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Frequency Regulation Control of Wind Turbine Incorporating Stepper Motor in Pitch System

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***Abstract*—**This paper describes the presentation of a stepper motor in the pitch control system to regulate frequency. The controller sense the frequency deviation. If the frequency deviation is positive the stepper motor will recommend the motor to pitch the turbine blade slightly away from wind pressure. Similarly if the frequency deviation is negative the stepper motor will recommend the motor to pitch the turbine blade slightly towards wind pressure. The blade pitching is performed by another motor. The frequency controlled by conventional hydraulic mean is costly complex and quite slow in response. They consume enough time during big load changes. In this research a stepper motor is being used for frequency control. A stepper motor is economical capable of fast action and easy to control. The position of the stepper motor is controlled by a PI Proportional Integral controller. Thus a proposed frequency control system incorporating a stepper motor in pitch control system is modeled, designed and simulated in Matlab/ Simulink. The frequency control through stepper motor improves the Transient and steady state performances are enhanced and moreover it reduces frequency spikes**.**

***Keywords*—** Generator, Wind Turbine, stepper motor, Pitch actuator, Proportional Integral controller.

I. INTRODUCTION

Renewable Energy resources are those which are being continuously produced in nature and inexhaustible. They are not depleting with a time being as compared to the non-renewable. Renewable energy resources are abundant in nature. They are economical source of power generation to meet the increasing demand of power. [1] Pakistan has a great potential of wind which can be exploited sufficiently for electric power generation. Pakistan has a great potential in Sindh province at a place name Garo Kethi Bandar has a potential of 3.4 million alone beside this coastal area of Karachi and Baluchistan province has abundant wind source[2]. More efforts are required from the government as wells from the private sector to exploit this resource and cope power shortage crises. One of the challenges in developing wind turbine plant related with the frequency control system. The frequency control system is intentional to be cost effective .Moreover, the frequency control system is expected to be less complex and more reliable. It must be smart and fast responsive as changes occur from nature and consumer. Conventionally, hydraulic control is used to control the frequency of wind turbine , though the hydraulic frequency control are expensive, complex and slow in response.Furthermore, hydraulic control are less reliable. Therefore, the objective of this paper is to model ,design and simulate a less expensive, less complex and fast frequency control system for wind turbine by deploying a stepper motor in the pitch control system .Stepper motor are economical and easy to control they are much faster than hydraulic means frequency control. Thus, a robust controller is required to control the pitch actuator to pitch the blade of a turbine as a function of wind speed. The frequency sensor will sense the frequency deviation from nominal frequency. The PI controller will compensate the error by modification of pitch angle through a controlling component stepper motor. If frequency deviation is positive it means that frequency produced is more than nominal frequency, the PI controller will send a command signal to pitch the blade away from the wind pressure.so that the comparatively less percentage of wind pressure is exerted on wind turbine. Similarly if frequency deviation is negative it means that frequency produced is less than nominal frequency, the stepper motor will send a command signal to pitch the blade towards the wind pressure.so that more percentage of wind pressure is exerted on wind turbine In fact the stepper motor act as a governor, which controls the frequency according to the wind speed. Stepper motor arrange the turbine blade at most precise and accurate angle as compared to hydraulic frequency control. The controller is capable of reducing frequency spikes.

II. MATHEMATICAL MODELLING AND CONTROLLING DESIGN

The major constituents of the frequency control system compressing the wind turbine are shown in Figure 1 before designing the frequency control system, the appropriate and general mathematical model for each component should be obtained for modeling. The simplest and general transfer functions are used to model all the components in order to achieve the suitable results. The block diagram of the proposed control system is shown below

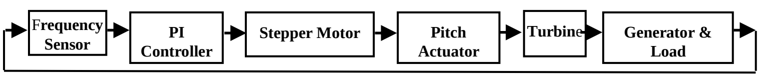

Figure 1. Block diagram of the proposed frequency control system

A.Turbine Model

Turbine Converts working fluid into mechanical energy but here in this model it converts kinetic energy of wind into mechanical energy. The output mechanical power of a turbine depends upon the speed of the wind i.e. higher the speed of the wind, the more mechanical energy it produces and vice versa respectively. The input power to the wind turbine is controlled by pitch the blades of turbine at most accurate angle accordingto the wind speed.

In general the transfer function of a turbine is given as [3]

$$\frac{\Delta P_m}{\beta} = \frac{1 - s}{1 + 0.5s} \quad (1)$$

Where ΔP_m is change in mechanical power produced from kinetic energy of wind and β is the change in position of the pitch of the wind turbine. [3, 4].

B. Generator and Load Model

The generator converts mechanical energy to the desirable electrical energy. The frequency of a synchronous generator is directly depends upon the balance of two powers parameters. The input mechanical power and output electrical power of the synchronous generator balance the frequency index [3, 5] Moreover, the frequency depends on the damping coefficients of the generator and the load connected to it.The load are of two types frequency sensitive load which effect frequency and non-frequency sensitive load which has no effect on frequency. The frequency sensitive load is inductive in nature while that of non-frequency sensitive load is DC in nature. The transfer function which illustrates the relationship between frequency deviation and change in power is modeled as [3]

$$\frac{\Delta f}{\Delta P_m - \Delta P_L} = \frac{1}{2Hs + D} \quad (2)$$

Where Δf is frequency deviation from nominal frequency ΔP_L is change in per unit non frequency sensitive load, H is the per unit inertia of rotating parts and D is the cumulative damping coefficient in the wind turbine mathematically Damping coefficient be expressed as [3, 4]

$$D = \frac{\Delta P_L}{\Delta f}$$

(3)

C. Controller Design

The controllers play a vital role in proposed frequency control system. It compensates the frequency error. The controller purpose is to control the position of stepper motor and as a result the pitch angle to retrieve the power from wind accordingly to speed .Different kind of controllers are used for sophisticated purposes but for the sake of simplicity proportional integral PI controller is proposed. The PI controller is a robust controller. The input and output relation by a transfer function relation to illustrates the use of PI controller. Here in this proposed frequency control mechanism, input to the PI controller is the frequency deviation from the nominal frequency and the output is the input angle of the stepper motor .The applied mathematical model of the PI controller is given as below

$$\frac{\theta i}{\Delta f} = K_P + \frac{K_I}{s} \quad (4)$$

Where θ_i is the input angle to the stepper motor, K_P is the proportional constant and K_I is the integral constant of the PI controller.

D. Stepper Motor Model

The frequency control of wind turbine was with conventional hydraulic frequency control. However the time of response was too big, the blade pitching is not precise and produces frequency oscillations. The hydraulic control Simulink model is simulated .the remedy of all this misfit is electrical control. [6].A stepper motor is a special type of synchronous motor without a mechanical load .It converts digital pulses into mechanical shaft rotation. It is used for precise position of blade to adjust pitch angle as a function of wind speed. Stepper motor is used to control the pitch control system according to wind speed by increasing or decreasing the step angle. The PI controller sense the frequency deviation .if the frequency change is positive the stepper motor will decrease the step angle as a result decrease revolution per speed. If it is negative the stepper motor will increase the step angle thus increasing revolution per speed. This relation can be better articulated with the a classical transfer function between the input angle of the PI controller and output angle of a permanent magnet stepper motor is given as

$$\frac{\theta_0}{\theta i} = \frac{K_m I_p N_r}{Js^2 + Bs + K_m I_p N_r} \quad (5)$$

Where θ_0 is the output angle of stepper motor J is the moment of inertia of rotor, K_m is the torque constant I_P is the phase current N_r is the number of rotor teeth and B is the viscous friction coefficient of permanent magnet stepper motor [7].

E. Frequency sensor & Pitch actuator model

The frequency sensor is a scalar miltiplier in this system while the pitch actuator model is a linear function with minmum and maximum extremes.The pitch actuator is composed of gear train which is used to turn the blades along the longitudiual axsis. The actuator model descrbies the dynamics between pitch demand β_d from the pitch controller and the measurement of a pitch angle $\dot{\beta}$

The change in pitch angle is given as below

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$$\dot{\beta} = \frac{\beta_d - \beta}{\tau_\beta} \quad (6)$$

From above equation the transfer function for actuator is

$$\frac{\beta}{\Delta\theta_0} = \frac{1}{\tau_\beta s + 1} \quad (7)$$

Where τ_β is a time constant and is taken as unity, it depends on pitch actuator, β is the Pitch angle of wind turbine and is the output of pitch actuator system. While $\Delta\theta_0$ is input to pitch actuator system [8].

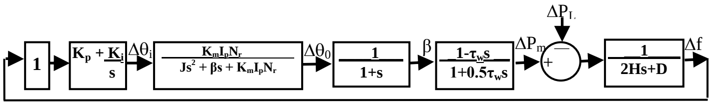

Figure 2. Transfer function model of the proposed frequency control systems.

F. Complete model

For simplicity and to achieve our results according to the bench marks we took all the models with their simplest Transfer functions**.** All the major components of proposed frequency control system has been modeled and designed in the former sections. Now putting together all the concerned transfer functions obtained from all components results in the block diagram of the flow chart. Therefore any kind of wind turbine can be modeled as shown in figure 2 for frequency regulation control.

G. Designing and Exploration

For the designing of proposed frequency control synchronous generator model is used [9]. The different parameters of generator model shown in Fig.2 are determined .A stepper motor with all general specifications is also selected for this mechanism.[10] The basic transfer function between the input and output angles of the permanent magnet stepper motor is determined from the mentioned description. The wind time constant depends on the speed of wind turbine plant. Here in this model the wind turbine constant is taken as unity Once all the basics parameters are known concerning wind turbine .the next important step is to tune the PI controller .For this purpose many well-known techniques are used the PI controller can be tuned using different techniques but Open Loop Bode techniques gives the best standard result (K_P= 7.28 and K_I = 1.05) figure (3) shows all the designed parameter for a wind turbine plant with 1 sec wind time constant.

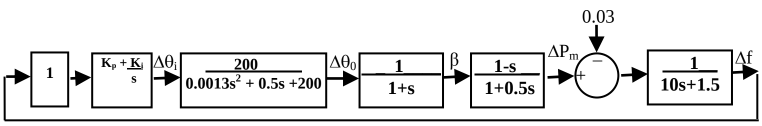

Figure 3. Block diagram of wind turbine plant with frequency control for 1 sec wind time constant

III. Simulations and Results

The frequency deviation of wind turbine was simulated for the conventional hydraulic control and new proposed electric control by controlling component stepper motor. Both the hydraulic control & stepper motor frequency control tis subject by same conditions to see the effect frequency deviation. Fig.4 shows that a 3% load change as disturbance was subjected to both the stepper motor model and hydraulic control system model to observe the frequency deviation, settling time and overshoot. From the simulation result it was observed that the frequency deviation is eliminated in lesser time 13.7 sec with percentage overshoot 19.3%.

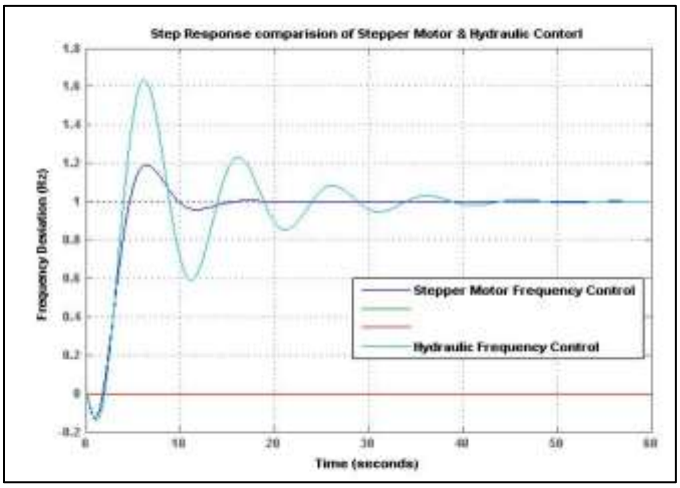

Figure 4. Simulation results of wind turbine plant

The performance of the proposed electrical control by means of stepper motor control is better than hydraulic frequency control. Thus frequency control electrically not only reduces the response time but also a precise blade pitching of wind turbine as compare to hydraulically frequency control. Table 1 presents the comparison between the conventional frequency control performances and the stepper motor control performances.

Table 1. Comparison Of Proposed Control System And Conventional Hydraulic Control

Performance	**Stepper Motor Control**	**Hydraulic Control**
Settling Time	13.7 sec	37.4 SEC
Overshoot	19.3%	63.5%
Frequency	1.19	1.63

From the comparison chat it can be observed that the electric control using a stepper motor show a prominent result concerning all the indigenous properties of control system. The settling time is fast as compared to the hydraulic control it produces 30 % faster result and response as compared to the hydraulic control system. The load pattern and wind pattern is not constant all the time rapidly with time. Hence the electric control using a stepper motor produces a fast response as compared to hydraulic control during wind speed changes or big load changes. The overshoot is greatly minimized in stepper motor control.it reduces approximately 45% of the overshoot as compared to the hydraulic control. The frequency deviation is also minimize in the stepper motor control it minimize 45 % of frequency deviation as compared to the hydraulic control. Moreover the frequency spikes and frequency oscillation is reduced up to greater extent to main the reliability of the wind turbine system.

CONCULSION

In a frequency control for a standalone wind turbine has been modeled designed and simulated. Simulations results have demonstrate that the controller is applicable for different capacities, types of loadings and wind speed of wind turbine. Moreover, from simulation results it is observed that frequency spikes are very low. Therefore, this controller can play crucial role in the rural electrification program of Pakistan especially the province of Sindh which has immense potential of wind resources.

RECOMMENDATIONS

In the future, the performance of the frequency controller with grid connected wind turbine can be investigated. In addition, the controller can be modified to engage electronic load controller for efficient load management.

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