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Original Research Article

Modelling and Implementation of a Hybrid Renewable Energy System for a Stand-Alone Application

Harrison Oyibo Idakwo[1*], P. I. Adamu[2], V. Stephen[3], I. Bello[4]

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

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***Corresponding author:** Harrison Oyibo Idakwo
Department of Electrical Engineering, University of Maiduguri, Borno State Nigeria

Abstract

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 175_{Wp}, Open-circuit voltage (V_{OC}) 21.6V, Maximum power current I_{mp} 9.72A, Maximum power voltage V_{mp} 18V, short-circuits current I_{sc} 10.2A, operating cell temperature T_c 25^0C, and Ideality factor A_m 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 fulfil the load requirements of the chosen location.

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

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I. INTRODUCTION

Rapidly developing renewable energy sources play significant roles in the current energy system. Globally, distributed energy generation (DG) is increasing [1, 2]. Market deregulation and environmental consequences are driving the increased usage of DGs [3]. Decentralized, adaptable distributed generation systems are proximate to the load they service. Distributed power generation uses renewable energy sources like solar, wind, hydro, geothermal, bioenergy, ocean, and cogeneration. Renewable sources are environmentally friendly [1]. 4.2 to 8.9% of the energy is wasted during transmission from the power plant to the consumer in a conventional power system [2]. Variations in voltage and current flow can also cause poor energy quality, disruptions, etc. The incorporation of different energy sources into a hybrid system is envisioned as a viable solution for decentralized energy generation [3, 4].

Hybrid renewable energy systems (HRES) utilize either a renewable energy source and one conventional energy source, or many renewable energy sources with or without a conventional energy source [5, 6]. As far as can be determined, there are several strategies for integrating alternate energy sources into HRES. These methods have been categorized into two broad categories: AC and DC Couplings [1, 6-9].

Researchers are now focused on non-conventional energy sources such as photovoltaic cells (PV), wind, hydro, etc. due to the rapid depletion of 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 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.

Tables 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

D/H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	5.5	5.2	4.1	3.9	3.3	3.8	3.1	2.9	2.7	3.0	2.8	2.7	2.9	2.4	2.1	2.2	1.9	1.8	1.6	1.9	2.2	2.4	2.5	2.7
2	5.0	4.2	3.4	1.8	2.2	2.6	3.4	3.4	3.4	3.6	3.8	2.8	1.4	1.2	1.2	0.8	1.6	2.4	2.6	3.0	4.5	3.8	4.7	4.6
3	6.9	5.8	3.7	2.9	3.2	4.4	4.7	5.7	4.9	6.7	7.5	5.4	4.2	6.3	4.2	5.3	4.9	2.9	2.7	3.1	1.9	1.5	2.1	2.3
4	5.1	5.7	4.5	3.7	4.6	5.6	5.9	7.5	6.4	6.3	7.2	4.7	4.9	4.3	2.9	3.1	2.7	2.9	3.4	4.1	3.1	2.4	3.4	4.4
5	7.2	6.2	5.6	6.8	6.2	5.9	7.1	2.9	3.4	3.8	5.6	4.9	3.6	5.3	4.4	5.6	4.9	6.4	5.9	6.1	7.2	5.4	3.6	4.1
6	6.4	4.7	4.3	4.7	5.3	4.1	4.3	3.6	3.1	4.3	4.2	5.1	5.4	7.1	6.4	8.9	6.7	7.4	6.5	6.1	5.7	5.3	3.4	3.9
7	9.3	7.3	4.5	3.2	3.7	4.9	5.4	5.3	4.5	7.1	7.2	3.9	4.4	5.6	2.9	2.1	4.3	3.2	3.8	3.7	4.1	3.9	2.7	3.0
8	7.8	5.7	4.9	4.3	5.1	6.4	3.8	2.9	3.1	3.3	2.7	2.9	2.5	2.4	2.3	2.5	2.4	2.5	2.7	3.1	3.3	3.5	3.0	2.9
9	6.3	4.9	4.7	5.2	6.7	7.1	6.3	4.9	5.4	3.4	3.9	3.3	4.5	5.4	5.1	3.5	3.9	3.2	3.1	2.9	3.0	2.7	2.6	2.4

10	5.8	4.7	5.1	3.7	4.8	4.4	4.6	5.1	4.3	5.2	4.8	3.9	3.3	3.4	3.1	2.9	2.7	2.4	2.9	2.6	2.5	2.1	2.3	2.1
11	7.1	6.3	3.7	3.4	3.5	2.9	4.1	4.5	4.7	4.1	4.6	4.4	4.2	5.4	5.1	5.9	5.0	5.3	5.1	4.4	4.2	3.4	3.1	2.9
12	8.6	5.4	5.3	5.1	5.2	5.4	5.9	6.1	6.7	7.2	4.5	4.6	3.7	3.1	2.9	3.0	3.1	3.1	2.9	3.0	2.4	2.2	2.7	2.9
13	10.6	8.3	9.4	10.4	7.4	7.1	6.8	4.3	3.2	2.4	5.4	5.6	4.3	3.4	5.3	6.2	3.9	3.4	5.2	4.5	5.4	2.9	5.1	3.4
14	5.9	5.6	7.6	6.7	4.9	4.1	3.5	6.3	3.5	4.4	5.4	6.2	4.8	5.6	4.5	5.6	8.7	4.3	2.9	2.1	2.2	2.4	2.7	2.3
15	6.5	5.1	3.4	4.4	5.3	3.2	4.5	5.6	3.5	3.4	4.5	4.7	6.4	3.9	4.5	4.6	5.6	4.7	3.1	4.2	3.5	3.9	3.2	2.0
16	7.1	4.8	3.8	3.7	5.7	5.4	4.6	4.7	4.8	3.4	3.9	3.7	4.5	4.5	4.7	4.3	4.4	3.4	5.3	3.9	4.8	5.1	3.7	2.9
17	9.1	6.5	4.5	4.7	5.7	5.6	4.9	7.5	7.3	7.2	4.3	4.7	5.6	6.4	5.4	4.7	3.8	4.9	5.4	6.1	3.9	4.5	3.5	2.8
18	6.4	3.7	4.5	4.7	4.4	3.6	5.6	5.7	4.5	5.6	3.9	5.7	4.8	8.9	4.5	7.3	4.3	4.2	3.9	3.1	2.9	2.7	2.6	2.8
19	7.5	6.7	6.9	7.3	7.4	8.1	5.3	4.9	4.7	4.9	4.1	3.9	3.5	3.6	3.3	3.7	3.5	3.7	3.8	3.5	5.6	3.4	3.7	2.9
20	9.3	7.8	7.5	8.3	7.8	6.7	5.4	3.9	4.6	4.4	3.4	4.5	3.9	4.2	3.7	4.5	4.1	2.7	2.9	3.1	2.8	2.7	2.8	2.1
21	4.9	4.2	4.3	3.4	6.5	5.6	4.3	4.5	3.9	4.1	2.9	4.1	3.4	3.2	4.3	5.1	2.9	4.3	3.4	3.3	2.9	4.1	3.1	2.9
22	8.3	6.3	4.8	5.1	3.9	3.4	5.1	2.9	2.8	2.7	3.4	3.1	4.3	3.5	4.5	3.4	4.1	2.9	2.7	2.8	3.1	2.9	2.0	1.9
23	6.7	5.6	4.3	4.5	4.1	3.8	3.3	2.9	3.1	4.3	4.1	3.9	4.1	3.4	3.7	3.5	2.7	2.7	3.1	2.2	2.4	2.8	3.0	3.2
24	7.5	5.9	7.4	7.1	6.8	4.3	3.2	2.4	5.4	5.6	4.3	3.4	5.3	6.2	3.9	3.4	5.2	4.5	5.4	2.9	5.1	3.4	2.4	2.1
25	5.4	4.2	3.7	3.4	3.5	2.9	4.1	4.5	4.7	4.1	4.6	4.4	4.2	5.4	5.1	5.9	5.0	5.3	5.1	4.4	4.2	3.4	3.1	2.5
26	8.3	7.2	3.4	4.4	5.3	3.2	4.5	5.6	3.5	3.4	4.5	4.7	6.4	3.9	4.5	4.6	5.6	4.7	3.1	4.2	3.5	3.9	3.2	2.1
27	7.4	6.7	4.5	4.7	5.7	5.6	4.9	7.5	7.3	7.2	4.3	4.7	5.6	6.4	5.4	4.7	3.8	4.9	5.4	6.1	3.9	4.5	3.5	2.8
28	7.6	5.7	7.4	7.1	6.8	4.3	3.2	2.4	5.4	5.6	4.3	3.4	5.3	6.2	3.9	3.4	5.2	4.5	5.4	2.9	5.1	3.4	2.4	2.1
29	8.3	7.4	7.5	8.3	7.8	6.7	5.4	3.9	4.6	4.4	3.4	4.5	3.9	4.2	3.7	4.5	4.1	2.7	2.9	3.1	2.8	2.7	2.8	2.1
30	6.1	4.5	4.3	4.5	4.1	3.8	3.3	2.9	3.1	4.3	4.1	3.9	4.1	3.4	3.7	3.5	2.7	2.7	3.1	2.2	2.4	2.8	3.0	3.2
31	5.3	4.7	5.4	5.3	5.1	5.2	5.4	5.9	6.1	6.7	7.2	4.5	4.6	3.7	3.1	2.9	3.0	3.1	3.1	2.9	3.0	2.4	2.2	2.7

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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**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	27.0	26.0	25.0	24.0	24.0	24.0	25.3	26.6	28.0	30.0	32.0	34.0	34.3	34.7	35.0	33.6	32.3	28.0	25.0	19.0	21.0	21.5	22.0	21.0
2	25.0	24.6	24.3	24.0	23.6	23.3	23.0	24.3	25.7	27.0	29.7	32.3	35.0	31.3	35.7	32.0	26.0	28.0	25.3	22.7	20.0	19.3	19.0	19.2
3	24.	23.	22.	22.	22.	22.	22.	22.	23.	24.	31.	33.	34.	24.	33.	31.	23.	25.	27.	25.	24.	27.	20.	20.
4	25.0	23.3	22.7	22.0	22.0	22.0	23.0	24.3	25.7	27.0	32.2	34.0	32.0	30.3	34.7	31.0	29.6	28.3	26.0	26.0	25.0	24.3	22.0	21.0
5	25.0	24.67	24.3	24.0	23.6	23.3	23.0	24.0	25.0	26.0	29.6	31.3	31.0	29.7	32.3	33.0	26.3	25.67	26.0	25.0	25.0	23.2	22.0	22.3
6	25.0	24.6	27.7	28.3	26.7	27.7	29.4	29.0	29.0	29.2	30.1	32.3	33.0	33.0	33.9	31.8	27.0	27.2	28.3	27.7	26.5	26.7	25.7	26.2
7	23.0	24.67	24.3	24.0	23.6	23.3	23.0	24.0	25.0	26.0	29.6	31.3	31.0	29.7	32.3	32.0	26.3	25.67	26.0	25.0	25.0	23.2	22.0	22.3
8	23.0	26.0	25.0	25.6	24.0	24.0	25.3	26.6	28.0	30.0	32.0	34.0	34.3	34.5	33.9	29.8	27.0	27.2	28.3	27.7	26.5	26.7	25.7	26.2
9	23.0	24.67	24.3	27.2	23.6	23.3	23.0	24.0	25.0	26.0	29.6	32.3	35.0	31.3	35.7	28.0	26.0	28.0	25.3	22.7	20.0	19.3	19.0	18.9
10	23.0	24.6	24.3	24.0	23.6	23.3	23.0	24.3	25.7	27.0	29.7	32.3	35.0	31.3	35.7	28.0	26.0	28.0	25.3	22.7	20.0	19.3	19.0	19.2
11	25.0	26.0	25.0	23.2	24.0	24.0	25.3	26.6	28.0	30.0	32.0	34.0	34.3	34.7	35.0	33.67	32.3	28.0	25.0	19.0	21.0	21.5	22.0	21.0
12	26.0	26.0	25.0	24.0	24.0	24.0	25.3	26.6	28.0	30.0	32.0	31.3	31.0	29.7	32.3	27.0	26.3	25.67	26.0	25.0	25.0	23.2	22.0	22.3
13	22.0	24.6	24.3	27.2	23.6	23.3	23.0	24.3	25.7	27.0	29.7	32.3	35.0	31.3	35.7	28.0	26.0	28.0	25.3	22.7	20.0	19.3	19.0	19.2
14	26.0	23.3	22.7	22.0	22.0	22.0	23.0	24.3	25.7	27.0	32.2	34.0	32.0	30.3	34.7	31.0	29.6	28.3	26.0	26.0	25.0	24.3	22.0	21.0
15	24.0	23.3	22.7	22.0	22.0	22.0	23.0	24.3	25.7	27.0	32.2	34.0	32.0	30.3	34.7	31.0	29.6	28.3	26.0	26.0	25.0	24.3	22.0	21.0
16	27.0	24.6	24.3	24.0	23.6	23.3	23.0	24.0	25.0	26.0	29.6	31.3	31.0	29.7	32.3	27.0	26.3	25.6	26.0	25.0	25.0	23.2	22.0	22.3
17	27.0	26.0	25.0	25.1	24.0	24.0	25.3	26.6	28.0	30.0	32.0	34.0	34.3	36.3	33.9	29.8	27.0	27.2	28.3	27.7	26.5	26.7	25.7	26.2
18	28.0	26.0	25.0	24.0	24.0	24.0	25.3	26.6	28.0	30.0	32.0	34.0	34.3	35.6	33.9	29.8	27.0	27.2	28.3	26.7	26.5	26.7	25.7	26.2
19	24.0	24.67	24.3	24.0	23.6	23.3	23.0	24.0	25.0	26.0	29.6	32.3	35.0	31.3	35.7	28.0	26.0	28.0	25.3	22.7	20.0	19.3	19.0	18.9

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31	30	29	28	27	26	25	24	23	22	21	20
29.7	26.0	29.1	27.3	28.2	26.0	24.0	25.0	24.0	25.0	28.0	26.0
26.0	26.0	24.67	23.3	23.3	26.0	26.0	26.0	24.6	26.0	26.0	24.6
25.0	25.0	24.3	22.7	22.7	25.0	25.0	25.0	24.3	25.0	25.0	24.3
24.0	25.1	24.0	26.1	22.0	27.2	24.0	23.2	24.0	23.1	24.0	27.2
24.0	24.0	23.6	22.0	22.0	24.0	24.0	24.0	23.6	24.0	24.0	23.6
24.0	24.0	23.3	22.0	22.0	24.0	24.0	24.0	23.3	24.0	24.0	23.3
25.3	25.3	23.0	23.0	23.0	25.3	25.3	25.3	23.0	25.3	25.3	23.0
26.6	26.6	24.0	24.3	24.3	26.6	26.6	26.6	24.3	26.6	26.6	24.3
28.0	28.0	25.0	25.7	25.7	28.0	28.0	28.0	25.7	28.0	28.0	25.7
30.0	30.0	26.0	27.0	27.0	30.0	30.0	30.0	27.0	30.0	30.0	27.0
32.0	32.0	29.6	32.2	32.2	32.0	32.0	32.0	29.7	32.0	32.0	29.7
34.0	34.0	31.3	34.0	34.0	34.0	31.3	34.0	32.3	31.3	34.0	32.3
34.3	34.3	31.0	32.0	32.0	34.3	31.0	34.3	35.0	31.0	34.3	35.0
35.7	34.7	29.7	30.3	30.3	36.6	29.7	34.7	31.3	29.7	34.6	31.3
33.9	33.9	32.3	34.7	34.7	33.9	32.3	35.0	35.7	32.3	35.0	35.7
29.8	29.8	29.0	31.0	31.0	30.8	31.0	33.67	34.0	35.0	33.6	28.0
27.0	27.0	26.3	29.6	29.6	27.0	26.3	32.3	26.0	26.3	32.3	26.0
27.2	27.2	25.67	28.3	28.3	27.2	25.67	28.0	28.0	25.67	28.0	28.0
28.3	28.3	26.0	26.0	26.0	28.3	26.0	25.0	25.3	26.0	25.0	25.3
27.7	27.7	25.0	26.0	26.0	27.7	25.0	19.0	22.7	25.0	25.0	23.7
26.5	26.5	25.0	25.0	25.0	26.5	25.0	21.0	20.0	25.0	21.0	20.0
26.7	26.7	23.2	24.3	24.3	26.7	23.2	21.5	19.3	23.2	21.5	19.3
25.7	25.7	22.0	22.0	22.0	25.7	22.0	22.0	19.0	22.0	22.0	19.0
26.2	26.2	22.3	21.0	21.0	26.2	22.3	21.0	19.2	22.3	21.0	19.2

Table 3: Hourly Irradiation in w/m^2 of Sabon Gida Kaduna

7	6	5	4	3	2	1	D/H
-	-	-	-	-	-	-	**1**
-	-	-	-	-	-	-	**2**
-	-	-	-	-	-	-	**3**
-	-	-	-	-	-	-	**4**
-	-	-	-	-	-	-	**5**
-	-	-	-	-	-	-	**6**
135	38	38	50	39	155	108	**7**
363	156	95	114	95	372	196	**8**
575	320	145	145	146	577	146	**9**
746	495	187	187	206	745	748	**10**
862	491	216	216	238	865	867	**11**
917	422	232	232	300	921	910	**12**
1100	278	442	232	232	917	928	**13**
812	261	378	217	217	866	868	**14**
650	208	630	218	188	477	730	**15**
439	148	232	147	399	204	586	**16**
290	117	107	97	381	333	386	**17**
123	54	78	162	157	40	160	**18**
-	-	-	-	-	-	-	**19**
-	-	-	-	-	-	-	**20**
-	-	-	-	-	-	-	**21**
-	-	-	-	-	-	-	**22**
-	-	-	-	-	-	-	**23**
-	-	-	-	-	-	-	**24**

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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	9	8
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34	44	54	41	35	54	41	56	67	132	123	107	77	56	48	121	63	36	54	147	44	37	37	136
143	215	78	112	195	230	314	138	315	203	191	87	121	415	345	111	191	111	138	373	298	103	94	361
212	145	138	215	134	316	231	312	412	198	134	434	415	523	314	280	346	200	200	574	448	173	145	573
176	454	584	415	516	189	178	198	611	814	713	1300	1125	916	814	565	735	570	241	186	746	495	186	744
187	313	414	187	415	178	192	192	516	516	478	914	615	756	750	457	630	357	279	840	641	259	238	856
194	297	312	169	467	152	232	232	414	543	514	718	493	814	615	310	719	422	300	1000	665	278	255	900
211	293	287	232	413	312	234	254	319	415	412	519	514	318	314	1475	768	460	279	843	642	256	278	867
212	298	293	163	297	311	192	312	213	314	345	434	383	415	321	783	668	415	303	775	657	261	302	711
234	211	194	241	283	246	213	159	202	415	415	318	297	718	282	687	525	361	297	652	612	245	313	455
123	134	138	165	192	213	256	189	196	314	375	192	311	283	415	312	369	284	271	497	507	192	270	148
134	159	126	174	123	156	312	192	154	298	297	282	187	312	289	243	204	181	196	319	350	321	194	98
171	156	157	142	132	123	282	135	121	152	134	198	192	156	167	102	68	78	91	132	155	165	89	42
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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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_o, R_s, R_{sh}) from the diagram in Fig.1 is given in equation 1 to equation 6 [23-25].

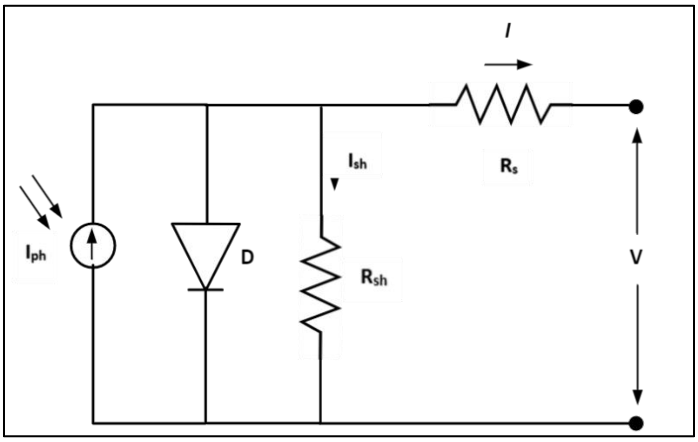

Figure 1: Single diode model

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

$$I = I_{ph} - I_0 \text{ x } [\exp [\frac{q.(V+I.R_s)}{n.KN_s.T}] - 1] - I_{sh} \quad (1)$$

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)

$$I_0 = I_{rs} *(T/T_n) \text{^}3*\exp [(q*E_{g0}*(1/T_n - 1/T)/ (n*K)] \quad (2)$$

Where I_0 is the saturation current, I_{rs} is the reverse saturation current, T_n is the nominal temperature, Eg0 is the band gap energy of the semiconductor, T, q, n are the same parameters as in equation (1).

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

$$I_{rs} = I_{sc}/[\exp(q*V_{oc}/n*N_s*K*T))-1] \quad (3)$$

Where I_{sc} is the short circuit current, V_{oc} is the open-circuit voltage, q, n, N_s, K and T are the same parameters as in equation (1).

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

$$I_{sh} = (V+I*R_s)/R_{sh} \quad (4)$$

Where I_{sh} is the shunt current, V is the PV voltage, I is the PV current, Rs is the series resistance and R_{sh} is the shunt resistance.

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

$$I_{ph} = [I_{sc}+\{K_i*(T-298)\}] *G/1000 \quad (5)$$

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)

$$P_{pv}= P_{Veff}*(P(pv\text{-}rated). *P_{Veff}*(G/G_{ref})). *(1+k_t.*(T_c-T_{ref})) \quad (6)$$

Where P_{Veff} 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, kt is the temperature coefficient, T_c is the cell temperature and Tref 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].

$$\frac{V(Z1)}{V(Z2)} = (\frac{Z1}{Z2})^{P} \quad (7)$$

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)

$$P = \frac{Ln[\frac{U(Z1)}{U(Z2)}]}{Ln[\frac{Z1}{Z2}]} \quad (8)$$

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

$$Pm = 1/2C_p\ (\lambda, \beta)\ \rho AW^3 \quad (9)$$

$$\lambda = w_T/V \quad (10)$$

$$Cp = ½[\ \frac{116}{\lambda_1} - 0.4\beta - 5\ ]exp^{\frac{-165}{\lambda}} \quad (11)$$

$$Tm = 0.5\rho ACpW/\ \lambda, \quad (12)$$

Where;

C_p is fraction of kinetic, λ is the tip speed ratio of the rotor blade tip speed to wind speed, β is the blade pitch angle, ρ 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.

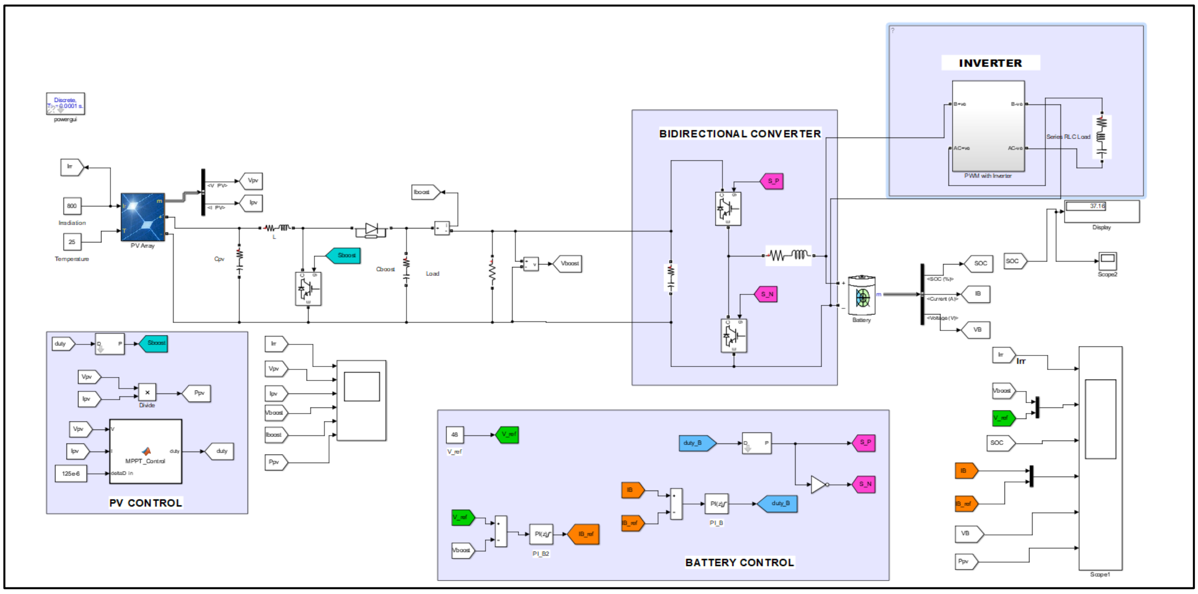

Figure 2: Simulink Model of the Solar PV energy module

ii. Wind Turbine Energy Module

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

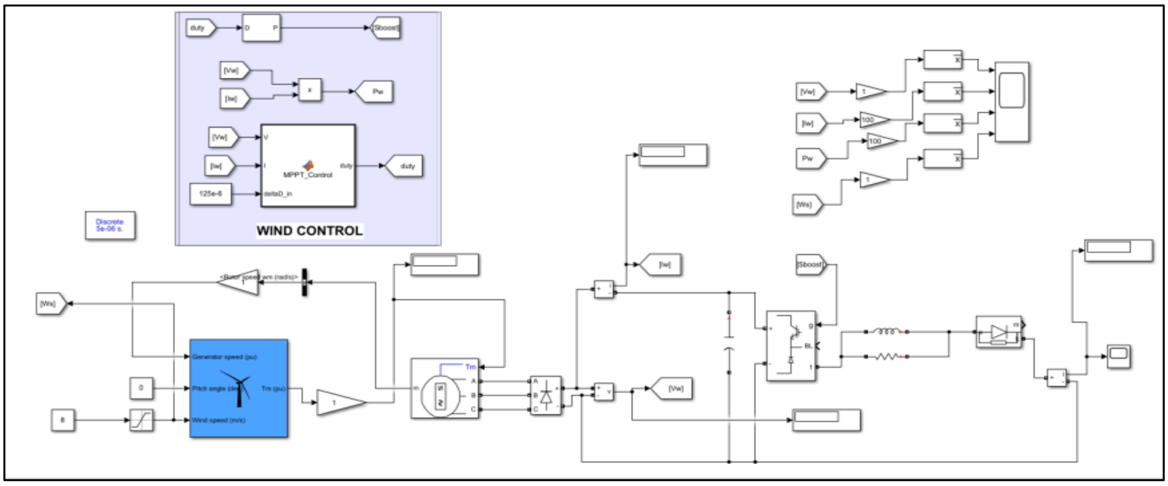

Figure 3: Simulink Model of the Wind Turbine Energy System

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.

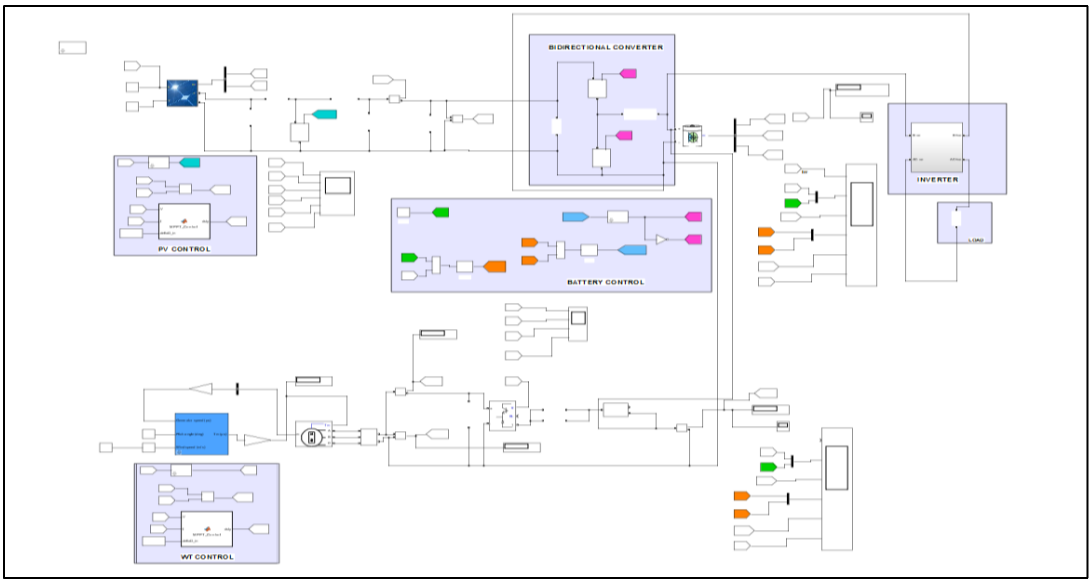

Figure 4: Integrated PV and WT Energy Model

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 locatio

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*

a) *Sizing of the PV Energy Source Based on the Load Demand of a Single Household*

In sizing the PV energy source, the load demand, the energy consumption of the selected location of study, the sun hours per day, solar irradiance and the number of solar panels need to be put into consideration [10] [28] [29].

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 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.

c) *Sun Hours Per Day*

For this study location, it is anticipated that there will be more sunshine between April and September, and unobstructed exposure to the sun for

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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

Np = total peak hour generated by the sunlight / Solar panel power rating

= 340Wp/175Wp = 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 x 2)/ (0.85 x 12) = 270AH

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 of 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.

Figure 6: Ratings of the PV Panel

Figure 7: Rating of the Wind Turbine

Fig. 8 shows the coupling of the PV and Wind turbine. DC coupling was used.

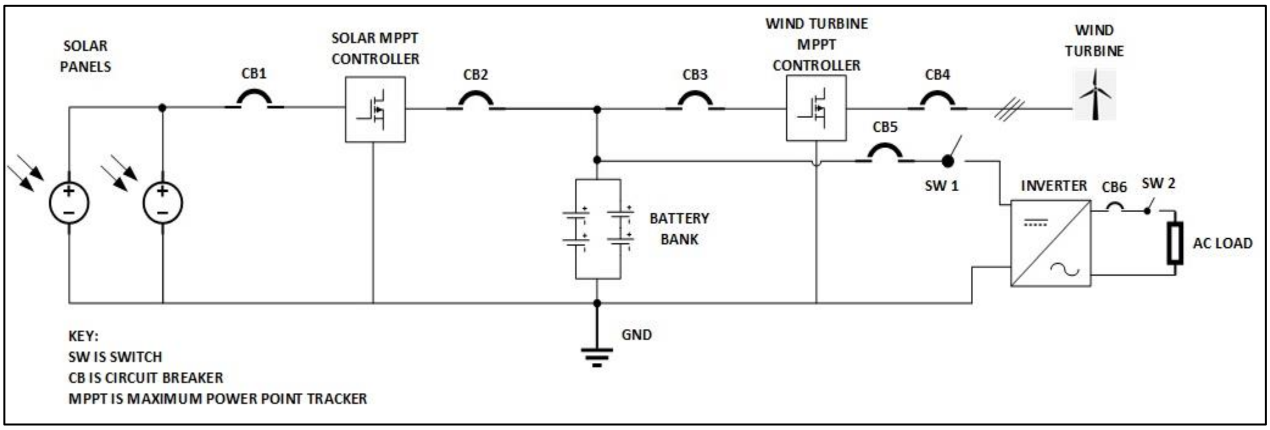

Figure 8: Circuit Diagram Showing the Coupling of the PV and Wind

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 31days (744hours) 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.

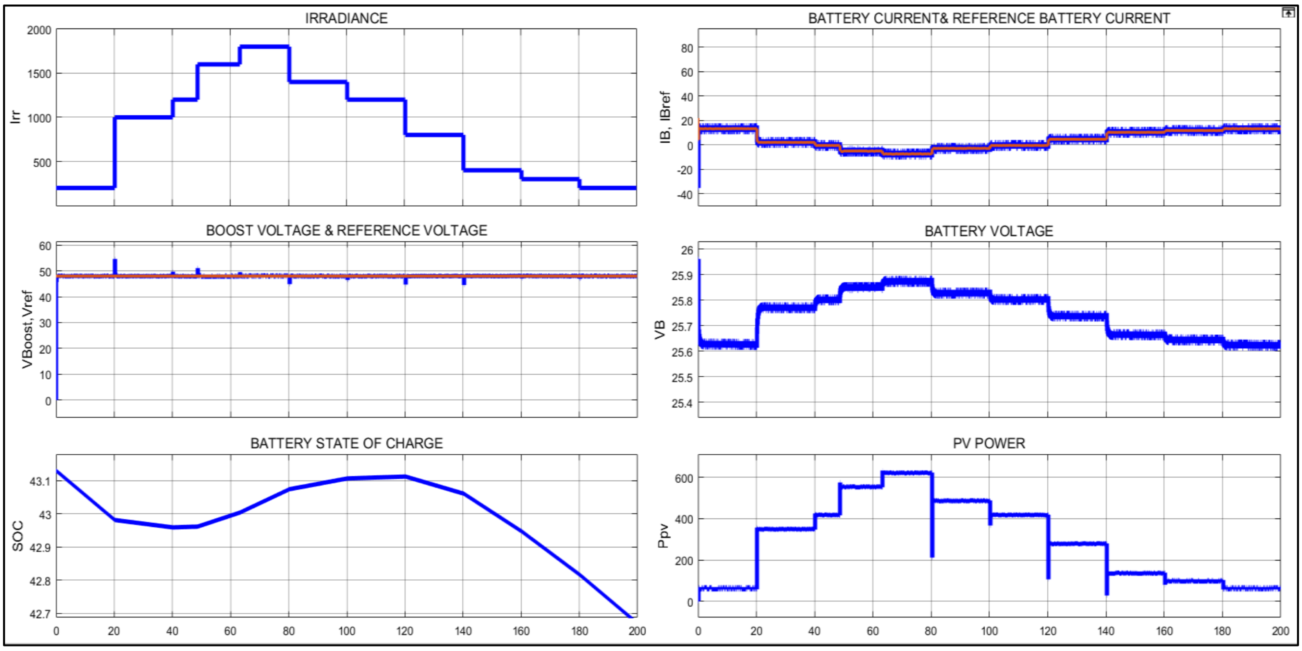

Figure 9a: Output Characteristics of the PV energy system

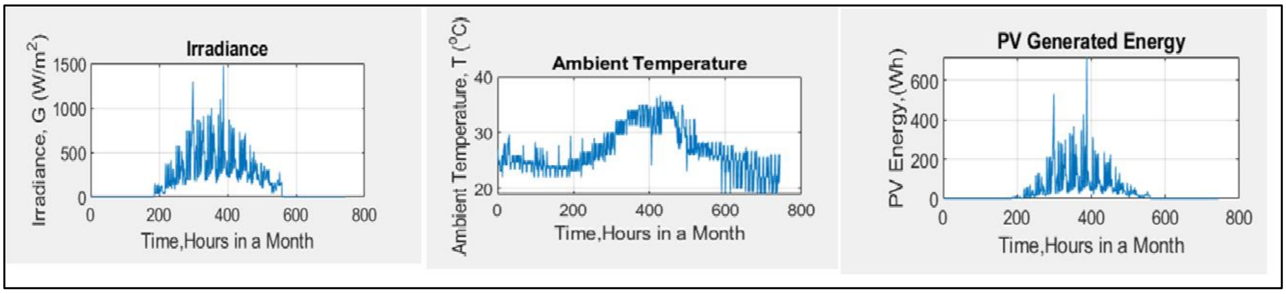

Figure 9b: Output characteristics of the Hourly Irradiance, Temperature and Generated PV Power

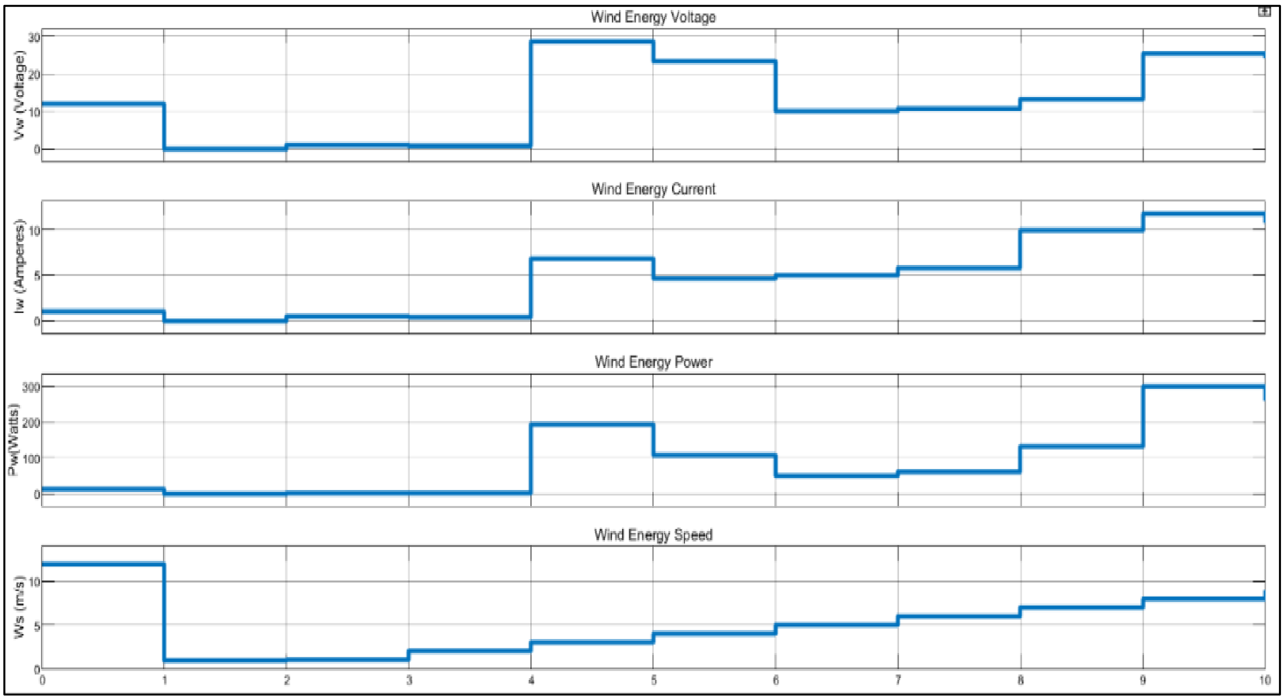

Figure 10a: Output characteristics of the Wind Energy System

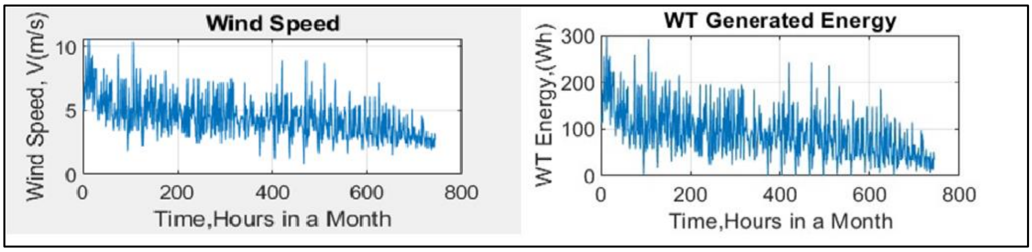

Figure 10b: Output Characteristics of the Wind Speed and Generated Wind Energy

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 620watts, while that of the Wind Turbine energy model was 301watts. 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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REFERENCES

1. Blaabjerg, F., Yang, Y., Yang, D., & Wang, X. (2017). Distributed power-generation systems and protection. *Proceedings of the IEEE*, *105*(7), 1311-1331. doi: 10.1109/JPROC.2017.2696878.
2. Anthony, R. N., & Navghare, S. P. (2016, April). An insight to distributed generation of electrical energy from various renewable sources. In *2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS)* (pp. 341-344). IEEE. doi: 10.1109/ICEETS.2016.7583777.
3. Hong, J., Yin, J., Liu, Y., Peng, J., & Jiang, H. (2019). Energy management and control strategy of photovoltaic/battery hybrid distributed power generation systems with an integrated three-port power converter. *IEEE Access*, *7*, 82838-82847. doi: 10.1109/ACCESS.2019.2923458.
4. Saad, N. H., El-Sattar, A. A., & Mansour, A. E. A. M. (2018). A novel control strategy for grid connected hybrid renewable energy systems using improved particle swarm optimization. *Ain Shams Engineering Journal*, *9*(4), 2195-2214. doi: 10.1016/j.asej.2017.03.009.
5. Anoune, K., Bouya, M., Ghazouani, M., Astito, A., & Abdellah, A. B. (2016, November). Hybrid renewable energy system to maximize the electrical power production. In *2016 international renewable and sustainable energy conference (IRSEC)* (pp. 533-539). IEEE. doi: 10.1109/IRSEC.2016.7983992.
6. Pranav, M. S., Karunanithi, K., Akhil, M., Vanan, S. S., Afsal, V. M., & Krishnan, A. (2017, July). Hybrid renewable energy sources (HRES)—A review. In *2017 International Conference on*

Intelligent Computing, Instrumentation and Control Technologies (ICICICT) (pp. 162-165). IEEE. doi: 10.1109/ICICICT1.2017.8342553.

7. Gyuk, I. P., & Eckroad, S. (2003). Final Report, December 2003', p. 512.
8. Obeng-Darko, N. A. (2018). Policy Trends on Renewable Energy for Decentralised Electrification as a Catalyst for Achieving Goal Seven of the Sustainable Development Goals in sub-Saharan Africa.: The Case of Ghana. *Renewable Energy Law and Policy Review*, *8*(4), 12-24.
9. Zhou, T., & François, B. (2010). Energy management and power control of a hybrid active wind generator for distributed power generation and grid integration. *IEEE transactions on industrial electronics*, *58*(1), 95-104. doi: 10.1109/TIE.2010.2046580.
10. Biswas, I., Dash, V., & Bajpai, P. (2012, December). Sizing optimization of PV-FC-battery system with hybrid PSO-EO algorithm. In *2012 Annual IEEE India Conference (INDICON)* (pp. 869-874). IEEE. doi: 10.1109/INDCON.2012.6420739.
11. Kandemir, S. Y., Yayli, M. O., & Acikkalp, E. (2021, May). Assessment of Electric Energy Generation using Wind Energy in Turkey. In *7th Iran Wind Energy Conference (IWEC2021)* (pp. 1-3). IEEE. doi: 10.1109/IWEC52400.2021.9467019.
12. Zhang, L., & Li, Y. (2011, March). Optimal energy management of hybrid power system with two-scale dynamic programming. In *2011 IEEE/PES Power Systems Conference and Exposition* (pp. 1-8). IEEE. doi: 10.1109/PSCE.2011.5772607.
13. Vasant, L. G., & Pawar, V. R. (2017, June). Solar-wind hybrid energy system using MPPT. In *2017 international conference on intelligent computing and control systems (ICICCS)* (pp. 595-597). IEEE. doi: 10.1109/ICCONS.2017.8250531.
14. Ajayi, O. O. (2010). The potential for wind energy in Nigeria. *Wind engineering*, *34*(3), 303-311. doi: 10.1260/0309-524X.34.3.303.
15. Idris, W. O., Ibrahim, M. Z., & Albani, A. (2020). The status of the development of wind energy in Nigeria. *Energies*, *13*(23), 6219. doi: 10.3390/en13236219
16. Santika, W. G., Urmee, T., Anissuzaman, M., Shafiullah, G. M., & Bahri, P. A. (2018, October). Sustainable energy for all: Impacts of Sustainable Development Goals implementation on household sector energy demand in Indonesia. In *2018 International Conference on Smart Green Technology in Electrical and Information Systems (ICSGTEIS)* (pp. 13-18). IEEE. doi: 10.1109/ICSGTEIS.2018.8709108.
17. Time and Data AS, 'Weather in Kaduna, Kaduna, Nigeria'. Accessed: May 20, 2022. [Online]. Available: https://www.timeanddate.com/weather/nigeria/kaduna
18. Ibrahim, K. A., Gyuk, P. M., & Aliyu, S. (2019). The effect of solar irradiation on solar cells. *Science World Journal*, *14*(1), 20-22.
19. Brano, V. L., Orioli, A., Ciulla, G., & Di Gangi, A. (2010). An improved five-parameter model for photovoltaic modules. *Solar Energy Materials and Solar Cells*, *94*(8), 1358-1370. doi: 10.1016/j.solmat.2010.04.003.
20. Elbaset, A. A., Ali, H., & Abd-El Sattar, M. (2014). Novel seven-parameter model for photovoltaic modules. *Solar energy materials and Solar cells*, *130*, 442-455. doi: 10.1016/j.solmat.2014.07.016.
21. Gaevskii, A. (2019, April). Method for determining parameters of PV modules in field conditions. In *2019 IEEE 6th International Conference on Energy Smart Systems (ESS)* (pp. 205-208). IEEE. doi: 10.1109/ESS.2019.8764239.
22. Teyabeen, A. A., Elhatmi, N. B., Essnid, A. A., & Jwaid, A. E. (2020, October). Parameters estimation of solar PV modules based on single-diode model. In *2020 11th International Renewable Energy Congress (IREC)* (pp. 1-6). IEEE. doi: 10.1109/IREC48820.2020.9310365.
23. Mwanyika, H. H., & Kainkwa, R. M. (2006). Determination of the power law exponent for southern highlands of tanzania. *Tanzania Journal of Science*, *32*(1), 103-107. doi: 10.4314/tjs.v32i1.18434.
24. Park, H., & Kim, H. (2013, November). PV cell modeling on single-diode equivalent circuit. In *IECON 2013-39th Annual Conference of the IEEE Industrial Electronics Society* (pp. 1845-1849). IEEE. doi: 10.1109/IECON.2013.6699412.
25. Soon, J. J., Low, K. S., & Goh, S. T. (2014, June). Multi-dimension diode photovoltaic (PV) model for different PV cell technologies. In *2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE)* (pp. 2496-2501). IEEE. doi: 10.1109/ISIE.2014.6865012.
26. Mwanyika, H. H., & Kainkwa, R. M. (2006). Determination of the power law exponent for southern highlands of tanzania. *Tanzania Journal of Science*, *32*(1), 103-107. doi: 10.4314/tjs.v32i1.18434.
27. Oyewole, J. A., & Aro, T. O. (2018). Wind speed pattern in Nigeria (a case study of some coastal and inland areas). *Journal of Applied Sciences and Environmental Management*, *22*(1), 119-123. doi: 10.4314/jasem.v22i1.22.
28. Basyoni, M. S. S., Basyoni, M. S. S., & Al-Dhlan, K. (2017). Design, Sizing and Implementation of a PV System for Powering a Living Room. *Computer*, *90*(8), 12. doi: 10.25125/engineering-journal-IJOER-MAY-2017-23.
29. Mamen, A., & Supatti, U. (2017, June). A survey of hybrid energy storage systems applied for intermittent renewable energy systems. In *2017 14th International Conference on Electrical*

Engineering/Electronics, *Computer*, *Telecommunications and Information Technology (ECTI-CON)* (pp. 729-732). IEEE. doi: 10.1109/ECTICon.2017.8096342.

30. Ezekwe, C. I. (1988). The solar radiation climate of Nigeria. *Solar & wind technology*, *5*(5), 563-571. doi: 10.1016/0741-983X(88)90048-3.
31. Njoku, H. O. (2014). Solar photovoltaic potential in Nigeria. *J. Energy Eng*, *140*(2), 04013020. doi: 10.1061/(ASCE)EY.1943-7897.0000145.
32. Chineke, T. C., Aina, J. I., & Jagtap, S. S. (1999). Solar radiation data base for Nigeria. *Discovery and innovation*, *11*(3/4), 207-210. doi: 10.4314/dai.v11i3.15556.
33. Ayodele, T. R., Ogunjuyigbe, A. S. O., Oyediran, E. O., & Ojo, O. (2015, September). Temperature based model for estimating the daily average global solar irradiation of Ibadan, Nigeria. In *AFRICON 2015* (pp. 1-5). IEEE. doi: 10.1109/AFRCON.2015.7331971.
34. Ibrahim, K. A., Gyuk, P. M., & Aliyu, S. (2019). The Effect of Solar Irradiation on Solar Cells. *Science World Journal*, 14(1), 4.
35. Falvo, M. C., & Capparella, S. (2015). Safety issues in PV systems: Design choices for a secure fault detection and for preventing fire risk. *Case Studies in Fire Safety*, *3*, 1-16. doi: 10.1016/j.csfs.2014.11.002.