Modelling and Implementation of a Hybrid Renewable Energy System for a Stand-Alone Application
Harrison Oyibo Idakwo*1, P. I. Adamu2, V. Stephen3, I. Bello4

1Department of Electrical Engineering, University of Maiduguri, Borno State Nigeria
2Department of Electrical & Electronics Engineering, Airforce Institute of Technology, Kaduna State Nigeria
3Department of Electrical Engineering, Nigeria Army University Biu, Borno State, Nigeria
4School of Biomedical Engineering Technology UMTH, Maiduguri, Borno State Nigeria

I. INTRODUCTION
Rapidly developing modern energy systems incorporate significant contributions from renewable sources. The recent adoption of distributed generation sources and microgrids powered by renewable sources such as solar cells, tidal wind, and fuel cells is one of the primary causes of rising global energy demand. Integration of different energy sources into a hybrid system is envisioned as a viable solution for decentralized energy generation. Consequently, this study aims to integrate two energy sources with storage devices to construct a hybrid renewable energy system that will provide reliable electricity for remote and off-grid installations in the Sabon Gida Community of Kaduna State. This will contribute to the attainment of the seventh United Nations Sustainable Development Goal (Affordable and clean energy) (UN). This study utilized the Felicity PV panel. Its cell specifications are as follows: Peak power 175Wp, Open-circuit voltage (VOC) 21.6V, Maximum power current (Imp) 9.72A, Maximum power voltage (Vmp) 18V, short-circuit current (Isc) 10.2A, operating cell temperature (To) 25°C, and Idelity factor (Amp) 1.5. For the wind turbine, a model WT-400 with a rated power of 400W, 12V output voltage, and a wind controller with a standby current of 3.6mA, rated at 12/24V auto output voltage were utilized. The maximum power output of the PV energy model based on the specified weather variable was 620watts, whereas the maximum power output of the wind turbine energy model based on the selected wind speed was 301watts. Based on design calculations, the projected load demand for the location under consideration was 304 watts. The prototype was implemented, tested, and validated. The test results indicate that the output power was sufficient to fulfill the load requirements of the chosen location.

Keywords: HRES, PV, Wind Turbine, MPPT, MATLAB.

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fossil fuels and their resulting impact on the environment. In addition, solar and wind energy resources, which are significant renewable energy sources, are freely accessible worldwide [6, 10, 11]. Due to the variable nature of renewable energy sources, however, power generation from renewable energy systems is intermittent and difficult to implement [6, 12, 13].

Consequently, this study explores combining two renewable energy sources with a storage device to power remote and off-grid facilities. Renewable energy sources are abundant, eco-friendly, and infinite. Solar PV and a wind turbine were used as renewable energy sources (RES); VRLA batteries were used as energy storage due to Nigeria’s high solar and wind energy potential [14, 15]. Simulation and validation were done using MATLAB and Simulink. This HRES will aid in reaching the United Nations’ seventh sustainable development goal (affordable and clean energy) (UN) [16].

II. METHODOLOGY

Modelling and design were accomplished as follows:

All the components (wind turbine, generator, converter, and MPPT) that comprise the wind turbine model were initially modelled in MATLAB/Simulink respectively. The merging of the two (2) models in Table 1, 2 and 3 shows the hourly temperature, Irradiance, and wind speed recorded, respectively.

Table 1: Hourly Wind Speed in m/s of Sabon Gida Kaduna

| DH1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----|---|---|---|---|---|---|---|---|---|
| 1   | 6.3 | 5.7 | 4.9 | 5.2 | 6.7 | 6.4 | 5.2 | 4.9 | 6.7 |
| 2   | 5.1 | 4.3 | 3.2 | 4.7 | 6.8 | 5.7 | 4.5 | 3.6 | 5.6 |
| 3   | 6.2 | 5.3 | 4.1 | 3.4 | 6.4 | 5.9 | 4.7 | 3.8 | 5.6 |
| 4   | 6.1 | 5.3 | 4.1 | 3.4 | 6.4 | 5.9 | 4.7 | 3.8 | 5.6 |
| 5   | 5.8 | 5.1 | 4.5 | 3.6 | 6.1 | 5.8 | 4.5 | 3.6 | 6.1 |
| 6   | 5.7 | 5.3 | 4.2 | 3.4 | 6.3 | 5.7 | 4.5 | 3.6 | 5.6 |
| 7   | 5.6 | 5.1 | 4.5 | 3.6 | 6.2 | 5.6 | 4.5 | 3.6 | 5.6 |
| 8   | 5.5 | 5.2 | 4.3 | 3.5 | 6.1 | 5.5 | 4.5 | 3.6 | 5.6 |
| 9   | 5.4 | 5.1 | 4.5 | 3.6 | 6.1 | 5.5 | 4.5 | 3.6 | 5.6 |

R2022a. The PV model is then followed by its solar counterpart (i.e., PV array, converter, and MPPT).

The merging of the two (2) models into a hybrid model and linkage to an MPPT (maximum power point tracker) controller to track the operating point at which maximum power was generated. Using the Perturb and observe approach, the controller was designed.

Finally, the system was simulated with an integrated battery storage system and charge controller to meet demand when the renewable energy source is unavailable. The controller was also modelled to regulate the battery's charge level (SOC).

Data was sourced primarily from the chosen location (Sabon Gida, Kaduna state) in March 2022 (the month of conducting this project) by measuring the hourly windspeed, temperature and solar irradiance with the aid of an anemometer, thermometer and solar irradiance meter, respectively. These data sets were compared with some published works of [17] to observe the similarities.
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| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 31  | 30  | 29  | 28  | 27  | 26  | 25  | 24  | 23  | 22  | 21  | 20  | 19  | 18  | 17  | 16  | 15  | 14  | 13  | 12  | 11  | 10  | 9  |
| 8.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.7 | 8.8 | 8.9 | 9.0 | 9.1 | 9.2 | 9.3 | 9.4 | 9.5 |

| 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 |

| 4.7 | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 |

| 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1 | 6.2 | 6.3 | 6.4 |

| 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 |

| 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | 5.4 |

| 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 | 4.9 |

| 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 |

| 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 |

| 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 |

| 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 |

| 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 |

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Table 2: Hourly Temperature in °C of Sabon Gida Kaduna

| D/H | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|
| 00  | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 00  | 24.0 | 24.6 | 25.0 | 25.3 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 28.0 | 29.6 |
| 01  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 02  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 03  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 04  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 05  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 06  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 07  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 08  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 09  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 10  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 11  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 12  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 13  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 14  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 15  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 16  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 17  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 18  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 19  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 20  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 21  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 22  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 23  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
| 24  | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 27.0 | 27.0 | 32.0 |
Table 3: Hourly Irradiation in w/m² of Sabon Gida Kaduna

| Date |
|------|
| 1    |
| 2    |
| 3    |
| 4    |
| 5    |
| 6    |
| 7    |
| 8    |
| 9    |
| 10   |
| 11   |
| 12   |
| 13   |
| 14   |
| 15   |
| 16   |
| 17   |
| 18   |
| 19   |
| 20   |
| 21   |
| 22   |
| 23   |
| 24   |

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From table 3, it can be seen that irradiation was not recorded between the hours of 1 to 6 hours and 19 to 24 hours. These hours are normally the early morning hours and late-night hours. No appreciable solar irradiation is received (on the dark side) during these hours, so there is no appreciable reflection of short-wave radiation [18].

A. Materials

The following materials were used in this research: Fully licensed MATLAB/Simulink R2022a software, a 32/64-bit Computer, Weather data, Wind turbine, PV modules, an MPPT Charge controller, a Lithium battery, and an Inverter.

B. Modelling

i. PV Model

The models of a PV cell can be classified as follows: Single parameter model (5 parameter model), Double Diode Model (7 parameter model), Triple diode model, and Modified Single diode model[19-22].

In the context of this research, the single parameter model will be used, since the Module to be used for physical implementation is a 5-parameter type.

The Mathematical equation for modelling a PV module for a five (5) parameter model (i.e. \( I_{ph}, n, I_0, R_s, R_{sh} \)) from the diagram in Fig.1 is given in equation 1 to equation 6 [23-25].

The mathematical model of the PV current is given by equation (1)

\[
I = I_{ph} - I_0 \times \left[ \frac{q(V+I R_s)}{n K N_s T} \right] - I_{sh}
\]

(1)

Where I is the PV current, \( I_0 \) is the saturation current, \( I_{ph} \) is the photodiode current, q is the charge of electron, V is voltage, \( R_s \) is the series resistance, n is the Ideality factor of the diode, K is the Boltzman constant, \( N_s \) is the number of cells connected in series, T is the operating temperature and \( I_{sh} \) is the shunt current.

The mathematical model of saturation current is given by equation (2)

\[
I_0 = I_{rs} \times (T/T_n)^3 \times \exp \left( \frac{q E_{g0} (1/T_n - 1/T)}{n K} \right)
\]

(2)

Where \( I_0 \) is the saturation current, \( I_{rs} \) is the reverse saturation current, \( T_n \) is the nominal temperature, \( E_{g0} \) is the band gap energy of the semiconductor, T, q, n, K and T are the same parameters as in equation (1).

Furthermore, the reverse saturation current is given by the Mathematical model in equation (3)

\[
I_0 = I_s \times (T/T_n)^3 \times \exp \left( \frac{q E_{g0}}{n K} \times (1/T_n - 1/T) \right)
\]

(3)

Where \( I_0 \) is the saturation current, \( I_s \) is the reverse saturation current, \( T_n \) is the nominal temperature, \( E_0 \) is the band gap energy of the semiconductor, T, q, n are the same parameters as in equation (1).

The shunt current could be evaluated using the Mathematical Model is given in equation (4)

\[
I_{sh} = \frac{I + I R_s}{R_{sh}}
\]

(4)

Where \( I_{sh} \) is the shunt current, V is the PV voltage, I is the PV current, \( R_s \) is the series resistance and \( R_{sh} \) is the shunt resistance.

The mathematical Model of Photodiode current is given by equation (5)

\[
I_{ph} = \left( I_{sc} + \frac{K T}{n N_s K T_s} \right) \times G/1000
\]

(5)

Where \( I_{ph} \) is the photodiode current, \( I_{sc} \) is the short circuit current, T, is the temperature, and G is the irradiance.

The power generated by the PV module is given by equation (6)

\[
P_{pv} = \frac{P_{PV_{eff}} \times (P(PV_{rated}) \times (1 + k_t \times T_{cell} - T_{ref}))}{G_{ref}}
\]

(6)

Where \( P_{PV_{eff}} \) is the PV efficiency, \( P(PV_{rated}) \) is the rated power of the PV cell, \( G \) is the Irradiance, \( G_{ref} \) is the irradiance at reference point, \( k_t \) is the temperature coefficient, \( T_{cell} \) is the cell temperature and \( T_{ref} \) is the temperature at standard ref condition.

ii. Wind Model
The mathematical model for the wind turbine is given by the equations below:

The power law exponent is determined using the relation in the work of [9].

\[ \frac{V(Z_1)}{V(Z_2)} = \left( \frac{Z_1}{Z_2} \right)^p \]  

(7)

Where \( V(Z_1) \) and \( V(Z_2) \) are the mean wind speeds at measurement height \( Z_1 \) and new height \( Z_2 \) and \( p \) is the power law exponent.

From equation (7)

\[ p = \frac{\ln \left( \frac{V(Z_1)}{V(Z_2)} \right)}{\ln \left( \frac{Z_1}{Z_2} \right)} \]  

(8)

The power developed by the wind comes from the turbine and is given by equation 9 as reported by [26] [27].

\[ P_m = \frac{1}{2} C_p (\lambda, \beta) \rho A W^3 \]  

(9)

\[ \lambda = \frac{w_T}{V} \]  

(10)

\[ C_p = \frac{1}{2} \left[ \frac{116}{\lambda^2} - 0.4\beta - 5 \right] \exp^{\frac{-165}{\lambda}} \]  

(11)

\[ T_m = 0.5 \rho A C_p W / \lambda \]  

(12)

Where:

- \( C_p \) is fraction of kinetic, \( \lambda \) is the tip speed ratio of the rotor blade tip speed to wind speed, \( \beta \) is the blade pitch angle, \( \rho \) is the air density, \( A \) is the area, \( W \) is the wind velocity, \( V \) is the velocity and \( T_m \) is the wind turbine output torque.

C. Simulink Models

i. PV Energy Module

The Simulink model of the PV energy module is given in Fig. 2.

![Figure 2: Simulink Model of the Solar PV energy module](image)

ii. Wind Turbine Energy Module

Fig. 3 Shows the Simulink model of the Wind Turbine Energy System.

![Figure 3: Simulink Model of the Wind Turbine Energy System](image)
iii. Integration of the PV energy module and Wind Turbine Energy Module

The integration of the PV energy module and the wind turbine energy module was successfully carried out and is given in Fig. 4.

Figure 4: Integrated PV and WT Energy Model

D. Design Calculations for Physical Implementation of the Project

The design calculation is very important to be able to size each renewable energy source for the load demand of the selected location.

i. Load Demand for the Selected Location (Sabon Gida community, Kaduna State)

A survey was carried out in the selected study location (Sabon Gida community in Kaduna state) to determine the daily electricity demand need of each selected household. Ten households were randomly selected for this study and the daily demand need for each household was on averagely estimated to be 400Watts based on the electrical appliances available within this selected household. The design calculation in this study focuses on the load demand of a single household.

ii. Sizing of the HRES

The total energy consumption is estimated at around 1,360 watt-hours or 1.36 kilowatt-hours per day. However, accounting for safety factor, it is recommended to add 25%, to account for losses in the system, or the use of an extra electronic device not accounted for [10, 28]. Thus, the new estimated value would be:

1,360 watt-hours x 1.25 (25% extra) = 1700 watt-hours or 1.7 kWh.

b) Energy Consumption

Here, a list of the power consumption of all the electrical appliances and devices that will be used by a single household from the selected households with an estimate of how long each appliance or device is switched-on while using energy each day was carried out. The power consumption (in watts) of each device was then multiplied by the number of hours it is on to give the daily electrical consumption in watt-hours, as can be seen in table 2.

Table 2: Load demand of a selected household in the Sabon Gida community

| S/N | Appliance                        | Watts | Hours/Day | Watts hour/Day |
|-----|----------------------------------|-------|-----------|----------------|
| 1   | Two (2) 50W Ceiling Fan          | 100   | 5         | 500            |
| 2   | Colored LED TV                   | 70    | 5         | 350            |
| 3   | Three (3) 20watts DC bulb        | 60    | 4         | 240            |
| 4   | Outside Security Light           | 50    | 3         | 150            |
| 5   | Decoder Set                      | 24    | 5         | 120            |
|     | TOTAL                            | 304   | 22        | 1,360 Whrs     |

The integration of the PV energy module and the wind turbine energy module was successfully carried out and is given in Fig. 4.
most of the day, such as from 9 am to 3 pm [29]. According to earlier studies, the cold season has the lowest solar insolation, with only four hours of daily daylight. [30-33]. Therefore, the total peak hours generated by the sunlight will be \( (1,360/4) = 340 \) Watts Peak or 340Wp.

d) Number of Solar Panel

Solar panels can have different voltage ratings depending upon their construction and size. It comes in 12V or 24V. In the context of this work, a 12V, 175Wp solar panel was used. The total number of solar panels \( (N_p) \) will be

\[
N_p = \frac{\text{total peak hour generated by the sunlight}}{\text{Solar panel power rating}} = \frac{340\text{Wp}}{175\text{Wp}} = 2
\]

e) Sizing of Battery

Recall that the amount of energy consumed per day was calculated as 1,360Whrs. This is the minimum amount of storage capacity required for a day. The number of days of battery back-up required is an essential factor. This is called “Autonomy”.

A standard number of autonomy days are usually 2 to 5 days [28]. Then the total amount of energy required for a minimum of two (2) days of storage for the selected household that consumes 1360 watt-hours daily is calculated as follows:

Appliances use 1360 Watt-hours/day, nominal battery voltage = 12 volts, days of autonomy will be 2 days and efficiency = 85%.

Battery capacity = \( (1360 \times 2)/ (0.85 \times 12) = 270\text{AH} \)

The total ampere-hours required is therefore 270Ah or greater of battery capacity at 12 volts.

f) Sizing the Solar Charge Controller

The solar panels above have a short circuit current (Isc) of 10.2A. The solar charge controller rating will therefore be:

2 solar panels with rated current of 10.2A each = 2 x 10.2 x 1.2 = 24.48 A or 30A.

The value 1.2 used here is the industry standard for excesses [28].

For this research, a 12/24V, 50A charge controller was used.

g) Sizing the Inverter

Recall that the total appliance wattage was 304W. For safety, the inverter should be considered 20-25% bigger in size. 25% of 304W = 76watts. Therefore, the inverter should be 400Watts with an input voltage of 12 volts. In the context of this research, a 12volt, 1000watts inverter was selected based on availability.

h) Sizing the Wind Energy Source

A 400 watts’ wind turbine was selected for the study based on the loading, cost and availability. The 400 watts’ wind turbine used alongside the selected inverter rating can supply the needed power that will be enough to satisfy the load demand (304watts) of the selected household.

E. Physical Implementation of the Integrated PV and Wind models

All the components were tested to confirm their workability and to ensure they were the selected ratings before the physical implementation was carried out as can be seen in Fig. 5.

Figure 5: Physical Implementation of the Integrated Prototype

The rating of the PV panel is presented in Fig. 6, while that of the wind turbine given in Fig. 7.
III. RESULTS AND DISCUSSION

The waveform of the PV characteristics is shown in Fig. 9a to confirm the workability of the PV energy system. It can be seen from the waveform that as irradiance is increased, the battery state of charge (SOC), the PV power, battery voltage and battery current increases, likewise in the same manner as irradiance is decreased, the battery state of charge (SOC), the PV power, battery voltage and battery current drops, satisfying the normal working condition of a solar panel [34]. This indicates that the state of charge (SOC) of the battery, the PV power, the battery voltage and the battery current are solely dependent on the amount of irradiation on the solar PV cell which in turn has a significant impact on the power quality of the output of the PV system as can be seen in the work of [35].

As stated earlier, the MPPT was designed using the perturb and observe algorithm. The output characteristics of the meteorological data (irradiance, and temperature) for the PV energy system and the hourly power generation for 31 days (744 hours) of the month of March is shown in Fig. 9b. The waveform of some of the wind characteristics is shown in Fig. 10a and 10b.
Figure 9a: Output Characteristics of the PV energy system

Figure 9b: Output characteristics of the Hourly Irradiance, Temperature and Generated PV Power

Figure 10a: Output characteristics of the Wind Energy System
It can be observed from Fig. 10b that as the wind energy speed is increased, power also increases, which verifies the workability of the model. This is so because wind speed largely determines the amount of electricity generated by a turbine. Higher wind speeds generate more power because stronger winds allow the blades to rotate faster. Faster rotation translates to more mechanical power and more electrical power from the generator [5, 11, 13]. Furthermore, it could be observed from Fig. 10a that the maximum power output for the wind turbine is 301 watts. Whenever there is an increase in the wind energy voltage, there is a corresponding increase in wind energy current and a corresponding increase in wind energy power. Similarly, whenever there is a decrease in the wind energy voltage, there is a corresponding decrease in the wind energy current and a corresponding decrease in the wind energy power.

Recall that the maximum power output from the simulated PV energy model based on the selected weather variable was 620 watts, while the maximum power output from the simulated wind turbine energy model was 301 watts subject to the selected wind speed, as can be seen from the graphs. The estimated load demand of the study location was 304 watts. The results of these tests show that the output power is enough to meet the load requirements of the chosen location.

IV. CONCLUSION

Modelling, simulation and physical implementation of a hybrid PV and Wind energy system for remote village application was presented in this work. The system was simulated within MATLAB/Simulink environment before a prototype was physically implemented. A remote location within the Sabon Gida community of Kaduna Stated was chosen as a case study. Ten households’ data were taken for reference purposes and the average load of a single household was used. An estimated load of 304W for a single household was arrived at. Results obtained confirmed the workability of the system. The output power from the simulated PV energy model was 620 watts, while that of the Wind Turbine energy model was 301 watts. These power outputs were adequate to meet the load requirement of the selected location capped at 304W.

AUTHOR CONTRIBUTIONS

H.O. Idakwo: Conceptualization, Methodology, Software, Validation, writing – original draft, Writing – review & editing. P.I. Adamu: Supervision, writing – original draft, Writing – review & editing. V. Stephen: review and editing. I.S. Bello: review and editing

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