JOURNAL OF SUSTAINABLE ENERGY VOL. 15, NO. 1, JUNE, 2024

DESIGN AND SIMULATION OF A MICROCONTROLLER-BASED DEVICE FOR SPEED COMPENSATION IN WIND TURBINE IN MINNA, NIGER STATE, NIGERIA

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Abstract - This work provides the solutions to the technical challenges of output power fluctuations and intermittencies associated with wind turbines due to a continuously varying input of wind speed and an everchanging wind direction. The design comprises of the wind sensing, electronic control and electric motor sections. Microcontroller technology using Atmega328P, integration of control algorithms, local wind data from wind sensors, precise motor control mechanisms and simulation techniques were applied. When incorporated into a conventional wind turbine, it equips the turbine with a wind-speed reinforcement capability. Simulation results show that the designed circuit has demonstrated tremendous capability to making-up for low power output emanating from low wind speed and to harvest available wind irrespective of originating wind direction. This, it does by generating appropriate speed compensation data in order to reinforce the rotors speed. It was recommended that the wind turbine control device so designed be modelled and evaluated in order to validate the optimized performance.

Keywords: renewable, wind-data, speed-reinforcement, power

1. INTRODUCTION

The rising concerns over global warming, environmental pollution, energy security and diminishing natural resources have increased interest in developing clean renewable and environmentally friendly energy sources such as wind, solar, hydropower, geothermal and biomass as the replacements for fossil fuels [1]. Wind energy can provide suitable solutions to the global climate change and energy crisis. The utilisation of wind power essentially eliminates emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and other harmful wastes as in traditional coal-fuel power plants or radioactive wastes in nuclear power plants.

Wind exists everywhere on the earth, and in some places with considerable energy density. The kinetic energy of the wind can be captured and converted into electricity [2]. Wind turbines are used for such conversion [3]. Wind turbines do not produce emission into the environment while generating electricity [4].

In order to design an efficient wind turbine, knowledge from diverse scientific fields is required: aerodynamics, mechanical engineering, electrical and electronic engineering, materials and industrial engineering, civil engineering, meteorology, and automatic control among others.

The electrical system of a wind turbine comprises all components for converting mechanical energy into electric power, as well as auxiliary electrical equipment and the control and supervisory system [5].

The endemic public power supply crisis in this part of the globe is obvious. This has manifested in form of frequent outages, rationing and grid collapse causing untold hardships and losses to electricity subscribers. There is dire need for alternative sources among which is wind power.

Electricity provided by wind driven turbines are not without some bottlenecks. Some of the challenges identified in this work are power output fluctuation (high-and-low) and output intermittencies (on-and-off) due to a continuously varying wind speed.

In view of the above problem, there is the need for a mechanism that will monitor the prevailing wind speed and initiate a reaction to make up for drop in wind speed and also realign the blade panel. Both actions are necessary conditions towards attaining the rated turbine output at all times.

Therefore, the aim of this study is to design and simulate a microcontroller-based device for speed compensation in wind turbine in Minna, Nigeria. This will be achieved by designing a circuitry incorporated with a microcontroller which is programmed to accurately measure and compensate for changes in wind speed and to develop a simulation environment where the microcontroller-based device can be tested and its performance evaluated.

A work of this nature draws its justification from the fact that international concerns generated by world governing bodies against global warming necessitated a shift in research on power generation to renewable energy sources [6] and wind power via wind turbine is a major contender.

Also, The Nigerian Electricity Regulatory Commission (NERC) has called for the generation of 20MW of electricity from renewable energy sources [7]. This work keys into these policy statements.

2. METHODOLOGY

2.1. Design formulation

The block diagram for the electronic control device for wind speed compensation in wind turbine is presented in Fig. 1.

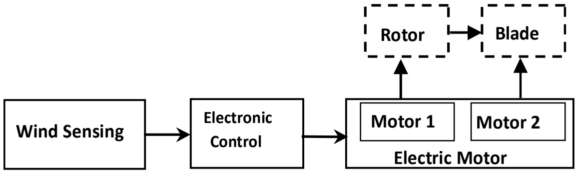


Fig. 1. Block diagram of the control device

The portion in solid lines is the electronic control section under design while the portion in dotted lines is an existing wind turbine intended to be controlled. The block description shall be discussed in the order presented in the block diagram.

2.1.1. Wind sensing section

The atmospheric parameter of interest here is the wind and the sensors concerned are the anemometer and wind vane for wind speed and wind direction respectively. Both sensors were integrated into turbine design for the purpose of regulating a turbine speed in response to wind parameters when necessary or to report sudden deterioration of the weather conditions [8]. Furthermore, in this research wind sensors were excluded in the simulation process. Instead, real data of wind speed and direction was acquired from the study area and incorporated in the program code and simulation.

2.1.2. Electronic control section

This is the intelligent part of the design [9], it makes decision based on whether or not to activate the regulating segment of this design. The wind sensors serve as input to this section which has the microcontroller and the motor driver as the major components.

2.1.3. Electric motor section

The output of the electronic control section will be used to drive two direct current electric motors. The role of both electric motors is to serve as a mechanical driver to the rotor and the blade panel when instructed. Motor 1 is to drive the rotor whenever wind speed is less than 3 m/s as recorded by the anemometer and decided by the microcontroller. Motor 1 can be connected to the rotor via a rotor wheel or pulley. The function of Motor 2 is to tilt the blade panel to interface with the wind whenever the current wind direction changes as recorded by the wind vane and instructed by the microcontroller. However, the scope of this current work is restricted to wind speed compensation.

2.2. Electronic circuit design

The electronic circuit was designed according to sections as discussed in 2.2.1 to 2.2.4.

2.2.1. Power supply section

The power supply section provides the electrical energy required by the device under test. The circuit diagram of the power supply circuit is show in Fig. 2.

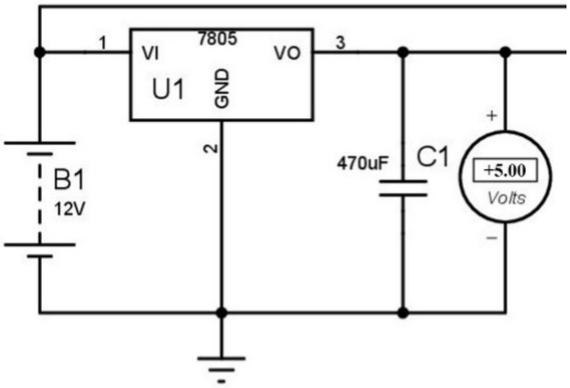


Fig. 2. Power supply section

The power supply section of the electrical circuit consists of a 12V DC battery, voltage regulator (7805), smoothening capacitor and voltmeter. The 12V DC battery powers the electrical circuit by generating 12V across as a result of the two 12V DC motors. The voltage regulator 7805 is a three-terminal, fixed-voltage IC that produces 5V of regulated DC output voltage. Therefore 7805 IC plays a vital role of converting the 12V to 5V, reason being that microcontroller (Atmega328P) operates on 5V DC while the smoothing capacitor 470µF smoothens the voltage released from voltage regulator to 5V in case of anomaly. Also, the voltmeter displays the numerical value of the voltage been released to the microcontroller.

2.2.2 Microcontroller Section

Microcontroller is the intelligent part of the design. Fig. 3 shows the schematics of the microcontroller.

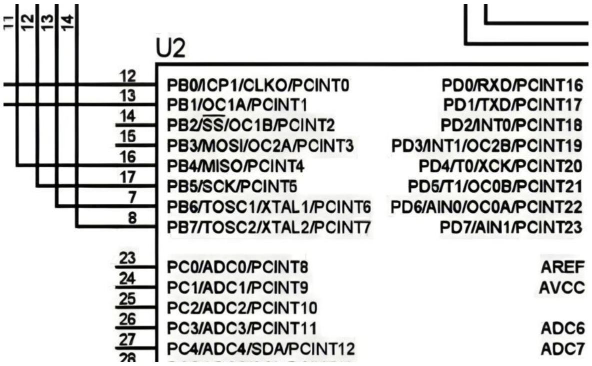


Fig. 3. Microcontroller (Atmega328P)

It makes decision on whether or not to activate the regulating segment of the design. It processes the signal from the sensors which serves as its input while been guided by sets of rules in C++ computer programming language. A high-performance microcontroller Atmega328P was used. The microcontroller has three different ports with various pins namely port B, C and D. Port B(s) are analogue port for connecting analogue peripheral devices such as the wind vane and anemometer in an ideal case of this research while ports C(s) and D(s) are digital pins which are connected to display unit(s) for executing programmed instructions [10].

2.2.3. Electric motor section

The electric motor section contains a motor driver and two 12V DC motors. The motor driver works in conjunction with the microcontroller. Motor drivers are current amplifiers that take a low-current control signal from a controller and turn it into a higher-current signal that can drive a motor. Motor driver L293D is a typical motor driver IC which enables DC motor to drive on either direction. It controls the speed and direction of two DC motors simultaneously [11]. The two DC motors consist of motor 1 for speed enhancement and motor 2 (stepper motor) positioning or directional change. As slated earlier, this work is concerned with turbine speed. Hence, less emphasis shall be placed on motor 2.

Pin2 and pin7 of the driver are connected to pin32 and 1 of the microcontroller. Pin3 is connected to one end of motor 1 and pin6 is connected to the other end of motor 1. Pin11 is connected to one end of motor 2 and pin14 is connected to the other end of motor 2. Pin16 VSS (Voltage Supply Source) connected to 5V to enable IC function while pin8 VS (Voltage Supply) is connected to 12V pin for running motors. Fig. 4 shows the motor driver and the two DC motors.

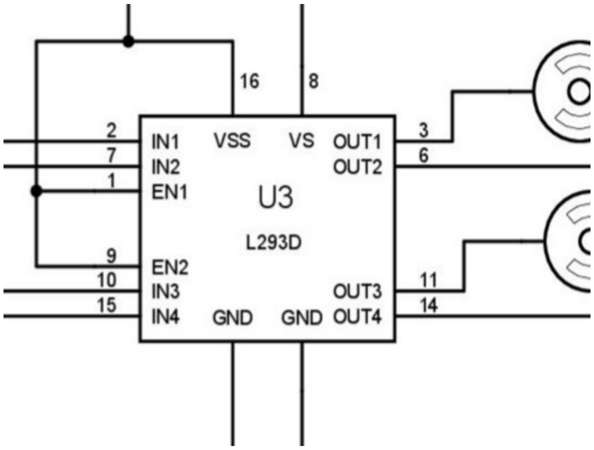


Fig. 4. Electric motor section

2.2.4. Display Section (LCD and Virtual Terminal Display)

LCD displays the wind speed and the steps of the simulation. The serial terminal consisting of the transmitting (Tx) and receiving (Rx) ports which transmits and receives signal between the microcontroller and the motor driver. Also, the virtual terminal is a pop-up display that show cases the enhanced data for wind speed compensation when running the electrical simulation design circuit; displaying the unenhanced data as zero (0) and displaying the numerical values of the enhanced data. Pin1 (VSS) is power supply ground, pin2 VDD (Voltage drain) is the 5V supply pin, pin3 VEE (Voltage emitter) is for contrast adjustment while Pin7 to pin14 are generally used in passing information to and from the LCD to the microcontroller. Such information includes to display data on LCD screen or control information (turning the display on or off). Fig. 5 shows the LCD connection to the microcontroller.

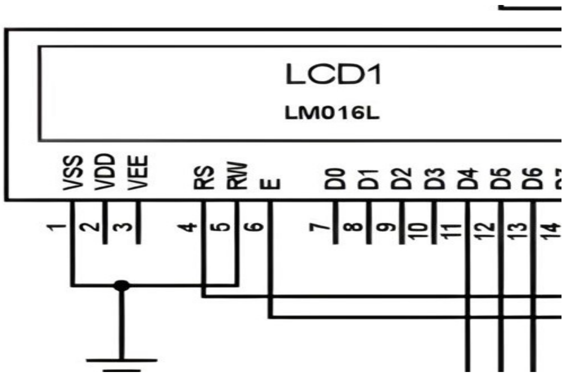


Fig. 5. Liquid crystal display

The overall circuit diagram of the wind turbine control device is the collection of the entire component sections. This is shown in Fig. 6.

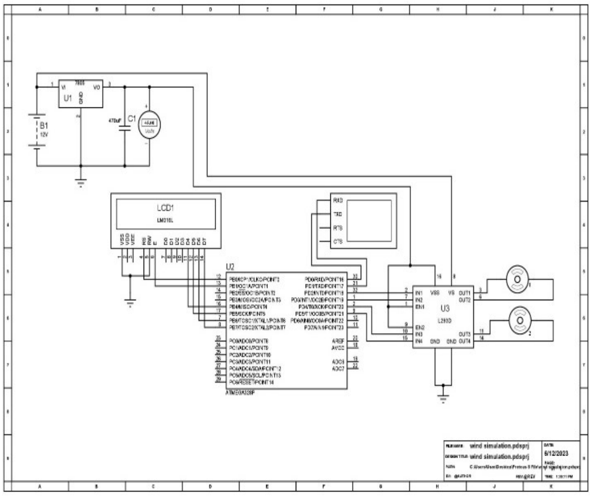


Fig. 6. Circuit diagram of the wind turbine control device

2.3. Software formulation

The wind turbine electronic control device is software-controlled. A well formulated software is necessary in providing the needed harmony between the skeleton (proposed hardware) and the brain (microcontroller) of the device. The software consists of a set of instruction written in C++ programming language.

2.3.1. Program code

Programming code is the instructions or set of rules given to a machine to create a computer program for a computer to execute [12]. Four program codes were formulated in this work. They are the code for the three categories of output power and the program code for the electrical simulation.

2.3.2. Program flowchart

Flowchart is a visual representation of the sequence of steps and decisions needed to perform a process [13]. In this work, the flowcharts for speed compensation is shown in Fig. 7.

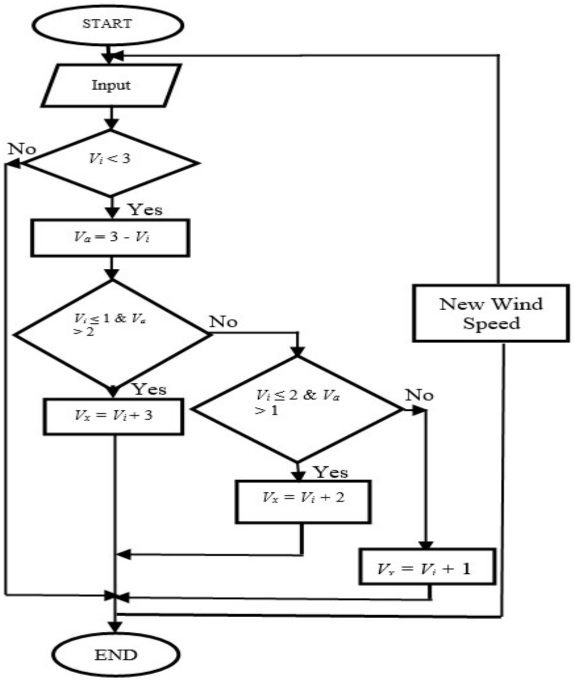


Fig. 7. Speed compensation flowchart

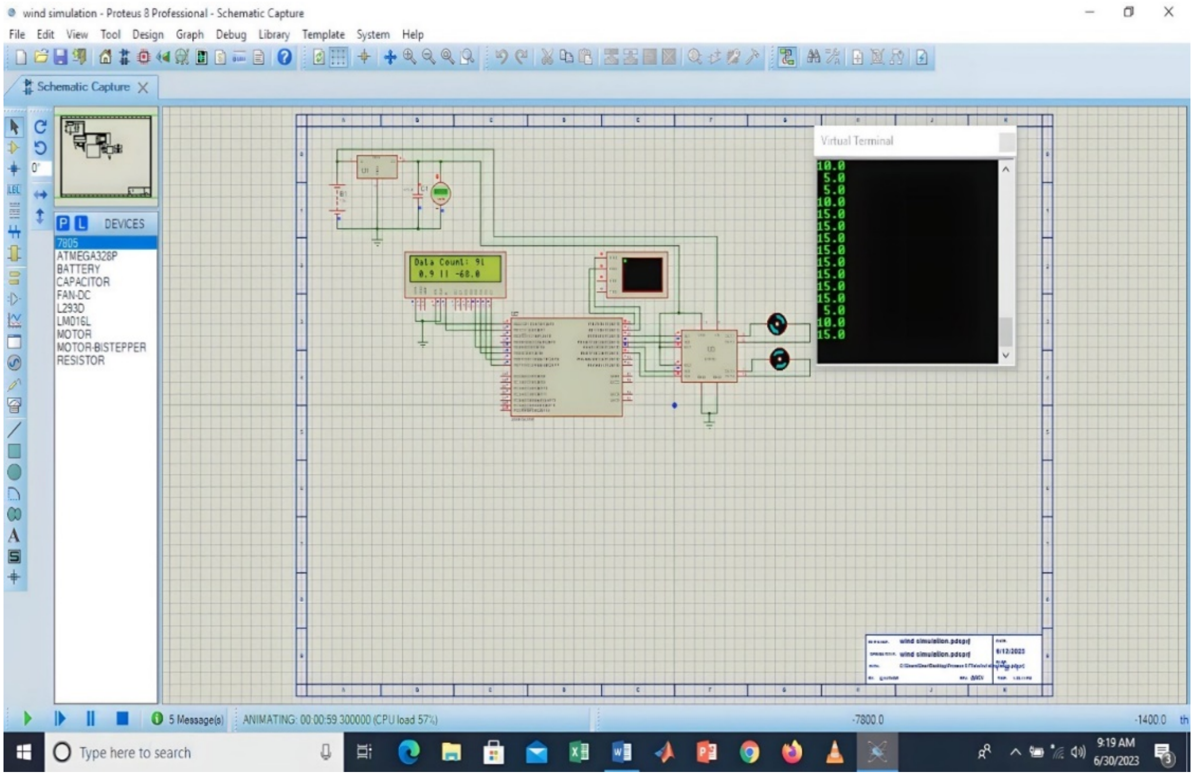
From Fig. **7**, the microcontroller does the comparison between the reported wind speed V_i (m/s) and a predetermined (cut-in) wind speed of 3m/s. If the reported wind speed is equal or greater than the cut-in speed, no process to contribute a fraction is required after the comparison. But if the reported speed is below the predetermined, it triggers a process of compensating for the drop in wind speed. First, the difference (V_a) is computed. After which a certain fraction of speed base on the difference computed is added to the rotor speed via the motor driver and subsequently the motor 1.

The fraction added when the wind speed is below the cut-in speed (3m/s) after comparison is in the order of 1, 2 and 3m/s; it implies that if $V_i \leq$ 1m/s and $V_a > 2$ a fraction of 3m/s is added, then if $V_i \leq$ 2m/s and V_a >1m/s a fraction of 2m/s is added otherwise a fraction of 1m/s is added. These processes produce the compensated wind speed (V_x). The process then continues with a new reported wind speed.

3. RESULTS AND DISCUSSION

3.1. Electronic circuit simulation

In order to evaluate the performance of the microcontroller-based electronic control circuit designed in section 2.2 as shown in Fig. 6 and section 2.3 as shown in Fig. 7 when connected to a wind turbine, the designed circuit was simulated using Proteus electronic simulation software. A screen shot of the simulation environment is shown in Fig. 8.



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Data Count: 91
 0.9 || -60.0
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10.0
 5.0
 5.0
10.0
15.0
15.0
15.0
15.0
15.0
15.0
15.0
15.0
 5.0
10.0
15.0
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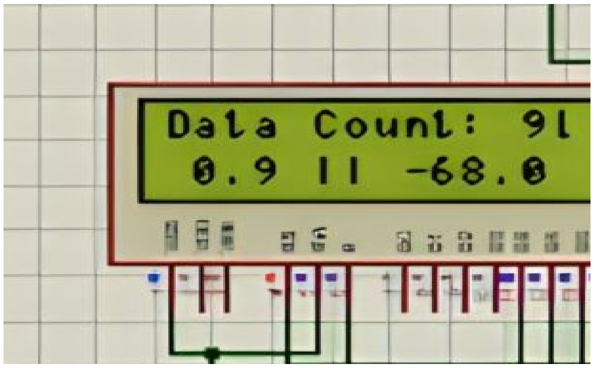
Fig. 8. Electrical simulation process

The major sections of the simulation circuit are the power, LCD, microcontroller (Atmega328P), the motor driver, stepper motor and DC motor sections.

To create and run the simulation, the following procedure was followed:

i. Create a new project in proteus software and name it.
ii. Click on schematic capture.
iii. Click P under the schematic capture to add up components to work space.
iv. Draw the circuit diagram with all the necessary components.
v. Open an Arduino integrated development environment (IDE) imbedded in the proteus software to develop software code efficiently.
vi. Compile the program which generate hex file and save
vii. Select and copy the hex file with the extension ".hex"
viii. Double click on the microcontroller to insert the hex file of code in the program file
ix. Click OK

Start the simulation by clicking the play icon.The obvious evidence of the electrical simulation are the LCD, virtual terminal display and the turning effect of the two DC motors. The LCD displays the current count of data set, wind speed and wind direction being inputted for processing as shown in Fig. 9.



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Data Count: 91
0.9 11 -68.0
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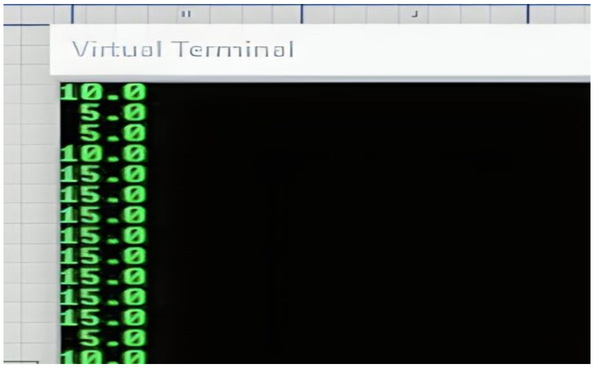
Fig. 9. LCD display of data count, reported wind speed and wind direction

The motor 1 for speed compensation turns in a clockwise direction to indicate the effect of the wind speed compensation carried out by the microcontroller. The microcontroller engage motor 1 to turn whenever the inputting wind speed is less than the cut-in speed of 3m/s, thus requiring compensation of magnitude given by the programmed design equations;

$V_a = 3 - V_i$, $V_x = V_i + 3$, $V_x = V_i + 2$ and $V_x = V_i + 1$

as stated in section 2.3.2. In the electrical simulation carried out in proteus, the compensated wind speed values required to make-up for the wind speed that are less than the cut-in wind speed were displayed numerically on the virtual terminal display as a pop-up display when running the electrical simulation.

A screenshot of the virtual terminal display is shown in Fig. 10.



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10.0
 5.0
 5.0
10.0
15.0
15.0
15.0
15.0
15.0
15.0
15.0
15.0
 5.0
10.0
```

Fig. 10. Virtual terminal display

3.2. Output power simulation

The power output of a wind turbine is directly influenced by the wind speed it encounters [14]. In the wind turbine simulation studies carried out, the relationship between wind speed and power output was examined in order to gain insights into the performance of the microcontroller-based compensation approach. The available power ($P_{available}$) that a wind turbine can extract from the wind is given by [15];

$$P_{available} = \frac{1}{2}\rho A v^3 C_p \qquad (1)$$

where;

ρ is the density of air, (kgm^{-3}); A is the swept area of the turbine blade, (m^2); v is the speed of the wind, (ms^{-1}) and C_p is the power coefficient of the wind turbine. These parameters were factored into the program code and simulated using MATLAB.

The power curve, a fundamental representation of the relationship in (1) is significant to this work. It is a plot of the output power against the recorded time interval of 5 minutes. To evaluate the performance of the designed wind turbine control device, output power was evaluated in three categories. The three categories comprising 48 data points each taken at 5 minutes intervals were discussed in section 3.2.1 to 3.2.3 and shown in Fig. 11, 12 and 13.

3.2.1. Uncompensated (unenhanced) output power curve

The uncompensated (unenhanced) output power curve was obtained from the uncompensated (raw) wind speed data as input. This has the raw wind speed data as measured or reported by the sensor. The plot of Fig. 11 shows that wind speed from 0 minute to 25 minutes is above the cut-in wind speed and the turbine generated a usable output power between 200W and 750W. Between 25 minutes and 33 minutes, the generated output power value dropped to 0W (no output), indicating a drop in the inputting wind speed below the cut-in value. Beyond this point, usable output power value rapidly increased to 300W at 40 minutes and followed again by a drop to about 10W at 45 minutes. This plot demonstrated the uncompensated output power of a typical conventional wind turbine characterized by sharp fluctuations indicating the intermittency and erratic nature of wind. The uncompensated portions were depicted by blue lines on the power curve.

3.2.2. Compensated (enhanced) output power curve

The inputted data for the compensated output power curve in this case was the compensation data generated from the proteus simulation as explained in section 3.1. It is characterized by plot which vanishes and appears at certain portions. From the origin to about 25 minutes, the plot of Fig. 12 vanished because wind speed compensation was not required at that portion. Between 25 and 33 minutes, the plot became visible, rising from previously 0W to a maximum of 300W. This indicates that the portion has undergone wind speed compensation and the level of compensation accomplished by the control device is proportional to the shape of the plot. It displays the level of compensation accomplished in order to augment the pit-fall of fluctuations that the uncompensated plot of Figure 11 presented. The compensated portions were depicted by red lines on the power curve.

3.2.3. Regulated (controlled) output power curve

The plot of regulated power output was derived from the combination of uncompensated and compensated wind speed data as input variables. Fig. 13 depicts the impact of the wind turbine control device designed in this work while in operation. It is more like a superimposition of Fig. 11 on 12 resulting in complimenting pit fall (low or no power) portions with the requisite make-up power portions. From the plot, the introduced regulation or modifications to the wind data have resulted in stable power generation throughout the entire spectrum of the turbines operation even during suboptimal wind conditions.

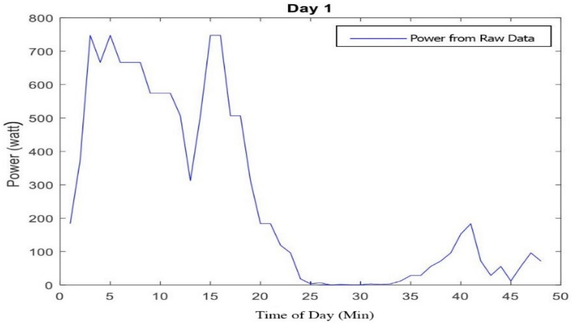

Fig. 11. Power output from raw data for day 1

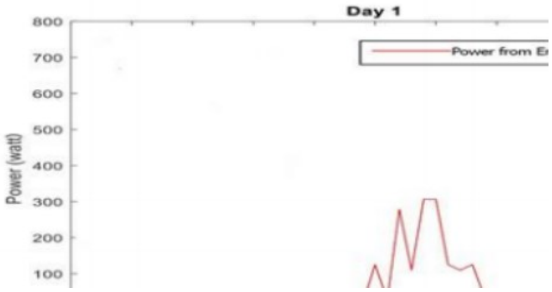

Fig. 12. Power output from compensated data for day 1

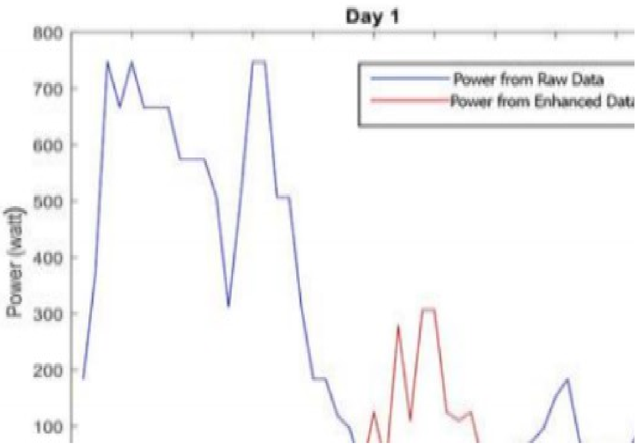

Fig. 13. Regulated power output for day 1

A get-together of all the uncompensated and regulated output power for a total of 3210 data points is shown in Fig. 14. It visually displays the level of regulation brought on board at a glance by comparing the uncompensated input with the regulated output across the presented power catch.

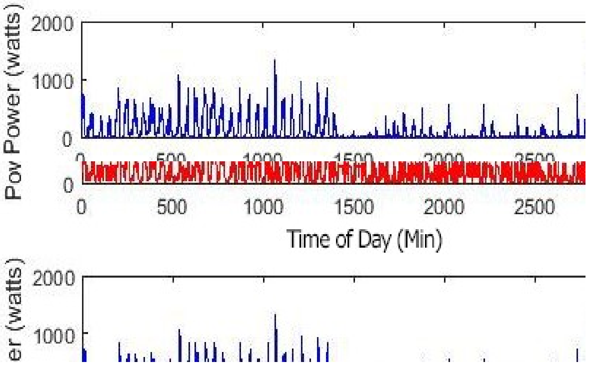

Fig. 14(a) & (b). Uncompensated & regulated Output Power

Fig. 14 (a) and (b) shows at a glance that the design put forward in this work resulted in enhanced energy capture at low speed. During low wind speed, the regulated power curve outperformed the uncompensated power curve, thereby effectively increasing stable energy production in wind turbines.

4. CONCLUSION AND RECOMMENDATIONS

Generally, the results obtained from the simulation shows the microcontroller-based compensation approach focused on identifying portions of the output resulting from wind speed below 3m/s and compensates by adding a controlled fraction to the wind speed data thereby preventing output power failure that ordinarily would have occurred at same portions. The effectiveness of the control device in maintaining a stable power output from the wind turbine is apparent in the way it optimizes the lower output power portions such that at such points, the turbine is able to initiate rotation and begin producing usable power. This work is significant in the sense that when incorporated into a wind turbine, effective electrical power supply during optimal and suboptimal wind conditions is enhanced. Also, this research when implemented will lead to a reduction in gaseous emissions associated with the combustion of fossil fuel in powered generating sets which are the popular alternative to public power. It is recommended that the designed and simulated microcontroller-based wind turbine control device should be modelled and evaluated in order to validate the optimized performance.

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