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Speed and Direction Control Design for Horizontal Axis Wind Turbine With Profitable Power Production

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Abstract— This paper mainly deals with a case study about the design of speed control of horizontal axis wind turbine using a programmable logic controller which is interfaced with an ultrasonic anemometer. The ultrasonic anemometer is capable of monitoring both speed and direction and the programmable logic controller can be used to control the speed and direction of rotation of blades. Its main advantage is that using the ultrasonic technique it has no moving parts, allowing for the utilization in a variety of applications requiring low maintenance and fast response to rapid wind gusts. The proposed system presents a simple idea representing a design for controlling the speed of blades whenever the blades rotate beyond the survival speed and also for changing the direction of the blades according to the directional change of wind.

Keywords— Wind Energy; Ultrasonic Anemometer; Wind Speed and Direction Measurement Of Wind Blades; Programmable Logic Controller.

I. INTRODUCTION

In recent years renewable sources of power are being increasingly exploited to address the challenges of climate change and fossil fuel depletion. Wind power is one of the few renewable energy sources capable of rapidly satisfying a reasonable proportion of future energy requirements. Wind turbines will be expected to significantly increase the power outputs with an improved efficiency and reliability. Since the population of India keeps on increasing, the implementation of wind turbines with most profitable power production is needed to satisfy the future power needs. Wind energy, with an average growth rate of 30%, is the fastest growing source of renewable energy in the world. India occupies the fifth place in the world in wind energy generation after USA, Germany, Spain, and China. Since the maximum speed of wind blade is from 55 mph to 161 mph, it is necessary to control the speed of the blade to avoid accidents. And in order to improve the power production the wind has to be consumed completely while the direction of wind changes the blades' direction have also to be changed to obtain maximum power production. Both the speed and direction is monitored using a transducer called arduino based ultrasonic anemometer[4] and the control action is taken by Delta PLC (Programmable Logic Controller).

II. ULTRASONIC ANEMOMETER

An ultrasonic anemometer is a device which is used to measure the speed of the wind using ultrasonic sound, which means an anemometer which measures wind speed by means of the properties of wind-borne sound waves; it operates on the principle that the propagation velocity of a sound wave in a moving medium is equal to the velocity of sound with respect to the medium plus the velocity of the medium. The cup anemometers which come under mechanical transducers are most commonly used. They have a deliberate disadvantage. They work using cups which will rotate when wind blows. So it completely based on the moving parts. And if the wind blows more the surviving speed of blades the cups also rotate too fast and cause damage to the anemometer. Thus the anemometer fails to measure the wind speed so the wind blades will go out of control which will cause enormous damage. In this proposed system the cup anemometer is replaced with arduino based ultrasonic anemometer. The main advantage of ultrasonic sensor over cup anemometer is that it has no moving parts.

A. Time of flight in Ultrasonic Anemometer

An Ultrasonic Anemometer measures the time taken for an ultrasonic pulse of sound to travel from the North transducer to the South transducer, and compares it with the time for a pulse to travel from S to N transducer [1]. Likewise times are compared between West and East, and East and West transducers. Ffor example, a North wind is blowing, and then the time taken for the pulse to travel from N to S will be less than from S to N, whereas the W to E, and E to W times will be the same. The wind speed and direction can then be calculated from the differences in the times of flight on each axis. This calculation is independent of factors such as temperature. Reliability is another advantage of ultrasonic devices, always for the absence of moving parts. When the mechanical transducer froze, it became inoperable or inaccurate on the contrary the ultrasonic pulse is often sufficient to prevent the formation of ice, even if these devices are often heated to avoid this problem.

And also the ultrasonic anemometers are used to measure low wind speed which is inaccurate in cup anemometers. At present the main disadvantage of ultrasonic devices is the initial cost. It is a 2D anemometer which has two pairs of ultrasonic transducers corresponding to north, south, east and west directions the speed of a sound wave in air depends upon the properties of the air, namely the temperature and the pressure. At normal atmospheric pressure, the temperature dependence of the speed of a sound wave through air is approximated by the following equation: $v = 331.45 \text{ m/s} + (0.6 * T)$ where T is the temperature of the air in degrees Celsius. Since the speed of a wave is defined as the distance which a point on a wave (such as a compression or a rarefaction) travels per unit of time, it is often expressed in units of meters/second. In equation form, this is: speed = distance / time,

Fig. 1: Ultrasonic Anemometer.

This anemometer main works on the principle of time of flight. Time of flight (TOF) is a property of an object, particle or acoustic, electromagnetic or other wave. It is the time that such an object needs to travel a distance through a medium. Ultrasonic anemometers mainly operate based on the pulse detection technique, which requires a pair of ultrasonic transducers: a transmitter and a receiver. When the measuring operation cycle starts, the transmitter send a short train of waves, which will propagate to the receiver through air flow. Systems typically use a transducer which generates sound waves in the ultrasonic range, above 18 kHz, by turning electrical energy into sound, then upon receiving the echo turn the sound waves into electrical energy which can be measured and displayed.

The time taken by the receiver to receive the signal gives the speed of the air. Since the temperature of air affects the sound waves sent by the transmitter the sound waves travel slowly. Thus at high altitude when the speed of wind is high the sound waves travels slowly thus the receiver will receive low sound which correspond to low output voltage. From the output voltage the surviving speed of blades can be calculated and the pitch motor is switch off to stop the rotation of blades. The proposed system involves the design of ultrasonic anemometer using arduino.

B. Arduino Uno

Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an In Circuit Serial Programing (ICSP) header and a reset button. It generally involves two parts, an analog part and a digital part[2]. The analog part is for receiving the signals from the transducers and the digital part involves arduino uno (Atmega 328). The output of the ultrasonic transducer gives the speed of air while the direction of air can be calculated by detecting which ultrasonic receiver receives the low sound signal.

When the direction of wind changes the output of the ultrasonic receivers would change. By analysing which receiver receives low sound we can be able to detect the direction of wind. The yaw system of wind turbines is the component responsible for the orientation of the wind turbine rotor towards the wind. The yaw drive is an important component of the horizontal axis wind turbines' yaw system. To ensure the wind turbine is producing the maximal amount of electric energy at all times, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes.

A signal conditioning unit is developed for an accurate output. In the arduino a program has been developed which will determine the speed and direction of the wind based on the output of the ultrasonic transducers. The output will be displayed on a liquid crystal display. The liquid display will display the current speed of the air in km/hr and also the direction of the wind. The Arduino hardware platform already has the power and reset circuitry setup as well as circuitry to program and communicate with the microcontroller over USB. In addition, the I/O pins of the microcontroller are typically already fed out to sockets/headers for easy access on the software side, Arduino provides a number of libraries to make programming the microcontroller easier.

The simplest of these are functions to control and read the I/O pins rather than having to fiddle with the bus/bit masks normally used to interface with the Atmega I/O (This is a fairly minor inconvenience). More useful are things such as being able to set I/O pins to PWM at a certain duty cycle using a single command or doing Serial communication. So the usage of arduino is highly recommended here. The following block diagram represents the outline of working of arduino based ultrasonic anemometer.

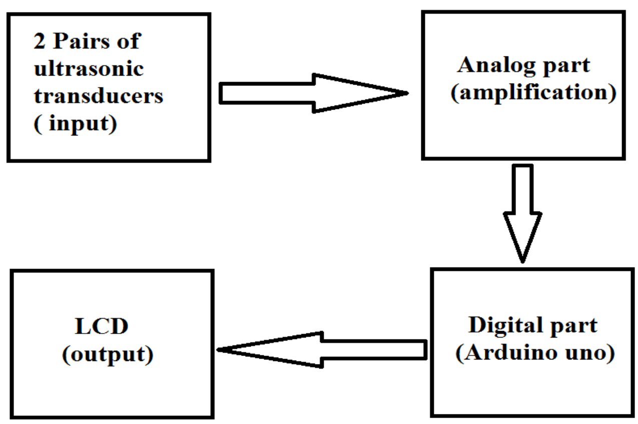

Fig. 2: Block Diagram of Arduino Based Ultrasonic Anemometer

Thus by using this anemometer the speed and direction of wind can be measured and displayed.

III. PROGRAMMABLE LOGIC CONTROLLER

A Programmable Logic Controller is an industrial application control system that continuously monitors the state of input devices and makes decisions based upon the custom program to control the state of output devices.As PLC's have solid state switches, they can provide unlimited switching cycles so they can be used to create PWM signals. PLC's are re-programmable. A very complex logic can be created without the need of complex wiring. Multiple devices are embedded in a single PLC like Timers, Memory Shells etc. and also multiple sensors can be attached like temperature, humidity, motion, speed etc. For these advantages PLC is recommended for the control of Wind Turbine Generator blades. In this proposed system Delta PLC has been used which works using the software called Wplsoft 2.42.Here the PLC is mainly used to control the speed and direction of the wind blades[3]. If the speed of the wind exceeds than 161 mph or 55 km/hr the blades will get damaged and also cause serious problems. And also the uncertainty of the wind will reduce the rotation of wind blades which will lead to reduction in power production. The existing method to solve this problem which involves the controlling of wind blades with the help of mechanical sensors which is not highly accurate and will not work during winter season also in storms. The proposed system will solve this problem by using a programmable logic controller which would work in all conditions.

IV. WORKING OF THE PROPOSED SYSTEM

The speed and direction from the ultrasonic anemometer are given as the input to the PLC. The following block diagram gives the flow of the process.

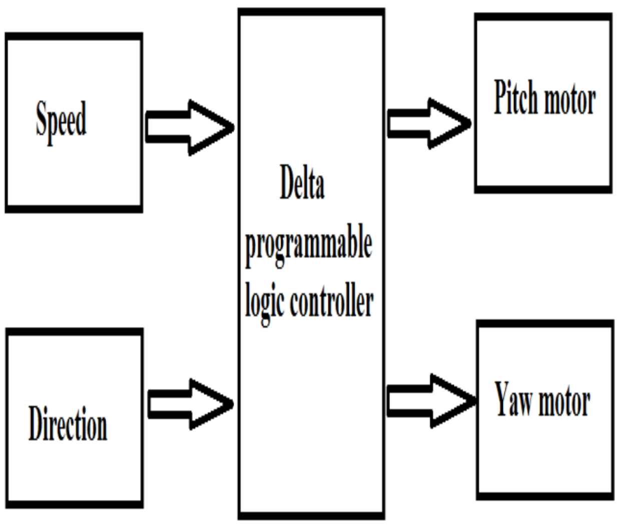

Fig. 3: Block Diagram of the Proposed System

The following program has been developed in wplsoft 2.42 and uploaded into the PLC.

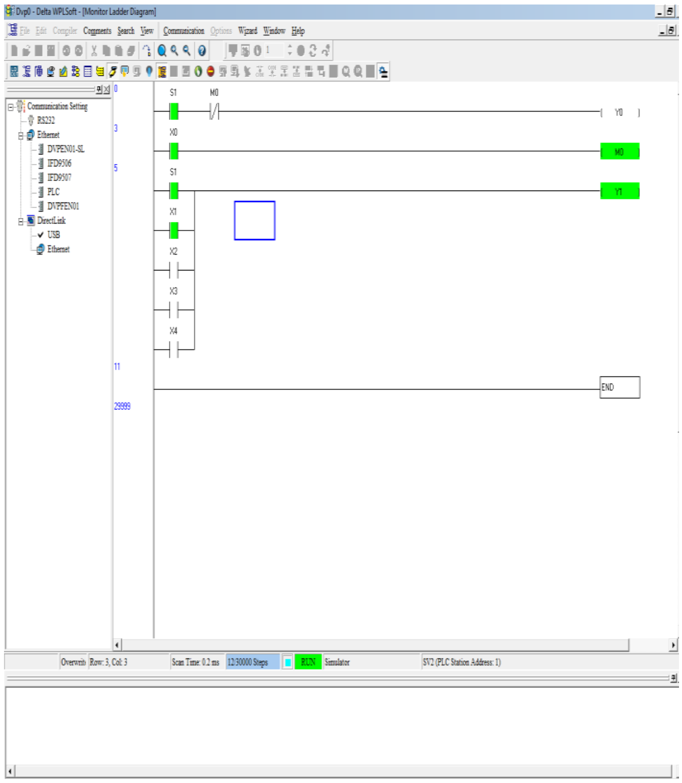

Fig 4: PLC ladder Logic in Delta WPL Soft for Speed and Direction Control.

In Fig. 4. A simulation of the process to control the speed and direction of the horizontal axis wind turbine is shown. The following switches and loads are used as the inputs and outputs.

- S1 Main power supply switch
- X0 Switch for pitch motor (speed)
- X1 Ultrasonic sensor 1 (direction)
- X2 Ultrasonic sensor 2 (direction)
- X3 Ultrasonic sensor 3 (direction)
- X4 Ultrasonic sensor 4 (direction)
- M0 Memory coil
- Y0 Pitch motor (for speed)
- Y1 Yaw motor (for direction)

The switch S1 is the main power supply switch which starts the entire process. The switch X0 is the switch to turn on the pitch motor which should be controlled for speed (when the speed exceeds 55 km/hr that is the surviving speed of wind mill’s blades). The switches X1, X2, X3, X4 are Ultrasonic sensors which are to be connected with Arduino. When the main power supply switch S1 is turned on all the motors will be switched on. Then if the speed exceeds the surviving speed then the supply to the pitch motor Y0 will be shut off. So the rotation of blades will be stopped which would save the Wind Turbine Generator. This is done with the help of a memory coil. The ultrasonic transducers X0, X1, X2, X4 will determine the direction. The output voltage of the transducers gives the direction. The yaw mechanism is responsible for the direction change so the yaw motor is connected as output load Y1.

Thus whenever the speed of the wind blade exceeds than their survival speed the PLC will take the control action to stop the pith motor which is responsible for wind blades' rotation. And whenever the direction of the wind changes the PLC will control the yaw motor of the wind turbine system in order to change the direction of the wind blades accordingly. The overall working of the proposed system is given by the following block diagram.

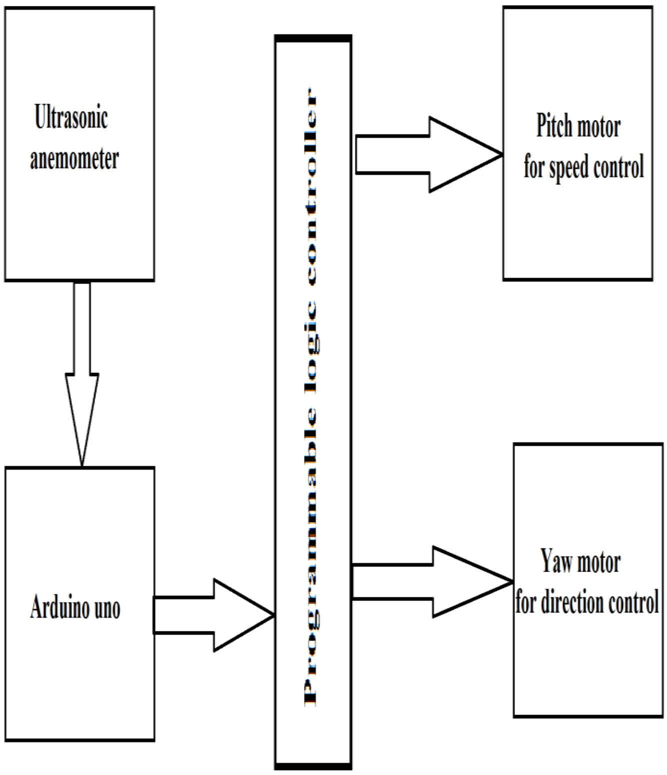

Fig. 5: Block Diagram of Overall System.

V. CONCLUSIONS

Thus by using this arduino based ultrasonic anemometer the speed and direction of the wind blades can be encountered efficiently with the help of delta programmable logic controller which is handy and having easier ladder logic. By using this proposed system a prototype of anemometer can be easily developed but further enhancements have to be enforced to make this anemometer for measuring the speed and direction of horizontal axis wind turbine accurately.

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