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A Novel Method For Regulation Of Wind Speed Of Wind Turbines

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Abstract

Wind turbines, whenever the wind speed overshoots the permissible limit, are shutdown to avoid damage to the blades. To avoid such shutdown, the wind speed regulation is proposed for horizontal wind turbine duct. Presently the ducts are used to increase the velocity of the wind by venturi effect. In this paper, a method is proposed to use the regulator valves to control the air flow inside the duct. The regulator valve can be controlled by applying proper electrical signals, which may be generated using PIC Microcontroller for high and low wind speeds. This method has been simulated on Matlab/Simulink tool and the results are presented, which shows the satisfactory performance of the turbine at various speeds.

Keywords- Wind Speed Regulation, Horizontal Wind Turbine, Shutdown of wind turbines at High Wind Speed.

I. INTRODUCTION

Because of the environment pollution problems and the economic benefits of fuel savings, there has been growing interest in Wind Energy Conversion Systems. Wind Power is the conversion of wind energy into useful form of electrical energy by using wind turbines.

The average available wind power per unit area is directly related to the average of the wind speed, which is given by[6]

$$\frac{Pa(t)}{A} = 0.5\rho[v(t)]^3 \quad W/m^2 \quad (1)$$

Where
P_a (t) - Available wind power
A - Swept Area by the rotating blades of the wind turbine
ρρ - Air Density
v (t) - Velocity of the Air

From the above equation, it can be concluded that if the velocity of the wind is increased, the wind power per unit area can be increased. The increase in velocity of the wind can be achieved by the ducted wind turbines (DWT).The ducted wind turbine is an emerging micro-grid technology.

In Practice, a wind turbine's output will vary. There will be periods when there is insufficient wind for the machine to generate any power at all, and times when the wind speeds are so high that the machine has to be shutdown to prevent damage.

To avoid the shutdown of the machine at high wind speed, a control system is proposed for ducted horizontal axis wind machines in this paper.

Automatic control system is one that makes the required adjustments automatically, without human intervention. It is common to separate control system descriptions into two broad categories – process control and servomechanisms – depending upon how the physical variable is expected to behave in time. In many instances, the objective of a control system is to force a physical variable to remain constant in time and equal to some desired value. This type of control is often called a process control system. Process control is encountered, in automated manufacturing operations, such as in chemical and petrochemical industries where temperature, flow rates, levels, and so on are forced to maintain constant values. Such control is often also called regulation and the desired value is called set point [5].

Another type of control system objective is to force a physical variable to change in time, but in a precisely prescribed manner. That is, the physical variable will be forced to follow or track some target value as it changes in time. The term servomechanism is frequently used to describe such control by reference to a historical approach to providing the control. A common example of this kind of control system is in industrial robot arm motion, where the arm must follow a specific path in space as a function of time.

In this paper, a process control system is proposed to control the flow rate of the wind to the ducted wind turbines.

II. SAFETY SYSTEMS USED FOR HIGH WIND IN EXISTING WIND TURBINES

The reliable, safe and beneficial operation of wind turbine requires the use of a number of Engineered Safety Features (ESFs), much like any other engineered device. Identification of the possible failure modes under severe wind conditions will lead to future even more reliable and safer wind turbine designs. Below is some of the safety systems used for safety of the wind turbines due to high wind.

A. Wind Velocity: - In the existing wind turbines, the wind velocity is measured and controlled by the computer in two ways. First, gusts of wind are registered and if they are too strong, the turbine is stopped. The average wind speeds are measured over periods of 10 minutes, and the wind turbine is stopped if they are too high.

B. All modern large wind turbines use a combination of speed control in the power extraction region and pitch and speed control at the shoulder of the power curve to prevent power output exceeding the rated capacity.

The control system proposed in this paper will also be considered as a safety system for the wind turbines at high wind speeds.

III. DUCTED WIND TURBINES

Horizontal axis Wind turbines (HAWT) are normally used for Electricity generation and have a greater efficiency than the vertical axis wind turbines (VAWT). One type of HAWT is the unconventional modern ducted rotor wind turbine. The ducted-rotor is a turbine inside a duct. It can operate in a wide range of wind speeds. It doesn't use gear box, which makes it lighter. The duct design operates on the principle of venturi effect.

The venturi effect is the jet effect; as with a funnel the velocity of the air increases as the cross-sectional area decreases, with the static pressure correspondingly decreasing.

As mentioned in equation (1), by increasing the velocity of the air, the power input to the wind turbine can be increased. The velocity of the air can be increased through venturi effect by placing a duct at the suction end of the wind turbine.

There are two possibilities of Ducted wind Turbine (DWT).

A. Integrated into the façade of the building. This is an emerging micro grid technology.

B. Stand-alone duct for a Horizontal Axis Wind Turbine (HAWT) as shown in Fig.3.1[7].

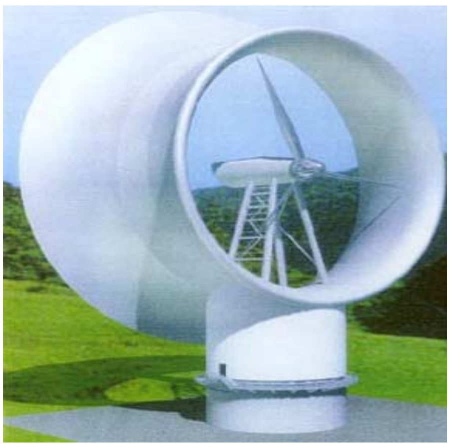

Fig.3.1. Ducted Wind Turbine

The proposed control system is for both the types, but in this work the analysis is done for the second type i.e. stand alone duct for a Horizontal Axis Wind Turbine (HAWT), using Matlab/Simulink.

IV. WIND SPEED REGULATION

Fig.4.1 shows how the wind flow to the wind turbine is controlled by the proposed control system. Fig.4.2 shows the block diagram of the modified Control System from Reference [1]. The wind speed sensor senses the actual wind speed and sends it to the microcontroller. The output of the microcontroller is the error signal between actual wind speed and the set wind speed. This output is given to the regulator valve. The speed of the wind can be controlled in the ducted rotor using the regulator valve which can be controlled using the microcontroller. The advantage is that the wind flowing through the duct can be controlled. Thus, for high wind speeds the wind turbine need not be shutdown. By using the valve, the wind speed hitting the turbine can be slowed down for high wind. For low wind, the wind speed can be increased by again controlling the valve. The valves that may be used are of different types. The detailed discussions of the valves that can be used are presented in the valves section.

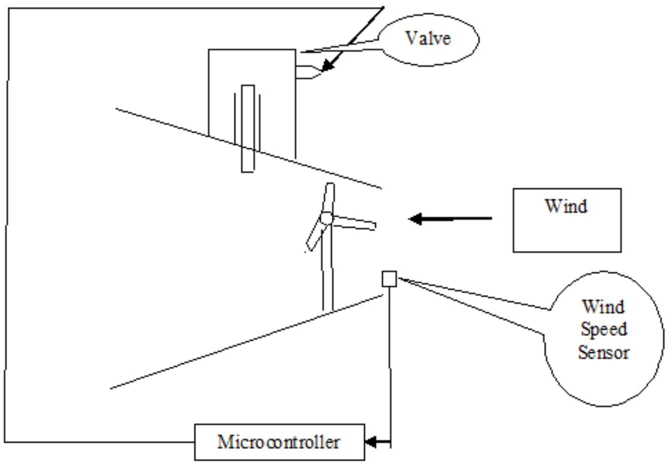

Fig.4.1.Control System Model

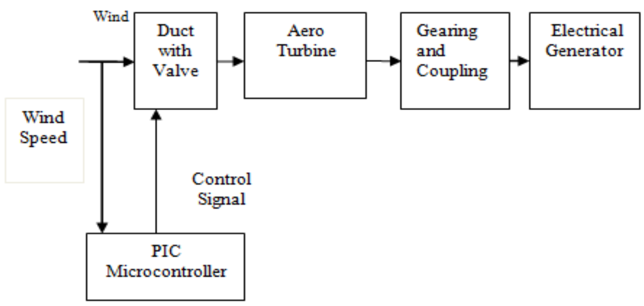

Fig.4.2 Block diagram of the control system

V. REGULATOR VALVE OPTIONS

Many options are available for the valves which can be used for the controlling of the wind through the duct. The options are as follows:

1. Solenoid valve
2. Pneumatic Bladder Valve
3. PVC Coated Fiber Reinforced Plastic Globe valve
4. Unplasticized Polyvinyl Chloride Ball valves

The solenoid valve can be directly controlled by applying proper electrical signals, which may be generated using control devices like Microcontroller/Microprocessor, PLC, etc. So, The Solenoid valve is proposed to use in this wind speed regulation. The Globe valve, Ball valve cannot be directly controlled by the output of the microcontroller. Instead, the stepper motor will have to be placed in between the microcontroller and the valve to control the Globe valve and Ball Valve. Economically, The Unplasticized polyvinyl chloride (UPVC) Ball valves will be better Since the UPVC Cheaper, but this cannot be directly controlled like Solenoid Valve, they need stepper motor to control it [8].

VI. WIND SPEED SENSORS

The Wind Speed Sensors are used to measure the speed of the wind. This sensors output is in digital form. This digital output is given to the PIC Microcontroller. The wind speed measuring device is called Anemometer. Anemometer can be divided into two classes: those that measure the wind speed and those that measure the wind's pressure. Since there is a close connection between both the speed and pressure, an anemometer that is designed for one will give information about both. There are different types of anemometers available to measure the speed and pressure of the Wind. Out of the several types, the three cup anemometers are currently used as the industry standard for wind resource assessment studies [9]. So, three cup anemometer is suggested for implementing the control system suggested in this paper.

VII. ANALYSIS OF THE DWT MODEL

Fig.7.1 shows a modified simple model of a ducted wind energy conversion device making use of the pressure differentials of the action of the wind [3].

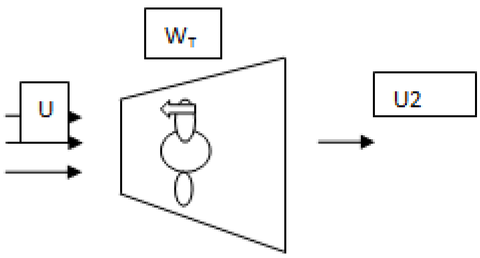

Fig.7.1 A Simple model of a ducted WECS

Analysis of this model shows that the power extracted from the air stream is [4]

$$W_T = \rho A U_2 \left[\frac{\delta U^2}{2} - \frac{U_2^2}{2C_v^2}\right] \quad (2)$$

Where
ρ - Air density
A - Cross sectional Area of the Wind turbine blade
δ - Differential pressure coefficient between inlet and outlet
U - Inlet Air Velocity
U_2 - Outlet Air Velocity
C_v - Duct Velocity Co-efficient
W_T - Wind Turbine Output

Differentiating equation (2) with respect to U_2 and equating it to zero, gives the maximum power condition:

$$U_2 = C_v U \sqrt{\frac{\delta}{3}} \quad (3)$$

Substituting this into equation (2) gives the maximum power output:

$$W_{Tmax} = \frac{C_v}{3\sqrt{3}} \rho A \delta^{1.5} U^3 \quad (4)$$

The power output of the component is therefore a function of the duct velocity co-efficient (C_v), the opening area A and the free stream velocity of the wind, U.
The power coefficient for maximum power extraction from the air stream is

$$C_p = \frac{2}{3\sqrt{3}} C_v \delta^{1.5}$$

According to air-duct minor loss diagram [10], it has been proved that C_v to be close to 1.25 for the cone shaped air-duct that is used in this control system.
And the power extracted from the air stream is

$$W_{Tmax} = C_p P_w$$

Where

$$P_W = \frac{1}{2} \rho A U^3$$

By controlling the δ, i.e. the differential pressure coefficient, the power can be extracted from the air stream irrespective of wind speed using the proposed system.

$$\delta = \delta_i - \delta_o$$

Where δ_i is inlet surface pressure coefficient, δ_o is outlet surface pressure coefficient.

The Analysis was done in Matlab 7.

The Model equation is

$$\frac{d(volume)}{dt} = A\frac{dH}{dt} = b\delta_i - a\sqrt{H}$$

Where A is the area of the duct, H is the height of the duct.

VIII. CONTROL ALGORITHM

The objective of this control system is to maintain the rate of air flow to the wind turbine at desired rate. This is done by adjusting the valve that controls air. Here is the control algorithm to achieve this objective.

1. Desired wind speed is taken as the input to the PIC Microcontroller.
2. The wind speed sensor gives the actual speed of the wind that is available at the Wind Turbine.
3. The difference in desired and actual wind speed is manipulated in the PIC Microcontroller and the commands from it operate the Motor.
4. The commands from the PIC Controller operate a motor which controls the valve to open, close and stop.
5. When the desired wind speed is less than the actual wind speed, then the PIC Microcontroller commands the motor to close the valve, till it comes to the desired wind speed.
6. When the desired wind speed is more than the actual wind speed, then the PIC Microcontroller commands the motor to open the valve, till it comes to the desired wind speed.
7. When the desired and actual wind speeds are equal, the PIC Microcontroller commands the motor to stop.

The flow chart of this control algorithm is shown in Fig.8.1.

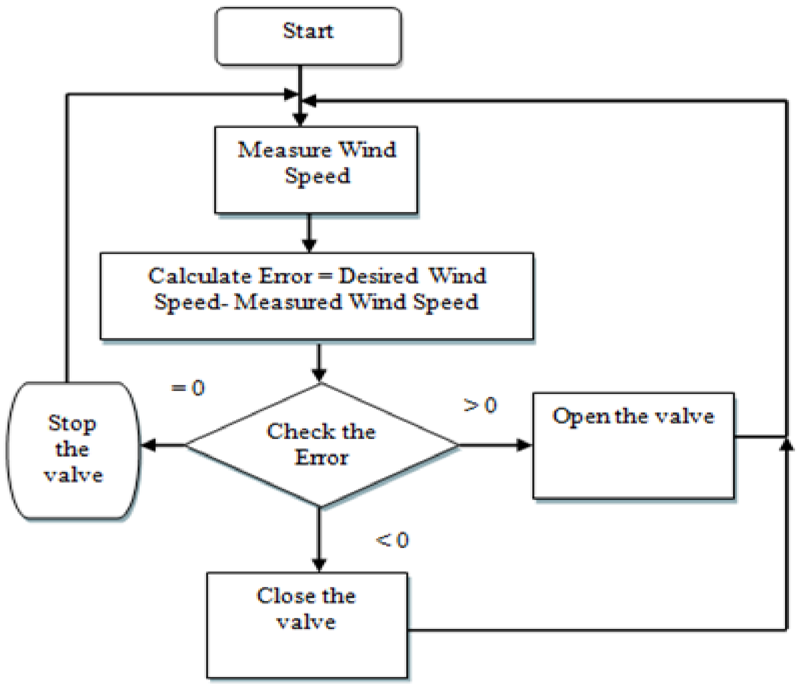

Fig.8.1.Flow Chart of the Wind Speed Control System

IX. SIMULATION RESULTS

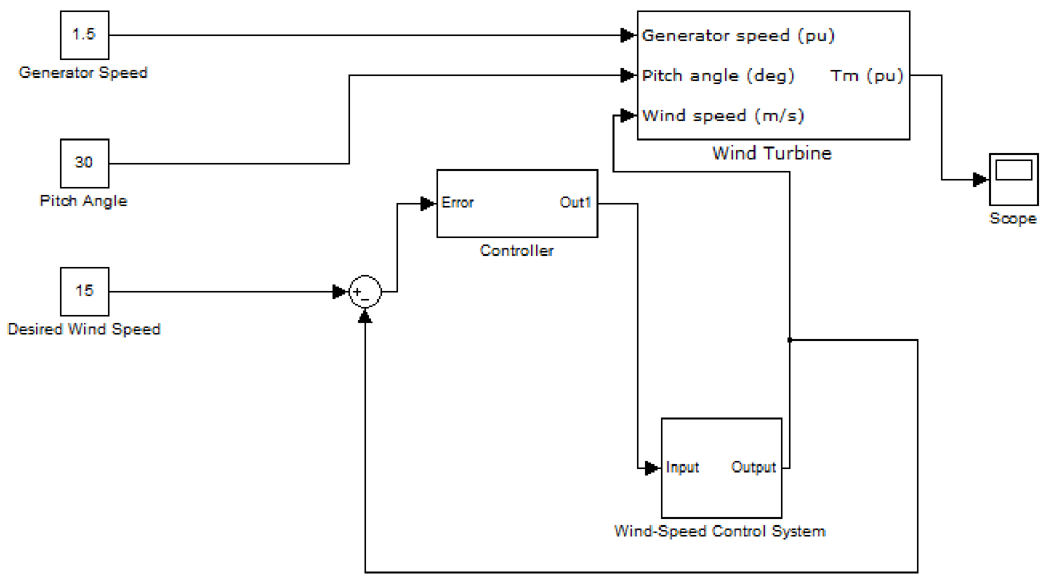

Fig.9.1. Matlab Simulink Model of the Wind Speed Regulation

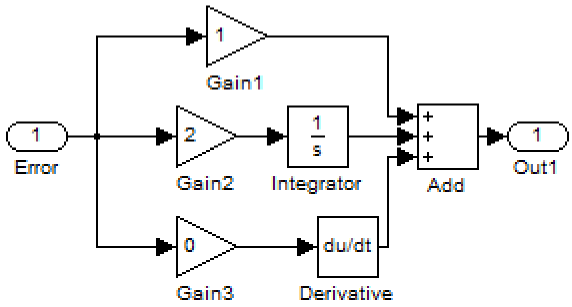

Fig.9.2. Matlab Simulink Model of the PID Controller

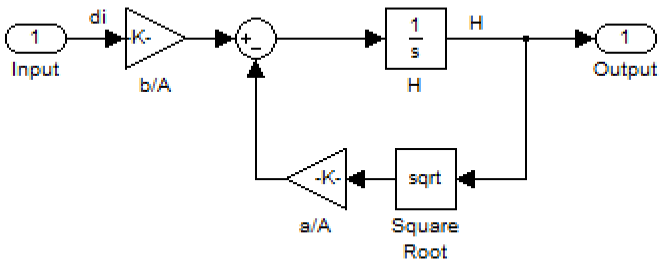

Fig.9.3. Matlab Simulink Model of the Wind Speed Control System

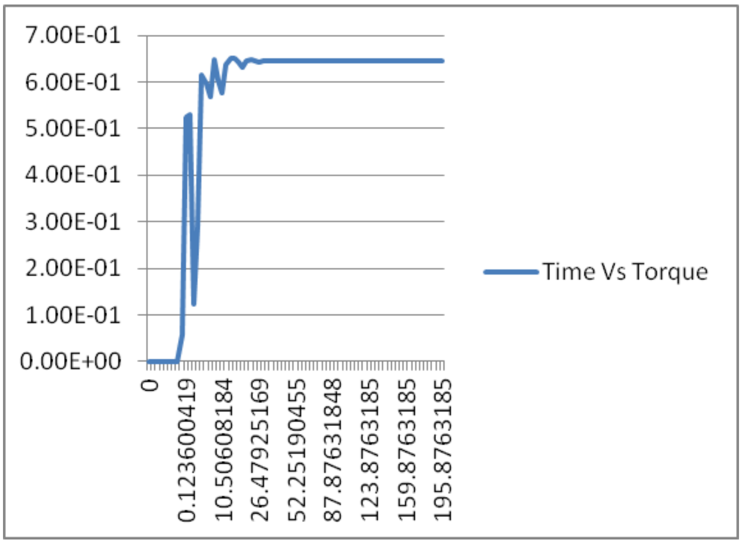

Fig.9.4. Time vs. Torque Output of the Wind Turbine in the scope of the Simulink Model

The Wind Speed Control System was simulated using the Matlab/Simulink [2]. The model is as shown in the Fig.9.1. The PID Controller was used since it has got a smaller maximum overshoot. This is shown in Fig.9.2.The Controller and the wind speed control systems were designed. The Wind speed control system is shown in Fig.9.3.The regulated wind was given to the Wind Turbine Model.

The time vs. Torque output of the wind turbine is analyzed from the scope of the wind speed regulation model. The torque remains constant at 0.65 N-m after 40 Seconds. The graph is shown in Fig.9.4.

X. CONCLUSION

By this method, it is suggested that the wind speed can be controlled using a duct and a valve. Using this method, smooth wind flow can be given to the wind turbines. This method has the following advantages:

1. The wind turbine blades can be protected from high wind speeds by controlling the valve. By this way, the wind turbines operating speed of the wind can be increased.
2. The safety system mentioned in Item II can still be used along with this method which again increases the stability of the wind turbines for high wind speeds.References

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