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Development of Vertical Axis Wind Turbines and Solar Power Generation Hybrid System

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Abstract: Solar-Wind power generation is a typically new approach in several countries such as The United States of America, United Kingdom and others while other nations are progressively focusing on combining both solar and wind in order to generate efficient energy in their countries. Solar-wind has become an independent, sustainable and clean energy solution, yet, this has not been adopted in many countries. This energy is estimated to overcome the demand of power in the future because of its ability to produce several megawatts of power with zero emission. The aim of this study is to design and develop a hybrid wind and solar energy generation which can increase the electrical energy's efficiency by using the wind turbine and solar panels. The implemented system aims at providing an amplified alternative source of renewable energy to cater for the already diminishing, pollutant and scarce traditional fuels such as oil, gas and coal. The implemented hybrid design consists of an improved design for the VAWT (Vertical Axis Wind Turbine), whereby two VAWT designs i.e. cup shaped and Savonius are compared in terms of performance and efficiency. The system also consists of two solar panels which are used to supplement the power generated especially during hot days when the wind speed is low. The experimental results show that the proposed system is able to generate a maximum power of 75.05W and a minimum power of 18.2W. However, in order to achieve these results a PMSG (Permanent Magnet Synchronous Generator) design from a recycled stepper motor is proposed in this research and implemented with a total number of 9 copper wound coils for the stator and by using rare earth magnets for the rotor (shaft).

Keywords: Hybrid System, Electricity Generation, Permanent Magnet Synchronous Generation, Renewable Energy, Solar Energy, Solar Panel, Wind Energy, Wind Turbine, Solar-Wind.

1. Introduction

Solar-Wind power generation is a typically new approach in several countries such as The United States of America, United Kingdom and others while other nations are progressively focusing on combining both solar and wind in order to generate efficient energy in their countries. Solar-wind has become an independent, sustainable and clean energy solution, yet, this has not been adopted in many countries. This energy is estimated to overcome the demand of power in the future because of its ability to produce several megawatts of power with zero emission [1].

Moreover, Solar-Wind is considered as a non-toxic natural source for electricity generation. However, maximum power supply from a single solar power generation or wind turbine could be costly which is why the combination of solar energy harvest and wind energy harvest will provide a cost-effective power supply, capable of providing energy-cost saving, perform 24-hours of operation and able to generate 5 clean, efficient and cost-effective energy when compared with single source of energy and fossil fuel.

Hybrid energy system is one of the non-conventional methods in which two or more types of energy sources are used to power the load. A hybrid energy system can be defined as an energy system which has been created to retrieve power from two sources of energy. In the proposed hybrid energy system, solar and wind energies are combined which makes the system less costly, reliable, and efficient and produce less emission. These two types of energies are free and widely available around the world; thus, it is crucial to investigate which location will result in higher extraction of these two types of energies.

However, power generation of single wind-based power generation field is not sufficient to provide nonstop power generation. Consequently, these energies are seasonal; for example, there is less wind during the day, therefore combination and optimization of equipment such as solar photovoltaic or wind turbines can increase the efficiency and reliability of the system. Therefore, a hybrid power harvesting and generation system will have

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the capability of providing 24-hours grid quality electricity to consumer or load. This system will provide better efficiency, an environmental friendly system, flexibility and reliability. The proposed system will decrease maintenance costs and utilize sun and wind energy that is available fully freely during the day as well as at night. The proposed system will also provide the opportunity for expanding the capacity of the hybrid system to meet up with the increasing demand in the future.

Therefore, the aim of this paper to design and develop a hybrid wind and solar energy generation which can increase electrical energy's efficiency by implementing wind turbine and solar panels. This aim can be achieved by the following objectives:

1. To design and develop the prototype of the hybrid energy system.
2. To implement a new control system to increase the efficiency of energy generation.
3. To evaluate the performance of the hybrid energy generation system.

2. Novelty

The performance and efficiency of wind turbine and solar panel for power distribution is usually difficult to understand. Leading and lagging changes in wind and solar is crucial because it allows users to relate or correlate the hybrid system power output and the physical configuration of the hybrid system. This developed project is based on improved design for cup shaped VAWT and Savonius VAWT; both are compared in terms of performance and efficiency. The major enhancements are the design and testing of number of blades for the VAWT. Moreover, the real time monitoring of the generated power has been included and the effect of temperature on the solar panel configuration for power optimization has been studied.

3. Related Work

This area of development has motivated researchers and power engineers as this system will take advantage of local resources such as solar-wind to eliminate or reduce the utilization of fuel for energy production [2]. Nonetheless, finding solution to the non-linear performance a standalone solar or wind renewable energy is a challenge which researchers believe hybrid technology as the solution to this problem [3]. Therefore, a hybrid system is becoming important because firstly, in solar and wind energy power generating system, wind does not usually flow continuously while the radiation of sun is usually present at approximately 8 to 10 hours daily and secondly, continuous power is important to human kind. Thus, the hybrid system is the solution to this power shortage or breakage energy crises [4].

Researchers in [5] describe Photovoltaic power generation as the process of converting solar energy into direct current electricity. This can be achieved by using semiconducting materials that detect the potential effect of the photovoltaic. The applications of photovoltaic in different power systems can be grouped into two categories; stand-alone system (also referred to as off-grid) and grid linked system (also referred to as on-grid).

Stand-alone system is typically incorporated with another energy source to empower the consistency of the energy generation system. This can be found in the use of wind energy or power generator that is known as hybrid system. The main aspects that distinguish the two systems is the storage through which the produced power energy is ultimately stored in special batteries linked to the off-grid system [6]. On the other hand, the public grid utility is known to help provide a reliable space for keeping the excess created energy from on-grid system [7]. However, the utilization of on-grid systems is commonly seen in different countries due to its role in providing incentives ways to convert energy sources.

Moreover, the world consists of a huge potential of wind energy resources which should be utilized for power generation since this energy provides a unique extraction technical identity while recent design focus on producing a lighter weight, stronger and more efficient blades [8]. Wind turbines have early recorded a versatile and a great degree design configuration. However, there are a few challenges still commonly present to available design which include low starting torques, lower efficiency, turbine blades lift force, foundation integration and poor building. Nonetheless, numerous researches have recently came up with different innovative design which allow them to approach this issue leading to two different main type of configuration which are horizontal axis wind turbine configuration and vertical axis wind turbine configuration [9].

Several works have been approached on the development of solar-wind hybrid system [10] proposed and designed a hybridization of solar-wind energy system focused on generating power in rural area. Their work is determined to simulate and analyze a small-scale standalone PV/Wind system using different parameters. The system simulates by using MATLAB software while type of data used as input parameters were metrological data and provides a different equation related to available wind power while mathematical equation of solar was based on single diode type and parameters such as series resistor, Rs, shunt resistor, R_{sh}, current I are all extracted for data analysis. The experimental setup of wind turbine system was based on PMSG while solar energy conversion system uses existing PV panel control kit. This was tested in e-PAD laboratory.

Hybrid system for Local PV-Wind approached by [11] to supply electricity for industry, this proposed system comprises of a mounted PV solar cell array along with battery on wind generator. The complete system unit also includes an inverter circuit which allow DC power to convert into AC, electrical heating load, electrical lighting load junction box, several fuses and test instrument for monitoring and testing the current, harmonic contamination, voltage and power factor of the entire system. Another approach made on implementing wind energy system in combination with solar energy and battery for storage capability which explained the implementation of wind energy source capturing kinetic energy in a rotor design to consist of two or multiple blades which they are mechanically coupled with electrical generator. However, a PV system is constructed by utilizing series and parallel of multiple solar cells to achieve optimum power for the proposed hybrid system. The system also includes battery storage system, power electronics, control system. In this approach, battery utilizes converter outputted electrical energy into chemical energy for storage purpose, thus, this charge based on power generated from PV and Wind turbine to battery and discharge based on load request over time. The system approaches maximum power point tracking for PV module and wind turbine which improves the overall performance of the entire hybrid system. Simulation was carried out based on proposed system using MATLAB Simulink software considering 10kW wind/BESS/PV power output while maximum rated output power achieved at 8.5kW [12].

However, modelling and analysis of indication generator excitation by wind turbine variable speed has been approached by various modeler, induction machine has been widely used for various application as a means of converting electrical energy into mechanical energy or vice-versa while many wind powers use induction machine due to their economical factor, reliability and ability to operate with variable speed control system. Although it was noted that induction machine could have drawbacks which required reactive power for excitation, the problem related to current excitation and power generation is well discussed in [13] work.

A Solar-wind hybrid system was developed and implemented for a new engineering complex for the technical university of Mombasa. The system comprised of electrical energy that was generated from wind and solar PV-Systems which also served as an alternative and best method when compared to fossil fuel energy generating system. The method approach first analyzed the building load power demand in relation to the building lighting, refrigerator and other appliance that required electricity. An analysis was conducted based on the solar intensity of the building roof and wind speed patter of the building via RET screen software. The result simulated with HOMER software showed that, optimized mix of PV and wind power with storage rely upon individual subsystems [14].

Literature has shown that wind turbine configurations used by various researches are either vertical or horizontal whereby the connections of the solar panel cell circuits are in series and parallel. It has also been shown that the purpose of integrating the system with microcontroller is to guarantee that, there is optimum use of resources and to increase the efficiency of the system and overall performance.

Moreover, related work approach includes plan of a hybridization of solar-wind energy system, Microcontroller based hybrid renewable energy system, Hybrid system for Local PV-Wind approach, Single diode equivalent circuit which include diodes connected in series, shunt resistor and series resistor, maximum power point tracking algorithm application is also proposed and designed. Other configurations suggested including wind energy system in combination with solar energy and battery for storage capability, a PV system construction by utilizing series and parallel multiple solar cells, modelling and analysis of indication generator excitation by wind turbine variable speed, Wind energy and solar energy power generation system, MATLAB.

Lastly, based on the literature, the hybrid system will be a welcomed addition to contribute to the supply of energy and power that is in great demand regardless of the limited supply. One of the main issues identified from the literature is the lack of an efficient monitoring system for the power generation. Similarly, the conditioning circuitry developed for the hybrid system is not effective thereby resulting to some power losses and leakages. These loopholes will be improved when implementing the proposed hybrid system for our study.

4. THEORY

A. Wind Turbine Output Power

In order to understand wind turbine output power, it is very important to understand the wind speed, power coefficient and area of turbine blade. Equation 4.1 is used to calculate the power available (output).

$$P_{Available} = \frac{1}{2}\rho A V^3 C^p \quad (4.1)$$

Whereby:

A - Area of the turbine blade.

V - Wind speed.

ρ - Air density.

C^p - Power coefficient.

Equation 4.2 is used in the calculation of the area of the blades for the wind turbine.

$$A = \pi r^2 \ (Area) \quad (4.2)$$

Where:

r = l (length) and $\pi - constant$

The power coefficient required for the calculation of the power output for the wind turbine calculates by considering the theoretical power rating of the wind turbine as in Equation 4.3.

$$C^p = \frac{Actual\ power\ produce\ by\ turbine}{Theoretical\ power\ produce\ by\ wind} \quad (4.3)$$

B. Solar Power Efficiency

One of the important tests to be carried out after implementation of the proposed hybrid power generation system is the power efficiency of the solar panel. This will be obtained by using Equation 4.4.

$$\eta = \frac{P_m}{E \times A_c} \tag{4.4}$$

Where:

η is the solar efficiency.

P_m is the maximum power output.

A_c is the area of collector.

E is the incident radiant heat flux.

C. Total Power Generation

By assuming that the total power comsumed is approximately 100watts for about 6 hours per day, therefore conversion of the comsumed power can be achieved to kwH per day using the Equation 4.5.

$$Total\ power\ generation = 100watts \times \frac{2\ Kilowatt}{1000watts} \times \frac{6hours}{day} = \frac{1.2kwh}{day} \tag{4.5}$$

5. METHODLOGY

The proposed system comprises of five major sections which includes the wind section, solar section, inverter, storage section and GUI. The Solar section consists of the mechanisms that utilized in harvesting solar energy from the sun's radiation and to convert it into electricity. The wind section involves the conversion of wind energy into electricity whereas the storage section ensure that extra power generated by solar-wind are stored for further usage. The GUI section is typically where current and voltage are displayed for the purposes of monitoring. The main idea of the proposed methodology is to generate continuous power during the day and night and to keep monitoring power produced over time.

The hybrid power generation relies on power harvested from wind and solar energy using the combination of two solar panels and a wind turbine as shown in the flowchart in Figure 1. The power harvested from these two sources is led to a charge controller to regulate the rate of flow of current produced. The boost converter circuit was connected to the charge controller to step up the DC power generated. A lithium polymer ion battery (LiPo) and an inverter were then connected to the boost converter; whose work was to store the generated power and convert the DC power to AC respectively. The output of the inverter was connected to a conditioning circuitry consisting of a rectifier to direct the current to flow in one direction.

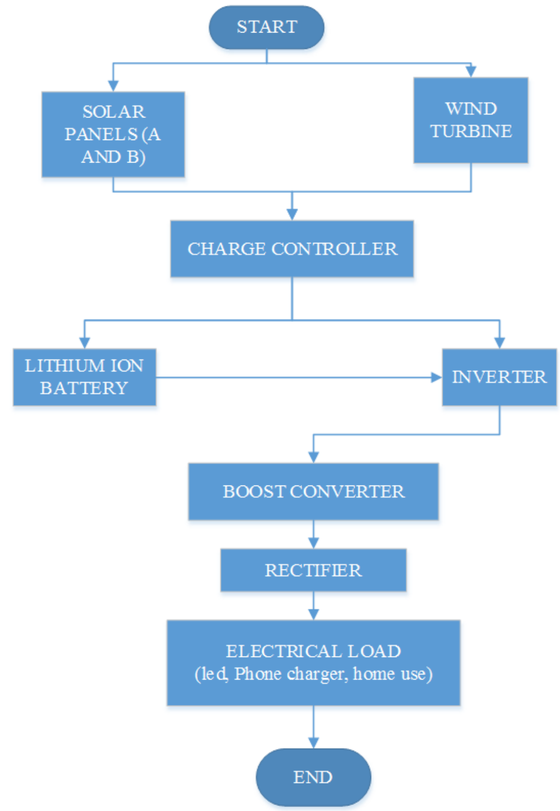

Figure 1. Hybrid System Block Diagram

The hardware part of the proposed hybrid system for power generation is very important for the entire system. The hardware consists of parts and components that were used to harvest the wind and solar energy. These consist of components like microcontroller (Arduino), motion sensor, solar panel, wind turbine, servo, DC motor and others.

The construction of the hybrid power generation system consists of two main parts i.e. the mechanical construction and the electronic construction. A schematic showing the connection of both the electronic and hardware connections is illustrated in Figure 2.

The mechanical construction consists basically of the parts that were used to generate the initial/raw power and motion for the implemented hybrid system. The hybrid mechanical construction and part measurements is as shown in Figure 3 and Table 1.

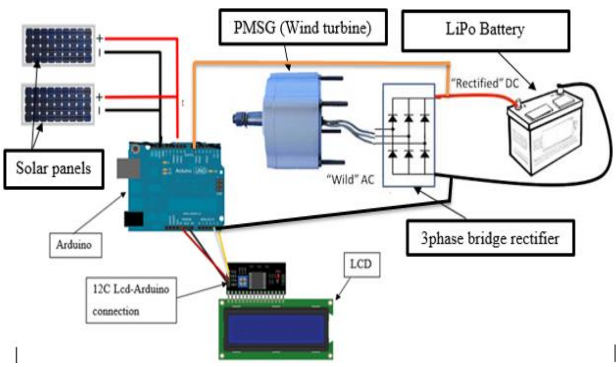

Figure 2. Hybrid System Schematic Diagram

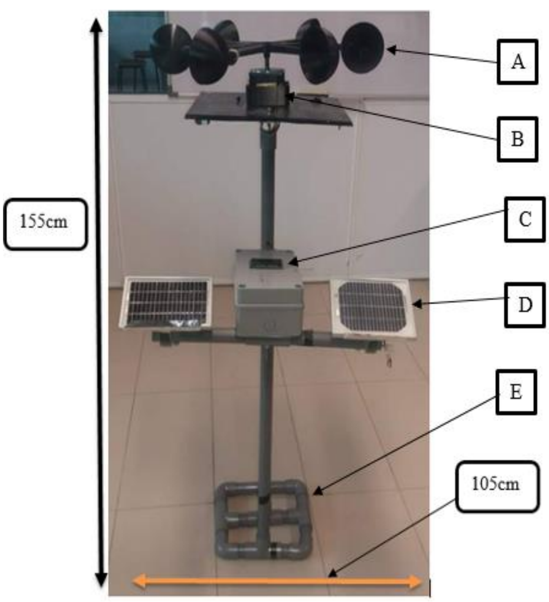

Figure 3. Hybrid System Construction (Front View)

TABLE 1. HARDWARE MEASUREMENT.

Part	Description	Size (L× *W*)
A	Cup turbine	19.5cm by 19.5cm
B	PMSG motor	11.5cm by 12.2cm
C	Circuit box	12.5cm by 15.6cm
D	Solar panel	18cm by 15cm
E	Stand	16.3cm by 15.8cm

The design for the Vertical Axis Wind Turbines (VAWT) consists of mainly recycled carbon polymer materials for the first design i.e. cup shaped turbine whereas the second design i.e. Savonius turbine is mostly constructed from recycled PVC pipes.

A Low RPM Permanent Magnet Synchronous Generator (PMSG) was implemented in the hybrid system to help convert the kinetic energy harvested from the wind (VAWT) to electrical energy. To achieve, this a recycled stepper Motor was used to provide the necessary stator coils and housing for the shaft.

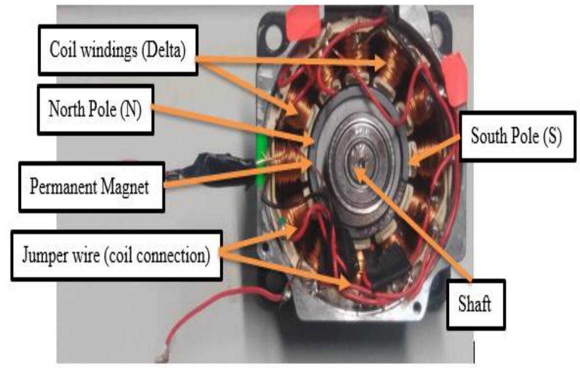

Figure 4. Low RPM Permanent Magnet Synchronous Generator

Moreover, the cup shaped wind turbine consists of mainly 6 major arms that are spatially mounted on a vertical shaft consisting of cup shaped airfoils. Snap fit connections were used to connect each arm onto the centralized vertical shaft for the sole purpose of attaching and removing each arm when the need arise. The ease of connecting and disconnecting the arms later helped when testing was being conducted to establish the efficiency of the system based on the number of arms attached.

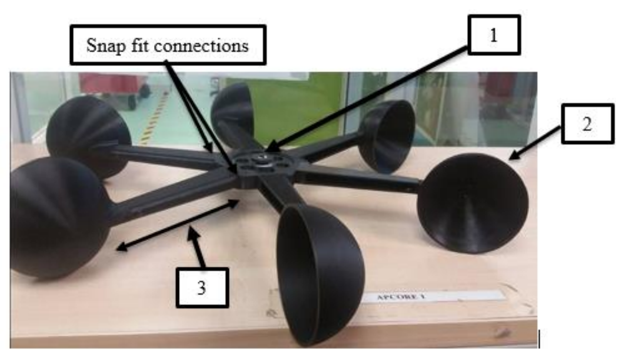

Figure 5. Cup Shaped Turbine

In the construction of the Savonius Vertical Axis Wind Turbine, the number of blades was given priority since the number of blades has a significant direct impact on the efficiency and overall stability of the design. As a result, a two blades configuration was selected with the aim of increasing both efficiency while reducing the costs of construction. The 2 blades configuration also helped reduce the amount of materials used for construction such as bearings, shaft diameter, base, and time. The two blades configuration also assisted in reducing the rotational vibrations and torque ripples associated with the use of 3 and 4 axis blade configurations as discovered by [15].

Therefore, the entire Savonius turbine is mounted on a frame consisting of a vertical shaft of diameter 1.7cm. The two blades configuration consists of solid aerodynamic U-shaped airfoils. Each blade designed has a diameter of 15cm and is 25cm long.

The solar panels were basically used to harvest the solar energy from the sun and convert it to electrical energy for consumption. The implemented system consisted of two solar panels each with a power rating of 12V DC. Each solar panel measured 150mm by 180mm as shown in Figure 6.

Figure 6. Solar Panel

The solar panel implemented for the hybrid system has a maximum power rating of 2W and has the specifications illustrated in Table 2.

TABLE 2. THEORETICAL VALUES FOR THE SOLAR PANEL (MODEL NO. SW2).

Specifications	Value
P_{max}	2W
V_{mp}	17.5 V
I_{mp}	0.115A
V_{oc}	21V
Test condition	AM1.5, 25^0C, 1000W/m^2

6. EXPERIMENTAL RESULT

This section illustrates the hardware design and simulation results of the proposed system. The experimental results show that the system was able to generate ample voltage and current for both the PMSG generator (wind turbine) and the two solar panels as illustrated in Table 3. The hybrid system implemented was able to generate maximum power, voltage and current of 48.13W, 17.9V and 4.21A. These results were mainly achieved when the sunlight intensity was ideal for solar power harvesting and optimum wind speed for power harvesting using the VAWT (PMSG). The maximum output power obtained during testing was 48.13W whereas the minimum power generated is 18.18W as illustrated in Table 3. Both modelling and experimental results demonstrated that the system is able to achieve higher efficiency based on the data measured during testing and in comparison with other similar systems analyzed in the Literature reviewed. The system is also able to produce electric power, especially during periods of unfavorable environment conditions whereby the electric power generated is able to fully charge the 12V LiPo battery in under 5 hours. This is because as one of the weather elements e.g. wind speed is low, the other element i.e. solar energy is high. This means that the system will rely more on power generated from the solar energy rather than wind power and vice versa.

TABLE 3. POWER GENERATED BY THE HYBRID SYSTEM.

Description	Hybrid system
Voltage (Max)	17.9V
Current (Max)	4.21 A
Voltage (Min)	8.3V
Current (Min)	2.19A
Power (Max)	48.13W

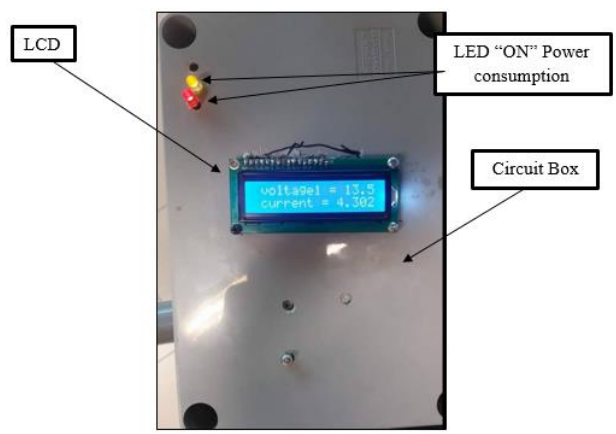

Figure 7. LCD Results

Therefore, several different experiments were conducted on the power hybrid generating system with the aim of establishing the ideal conditions for the prototype constructed to operate. These tests were also aimed to measure the performance and efficiency of the system.

A. Angle of Elevation of the Solar Panel

A test was conducted to establish the best angle of elevation for the solar panel to be mounted for adequate power generation as shown in Figure 8. According to [15], the angle of elevation is an integral part when setting up the solar panel to allow the photovoltaic cells to be exposed to maximum sunlight.

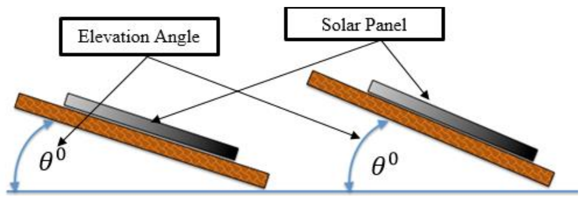

Figure 8. Pitch Angle Elevation

Therefore, this test was carried out to establish an ideal angle for the solar panel elevation as illustrated in Figure 8. According to [15], the angle of elevation can be decided upon based on a simple formula which is dependent on the Latitude of location of the city. Kuala Lumpur is located along 3.1390°N (Weather at Kuala Lumpur in 2016). Thus,

$$\text{Pitch Angle } (\theta) = \pm\{(\emptyset \times 0.9) - 23.5\} \text{ degrees} \quad (6.1)$$

Where:

$\emptyset$ = Latitude of Kuala Lumpur, Malaysia (3.1390° N)

$$(\theta) = \{(3.1390 \times 11.45) - 3.5\} \pm 8^0 = 32.44^0 \pm 8^0$$

The overall angle of elevation of the solar panels against the earth's horizontal surface was set based on 32.44^0. The angles set for testing were based on the theoretical value of 32.44^0 as illustrated in Table 4.

TABLE 4. ANGLES OF ELEVATION SET FOR TESTING.

Description	Angle (Degrees)
Theoretical value (Angle A)	32.44^0
+ 8^0 (Angle B)	40.44^0
- 8^0 (Angle C)	24.44^0

B. *Effect of Temperature on the Solar Panel*

An experiment was carried out to investigate the effect of temperature on the solar panel. According to [16], the performance and efficiency of a solar panel is dependent on the temperature whereby as the temperature rises above a certain limit, the solar panel begins degradation and therefore reduced performance. This therefore provides a challenge in harvesting electric power from the photovoltaic cells. A temperature sensor LM35 was used to collect the temperature readings of the solar panel during testing as illustrated in Figure 9. The solar panel angle of elevation was set to 24^0 since the maximum power generated when the panel was elevated at an angle of 24^0 was 1.7584W which is near the maximum theoretical power rating of the solar panels i.e. 2W as shown in Table 2.

Testing of the solar panels was conducted for 20 days, whereby the voltage, current and power generated at the different corresponding temperatures was recorded. The experimental results shows that the least amount of voltage, 4.6V was generated when the temperatures were very high i.e. 34°C and the highest voltage 15.1V when the temperatures were low i.e. 29°C. Figure 9 shown that as the temperature increased, the amount of power generated increased until the temperature reached 29°C from where the amount of power started reducing as the temperatures increased beyond 30°C.

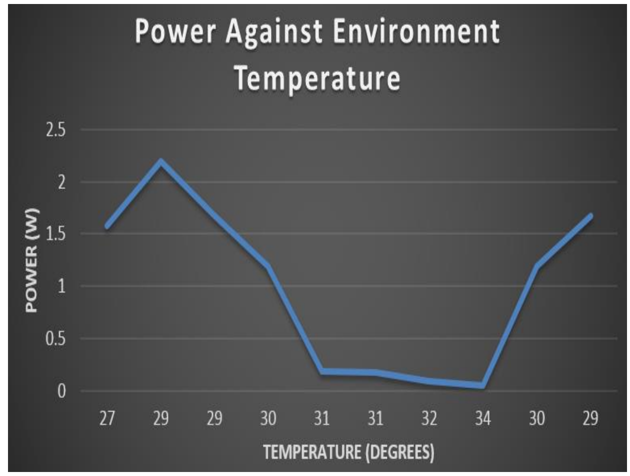

Figure 9. Power Generated Against Temperature (Solar Panel)

The hybrid system was tested separately and then tested as hybrid system. The power output for the solar panels with the elevation angle of 24° is shown in Table 5.

TABLE 5. POWER GENERATED BY SOLAR PANELS.

Date	Time	Voltage (v)	Current (A)	Power (V×I) (W)
Mon 3rd July 2017	7:00am	15.1	0.111	1.68
	8:00am	13.9	0.100	1.39
	9:00am	15.2	0.111	1.69
	10:00am	14.6	0.110	1.61
	11:00am	14.9	0.112	1.67
	12:00pm	13.6	0.109	1.48
	1:00pm	15.7	0.112	1.75
	2:00pm	14.2	0.110	1.58
	3:00pm	15.1	0.111	1.68
	4:00pm	14.2	0.109	1.55
	5:00pm	15.0	0.111	1.67
Total Power				17.75

The power output for the wind turbine with 6 cup blade is shown in Table 6.

TABLE 6. POWER GENERATED BY VERTICAL AXIS WIND TURBINE.

VAWT Type	Date	Time	Voltage (v)	Current (A)	Power (V×I) (W)
Cup Shaped	Tue 18th July 2017	7:00am	9.8	1.303	12.78
		8:00am	14.2	1.494	16.90
		9:00am	10.4	1.318	13.85
		10:00am	12.8	1.427	18.29
		11:00am	13.6	1.501	20.43
		12:00pm	12.8	1.429	12.05
		1:00pm	9.5	1.298	15.33
		2:00pm	10.8	1.319	13.32
		3:00pm	9.8	1.303	14.78
		4:00pm	10.1	1.319	13.32
Total Power					151.05

C. *Efficiency of the Wind and Solar Hybrid System*

The overall power output of the hybrid system is shown in Table 7. The hybrid system was tested continuously throughout a period of 20 days, 12 hours per day and was able to achieve a maximum power output of 75.05 watts when the VAWT and the two solar panels were combined together to give the overall output power. The maximum voltage generated by the system when solar and wind conditions were favourable, was 17.9V with a maximum peak current of 4.193A. However, the hybrid system would have produced more power under optimum conditions i.e. high wind velocity and maximum solar intensity. However, these optimum conditions are rare and hard to come by.

The implementation of a Permanent Synchronous Generator (PMSG) played a huge role in the increased power output of the hybrid system in comparison to those used by other researchers. The use of optimization techniques such as the use of the 9 coils configuration and the Neodymium earth magnets in the PMSG played a vital role in increasing the output of the system especially at low speeds.

TABLE 7. POWER GENERATED HYBRID SYSTEM.

Date	Time	Voltage (v)	Current (A)	Power (V×I) (W)
Mon 14th Aug 2017	7:00am	8.3	2.193	18.2
	8:00am	9.6	2.219	21.3
	9:00am	10.9	3.214	35.03
	10:00am	14.5	3.319	48.13
	11:00am	17.9	4.193	75.05
	12:00pm	15.8	3.419	54.02
	1:00pm	14.6	3.902	68.67
	2:00pm	17.8	4.191	74.60
	3:00pm	15.6	3.209	50.06
	4:00pm	17.4	4.211	73.27
	5:00pm	17.6	4.205	74.01
	6:00pm	14.8	3.320	49.13
	7:00pm	9.2	2.198	20.22
Total Power				661.69

D. *Cup Shaped and Savonius Turbine Comparison*

Data in terms of power generated was collected from the different blade configurations for the cup shaped turbine and the Savonius turbines for 21 days, based on the test conducted and the resulting data as described in Table 8 and Table 9.

TABLE 8. POWER GENERATED (6 AXIS CONFIGURATION).

VAWT Type	Date	Time	Voltage (v)	Current (A)	Power (V×I) (W)
Savonius (wind speed = 7.5m/s)	Tue 18th July 2017	7:00am	8.3	1.205	10.01
		8:00am	9.2	1.293	11.90
		9:00am	9.5	1.295	12.30
		10:00am	10.3	1.321	13.61
		11:00am	9.3	1.293	12.02
		12:00pm	9.1	1.291	11.75
		1:00pm	9.1	1.290	11.74
		2:00pm	11.6	1.410	12.76
		3:00pm	9.8	1.302	12.75
		4:00pm	9.6	1.297	12.45
Cup Shaped (wind speed = 7.5m/s)	Tue 18th July 2017	7:00am	9.8	1.303	12.78
		8:00am	14.2	1.494	16.90
		9:00am	10.4	1.318	13.85
		10:00am	12.8	1.427	18.29
		11:00am	13.6	1.501	20.43
		12:00pm	12.8	1.429	12.05
		1:00pm	9.5	1.298	15.33
		2:00pm	10.8	1.319	13.32
		3:00pm	9.8	1.303	14.78
		4:00pm	10.1	1.319	13.32

TABLE 9. POWER GENERATED (4 AXIS CONFUGURATION).

VAWT Type	Date	Time	Voltage (v)	Current (A)	Power (V×I) (W)
Savonius (wind speed = 7.5m/s)	Mon 17th July 2017	7:00am	8.3	1.209	10.03
		8:00am	8.6	1.211	10.41
		9:00am	7.7	1.207	9.29
		10:00am	8.1	1.204	9.75
		11:00am	7.9	1.208	9.54
		12:00pm	8.4	1.210	10.16
		1:00pm	7.8	1.207	9.41
		2:00pm	7.7	1.207	9.29
		3:00pm	7.5	1.204	9.03
		4:00pm	7.6	1.207	9.17
Cup Shaped (wind speed = 7.5m/s)	Mon 17th July 2017	7:00am	8.8	1.212	10.67
		8:00am	9.2	1.294	11.90
		9:00am	9.6	1.298	12.46
		10:00am	9.8	1.301	12.75
		11:00am	9.6	1.297	12.45
		12:00pm	9.3	1.296	12.05
		1:00pm	9.5	1.298	12.33
		2:00pm	9.8	1.302	12.76

It was observed that the efficiency of the Vertical Axis Wind Turbines for both types, kept on increasing with increase in the number of blades for each design. However, the Cup shaped turbine produced greater efficiency (power output) of 20.43W in comparison to the Savonius type which produced 13.61W as illustrated in Figure 10. The maximum voltage realized from the 6-axis cup shaped wind turbine was 14.2V whereas the Savonius turbine generated 11.6V. This variation in performance was mainly due to the lower drag generated by the cup shaped turbine, whereas the Savonius turbine produced much higher drag resulting from the limited aerodynamic design.

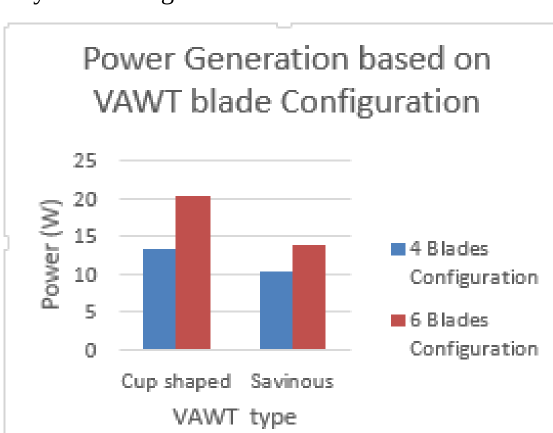

Figure 10. Power Generation Based on the Number of Blades

From results obtained, it was observed that power generation varied based on the time of day during the month of July 2017 whereby maximum power was generated during the evening in comparison to morning time. Therefore, based on the high efficiency realized from the Cup shaped VAWT, it was selected to be used for the hybrid system.

7. Conclusion

To conclude, a hybrid wind and solar energy generation was designed and developed. The hybrid system implemented was able to generate maximum power, voltage and current of 48.13W, 17.9V and 4.21A. These results were mainly achieved when the sunlight intensity was ideal for solar power harvesting and optimum wind speed for power harvesting using the VAWT (PMSG). The maximum output power obtained during testing was 48.13W whereas the minimum power generated is 18.18W.

One of the main limitations was the difficulty in finding ideal conditions of operation for both solar and wind power generation, for the hybrid system to operate at optimum levels; ideal conditions of fairly strong winds and sunny conditions are necessary for the wind and solar power harvesting respectively. Another limitation faced during implementation of the system was that of stability. Despite using a power conditioning circuit to help reduce fluctuations experienced from the two different types of energy sources, an abrupt change in the power output from one of the sources i.e. either solar or wind output; contributed to a change in the load which could have a damaging effect to the circuitry and the battery used for storage in the long run.

For future work, a more reliable stabilization circuit can be implemented. A Nano-antenna module can also be integrated into the hybrid generation system in order to reduce or eliminate any kind of fluctuations and disruptions (load shedding).

Furthermore, to increase the efficiency of the solar and wind energy harvesting mechanisms, further research can be conducted to establish the best mounting positions for the solar panels and wind turbines. This can be accomplished by using sensors to facilitate digitally controlled mounting systems that adjust the positions of the solar panels and wind turbines based on the direction and angle of high solar intensity or high wind speed.

Lastly, another area that can be researched upon for improvement of the hybrid system is the design of the drive train for the wind turbines. The drive train mainly consists of the gear box that is employed in stepping up the overall velocity of the system generator by varying the transmission configuration of the wind turbine. By further developing the drive train the speed of rotation for the wind turbines can be increased even when the wind speed is minimum, thereby leading to the generation of more power output.

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