International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Impact Factor (2024): 7.741

An Outdoor Portable Hybrid Wind-Solar Energy Harvester for Charging Portable Mobile Devices

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Abstract: ***In Nigeria, frequent and prolonged power supply unavailability has been a problem; especially in rural areas where means of charging cellphones and other mobile electronic appliances are done by using generators which are 'unclean' and very financially consuming. Nigeria is a place of abundant renewable energy resources and can make use of them to provide means of charging and electrification. This paper presents the design and implementation of an outdoor portable hybrid wind-solar energy harvester that can be used to charge portable mobile electronic devices in times of mains power interruptions, in the absence of electrical sources, during outdoor activities away from home and especially in rural areas where there might be no supply of electricity. The portable hybrid wind-solar system uses a solar panel with LM2596 buck converter, a wind turbine with mini boost converter and 18650 power bank for ensuring efficient charging of the batteries and provision of charging for external mobile devices. The harnessed power from the sun via the solar panel and from the wind by the wind turbine is used to charge the battery through a power multiplexer. Additionally, the power bank module boosts the output voltage of the battery which can then be used to charge phones and other small electronic appliances via USB port. Tests were carried out on the system outdoor at daytime in a city in Southwestern Nigeria to study its performance. The solar panel was able to provide enough power to charge the batteries during the daytime; but for the wind turbine, the wind speed at the test location was not high enough for it to generate enough voltage and power needed to charge the batteries as fast as the solar panel. Nevertheless, the wind turbine can produce sufficient voltage needed to charge the batteries if the wind speed is high enough. Highest combined output power from the developed portable hybrid harvester during the day is 18.43 W with 100% sunshine and wind speed of 1.54 m/s.***

Keywords: hybrid wind-solar energy harvester, solar panel, wind turbine, wind speed, battery

1. Introduction

Energy and power situation in Nigeria has been a major and persistent concern for all over the years. Over 60% of the population grapples with limited or no access to affordable electricity, underscoring the urgency of addressing the energy crisis [1]. In Nigeria, there is heightened demand for power, which is aggravating the existing inadequacies in supply. This issue is particularly pronounced in rural settlements where grid systems are absent, emphasizing the need to explore renewable energy sources. The shortage of electricity in Nigeria's rural regions underscores the importance of diversifying into renewable energy solutions.
The state of energy crisis in Nigeria with respect to electric power generation and distribution has been responsible for many problems which include closure of most industries, low productivity and other adverse macroeconomic implications [2]. About 75% of people living in sub-Sahara part of Nigeria do not have access to electricity. Even those that are connected to the grid still have energy shortages. The populace uses fuel or diesel-generators (non-renewable energy) for charging cell phones and batteries.

With scarcity of resources, most of them cannot withstand the high cost of maintaining and buying fuel for their generators to charge their phone batteries [3]. With the abundance of renewable energies like wind and solar in Nigeria especially in the northern states, power can be generated by a wind turbine and solar panel which is easy to set up and maintain with little or no pollution. This will decrease the need for expensive power generators that are normally used in charging batteries that produce a lot of carbon dioxide and poisonous carbon monoxide [4], [5].

Hybrid wind-solar energy configurations present themselves as a cost-effective alternative to the expensive grid extensions, especially in rural areas globally [6]. The deployment of a small-scale, economically viable hybrid wind-solar energy harvester can offer a practical remedy for charging mobile electronics and providing lighting in these areas. Renewable energy sources, particularly solar and wind power, have gained widespread acceptance for their environmentally friendly characteristics and sustainable attributes.

Solar power, harnessed through photovoltaic (PV) cells typically made of silicon, directly converts sunlight into electricity. Solar systems, whether distributed on rooftops, in communities, or through expansive solar farms, contribute to local electricity generation without releasing harmful emissions of greenhouse gases. A significant advantage lies in their reliability, low maintenance requirements, and the ability to produce energy wherever sunlight is available. Unlike some other renewable sources, solar panels exhibit longevity without frequent replacements. However, solar energy production relies on sunlight availability, necessitating the integration of backup rechargeable batteries for energy storage. This addresses the intermittent nature of sunlight, allows solar energy to be utilised during night-time, especially in residential areas, for operations like charging of phones, and providing lighting. To reduce the difference in output voltage from solar panels, solar power systems require voltage regulation and charging circuits for rechargeable batteries.

Wind power is another prominent renewable source and presents distinct advantages and challenges. Wind turbines have a relatively smaller environmental footprint, releasing minimal emissions and reducing reliance on fossil fuels. Despite their positive environmental impact, if in groups, they can alter landscapes and generate noise as the blades rotate. There is potential harm to birds and bats from collisions with turbine blades.

The integration of solar and wind power in a hybrid form produces a strategic solution to optimize the benefits of both sources. Solar energy is available during the day, and wind power is available both day and night though might be intermittent. Existing literature revealed that several scholars and engineers in several places of the world have put in immense efforts into the design of reliable solar chargers and hybrid solar-wind systems which cannot be exhausted in this paper. The publications are intended for diverse purposes such as design for off-grid applications, modelling, simulation, analysis, optimization, etc. [7] – [18].

[19] developed an indigenous hybrid solar - wind power system to generate bulk electricity for heavy duty use for rural communities, and information and communication technology infrastructures. DC power produced from the PV and wind turbine systems are transported to a DC energy mix controller. The controller is bidirectional and connected to a DC-AC float charging-inverter system that provides charging current to a heavy-duty storage bank of batteries and at the same time produces AC power to supply AC loads.

[20] developed an electrical power generation system by integrating simultaneously solar energy with Nano-antenna, wind energy and non-conventional energy sources. The set-up consists of combination of PV solar-cell array and Nano-antenna array, a mast mounted wind generator, lead-acid storage batteries, an inverter unit to convert DC power to AC power, electrical lighting loads, heating loads, and associated wiring.

[21] showed that both wind and solar units work efficiently together as renewable sources in replacement of expensive portable chargers. The authors used a dynamo to convert rotational (mechanical) power of a wind turbine into electrical power (DC) through a commutator. The dynamo was able to produce voltage ranging from 8V to 10.5V for turbine rpm 280 to 380 respectively. For the solar unit, a 12V, 5-watt solar panel was used that generated 16.5V at 400 mA when the sunshine was at its peak.

[22] developed a multiple battery charging system containing solar panels connected directly to rechargeable batteries and storing energy by fetching abandoned solar energy. The fully charged batteries can charge other batteries and devices of variable voltage requirements such as cell phone batteries of 5V and 3.7V, and pencil batteries ranging from 3 - 9V.

Charging smart devices while travelling has always been a challenge. Solar panels can be of use in such cases but are hindered of power generation in cloudy weather or the absence of enough battery storage. As a solution to this problem, [23] developed a dual mode portable mobile charger which combines two sources: solar panel for use during daytime and a hand crank generator for use at night or when there is no sunshine. They used DC generator of 12V/600mA, which was driven by direct physical movement of hand crank through a connected gear train. Solar panel of 6W (6V/500mA) produced enough DC power to charge 1000mAh battery fully within 2 hours.

[24] constructed and tested the idea of a portable solar cap that is wearable and can charge mobile or rechargeable batteries (power bank) on the go. According to the authors, the amount of time it took the solar cap to charge a mobile phone fully is almost same as the time the phone requires to be fully charged from utility grid.

[25] developed a mobile solar hat/cap charger for outdoor workers like farmers, labourers, rickshaw pullers etc. A single hat contains 30 polycrystalline silicon solar cells arranged in a special way to produce the required current to charge a mobile phone. The solar hat/cap showed a good performance by charging a mobile phone of 900mAh capacity from 7% to 67% within 105 minutes.

Backpacks with mobile or other smart device charging facilities have now been used widely and are getting popular day by day. The system can be economical, user friendly, environmentally friendly and sustainable if solar energy is harvested and stored in rechargeable batteries, and then used to charge mobile devices while walking or carrying the backpack. Energy harvesting and charging can be done simultaneously while the user is walking or doing something else. This idea of mobile backpack charger was implemented by [26]. Solar cells of 5W/12 V were glued above the backpack and used to power the circuit with maximum output voltage of 12 V at no load and 11.25 V under load conditions. At the mobile charging end, voltage was found to vary from 4V – 5.1V along with peak current of 240 mA. With that output, mobile charging was found good.

[27] represented their system as portable hybrid solar charger, but the system seems little difficult to be carried out because of its fixed type of wind turbine with large stand. This type of hybrid system can be considered for large scale power generation. Windy regions receiving average bright sun hours can benefit much through this type of installation.

[28] constructed a solar charger with output voltage of 5V and an average of 800mA current. With that capacity it can charge a 4800mAh mobile phone battery fully within 4-5 hours.

[29] developed a 5 kW standalone wind and solar power combined system. The device consists of four solar panels of 120 W each, a 1.5 kW wind turbine, a solar charge controller, remote power storage, battery and battery control. The hybrid energy tower is a combination of a vertical axis wind turbine (VAWT) and solar panel. The hybrid device was suitable to be used on highways, and in other applications.

[30] used wind data obtained from a weather station and locally sourced materials to develop a small-scale horizontal axis wind turbine (HAWT) to make a hybrid solar-wind power system for irrigation purposes. The second energy source was a 40 W solar tracking system to give a more stable power supply.

[31] developed a smart turbine wind energy harvester (STEH) incorporating a home chimney pinwheel (HCP) as a VAWT, a brushless electromagnetic converter and super capacitors with a power management module. The system also makes use of IoT with cloud storage with LoRa transceivers, for monitoring and storage of energy data produced by the STEH.

With the growing demand for clean and on-the-go power solutions, there is a clear need for portable wind-solar hybrid charging system designed specifically for charging portable gadgets. This work develops a sturdy, compact hybrid system that taps into the combined power of wind and solar energy to guarantee a reliable and sustainable energy source for a range of portable electronic devices.

Therefore, the aim of this work is to develop an outdoor portable and economically viable hybrid wind-solar charging system for portable mobile electronic appliances in developing tropical countries. The objectives are to develop a small-scale system incorporating a wind turbine and a solar panel to form a hybrid wind-solar energy source; to implement power conditioning and charging circuits to combine their electric outputs to charge batteries; and to incorporate a battery-5V boost converter for USB port outputs.

The work involves two main phases: the design and implementation of an operational small wind turbine for harnessing wind energy, and a portable solar power system. Section two discusses briefly solar panels and wind turbines. Section three discusses the materials and methods. Section four presents and discusses the results and section five concludes the paper.

2. Hybrid Power Systems

Hybrid power systems are systems that combine two or more energy sources to provide increased efficiency and sustainability of energy supply. A common example is the wind-solar hybrid system that combines wind and solar energy. In general, renewable hybrid systems often have more economic and environmental benefits than stand-alone renewable systems.

2.1 Solar Panel

A solar panel (a photovoltaic (PV) module) is an assembly of photovoltaic cells. Each PV cell is made up of semiconductor material, such as silicon. However, it is rarely used individually but many PV cells are connected in parallel or in series to achieve high voltage and power output as possible. Cells connected in series increase the voltage output while cells connected in parallel increase the current [3].

There are three basic types of solar panels. They are monocrystalline, polycrystalline and thin-film solar panels. Monocrystalline solar panels are of high-purity silicon. They have the highest efficiency, typically 15-20%. They are space-efficient and live the longest [32]. Their disadvantage is that they are the most expensive.

Polycrystalline solar panels are more cost-effective to produce compared to monocrystalline panels. They have lower silicon purity compared to that of monocrystalline panels. However, they are not as efficient as the monocrystalline solar panels. They have efficiency of about 13-16%. Also, they have lower space-efficiency. Nevertheless, polycrystalline panels have made significant advancements in recent years.

Thin-film solar panels are manufactured by depositing one or several thin layers of photovoltaic material onto a substrate. They have efficiencies between 7-13%. There are several types of them such as organic photovoltaic cells (OPC), amorphous silicon (a-Si), etc. Their mass-production is simple and easier than crystalline-based solar cells. They can be made flexible, which opens new applications. High temperatures and shading have less effect on their performance. Their disadvantages are that they are generally not useful in most residential situations because they have low space-efficiency and tend to degrade faster than the other two types.

The output power of a solar panel is given in Equation (1) as:

$$P_s = AG\eta \tag{1}$$

where P is the output power in watts (W), A is the area of the solar panel in square meters (m^2), G is the solar irradiance in watts per square meter (W/m^2), and η is the efficiency of the solar panel (usually expressed as a decimal).

The fundamental limits of solar charging are mostly related to sunshine dependency. The efficiency of solar panels is significantly reduced during cloudy days, at night, or in shadowed areas or areas with lower sun angles, which results in less energy harvest and reduces the charging rate.

2.2 Wind Turbine

A wind turbine is a device that converts the wind's kinetic energy into electric energy. The energy available for conversion mainly depends on the wind speed and swept area of the turbine blades. The wind turns the blades, which in turn spins a shaft which is connected to an electric generator. This generator thus converts the mechanical energy produced by the spinning effect of the shaft, to electrical energy. Wind turbines can rotate about either a horizontal axis (HAWT) or vertical axis (VAWT). HAWT is older, more common and generally more powerful than VAWT.

HAWTs have the main rotor shaft and electrical generator at the top of a tower and must be pointed in the direction of the wind. A simple wind vane is used to point small turbines in the direction of the wind while large HAWTs use a wind sensor with a servo motor. Most HAWTs have a gear box which converts the slow rotation of the main rotor shaft into a faster rotation that can drive an electrical generator.

VAWTs do not need to be pointed in the direction of the wind to be effective. This is an advantage where the wind direction is not constant. A direct drive from the rotor assembly to a ground-based gearbox and generator is possible, thus improving the accessibility for maintenance purposes.

The expected output power of the wind turbine can be calculated using Equation (2).

$$P = \tfrac{1}{2} A \rho V^3 C_p \quad (2)$$

where A is the area swept by the turbine blades (πr^2); r is the radius of the circular path created by the rotational motion of the blade, which is also the length of each blade, ρ is the density of air, and C_p is the Betz Power coefficient. According to [33], no turbine can capture more than 0.593 (59.3%) of the kinetic energy in the wind.

3. Methodology

3.1 Overview

Figure 1 shows the functional block diagram of the system. These include the solar panel, wind turbine, buck converter, boost converter, battery and power bank module. As shown in the diagram, the outputs from the wind turbine and the solar panel are each fed into buck and boost converters. The outputs of the boost and buck converters are multiplexed and fed into power bank module. Hence the input and output of the battery comes from and goes into the power bank module.

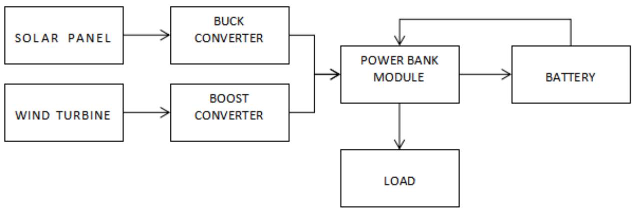


Figure 1: Block diagram of the portable hybrid wind-solar energy harvester.

3.2 Description of Each Block

3.2.1The Solar Panel Selection

The first step taken was to select the type of solar panel to be used. It is desirable that the cost be minimized as much as possible. When choosing a solar panel, it is important to consider factors such as the specific energy requirements, availability, budget constraints, and environmental conditions. Polycrystalline panels offer a compelling option that balances cost, efficiency, and durability, making them a better choice for this work.

For the solar panel's rating, some calculations were made to ensure that the batteries could be charged entirely by the sun independent of mains supply. Batteries are rated in milliamp-hours (mAh). An average phone battery has a capacity of 3000 - 4000 mAh. Given a typical value of 3500 mAh, and if one plans on using 100% of its power for two days, total capacity will be 3500 mAh×100% × 2 = 7000 mAh. A 7500 mAh battery would be sufficient. But since this battery charger is adapted, with its two USB ports to charge two phones comfortably at once, then the total battery capacity will be doubled, that is, 7500 × 2 = 15000mAh capacity. A 3.7 V battery is to be used, therefore converting the battery capacity to watt-hours, this would be (15000 mAh x 3.7 V)/1000 = 55.5 Wh.

Solar panel sizes are measured in watts (W) and their power output is measured in watt-hours (Wh). The panel's output capacity must at least be equal to the battery capacity. The panel's output capacity, W_p (Wh) is related to the panel's rating, P_s (W) by Equation (3),

$$P_s = \frac{W_p}{TN} \quad (3)$$

where T is the period of direct sunlight (hours), and N is the percentage production. The % production is 100% - losses (%). The losses can come from inefficiencies in the panels, the charger, or the device being charged.

15% loss was generously assumed which makes the % production to be 85%, and assuming a daily average period of direct sunlight of 5 hours, then the solar panel rating is:

$$Ps = 55.5/ (5 \times 0.85) = 13.05 \text{ W}$$

The required voltage for charging the 3.7V battery is 4.2 V whereas the output of the system is 5V. Although there are converters for stepping up and down the voltage level before the USB ports, it is still essential to have the solar panel be able to produce a voltage that is equal or greater than the required voltage. Therefore, the solar panel used has a rated nominal voltage of 9V and rated power of 15W. The solar panel used for this work is shown in Figure 2. It is a polycrystalline type that is made up of 36 solar cells. It is of 15W maximum power, 3% maximum power tolerant, 10.8V open circuit voltage, 1.83A short-circuit current, 9V maximum power voltage, and 1.67A maximum power current.

Figure 2: Solar panel used for the work

3.2.2The Wind Turbine

The components of the wind turbine include blades, which convert the wind energy to rotational shaft energy, an electromagnetic converter, and a pipe that supports the structure. The whole set was physically configured to act as a horizontal-axis wind turbine.

a) The Electromagnetic Converter

Since portability and lightweight is of major interest in this work, therefore, an off-the-shelf 12V BLDC (brushless DC) motor from a desktop computer power supply unit fan was used because of its low inertia, lightweight and brushless operation. The BLDC motor has three sets of coils with three output terminals, but two terminals with additive output voltage were used. The driving electronic circuitry of the

BLDC motor was removed to use it as an alternator. The BLDC motor was used in outrunning mode and diodes were connected to the output to rectify the output alternating trapezoidal voltages to DC.

b) Turbine Blades

From Equation 2, the dimensions of the turbine blades have a significant effect on the power output of the turbine. The longer the blades, the wider the area swept by the blades and the higher the output power of the wind turbine. However, the longer the blades, the more the weight of the blades, which would act as additional load and affect the inertia of the BLDC motor consequently reducing the speed. According to literature, using three blades instead of two blades increases the efficiency of the wind turbine by 3 percent, but the increase in efficiency by using four blades is relatively very negligible. In view of this, the blades of the BLDC fan used is three; of length 12cm and made of very light, thin but firm plastic. The wind turbine with the blades is shown in Figure 3.

Figure 3: The blades of the wind turbine

3.2.3Buck Converter

The buck converter used for this work is the LM2596 DC - DC Buck Converter with voltage display. It is a widely used buck converter integrated circuit (IC) that provides step-down voltage regulation. It allows for adjustable output voltages, providing flexibility for different requirements. The LM2596 has a reference voltage (typically 1.23V) that it compares to a fraction of the output voltage. A feedback loop is established by connecting a resistor divider network from the output to the feedback pin of the LM2596. The LM2596 continuously compares the reference voltage to the feedback voltage. If the output voltage deviates from the desired value, the LM2596 adjusts its internal switching transistor to bring the output voltage back to the set point. LM2596 uses pulse-width modulation (PWM) to control the switching of its internal transistor, and the average output voltage is adjusted by varying the width of these pulses [34]. The LM2596 is shown in Figure 4(a) and its circuit diagram in adjustable configuration in Figure 4(b).

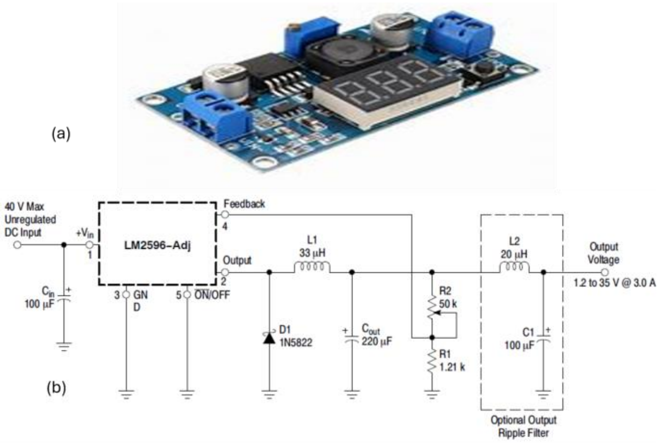


Figure 4: (a) The LM2596 Buck Converter. **(b)** Circuit Diagram of LM2596 buck converter in adjustable configuration [34].

3.2.4Boost Converter

The boost converter used for the output of the small wind turbine is a low input voltage mini DC-DC boost converter module that takes low input voltages (such as from AA batteries, energy harvesters, TEGs, etc) to 3.3V - 5V enough to charge the battery. The boost converter was used for the output of the wind turbine because the wind turbine produces low voltages and low currents. TPS61200EVM-179 module with TPS61200 chip was adapted to serve this purpose [35].

3.2.5Battery

The portable wind-solar charging system includes an energy storage which stores the DC output of these sources and gives power via the USB ports. The energy storage is 5 Li-ion batteries rated 3.7V each. The batteries were carefully assembled in parallel by soldering connecting wires across their positive and negative terminals. Each battery has a rating of 3000mAh and thus its parallel connection gives 15000mAh. The battery is shown in Figure 5.

Figure 5: Li-ion batteries connected in parallel.

3.2.6Power Bank Module

The power bank module used is the dual USB 5V 1A/2A 18650 Lithium Battery Charging Power Bank Module with in-built lithium battery protection. The module converts 3.7V battery power to a stable 5V output capable of delivering up to 2A current. It is designed for use as portable power banks or charging modules for one or more lithium-ion batteries. The module ensures efficient power conversion with built-in protection features such as overcharge, over-discharge, over-current, and short circuit protection. The module has on-board LEDs to indicate charging and discharging, with 4-level indication for showing the energy level of the battery, and non-working state automatic shutdown. The module is compact and ideal for charging USB devices such as smartphones, tablets, etc. [36]. The module is shown in Figure 6.

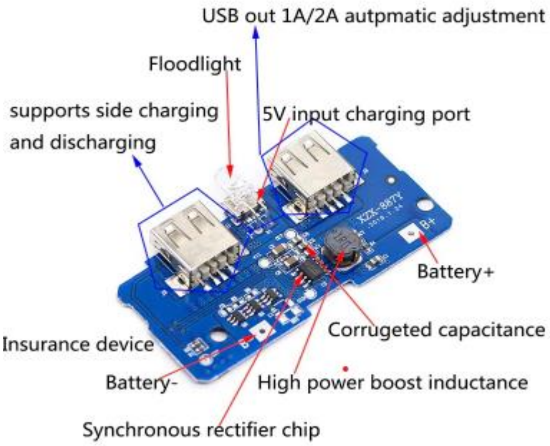


Figure 6: The dual USB 18650 power bank module.

3.3 Assembly of the System

To assemble the wind turbine, a PVC pipe was used to make the tower to support the turbine. The motor was mounted on top of the tower and secured to the fan with a screw. The motor was wired to a male DC jack connector.

The LM2596 buck converter was carefully calibrated and adjusted to generate a steady 5V when it received the higher voltage as input from the solar panel. The calibration was done using a screwdriver, a multimeter and the sun's irradiance. The input of the boost converter was wired to a female DC jack to allow for easy connection and disconnection of the solar panel. The solar panel was also wired to a male DC jack. The boost converter for the wind turbine was calibrated and had its input wired to a female DC jack as well.

The output of the boost and buck converters were wired to the power bank module through power multiplexers. This was done to take advantage of the module's charge controlling capabilities. The negative terminals of the converters were connected to the ground (GND) terminal on the module while the positive terminals of the module were wired to the VIN terminal on the module. The power multiplexer consists of diodes connected between the converters and the power bank module. These diodes, which were positioned carefully, were essential in stopping the reverse current from flowing from the battery to the solar panel and wind turbine. This preventive step guards against any problems related to reverse current and guarantees the stability and integrity of the entire charging system.

The negative and positive terminals of the battery were then connected to the negative (B-) and positive (B+) terminals of the power bank module. The entire system was then placed into its casing to mark out where would be appropriate locations for them to stay. The input and output points for the power bank module and the converters were then drilled and held in place using glue. The entire casing was covered, and the system was tested to ensure appropriate functioning of all its parts. Figure 7 shows the work in assembly and testing phase.

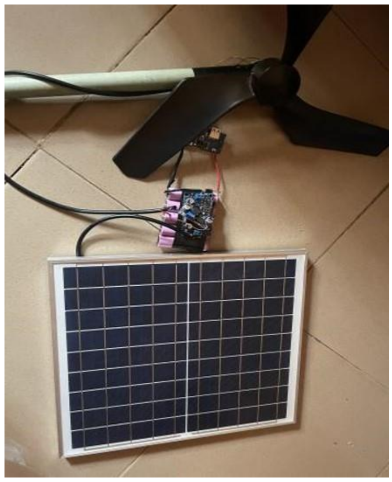


Figure 7: System during assembly and testing "(b)".

4. Results and Discussions

4.1 Solar Panel Testing

The solar panel was tested at different times during the day to determine how the output varies with changing weather conditions. The results of the measurements are presented in Table 1. The results recorded for the voltage and current are open-circuit voltage and short-circuit current respectively. The output power was calculated by multiplying the voltage by the current.

Table 1: The solar panel's output voltage and current during the daytime

Time	Voltage (V)	Current (A)	Power (W)
8:00	7.21	0.75	5.41
10:00	8.04	1.1	8.8
12:00	10.21	1.8	18.37
14:00	9.54	1.52	14.5
16:00	8.1	1.13	9.15
18:00	6.3	0.5	3.15

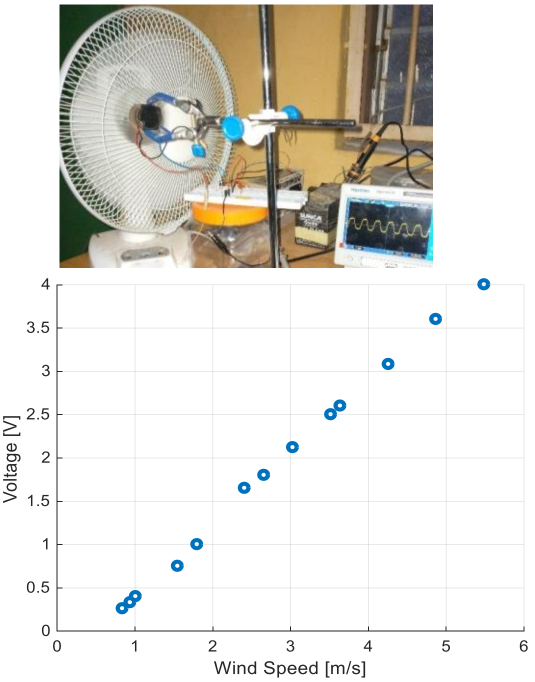
From Table 1, it can be observed that the solar panel gave voltage output greater than 4.2 V. This implies that the solar panel will be able to provide charge conveniently during the daytime. Therefore, regardless of the input from the wind turbine, the hybrid system can provide enough voltage and current to conveniently charge the batteries during the day.

4.2 Wind Turbine Testing

The wind turbine was first tested inside the laboratory with wind produced from an electric fan of varying speed. Figure 8(a) shows the small wind turbine (with shorter blades) under test in the laboratory, and Figure 8(b) shows the open-circuit output voltage with wind speed. The output voltage shows a linear relationship with wind speed with the voltage reaching as high as 4V at high wind speeds.

For outdoor test, a site inside a university campus in Akure, which lies in southwestern part of Nigeria (5.19 E, 7.25 N), was used. The city's climate is tropical, and it is in the region where the warm, moist air from the Atlantic Ocean meets the hot, dry and dust-laden air from the Sahara Desert. The voltage output corresponding to each wind speed was measured six times during the day. Subsequently, the expected power output of the wind turbine based on Equation 2 was calculated for each of the wind speed measurements recorded. Length of turbine blade is 12 cm, swept area is $0.045m^2$, air density is $1.23\ kg/m^3$, and C_p is the Betz power coefficient which is assumed to be 0.593 for this wind turbine. The results of these measurements and calculations are presented in Table 2. Figure 9 shows the mean monthly variation of wind speed over Akure for a year as measured by [37].

(a)



(b)

Figure 8: (a) The wind turbine (with short blades) under test, **(b)** The open circuit output voltage with wind speed.

Table 2: Data collected from the developed portable Wind Turbine

Time of the Day	Wind Speed (m/s)	Output Voltage (V)	Expected Power (W)
8:00	0.51	0.12	0.002
10:00	1.02	0.43	0.017
12:00	1.12	0.48	0.023
14:00	1.23	0.67	0.031
16:00	1.44	0.54	0.049
18:00	1.54	0.73	0.059

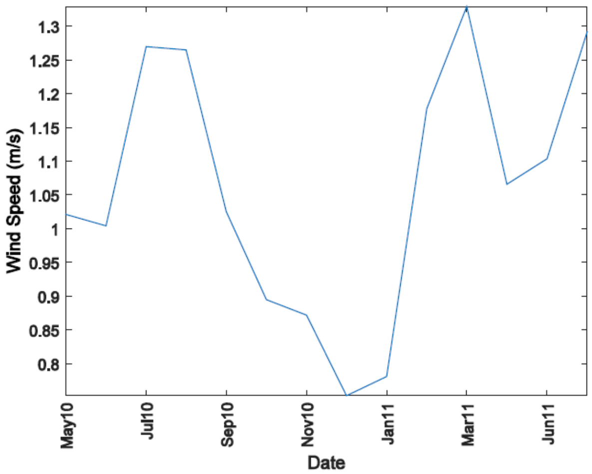


Figure 9: Mean monthly variation of wind speed for Akure for a year according to [37].

From Table 2, it is observed that throughout the test period, the wind speed never exceeded 2 m/s. The highest wind speed recorded was 1.54 m/s, which supports the fact that wind speed in Akure is relatively low as shown in Figure 9 (mean monthly variation within 0.7 – 1.4 m/s). During the day, the highest wind speed was in the evening by 6:00pm and was lowest in the morning at 8:00am. The highest output voltage recorded for the wind turbine was 0.73 V at the highest wind speed. However, the hybrid system designed requires an input voltage of 4.2V to charge the battery which is supplied by the boost converter connected to the output of the wind turbine, but due to current requirements coupled with the relatively low speed of wind in Akure, the wind turbine will not be able to charge the battery as fast as the solar panel at the test location.

4.3 Total Output Power of the Hybrid Harvester

The total power generated by this system is given as the addition of the power generated by the solar PV panel and the power generated by the wind turbine. For the results collected from testing the solar panel and the wind turbine, the highest power outputs of the wind turbine and solar panel are 0.059 W and 18.37 W, respectively. Thus, the highest power output of the entire developed portable hybrid solar-wind system is:

$$P_T = 0.059 + 18.37 = 18.43\ W.$$

5. Conclusion

A portable hybrid solar-wind charger for mobile devices that can be used outdoor and in residential buildings in the tropics has been implemented and tested outdoors. The results of the outdoor tests carried out on the wind turbine showed that the wind speed was highest in the evening. The highest voltage the wind turbine generated throughout the test period was 0.73 V at wind speed of 1.54 m/s corresponding to output power of 0.059 W.

The results of the tests carried on the solar panel showed that it produced the required voltage and power output. This implies that the hybrid system was available for use despite the input from the wind being little during those periods. Low wind speeds at the test location, coupled with the small-scale implementation of the wind turbine however, made it difficult for the wind turbine to generate as much power and voltage as was needed for fast charging. Thus, to generate substantial power, the wind speed must be high.

The work looks to be of great use in a country like Nigeria where there is an abundance of renewable energy sources and yet erratic electricity supply to rural towns and even urban ones. This system will prove to be useful to people who live in places where there is no access to electricity and to people who sojourns to such places. This system is available but not limited to charging phones, power banks and other electronics that can be charged with the aid of a USB cord. To generate enough power and voltage, the wind turbine can be used while in a moving vehicle, where the wind speed is very high and thus enabling it to generate enough voltage for fast charging. From test and measurements, the highest power output of the entire developed portable hybrid solar-wind energy harvester is 18.43 W.

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