t) + self-consumption saving for year (t)

The net present value (NPV) is determined as:

$$\text{NPV} = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \quad (6)$$

where;
R_t = Net balance (income-expenses) for the year (t).
i = Discount rate that could be earned in alternative investments.
n = The lifetime of the system.

The NPV of case A is-2,101,533.09 NGN while the NPV of case B is-5,563,574.10 NGN. The internal rate of return (IRR) is the ratio of the discount rate that makes the NPV of all cash flows equal to zero. The IRR of case A is-10.42% while the IRR of case B is 0%. The ROI is the ratio of the net benefit against the initial investment which measures system profitability. A negative ROI indicates that the system is not profitable.

$$ROI\ ratio\ = {Net\ benefit\ at\ the\ end\ of\ lifetime}/{Total\ investment} \quad (7)$$

The ROI for case A is-74% while for case B it is-196%. This indicates that for both cases the system is not profitable:

CASE A: Inflation rate: 0% Discount rate: 0%
CASE B: Inflation rate: 22% Discount rate: 18%

Table 6. Simulation result for both cases

Case A		Case B	
System summary	Prices	System summary	Prices
Total installation cost	2,838,040 NGN	Total installation cost	2,838,040 NGN
Operating costs	159,328 NGN/year	Operating costs (incl. inflation 22%/year)	1,895,917.75 NGN/year
Excess energy (battery full)	1150 kWh/year	Excess energy (battery full)	1150 kWh/year
Used solar energy	2950 kWh/year	Used solar energy	2950 kWh/year
Used energy cost	102,124 NGN/kWh	Used energy cost	418.875 NGN/kWh
EEDC tariff	66.5 NGN/kWh	EEDC tariff	66.5 NGN/kWh
Return on investment	Outcome	Return on investment	Outcome
Payback period	Unprofitable	Payback period	Unprofitable
	-2,101,533.09 NGN	NPV	-5,563,574.10 NGN
IRR	-10.42%	IRR	0.00%
ROI	-74%	ROI	-196.0%

5. CONCLUSION

Electricity utility bill (consumption tariff) is paid in most homes (homes connected to the grid) every year. These bills are issued on the rationale that a certain amount of electricity for a set period of time is worth an amount of money. Problems though still occur with regards to the frequency of electricity supply and the areas of grid coverage especially in the country Nigeria. This study, has attempted explore a solution to these problems through the sizing and analysis of an off-grid PV system for a residence in Obollo-Nsukka, Nigeria (6.876°N, 7.403°E, 389 m). The study presents the off-grid PV system as a feasible alternative for the conventional electrical power supply. From the analysis it can be seen that the cost for installing such a system is 2,838,040 NGN and the minimum maintenance amount is 159,328 NGN/year. It can also be seen from the analysis that the electrical tariff which is 66.5 NGN/kWh in comparison to the used energy cost of the PV system (102,124 NGN/kWh and 419 NGN/kWh for cases A and B respectively) is cheaper. It can also be observed that it is unprofitable financially to construct such a system.

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REFERENCES

[1] R. Raff, V. Golub, and J. Perko, "Comparative analysis of an off-grid PV system for different types of batteries," *International Journal of Electrical and Computer Engineering Systems*, vol. 9, no. 1, pp. 11–19, 2018, doi: 10.32985/ijeces.9.1.3.
[2] A. Ghafoor and A. Munir, "Design and economics analysis of an off-grid PV system for household electrification," *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 496–502, Feb. 2015, doi: 10.1016/j.rser.2014.10.012.

[3] M. Ali, A. Yousaf, and F. G. Seharan, "Feasibility evaluation of stand-alone photovoltaic systems for residential loads," in *2018 9th International Renewable Energy Congress, IREC 2018*, Mar. 2018, pp. 1–4, doi: 10.1109/IREC.2018.8362463.

[4] C. Oton, T. Iqbal, and S. John, "Load analysis and design of a stand-alone solar PV power system for a secondary school in Nigeria," Presented at Memorial University of Newfoundland, 2020.

[5] A. A. Adesanya and C. Schelly, "Solar PV-diesel hybrid systems for the Nigerian private sector: an impact assessment," *Energy Policy*, vol. 132, pp. 196–207, 2019, doi: 10.1016/j.enpol.2019.05.038.

[6] F. Ferrara, A. Gimelli, and A. Luongo, "Small-scale concentrated solar power (CSP) plant: ORCs comparison for different organic fluids," *Energy Procedia*, vol. 45, pp. 217–226, 2014, doi: 10.1016/j.egypro.2014.01.024.

[7] D. Palit, "Solar energy programs for rural electrification: experiences and lessons from South Asia," *Energy for Sustainable Development*, vol. 17, no. 3, pp. 270–279, Jun. 2013, doi: 10.1016/j.esd.2013.01.002.

[8] C. M. and A. Yadav, "Water desalination system using solar heat: a review," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 1308–1330, Jan. 2017, doi: 10.1016/j.rser.2016.08.058.

[9] A. Shahid, "Smart grid integration of renewable energy systems," *7th International IEEE Conference on Renewable Energy Research and Applications, ICRERA 2018*, pp. 944–948, 2018, doi: 10.1109/ICRERA.2018.8566827.

[10] I. A. Ibrahim, A. Mohamed, and T. Khatib, "Optimal modeling and sizing of a practical standalone PV/battery generation system using numerical algorithm," *2015 IEEE Student Conference on Research and Development, SCOReD 2015*, pp. 43–48, 2015, doi: 10.1109/SCORED.2015.7449372.

[11] M. A. Salam, A. Aziz, A. H. A. Alwaeli, and H. A. Kazem, "Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman," *International Journal of Renewable Energy Research*, vol. 3, no. 3, pp. 470–475, 2013.

[12] N. M. Kumar, "Simulation tools for technical sizing and analysis of solar PV systems," *6 th World Conference on Applied Sciences, Engineering and Technology*, no. September, pp. 26–27, 2017.

[13] P. Viveros, F. Wulff, F. Kristjanpoller, C. Nikulin, and T. Grubessich, "Sizing of a standalone PV system with battery storage for a dairy: a case study from Chile," *Complexity*, vol. 2020, pp. 1–17, Dec. 2020, doi: 10.1155/2020/5792782.

[14] X. Sun, M. R. Khan, C. Deline, and M. A. Alam, "Optimization and performance of bifacial solar modules: a global perspective," *Applied Energy*, vol. 212, pp. 1601–1610, Feb. 2018, doi: 10.1016/j.apenergy.2017.12.041.

[15] J. E. M. Haverkort, E. C. Garnett, and E. P. A. M. Bakkers, "Fundamentals of the nanowire solar cell: Optimization of the open circuit voltage," *Applied Physics Reviews*, vol. 5, no. 3, p. 031106, Sep. 2018, doi: 10.1063/1.5028049.

[16] R. Boukenoui, R. Bradai, A. Mellit, M. Ghanes, and H. Salhi, "Comparative analysis of P&O, modified hill climbing-FLC, and adaptive P&O-FLC MPPTs for microgrid standalone PV system," *2015 International Conference on Renewable Energy Research and Applications, ICRERA 2015*, pp. 1095–1099, 2015, doi: 10.1109/ICRERA.2015.7418579.

[17] G. S. Reddy, M. Premkumar, S. Ravi, and L. Abualigah, "An intelligent converter and controller for electric vehicle drives utilizing grid and stand-alone solar photovoltaic power generation systems," *International Journal of Applied Power Engineering*, vol. 12, no. 3, pp. 255–276, Jul. 2023, doi: 10.11591/ijape.v12.i3.pp255-276.

[18] V. A. Kusuma, A. A. Firdaus, S. S. Suprapto, D. F. U. Putra, Y. Prasetyo, and F. Filliana, "Leveraging PSO algorithms to achieve optimal stand-alone microgrid performance with a focus on battery lifetime," *International Journal of Applied Power Engineering*, vol. 12, no. 3, pp. 293–299, Jul. 2023, doi: 10.11591/ijape.v12.i3.pp293-299.

[19] N. Adhikari, B. Singh, and A. L. Vyas, "Design, control and performance analysis of a standalone solar-PV energy generating system," *International Journal of Renewable Energy Technology*, vol. 6, no. 1, p. 65, 2015, doi: 10.1504/ijret.2015.067517.

[20] D. S. Rajput and K. Sudhakar, "Effect of dust on the performance of solar PV panel," *International Journal of ChemTech Research*, vol. 5, no. 2, pp. 1083–1086, 2013.

[21] A. Ajan and K. P. Kumar, "Performance analysis of OFF-GRID solar photo voltaic system," in *2015 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2015]*, Mar. 2015, pp. 1–5, doi: 10.1109/ICCPCT.2015.7159350.

[22] R. Ahmad, A. F. Murtaza, and H. A. Sher, "Power tracking techniques for efficient operation of photovoltaic array in solar applications – a review," *Renewable and Sustainable Energy Reviews*, vol. 101, pp. 82–102, Mar. 2019, doi: 10.1016/j.rser.2018.10.015.

[23] P. R. Satpathy, S. Jena, and R. Sharma, "Power enhancement from partially shaded modules of solar PV arrays through various interconnections among modules," *Energy*, vol. 144, pp. 839–850, 2018, doi: 10.1016/j.energy.2017.12.090.

[24] V. Baharwani, N. Meena, A. Dubey, U. Brighu, and J. Mathur, "Life cycle analysis of solar PV system: a review," *International Journal of Environmental Research and Development*, vol. 4, no. 2, pp. 183–190, 2014, [Online]. Available: http://www.ripublication.com/ijerd_spl/ijerdv4n2spl_14.pdf.

[25] S. Bhakta, V. Mukherjee, and B. Shaw, "Techno-economic analysis of standalone photovoltaic/wind hybrid system for application in isolated hamlets of North-East India," *Journal of Renewable and Sustainable Energy*, vol. 7, no. 2, Mar. 2015, doi: 10.1063/1.4918792.

[26] J. Peng, L. Lu, and H. Yang, "Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems," *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 255–274, Mar. 2013, doi: 10.1016/j.rser.2012.11.035.

[27] A. Arcos-Vargas, J. M. Cansino, and R. Román-Collado, "Economic and environmental analysis of a residential PV system: a profitable contribution to the Paris agreement," *Renewable and Sustainable Energy Reviews*, vol. 94, pp. 1024–1035, Oct. 2018, doi: 10.1016/j.rser.2018.06.023.

[28] Y.-K. Choi, "A study on power generation analysis of floating PV system considering environmental impact," *International Journal of Software Engineering and Its Applications*, vol. 8, no. 1, pp. 75–84, Jan. 2014, doi: 10.14257/ijseia.2014.8.1.07.

[29] S. Dubey, N. Y. Jadhav, and B. Zakirova, "Socio-economic and environmental impacts of silicon based photovoltaic (PV) technologies," *Energy Procedia*, vol. 33, pp. 322–334, 2013, doi: 10.1016/j.egypro.2013.05.073.

[30] B. Sivaneasan, M. L. Lim, and K. P. Goh, "Overcoming solar PV intermittency using demand response management in buildings," *Energy Procedia*, vol. 143, pp. 210–215, Dec. 2017, doi: 10.1016/j.egypro.2017.12.673.

[31] A. Pal and S. Bhattacharjee, "Performance analysis of a standalone PV system under dynamic weather and loading conditions-a case study," in *2020 Fourth International Conference on Inventive Systems and Control (ICISC)*, Jan. 2020, pp. 256–260, doi: 10.1109/ICISC47916.2020.9171088.

[32] S. Deshmukh, A. R. Thorat, and I. Korachagaon, "Modelling and analysis of PV standalone system with energy management scheme," in *2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*, Jul. 2020, pp. 1–5, doi: 10.1109/CONECCT50063.2020.9198514.

[33] R. G. Satpute, S. B. Morey, P. A. Shende, and Y. B. Deshmukh, "Shunt faults analysis of solar PV-based ac standalone system," in *2019 International Conference on Innovative Trends and Advances in Engineering and Technology (ICITAET)*, Dec. 2019, pp. 73–78, doi: 10.1109/ICITAET47105.2019.9170218.

[34] A. K. Bhattacharjee, N. Kutkut, and I. Batarseh, "Review of multiport converters for solar and energy storage integration," *IEEE Transactions on Power Electronics*, vol. 34, no. 2, pp. 1431–1445, Feb. 2019, doi: 10.1109/TPEL.2018.2830788.

[35] M. Shafiullah, S. D. Ahmed, and F. A. Al-Sulaiman, "Grid integration challenges and solution strategies for solar PV systems: a review," *IEEE Access*, vol. 10, pp. 52233–52257, 2022, doi: 10.1109/ACCESS.2022.3174555.

[36] Solarkobo, "Era solar 340 W monocrystalline panel (Nigeria)," *https://www.solarkobo.com/*, 2022. https://www.solarkobo.com/product-page/era-solar-340w-monocrystalline-panel (accessed Oct. 21, 2023).

[37] "Forgo inverter deep cycle battery 12 V/200 Ah (Nigeria)." https://www.solarkobo.com/product-page/forgo-inverter-deep-cycle-battery-12 v-200 ah (accessed Oct. 21, 2023).

[38] "Epever 40 A 12/24 V MPPT solar charge controller (Nigeria)." https://www.solarkobo.com/product-page/epever-40a-12-24v-mppt-solar-charge-controller-nigeria (accessed Oct. 21, 2023).

[39] "10 kva felicity inverter." https://www.jumia.com.ng/felicity-10kva-felicity-inverter-257061912.html (accessed Oct. 21, 2023).

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