Speed Control of Horizontal Axis Wind Turbine

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Abstract - *This paper mainly deals with a design of speed control of horizontal axis wind turbine using a programmable logic controller which is interfaced with a cup anemometer. The cup anemometer is capable of monitoring speed and the programmable logic controller can be used to control the speed of the blades which is an impact of the rotation of blades. Its main advantage is that using the programmable logic controller is an easy technique allowing for the utilization of wind 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 using a prototype of cup anemometer which detects the speed of wind with the help of a colour sensor interfaced with arduino uno and a programmable logic controller for controlling the rotation of blades whenever the blades rotate beyond the survival speed. This proposed system will help to analyse the efficiency of using programmable logic controller for speed control than by using convention methods like mechanical brakes, fuzzy controllers and PID controllers.*

Key Words: **speed control, cup anemometer, colour sensor, arduino uno, and programmable logic controller.**

1.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. The advantages of wind energy are more apparent than the disadvantages. Next, harvesting wind power is a clean, non-polluting way to generate electricity. Unlike other types of power plants, it emits no air pollutants or greenhouse gases. The wind turbines harmlessly generate electricity from wind passing by. 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. The existing method is controlling the brake system using mechanical brakes which mainly depends upon friction. The proposed system deals with a PLC (programmable logic controller), which can easily cut off the supply to the pitch control system so the speed of the rotation of blades will be controlled easily. In our project the above method of controlling is achieved by using a prototype of cup anemometer which would find the speed with the help of a color sensor TCS230 and Arduino Uno which are interfaced with AB PLC through a TTL to RS232 connector cable.

2. HORIZONTAL AXIS WIND TURBINE

Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. The net effects on the environment are far less problematic than those of nonrenewable power sources. The Horizontal Axis Wind Turbine (HAWT) is the most efficient design for turning wind into electricity. The basic design allows two or more rotor blades to face into the wind. Since they are all being simultaneously moved, they form the least possible resistance to wind forces. The rotor blades of a Horizontal Axis Wind Turbine usually have an aerodynamic design. On a wing or rotor blade, the top side of the blade has a longer surface area than the bottom.

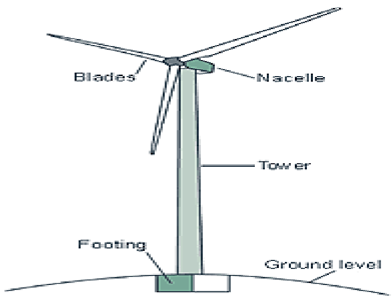

Fig -1: Horizontal Axis Wind Turbine

When the air moves over the top of the blade, the air must move faster than the air going under the bottom of the blade. This higher speed creates lift because the denser underside air pushes against the blade. The blades are hooked to a shaft so the lift on the blade forces the shaft to spin. HAWT designs vary in size from the very small to the commercial grade generators. Most are installed on towers to help them reach high above the ground where airflow is strongest and most constant. Even so, the larger the rotors the more likely there is to be varying forces on different parts of the turbine. This means that HAWTs must be rugged and well supported right down to the foundation. Also, at very high wind-speeds, generators and rotors can be damaged, so in most windmills safety features are built in that allow the rotors to not take so much wind and even to disconnect the rotors from the generator.

Braking systems are also used to slow turbines in very high wind-speeds[1]. Another method of avoiding damage in high winds some wind generators are designed to tilt back at higher wind-speeds so that the rotors become less efficient, thereby creating less stress. Smaller turbines generally spin at faster rpm speeds than the large commercial models. The larger models are slowed to avoid killing birds and also because higher speeds create greater wear and tear on larger devices. Most of the wind generating devices available for both home and commercial use is Horizontal Axis Wind Turbines. But due to the ruggedness[2] of mechanical brakes the control system can't able to work effectively.

3. CUP ANEMOMETER

A cup anemometer consisted of four hemispherical cups mounted on horizontal arms, which were mounted on a vertical shaft. The air flow past the cups in any horizontal direction turned the shaft at a rate that was roughly proportional to the wind speed. Therefore, counting the turns of the shaft over a set time period produced a value proportional to the average wind speed for a wide range of speeds.

Fig -2 Cup anemometers

On an anemometer with four cups, it is easy to see that since the cups are arranged symmetrically on the end of the arms, the wind always has the hollow of one cup presented to it and is blowing on the back of the cup on the opposite end of the cross. Theoretically, the speed of rotation of the anemometer should be proportional to the wind speed (because the force produced on an object is proportional to the speed of the fluid flowing past it), however, other factors influence the rotational speed including turbulence produced by the apparatus, increasing drag in opposition to the torque that is produced by the cups and support arms, and friction of the mount point. The three-cup anemometer also had a more constant torque and responded more quickly to gusts than the four-cup anemometer. Wind direction is calculated from the cyclical changes in cup wheel speed, while wind speed is determined from the average cup wheel speed. Anemometers are vital components of utility-scale wind turbines. These wind sensors measure wind speed and direction at the site of a given turbine, which determines the performance of the turbine's output. A standard wind turbine power curve shows power output (kW) at a range of wind speeds (m/s). Turbines operate in a relatively narrow range of wind speeds, cutting in at around 3 m/s and cutting out at around 25 m/s. The turbine blades will not efficiently turn below the cut-in speed, and wind speeds above the cut-out speed may cause damage to the turbine blades or other components. The anemometer is the sensor that measures wind speed, points the blades into the wind to optimize power output, and signals the turbine to operate or feather its blades.

Mechanical sensors used to measure wind speed can be described as having three hemispheric cups attached to arms on a vertical axis turn in the wind at a speed proportional to wind speed. Wind direction is measured by another type of mechanical sensor a vane anemometer that combines a small horizontally oriented propeller and tail to turn the axis perpendicular to the wind direction and the propeller blades transmit wind direction to the turbine.

3.1 PROTOTYPE OF CUP ANEMOMETER

A prototype of cup anemometer is designed in order to find the speed of wind blades. Here we are using paper cups and straws to design the prototype. The main thing in this design is one of the cups has to be in blue color. The blue colored cup is the starting point of the rotation. When these cups attain one complete revolution ie. the blue colored cup reaches the starting point again, it will correspond to a particular speed based on the time taken to reach its starting point.

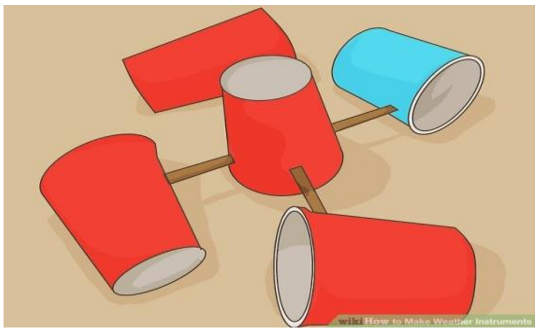

Fig -3: Paper cup anemometer

The speed calculation is given by ten turns per minute is equal to 1 miles per hour in commercial use i.e. 10 turns/min = 1 mph. In the developed prototype the blue colored cup is the starting point. So whenever the blue cup completes 10 turns per minute it is understood that the speed of wind is 1 mph. For example if the anemometer spins 20 turns in one minute then the wind speed is 2 mph or if it rotates 5 spins per minute then the wind speed is 0.5 mph.

4. TCS 230 COLOUR SENSOR

The TCS230 colour sensor is a RGB sensor chip to detect colour. It also contains four white LEDs that light up the object in front of it.

Fig -4: TCS230 colour sensor

Here are the sensor specifications:

- Power: 2.7V to 5.5V
- Size: 28.4 x 28.4mm (1.12 x 1.12″)
- Interface: digital TTL
- High-resolution conversion of light intensity to frequency
- Programmable colour and full-scale output frequency
- Communicates directly to microcontroller

The TCS3200 has an array of photodiodes with 4 different filters. A photodiode is simply a semiconductor device that converts light into current. The sensor has:

- 16 photodiodes with red filter – sensitive to red wavelength
- 16 photodiodes with green filter – sensitive to green wavelength
- 16 photodiodes with blue filter – sensitive to blue wavelength
- 16 photodiodes without filter

By selectively choosing the photodiode filter's readings, you're able to detect the intensity of the different colors. The sensor has a current-to-frequency converter that converts the photodiodes' readings into a square wave with a frequency that is proportional to the light intensity of the chosen colour. This frequency is then, read by the Arduino – this is shown in the figure below.

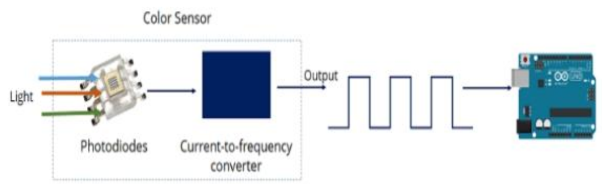

Fig -5: Colour sensor output (as frequency) to arduino

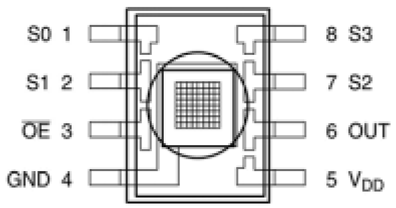

Fig -6: TCS230 colour sensor pin out

The pin description of TCS 230 colour sensor is given below.

Table 1: Pin description

Pin Name	I/O	Description
GND (4)		Power supply ground
OE (3)	I	Enable for output frequency (active low)
OUT (6)	O	Output frequency
S0, S1（1， 2）	I	Output frequency scaling selection inputs
S2, S3（7， 8）	I	Photodiode type selection inputs
VDD（5）		Voltage supply

To select the colour read by the photodiode, you use the control pins S2 and S3. As the photodiodes are connected in parallel, setting the S2 and S3 LOW and HIGH in different combinations allows you to select different photo diodes. Since we are using blue and red colour for detection S2 and S3 have to be low, high and low, low respectively. For the Arduino, it is common to use a frequency scaling of 20%. So, set the S0 pin to high and the S1 pin to low.

5. ARDUINO UNO WITH COLOR SENSOR

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 Programming (ICSP) header and a reset button. Arduino Uno is to be interfaced with color sensor for sensing the color from the developed prototype of cup anemometer. The Uno board is connected with the color sensor TCS230 which will detect the blue color from the developed prototype. The TCS230 senses color light with the help of an 8 x 8 array of photodiodes. Then using a Current-to-Frequency Converter the readings from the photodiodes are converted into a square wave with a frequency directly proportional to the light intensity. Finally, using the Arduino Board we can read the square wave output and get the results for the color.

The following program has to be uploaded in arduino Uno for detecting blue color (as reference point) and red color (to differ from the referenced cup).

```
;// TCS230 or TCS3200 pins wiring to Arduino
int count=0;
#define S0 4
#define S1 5
#define S2 6
#define S3 7
#define sensorOut 8

// Stores frequency read by the photodiodes
int redFrequency = 0;
int redColor=0;
int blueColor=0;
int blueFrequency = 0;

void setup() {
  // Setting the outputs
  pinMode(S0, OUTPUT);
  pinMode(S1, OUTPUT);
  pinMode(S2, OUTPUT);
  pinMode(S3, OUTPUT);

  // Setting the sensorOut as an input
  pinMode(sensorOut, INPUT);

  // Setting frequency scaling to 20%
  digitalWrite(S0,HIGH);
  digitalWrite(S1,LOW);

  // Begins serial communication
  Serial.begin(9600);
}
void loop() {

 digitalWrite(S2,LOW);
  digitalWrite(S3,LOW);

  // Reading the output frequency
  redFrequency = pulseIn(sensorOut, LOW);
  // Remaping the value of the RED (R) frequency from 0 to 255
  // You must replace with your own values. Here's an example:
  // redColor = map(redFrequency, 70, 120, 255,0);
  redColor = map(redFrequency, 20, 35, 255,0);

  // Printing the RED (R) value
  Serial.print(" \n R = ");

  Serial.print(redColor);

  delay(100);

  // Setting BLUE (B) filtered photodiodes to be read
  digitalWrite(S2,LOW);
  digitalWrite(S3,HIGH);


  // Reading the output frequency
  blueFrequency = pulseIn(sensorOut, LOW);
  blueColor = map(blueFrequency, 40, 60, 255, 0);
  // Printing the BLUE (B) value
  Serial.print(" B = ");

  Serial.println(blueColor);
  delay(100);
   if(blueColor>redColor)
  { count=count+1;
  Serial.print("count=");
  Serial.print(count);
  }
  else
  {
    Serial.print("no count");
  }*
 delay(2000);
```

By uploading the above program in arduino Uno the number of times the blue color cup is sensed is calculated from which the speed of wind can be calculated easily by detecting the number of counts per minute using a stopwatch. Since it is calculated that 2 to 4 spins in ten will be equal to 1 mph or 10 spins per minute is equal to 1 mph from which speed can be calculated easily.

6. PROGRAMMABLE LOGIC CONTROLLER FOR SPEED CONTROL

So by using this prototype of cup anemometer the speed of wind is calculated. The next main objective is speed control. This can be done using programmable logic controller (PLC) rather than using conventional controllers like PID or Fuzzy based PID. For our paper we are using Allen Bradley (AB) PLC. The PLC and the arduino board are connected using RS232 to TTL connector cable, from which the speed calculated from arduino is given as the input to PLC. The connection from arduino to PLC is given below.

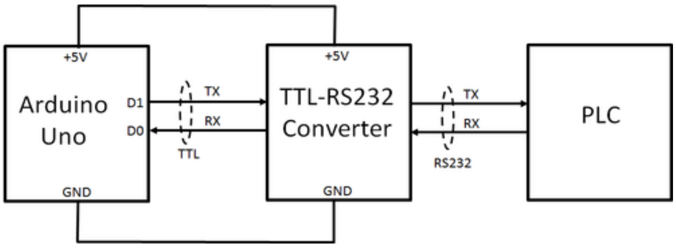

Fig -7: Arduino to PLC connection diagram

For AB PLC RS Micro started Lite software has been used to upload our program. The ladder diagram simulation for speed control of wind blades is uploaded and verified.
So whenever the speed exceeds the surviving speed i.e. above 89 mph our PLC will take the control action by cut off the supply to the pitch motors. The diagrammatic representation of control is given below.

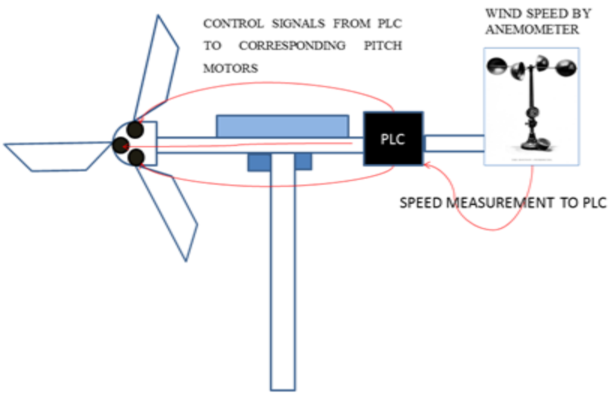

Fig -7: Pitch motors control using PLC

Since the pitch motors[3][4] are responsible for speed of rotation this control action will be much more effective than using conventional mechanical brakes.

7. OVERALL WORKING OF OUR SYSTEM

The overall working of the proposed system is given by the following block diaram.

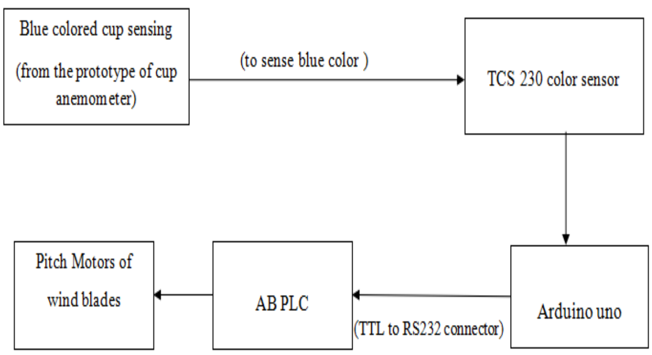

Fig -7: Block diagram of proposed system

Thus the colour sensor senses blue colour as a refernce and gives the speed by measuring the number of times it detected using arduino uno and the speed is controlled by shutting off the pitch motors of wind blades which are responsible for speed with AB PLC.

8. CONCLUSION

Thus by using this proposed system the speed of the wind blades can be encountered efficiently with the help of allen bradley programmable logic controller which is handy and having easier ladder logic. The prototype of cup anemometer designed with the help of TCS 230 colour sensor and arduino uno measures the speed of wind. The speed control action is taken by PLC to control the pitch motors. Since the pitch motors are available as DC electric motors the PLC can be connected very easily. This proposed system is highly effective even the direction calculation also given to the PLC in futute to reduce the number of controllers used and also the using of PLC is handy, easy to operate and highly accurate when comparing to conventional controllers.

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