Development and Economic Analysis of a Hybrid Power of Photovoltaic and Wind Turbine System.

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Abstract

Energy is essential for economic and social development and are generated both by conventional and non-conventional means. However, because of greenhouse effect from conventional means, renewable means of photovoltaic and wind turbine hybrid power generating system was considered in this research. Different means of generating energy from renewable energy were reviewed and the hybrid power of this renewable energy was developed using mild steel as the foundation plate, steel pipe as the structural pole for the solar panel and wind turbine while the control system were mounted on the wall for easy operation and accessibility. The designed and fabricated part involved wind turbine blades, photovoltaic panel hanger. The maximum voltage and current generated during the experiment were 16.5V and 3.6A for photovoltaic power while that of wind turbine were 18.2V and 8.8A, The maximum power generated by hybrid power system when the output of photovoltaic power was connected to wind turbine output in series and parallel was 152.9W while the minimum power generated in series connection was 54.8W and in parallel was 86.4W. The mechanical and overall efficiencies of wind turbine power system were 54.2% respectively while the overall efficiency of photovoltaic power system was 16.9%.

Keywords: Renewable energy, Hybrid, Photovoltaic, wind power

1.0 INTRODUCTION

Energy plays a very vital role in human life and is required generally by the people in both urban and rural areas for various activities and access to affordable energy is essential for economic and social development. This energy may be obtained conventionally from fossils fuels and from renewable. The problems associated to this non-renewable energy generation (thermal power energy) have been on increase, these problems are on increase in oil price, limitation of fossil fuels and environmental pollution (Perkins, 2018). According to (Idris, Lamin, Ladan, & Yusuf, 2012), upon the availability of renewable energy sources in Nigeria, there is a wide energy deficit due to under- utilization of these energy potentials and to inherent fluctuation and intermittency of most renewable energy sources which have a negative impact on the smooth operation of energy generation. In (Ding, et al., 2018), there is need to improve renewable energy generation quality and quantity at a particular period which is very important. According to Elie et al., (2017), most energy expert agree that the energy generated from renewable source of about IMW can power 630 households and prevents carbon iv oxide (CO_2) emission of about 2500 ton/yr to the atmosphere and for this reason, more of the these type of energy generation are being developed and commissioned around the world. Wind energy is manifestation of solar energy which transforms the air in motion. The energy in wind is converted into rotary mechanical energy by the wind turbine invariably generating electricity by the generator attached to the turbine (Lacho & Avram, 2015) while that of solar PV cells convert the incident solar light energy directly to electricity in direct current (DC) form and the power generated by PV cells are subject to climatic conditions at the location (Prashant, Sanjay, & Kumar, 2018). The hybrid of solar and wind power with micro grid technology was designed for a remote area in Japan with pump storage technology to alleviate the problem of carbon II oxide and other toxic substance from Fukushima nuclear accident (Ma, Yang, Lu, & Peng, 2015).

According to (Anoune, Laknizi, Bouya, Astito, & Abdellah, 2018) a deterministic approach of sizing a hybrid of photovoltaic and wind power system was established using TRANSYS software to determine the electrical load while (Jain, Choi, & Kim, 2002) used discrete state algorithm method to develop a hybrid power plant of photovoltaic and wind in South Korea without storage system and also used PID regular analysis to develop a hybrid power of wind-diesel without storage system. Figure 1 below shows a schematic diagram of hybrid photovoltaic and wind power system

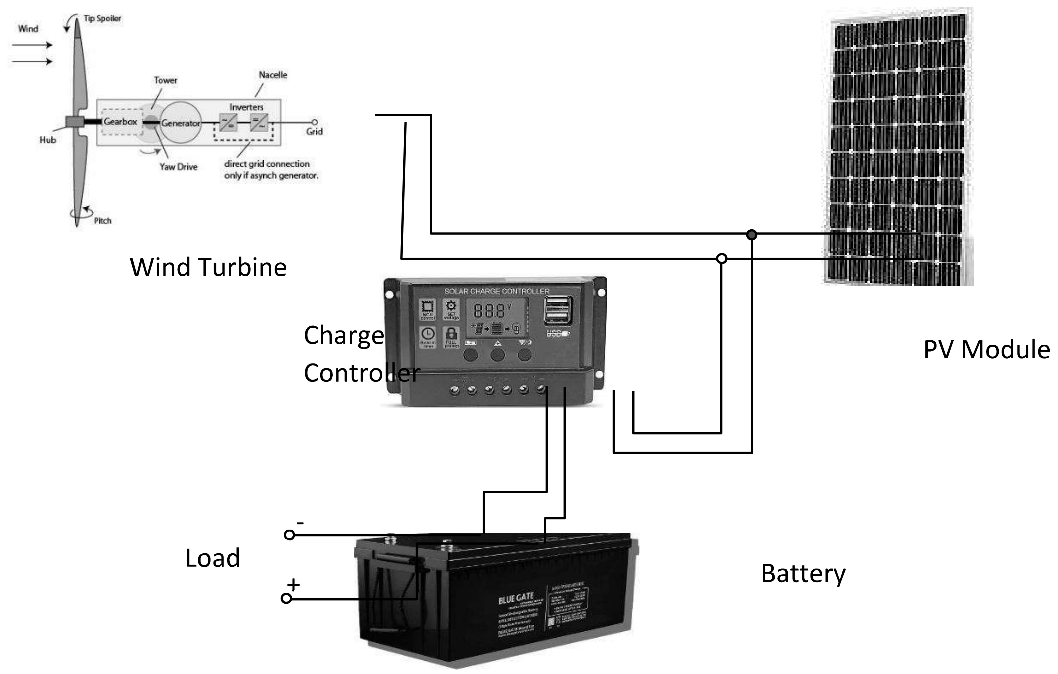

Figure 1: Hybrid of photovoltaic and wind power system

2.0 MATERIALS AND METHOD

2.1 Design Analysis

2.1.1Angle of Tilt (β) for PV

The maximum PV module tilting angle to enable maximum performance are calculated in the following section. The average time for sun rays in Minna between January and December is 7.5 hours starting from 9.00 am to 4.30 pm (Idris, Lamin, Ladan, & Yusuf, 2012)

*2.1.2 **Angle of inclination (θ) of the PCV***

This is the sun rays inclined angle to the photovoltaic and the equation for estimating angle of inclination according to (Nag, 2011)

$$\cos\theta = \sin\phi(\sin\delta.\cos\beta + \cos\delta.\cos\gamma.\cos\omega.\sin\beta) + \cos\varphi(\cos\delta.\cos\omega.\cos\beta - \sin\delta.\cos\gamma.\sin\beta) + (\cos\delta.\sin\gamma.\sin\omega.\sin\beta) \quad (1)$$

2.1.3 Angle of declination (δ)

The angle of declination is estimated using the equation 2 as presented in (Nag, 2011).

$$\delta = 23.45 \times \mathrm{Sin}[360/365\ (284 + n)] \quad (2)$$

2.1.4 Solar irradiance (S)

Solar irradiance (S) is the quantity of energy radiated to the earth crust; 1000W/m^2. Solar Insolation (I_s) is a measure of solar radiation received on a given surface area at a given time and is calculated by the equation

$$I_N = \mathrm{S}\cos Z_\theta \quad (3)$$

Where $Z_\theta = \cos^{-1}(\sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega)$ (4)

2.2 Wind Turbine Design Analysis

Location determines the wind speed necessary to operate wind turbine power system. The location of the power system in Nigeria determines the type of wind turbine to be installed. According to (Nag, 2011) the average wind speed of Minna is 5.36 m/s and maximum extractable power density was 55.12 W/m^2.Wind power is the maximum extractable power realized by a specific wind turbine in a particular location and this wind power were calculated using equation 5,the wind turbine swept area was estimated.

$$P_w = \rho \times A_r \times V_i^{\,3} \quad (5)$$

Where P_w is wind power, (W)
ρ is air density
A_r is rotor area (m^2)
$V_i$is wind speed at entrance to wind turbine (m/s)

2.2.1 Mechanical power in the rotor (P_T)

This is the available power generated by the rotor and transmitted same to the generator. The mechanical power of the rotor is calculated with the equation 6 as used by (Nag, 2011)

$$P_T = \rho \times A_s \times V_t^{\,3} \quad (6)$$

where V_t is turbine rotor speed.

2.2.2 Wind turbine electrical power (P_{wt})

The wind turbine power is the electrical power generated by dynamo which is the useful energy required to power electrical equipment. It was calculated using equation 7 as used by (Nag, 2011)

$$P_{wt} = \sqrt{3} \times I \times V \times \cos\varphi \quad (7)$$

2.3 Tower Design

The pole or tower that carries both the PV panel and the wind turbine is been subjected to axial loading and therefore was designed as a column with one end free and the other end fixed. According to (Rao & Parulekar, 2005) the critical load on a short column can be determined from equation 8

$$P_{cr} = \frac{C\pi^2 EI}{L^2} \qquad (8)$$

Where,

Pcr - critical load on the tower.
C – the column end condition.
E – young modulus of elasticity.
I – moment of inertia of the column cross section
L – effective column length.

2.3.1 Turbine Shaft Design

The turbine shaft conducted torsional energy from the rotor blade to the turbine generator and therefore, it is subjected to twisting moments only. The diameter, d of a shaft is related to the torque, T by equation 9

$$T = \frac{\pi d^3}{4}\tau \qquad (9)$$

Where
τ- Material shear stress. The diameter of the turbine shaft was estimated as 12 mm

Table 1: Specification of Dynamo

S/No	Item/Part	Specification
1	Generator type	Dynamo
2	Power rating	350W
3	Body material	Plain carbon steel
	Core material	Cast iron
4	Number of poles	4
5	No load current	35.6 A
6	Voltage	12V
7	Rated speed	2700 rpm
8	Gear ratio	15
9	Size	$\emptyset 150 \times 120$
10	Gearing system	Inbuilt and speed increaser
11	Type of speed	Variable speed constant frequency

2.4 Test running and Operation of the Power System

After the assembling of the major components of the hybrid power system, a field test was conducted and the following readings were recorded for one day, this includes the voltage, current and the power was calculated and displayed on the LCD. These readings were recorded for parallel and series connections. The time interval for the recording of the output data was two hours while the total time taken for the overall operation was twenty four hours. The power plant was first operated and recorded appropriately without load, later with load. The tables 2 and 3 present the results of testing the power plant without and with load. The data in table 2 was recorded at an interval of two hours.

Table 2: Voltage Generated by PV and Wind Power Plant without Load

S/No.	Time (Hrs)	PVC Voltage	WT Voltage	Total in series
1.	08 – 10	20	18.7	38.7
2	10 – 12	20.5	10.5	31.0
3	12 – 14	21.6	12.8	34.4
4	14 – 16	20.8	12.0	32.8
5	16 – 18	18.1	15.2	33.3
6	18 –20	0	15.2	15.2
7	20 – 22	0	18.5	18.5
8	22 – 00	0	20.2	20.2
9	00 – 02	0	20.5	20.5
10	02 – 04	0	22.0	22.0
11	04 – 06	0	19.9	19.9
12	06 – 08	5.4	18.5	23.9

The power output wires from the photo cells and wind turbine were connected to the charge controller and the results were recorded without load and later used to power two 3V bulbs. The voltage and current of hybrid power system was recorded from power controller. The output voltage and current of photovoltaic cell system were recorded from 08:00 hrs in the morning till 18:00 hrs (6'Oclock in the evening) when there was sunlight while the voltage and current generated by the wind turbine power were taken throughout the day and night but the wind speed to turbine rotor was not recorded. It can be seen that, the wind turbine performed better than the PV module with an average voltage of 17 V to 9 V during the testing period. The average voltage output for the test period is 26 V.

Table 3: Voltage Generated by PV and Wind Turbine Power Plant with load

S/No	Time (Hrs)	PVC voltage (V)	WTvoltage (V)	Total in Series Generated (V)
1	08 – 10	15.2	14.6	29.8
2	10 – 12	16.5	7.2	23.7
3	12 – 14	15.6	8.8	24.4
4	14– 16	14.8	8.2	23.0
5	16 – 18	14.3	12.2	26.5
6	18– 20	0	11.8	11.8
7	20– 22	0	14.6	14.6
8	22 – 00	0	16.8	16.8
9	00 –02	0	15.6	15.6
10	02 – 04	0	18.2	18.2
11	04 –06	0	14.2	14.2
12	06 – 08	2.8	13.8	16.6

When the output power from charge controllers from the two power systems were connected in series, the total output voltage was the sum of two results from each power systems but the current recorded was the smallest result gotten from the two systems. In table 4, at the time between 08 – 10 hrs, the result from photovoltaic system was 15.2 V while that from wind turbine was 14.6 V and the total voltage output was 29.8 V as presented table 4

Table 4: Current Generated by PV and Wind Turbine Power System without Load.

S/No	Time (Hrs)	PV (A)	WT (A)
1	08 – 10	3.6	8.2
2	10 – 12	3.6	8.3
3	12 – 14	3.2	8.6
4	14– 16	3.3	8.2
5	16 – 18	3.4	8.3
6	18– 20	0	8.2
7	20– 22	0	8.6
8	22 – 00	0	8.6
9	00 –02	0	8.6
10	02 – 04	0	8.2
11	04 –06	0	8.4
12	06 – 08	3.2	8.2

Wind turbine produce fairly steady current as compared with that of the PV module. this may because during the test period the wind current were more steady and stronger as compare to the fluctuating solar radiation.

4.0 CONCLUSION

The mounting of photovoltaic panel at 10m height and at the tilting angle of 15^o to the horizontal making the angle of inclination to be between 13.2^o and 25^o from sunrise to the sunset. During test a maximum rotor speed was 76 rev/min while the output speed of the turbine generator was 1140 rev/min. The maximum voltage and current generated during the experiment were 16.5 V and 3.6 A for photovoltaic power while that of wind turbine were 18.2 V and 8.8 A. The maximum power generated by hybrid power system when the output of photovoltaic power was connected to wind turbine output in series and parallel was 152.9 W while the minimum power generated in series connection was 54.8 W and in parallel was 86.4 W.The mechanical and overall efficiencies of wind turbine power system were 54.2% respectively while the overall efficiency of photovoltaic power system was 16.9%.

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