Performance Analysis of different controllers on pitch control of a wind energy system

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Abstract

This paper presents the analysis and comparison of various controllers applied for stabilization on a pitch control mechanism of a wind energy system. Since pitch control of a wind blade helps us in well harnessing of power from wind turbines, it is necessary to control and optimize it. Optimization of various PID controller parameters is also carried out. Since optimization requires a lot of iterations and calculations, MATLAB turned out to be a useful tool. We have applied GA and PSO optimization technique to get the best controller design. The performance comparison of pitch control mechanism for wind energy system for various controllers is also discussed.

Keywords: *wind energy systems, Genetic Algorithm, Particle Swarm Optimization technique, PID controller.*

1. Introduction

Wind energy that have been used for ages as an alternative energy has become more popular in recent years, because of the decreasing costs in energy systems, technological innovations and the interests in clean energy sources. Today small, medium and large sized wind energy systems are constructed. Enterprisers favor larger wind energy systems over the smaller ones, because they considered more cost-productive. However, since the wind energy is not steady and generators outputs is directly proportional to change of the cubic value of wind speeds, fluctuation in wind turbine generators output power is the point in question [4]. In such large sized wind energy systems, blade pitch angles should be controlled to prevent the damages upon turbine beyond the nominal wind speed [5].

Variable speed wind turbines generator provides opportunity to get more power than steady speed turbines. However, because of the fluctuations in wind speed, variable speed turbines output power (voltage and frequency) also changes. In order to acquire a good quality output power, appropriate control methods should be used in system, and most effective control method is the control of blade pitch angle [6]. The output power of a wind turbine is given by the following equation:

$$P_m = 0.5 C_p(\lambda, \beta)\rho \mathrm{A} v_{wind}^3 \quad (1)$$

PID controller is one of the methods to control blade pitch angle of the wind turbine thus, to know the exact values of the PID parameters is of some concern. In this research, first modelling of a wind energy system is carried out consisting of a permanent magnet synchronous generator. Then in section-3 Methodology for PID controller using GA and PSO technique presented. And in section-4 model of wind energy system with a PID controller is shown. At last, in section 5 and 6 results and conclusions are discussed.

2. Modeling of Pitch Control System

Pitch actuator systems can be hydraulic or electrical operated. The advantages of the electrical actuators are position accuracy and speed dynamic reaction. In electrical operated actuators, each blade individually is set by a servo motor. In this study, DC servomotor is used as an actuator.

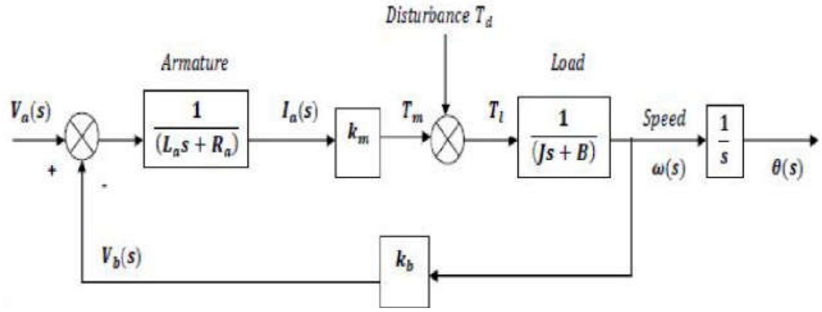

Fig.1. Equivalent block diagram of a pitch-controlling servomotor [2]

In the above block diagram of a servo motor, employed for pitch angle control of the wind energy system L_a, R_a, J and b are armature inductance, armature resistance, equivalent inertia and frictional coefficient respectively while K_m and K_b are proportionality constants. Except for miner difference in constructional features, a dc servomotor is essentially an ordinary dc motor. Physical requirements of servomotor are Low inertia and High starting torque. Low inertia attained with reduced armature diameter with consequent increase in armature length such that the desired power output is obtained. This dc servomotor can be consider as a linear SISO system having third order transfer function. Relation between shaft position and armature voltage is derived from the physical laws.

$$\frac{\theta(s)}{V_a(s)} = \frac{K_m}{s[(sL_a + R_a)(sJ + b) + K_m K_b]} \quad (2)$$

Where, disturbance torque T_d =0, J=0.01kg/ m^2, b=0.1n.m.s, kb=0.01 v/rad/sec, km=0.01n.m/amp, Ra=1 ohm, L=0.5H

Substitute above values in the above equation, we get

$$\frac{\theta(s)}{V_a(s)} = \frac{1}{s[(.5s+1)(0.02s+0.1)+0.0001]} \quad (3)$$

3. Methodology for PID Controller Tuning

For tuning of PID controller for pitch control of wind turbine blades, Out of the various optimization technique PSO and GA with IAE criterion has been employed.

3.1 Particle Swarm Optimization

The basic flow chart of the PSO algorithm is given in the figure 3 and is discussed as follows:-

Step-1 Specify the lower and upper bounds of the three controller parameters and initialize randomly the individuals of the population including searching points, velocities p_{best} and g_{best}.

Step-2 Calculate the fitness value of each individual in the population using the evaluation function.

Step-3 Compare each individual's evaluation value with its p_{best} .The best evaluation value among them p_{best} is denoted as g_{best}

Step-4 Modify the member velocity " v " of each individual " k ".

$$v_{j,g}^{(t+1)} = \omega \times v_j^{(t)} + c_1^* rand() \times (p_{best_{j,g}} - k_{j,g}^{(t)}) + c_c^* rand() \times (g_{best_g} - k_{j,g}^{(t)}) \quad (4)$$

Where $j = 1,2,3,........n$, $g = 1,2,3,........n$ where the value of ω is set. When g is 1, $v_{j,g}$ represents the change in velocity of K_p controller parameter. When g is 2, represents the change in velocity of K_i controller parameter. When g is 3, represents the change in velocity of K_d controller parameter.

Step-5

If $v_{j,g}^{(t+1)} > v_g^{max}$, then $v_{j,g}^{(t+1)} = v_g^{max}$ (5)

If $v_{j,g}^{(t+1)} > v_g^{min}$, then $v_{j,g}^{(t+1)} = v_g^{min}$ (6)

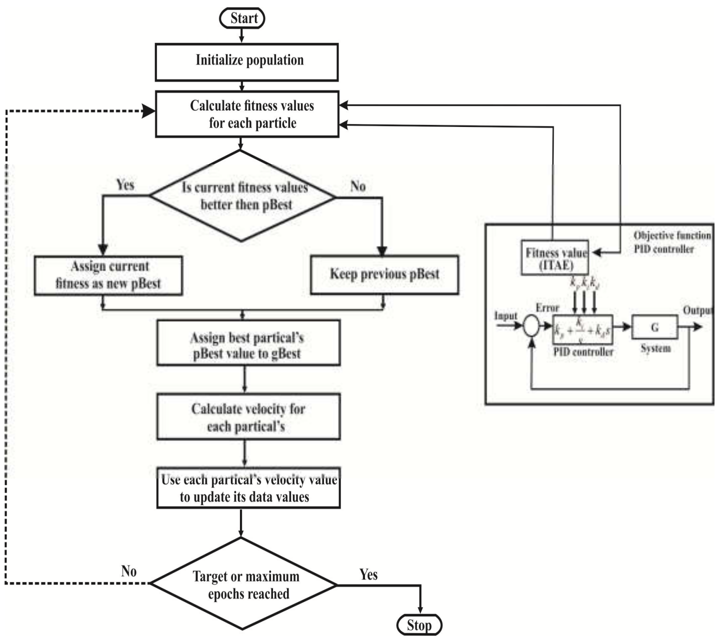

Fig.3. Flowchart of parameter optimizing procedure using PSO [10]

Step-6 Modified the member of each individual k .

$$k_{j,g}^{(t+1)} = k_{j,g}^{(t)} + v_{j,g}^{(t+1)} \quad (7)$$

$$k_g^{min} \le k_{j,g}^{(t+1)} \le k_g^{max} \quad (8)$$

Where k_g^{min} and k_g^{max} represent the lower and upper bounds, respectively, of member g of the individual. When g is 1, the lower and upper bounds of the K_p controller parameter are K_p^{min} and K_p^{max} respectively. When g is 2, the lower and upper bounds of the K_i controller parameter are K_i^{min} and K_i^{max} respectively. When g is 3, the lower and upper bounds of the K_d controller parameter are K_d^{min} and K_d^{max} .

Step-7 If the number of iterations reaches the maximum value, and then goes to step 8, Otherwise go to Step 2.

Step-8 Each individual generates the latest is an optimal controller parameter.

3.2 Genetic Algorithm

A genetic algorithm is an iterative and heuristic search procedure, which maintains a constant size population of candidate solutions. During each iteration step (generation), three genetic operators (reproduction, crossover, and mutation) are performed to generate new populations (offspring), and the chromosomes of the new populations are evaluated via the value of the fitness which is related to cost function. In the figure 4 functional flow chart of GA is discussed.

With the above description, the three steps in executing the genetic algorithm operating on fixed-length character strings are as follows:

Step-1 Randomly create an initial population of individual fixed-length character strings.

Step-2 Iteratively perform the following sub steps on the population of strings until the termination criterion has been satisfied:

A. Assign a fitness value to each individual in the population using the fitness measure.
B. Create a new population of strings by applying the following three genetic operations. The individual string(s) from the genetic operations in the population chosen with a probability based on fitness.

After the step-2 following three processes takes place

1. Reproduce an existing individual string by copying it into the new population.
2. Create two new populations from two existing strings by genetically recombining substrings using the crossover operation at a randomly chosen crossover point.
3. Create a new string from an existing string by randomly mutating the character at one randomly chosen position in the string.

Step-3 The best-so-far individual from the string is designated as the result of the genetic algorithm for the run. This result may represent a solution (or an approximate solution) to the problem.

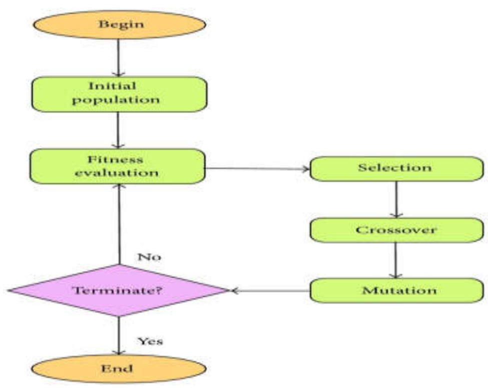

Fig.4 Flow Chart for Genetic Algorithm

4. Model of a Servomotor with PID Controller

A PID controller is used to reduce or eliminate the steady state error as well as to improve the dynamic response of the overall system. PID stands for proportional integral and derivative control, the proportional term amplifies the gain, and integral controller increases the type of the system by adding a pole at the origin and reduces the steady state error. And the derivative controller helps to improve the transient response by adding a finite zero to the open loop plant transfer function. The transfer function of a PID controller is given as

$$G_{pid}(s) = K_p + \frac{k_i}{s} + k_d s \quad (9)$$

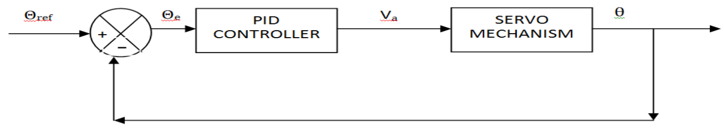

Fig.5. Block diagram of Servo mechanism with PID controller [2]

In the above block diagram the controller is in series with the open loop gain of the servomotor and is a unity feedback system. The output is pitch angle θ and the output of PID controller is voltage input of servomechanism. Therefore the Change in pitch angle θ(s) of the system respect to a change in input reference angle is given as:

$$\frac{\theta(s)}{\theta_{ref}(s)} = \frac{K_m \times G_{pid}}{s[(sL_a + R_a)(sJ + b) + K_m K_b] + K_m \times G_{pid}} \tag{10}$$

5. The Simulation Result under Matlab

The various step responses are simulated in MATLAB and there comparative analysis has been tabulated, using characteristic parameters of the step response of servomotor without PID controller is shown below.

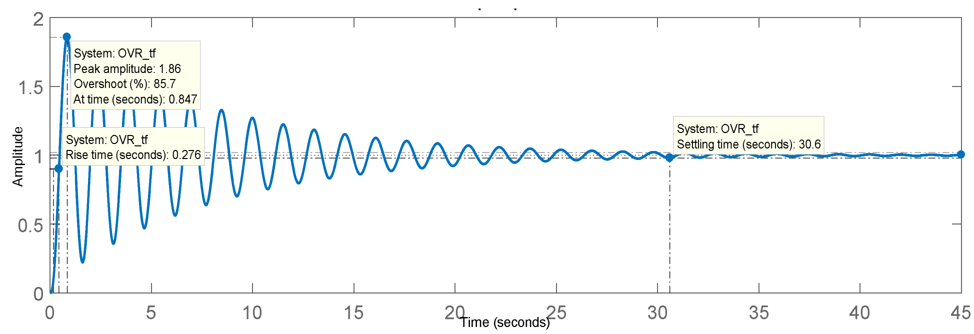

Fig.6. Step output of servomotor without PID controller

According to the above result the servomotor has a very large settling time as well as it has a very high peak overshoot and large number of oscillations are there. The time domain parameters of the step response are as follows, Rise Time: 0.276 seconds, Settling Time: 30.6 seconds Overshoot: 85.7%, Peak amplitude: 1.86 and Peak Time: 0.847 seconds. Thus to improve the step response PID controller is used in series with the open loop transfer function.

For further improvement we have applied the GA optimization technique for error minimization IAE criteria. The step response of the system is as shown below

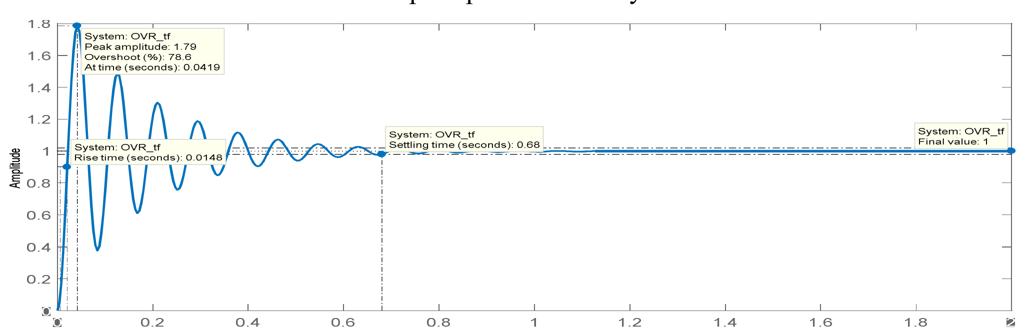

Fig 7. Step Response of GA-PID Tuned Servomotor

The genetic algorithm is made run for the 100 iteration. The optimum values obtained are a K_p =20.951, K_i =0.199 and K_d =28.055. by putting these controller parameters values in the system the step response is as obtained in figure 7 and the various time domain parameters are, Rise Time: 0.0148 seconds, Settling Time: 0.68 seconds, Overshoot: 78.6%, Peak amplitude: 1.79, Peak Time: 0.0419 seconds.

Still, for further improvement we have applied the PSO technique and for error minimization IAE criterion is used.

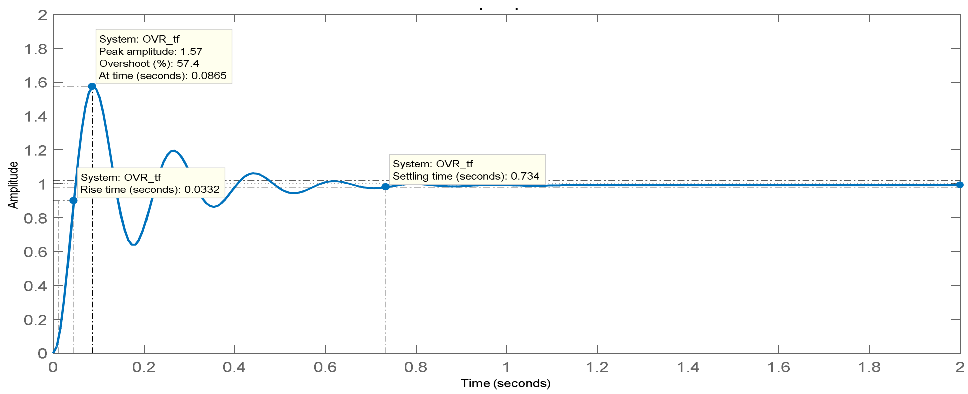

Fig.8. Step response of PSO-PID tuned servomotor

The PSO-PID tuned Servomotor for 100 iteration is simulated. The optimum values obtained are as K_p =1.8317, K_i =0.1103, K_d =6.3996. Thus the various time domain parameters obtained from step response of the above system are, Rise Time: 0.0332 seconds, Settling Time: 0.0734, Overshoot: 57.4%, Peak amplitude: 1.57, Peak Time: 0.0865 seconds.

From the above step responses it is clear that on employing GA and PSO technique on PID controller drastically improves the step response of the system.

It can be concluded from the above step responses that the behavior of pitch control mechanism changes drastically if PID controller is applied, the comparison is tabulated in the table given below.

Table I. Comparison of various parameters for different controllers

S. No	**Method**	**Overshoot**	T_s	T_r	T_p
1	Conventional servomotor without PID	85.7%	30.6	0.276	0.847
2	PSO-PID tuned	57.4%	0.0734	0.0332	0.0865
3	GA-PID	78.6%	0.68	0.0148	0.0419

It can be seen that the PSO-PID tuned controller produces best stability option for the Servomotor operation. Though GA-PID tuned servomechanism also gives satisfactory results moreover the settling time, rise time and peak time is better than PSO-PID tuned controller, but the percentage overshoot and number of cycle upto steady state is more than that of PSO-PID controller and hence in the stability concerns PSO-PID controller is best.

6. Conclusion

The analysis on this paper can be briefly said as various controllers optimization have been applied to the servo motor systems which are PID, PSO-PID tuned and GA-PID tuned. The time domain parameters of GA-PID controller is better than that of PSO-PID controller, but in terms of percentage overshoot and number of oscillations the response of PSO-PID controller is best and stable so according to this analysis PSO-PID tuned controller is comparatively more relevant and accurate.

7. Acknowledgement

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