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Design of a Microcontroller-Based Pitch Angle Controller for a Wind Powered Generator

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Abstract: Generation of electrical energy in wind power plants solely depends on the wind. Pitch angle controller systems that can detect the wind's speed, direction and can face the turbine to the wind's direction are valuable in such system to provide better utilization of kinetic energy which will be converted to electrical energy. The design of a Microcontroller-based Pitch Angle Control covered the design of a system that will measure the wind's speed, and sense it's direction and will turn the turbine facing the wind's direction in Yaw movement only once the given conditions are attained. The system was composed of 4 main hardware components: Anemometer, Wind vane, Microcontroller, and the Gear box. The anemometer measures the wind's speed; the wind vane detects the direction of the wind; the microcontroller acts as the brain of the system, performing the entire decision making, which commands the servo in the gear box; the gear box houses the servomotor and the gears and belt that is attached to the wind turbine's head. Actual simulation results showed that the pitch angle control will only function once the set value for the wind's speed is attained.

Key words: *Pitch Angle Controller, Yaw movement, Anemometer, Wind vane, Microcontroller*

INTRODUCTION

Wind power plants are considered one of the most promising generating plants in our time. It is considered as economic friendly and its primary source is renewable. Besides being the world's second largest producer of geothermal power, the Philippines has particularly good potential for wind farming [1].

A wind turbine uses airflow to turn its propeller connected to a shaft and onto a generator that will convert kinetic energy to electrical energy. However, problem with this system is that it is dependent on the magnitude of the wind. Furthermore, wind direction varies from time to time. Basic wind generators with simple pitch angle control such as downwind turbines with passive yaw systems, produces problems such as its sensitivity with the direction of the wind. Such system is only applicable in small scale turbines while larger turbines use hydraulics and side rotor yaw system which are costly [2]. In actual, turbine blades with head weights heavy and it can affect the rotation of the head towards the wind direction. That is why the design focused on resolving such issue.

The design for this was tested for small scale application only. The servo motor used can only accommodate up to 10 kg only. Also the wind-vane can only detect 8 directions only, thus the degree per step is 45°. The design can be expanded by putting more hall-effect sensors but the pins for the microcontroller must be taken into account. Implementing such numerous sensors, an IC must be used to minimize the pins going to the microcontroller. The design was more focused on the ability of the microcontroller to sense the wind's speed and direction and to command the servo motor to face the turbine to the wind's direction.

RESEARCH DESIGN AND DATA GATHERING PROCEDURES

The objective is to design a pitch angle controller for a wind powered generator. To ease the development of the system, a Design Flowchart, as shown in Figure 1, was formulated to have a generalized view of how the objectives can be answered.

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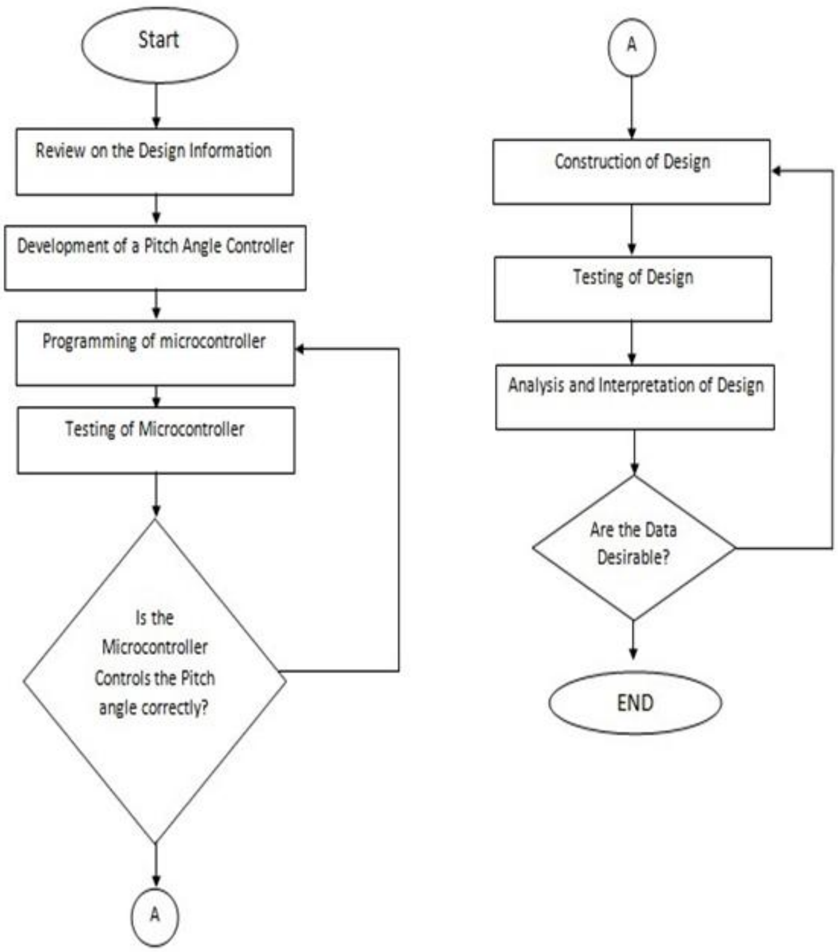

Fig 1 Design Flowchart

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A. **Review on the Design Information**

Wind Energy comprises of a number of major aspects such as wind power, sensors control system, pitch angle control and etc. In this design, it focused on the pitch angle control specifically the yaw movement of the nacelle.

B. **Development of Pitch Angle Control**

Using Wind instruments such as wind vane for the direction and anemometer for the speed, the microcontroller will be programmed to function as one and to control the wind instruments and the wind generator. Basically, the pitch angle of controller for the wind generator will only function when a certain or set wind speed is attained by the anemometer that is converted to voltage and sent to the microcontroller. When the wind speed slows down and didn't attain the speed, the microcontroller will disconnect the turbine to the circuit. For the wind instruments, Hall Effect switches are used to convert the wind direction and wind speed to a read-able quantity for a microcontroller which is voltage.

C. **Programming of Microcontroller**

The microcontroller serves as the main control for the wind generator. It is programmed to start the wind turbine when it attains a set speed, to follow the wind direction when it is functioning and to disconnect the turbine when the wind speed is too high. Specifically, an Arduino Diecimila microcontroller is used to execute the program [3-4] [5].

D. **Testing of the microcontroller**

Testing of microcontroller was implemented to ensure that it is functioning and to minimize errors before the design is implemented. The microcontroller was simulated using potentiometer for the wind speed and the sensor pins were shorted in order to have a logic zero for the wind vane that acts as wind direction.

Table 1 Angle Designation of the Sensors

Hall Effect Switch Number	**Angular position**
1	0
2	45
3	90
4	135
5	180
6	225
7	270
8	315

Angle designation is needed for the right sensor inputs in the program. There are two factors that affect the designation of angles: First, the gear ratio of the servo motor and the nacelle. Second, the number of sensors used for the wind vane. The gear ratio used for the servo motor and the nacelle is five-halves (2.5) is to one (1). On the other hand, Table 1 shows eight sensors used for the wind vane and the angle difference of the sensors is forty-five (45) degrees.

E. **Construction of the Design**

After testing whether the program for the microcontroller is working, a prototype was made starting from the wind turbine down to its wind instruments. The design will only serve a small scale prototype. The wind generator stood eight (8) feet up to ten (10) feet only based on the previous thesis, “Wind Technology Powered Aerator”, which was an effective height for a small scale prototype. As seen on Figure 2, two (2) bases were indicated, the first (1^{st}) base served

the wind instruments while the second (2^{nd}) base served the geared servo motor.

F. **Testing of the Design**

The design was tested if it verifies the specific objectives of the design. The system must follow the system generation shown in Figure 2

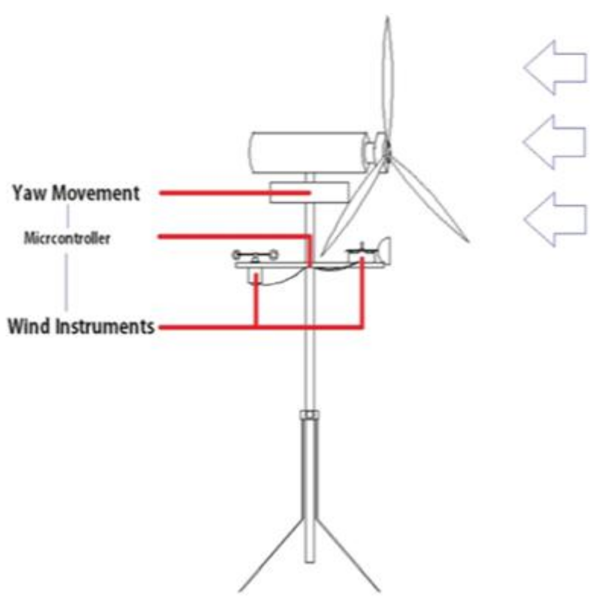

Fig 2 System Generation

When a certain wind speed is attained, the microcontroller will start the wind generator to function and let the pitch angle control find the highest possible wind speed. The wind speed gives mechanical input to the system, through a DC motor that is converted to voltage and read by the microcontroller. For the wind direction, Hall Effect Sensors are connected to the wind vane. Hall Effect sensors are supplied with five (5) volts and when an earth magnet is in near contact, the microcontroller will read a zero (0) volt input. From the microcontroller, it will command the servo motor to move where a hall effect is last passed by the magnet [6].

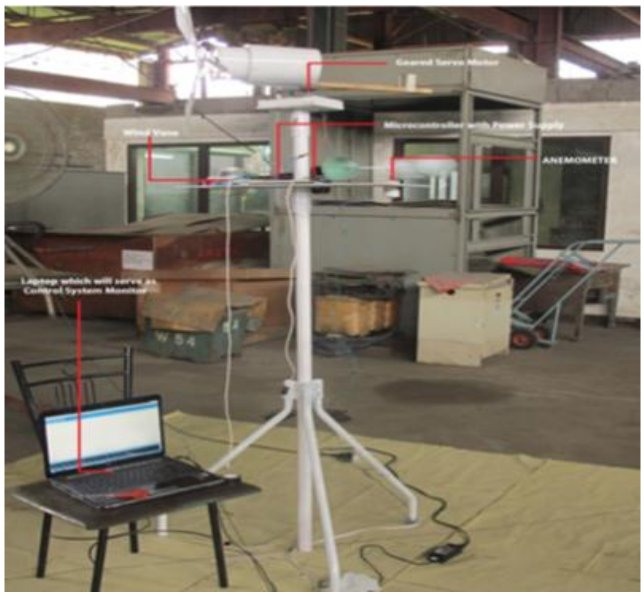

Fig 3 Actual Setup for testing of the Wind generator

As shown in Figure 3, the design is placed at the center while an industrial fan revolved around it in eight (8) directions. The nacelle of the turbine was observed if it follows the pointer of the wind vane. The industrial fan was approximately three-halves (1.5) meters away from the design. Based on testing, the wind speed in this point ranged from 22-24 m/s.

Table 4 Pitch angle control power shows when the pitch angle controller was turned on. In this testing, a constant distance of one (1) meter between the design and the industrial fan was established. Using a handheld anemometer, the wind speed of the fan was known.

Table 2 Voltage Comparison

Degrees	With Pitch Angle Control (V)	Without Pitch Angle Control (V)
0	1.42	1.44
45	1.39	0.8
90	1.5	0.1
135	1.46	0
180	1.47	0
225	1.42	0
270	1.45	0.1
315	1.35	0.7

The design was tested in a controlled environment that has industrial fan. The fan was directly facing the wind instrument and the wind generator. At a certain speed, the microcontroller was set at a certain voltage to a start the operation for the pitch angle control. A test value was included to know if the wind generator still functions at a normal wind speed. In addition, a maximum value was tested for the bad weather condition. It must be turned off when a high wind speed is read by the wind instrument. Table 2 shows a Voltage Comparison had an average wind speed of twenty-three (23) m/s with a constant distance of three-halves (1.5) meters between the design and the industrial fan is maintained. The accuracy of the pitch angle control using servo motor was tested in a controlled environment. The groups manually moved the pointer of the wind vane to a specific angle and the nacelle of the wind generator must imitate the angle of the pointer. The angle of the nacelle was measured by extending the line of the nacelle and measuring it by protractor using the base as the reference. The measured values are found in Table 3.

Table 3 Angle Difference

Wind Vane (degrees)	Nacelle (degrees)															Ave	Ave Percent Error
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00
45	50	45	50	40	40	50	45	45	50	55	45	50	50	40	45	46.67	1.82
90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90.00	0.00
135	140	135	140	140	130	135	135	135	135	140	130	140	135	145	145	137.33	0.86

DATA ANALYSIS

Measured and gathered data in this design must be evaluated. Analysis and interpretation was necessary in order to satisfy and prove the objectives. The process was based on the Figure 3 System Generation.

Table 3 shows the accuracy of the turbine's head with regards to the wind vane. For this, there were 15 trials for each angular position. The wind vane's magnet was positioned manually to trigger the hall-effect switches. For each trial, the angle of the head was measured. The actual value for each trial was 45° step difference which was the wind vane's angle. As seen in the table, there were angles of the nacelle that were not exact with the wind vane's angle. These were due to the problem with the design's chain. The chain was somehow loose, thus it still produced a movement even though the servo motor already stopped. Also taken into account was the gear that was coupled with the servo. In some instances, the gear tended to loosen because of the weight and thus it produced error to the accuracy of the system. The highest average percentage error was seen at the angle of 45° with an error of 1.82 and the others has less than 1.The Overall Percentage Error Average of the system was 0.69%, producing only small amount of error. Also the Overall Standard Deviation was 0.53, this indicates that the percentage error tends to be very close to the average value which is 0.69%.

Table 4 shows the function of the pitch angle control design. The system was designed in such a way that it will not start functioning until a set value was obtained. For wind speed 0-12m/s, the servo motor did not move even though there was a change in the wind vane angle, indicating that the system was still turned off. At such condition, the message in the controller was "There is not enough wind detected". For the wind speed 14-30m/s the servo motor moved and directed the turbine's head into the wind vane's position, indicating that the system was already turned on. The new message was "There is enough wind detected".

Table 4 Pitch Angle Control Power

Wind Speed (m/s)	Voltage	Power
0	0	off
2	0	off
4	0	off
6	0	off
8	0	off
10	0	off
12	0	off
14	0.345	on
16	0.885	on
18	1.305	on
20	1.68	on
22	2.145	on
24	2.43	on
26	2.925	on
28	3.22	on
30	3.51	on

There were 2 sets with 8 trials each. The First set was the system with Pitch Angle Control. After obtaining the voltages generated in every angle, the voltage produced in such system was somehow constant with an average value of 1.4275V.

RESEARCH FINDINGS

Figure 4 illustrates the characteristic of the generated voltage in such system; the voltage generated was constant since this was tested in a controlled environment with a wind speed constant. The Second set was the system with no Pitch Angle Control. The voltages generated for each angle was not constant and there were point that the generated voltage was 0.

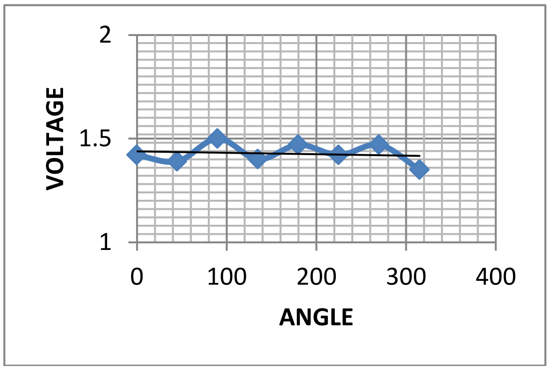

Fig 4 Voltage vs. Angle Graph of Wind Generator with Pitch Angle Control

The voltages were seen in Figure 5 after registering a voltage of 1.44V the voltage went down as the wind direction changes.

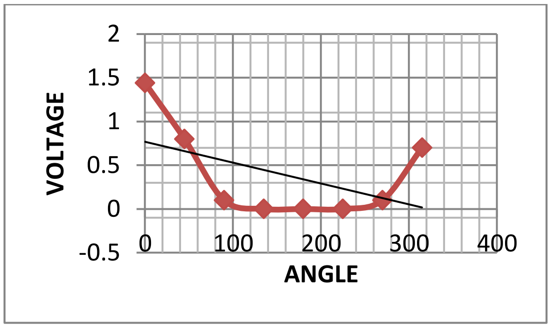

Fig 5 Voltage vs. Angle Graph of Wind Generator without Pitch Angle Control

Figure 6 shows both curves for both systems. This just shows that the generated voltage for a wind powered generator really depended on the magnitude of the wind utilized. It implies that the need for a pitch angle control in a wind powered generator is recommended.

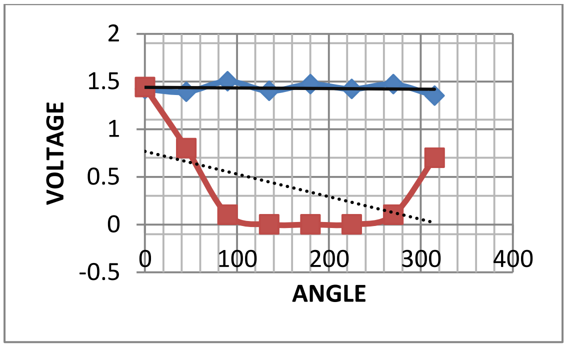

Fig 6 Voltage vs. Angle Graph Comparison

CONCLUSION

The Pitch Angle Control had its microcontroller unit functioned systematically. The first response of the system was based on the wind speed that is detected by the anemometer. At wind speed 0-13m/s, the system sent a message that "there is not enough wind detected". The servo motor did not move even though there was a change in the wind vane angle. At wind speed 14-30m/s, the system sent a new message that "there is enough wind detected", at this condition the second response of the system was based on the angle that is detected by the wind vane. When there was a change in angle, the servo motor also turned accordingly with the direction of the wind vane. Based on the percentage error and the standard deviation indicate that the system's works accurately.

Based on the results, the system functioned satisfactorily. The system was able to detect the wind's speed and direction and responded accordingly.

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