Title Control of Pitch Angles to Optimize the Aerodynamic Using Particle Swarm Optimization

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Abstract: - The main objective of this paper is to maximize the energy captured by the wind turbine. The wind turbine is an energy converter device that captures energy from the wind and converts it into useful work. The controlling the pitch of the blade is the most common means for adjusting the aerodynamic torque of the wind turbine when wind speed is above rated speed and various controlling variables may be chosen, such as generator power, generator speed and wind speed. Different methods are available to control the pitch angle. The particle swarm optimization control strategy may have the potential when the system contains a strong non-linearity, such as the control objectives include fatigue loads or wind turbulence is strong. The simulation results by using actual detailed model for wind power system confirm the effectiveness of the proposed methodology.

Key-Words: - Wind Turbine-Particle Swarm Optimization- Control-Pitch Angle

1 Introduction

The rapid transition to green technology anywhere in the world, wind power is emerging as a serious source of new clean energy. The most thorough studies to date find the potential of wind energy on land and near-shore to be approximately 72 Terawatts. Currently humans use about 7 Terawatts from all sources globally. At the end of 2009, the installed capacity of wind farms in Morocco reaches 253 MW, which is increased at the end of 2013 by 495 MW (+95.65 %). Morocco sees many good reasons for continuing the development of wind power, and the government has set the target of installing 2000 MW wind power in the electricity system by 2020. In the early stage of development of the wind energy, most wind farms have been equipped with fixed speed wind turbines and induction generators.

Since the wind generators can only operate at a constant speed, the power efficiency is fairly low for most wind speeds [1].

Then several research results have recently been reported on the wind turbine generators [21][22]. In PID (Proportional Integral Derivative) control was investigated under varying wind conditions to overcome the disadvantage of designing and tuning conventional PID controllers for capturing maximum wind power. In a previous work, we proposed an intelligent controller based on the genetic algorithm [21]. The modern heuristic techniques mainly include the application of the Artificial Intelligence (AI) approaches such as Particle Swarm Optimisation (PSO) [2]-[4].

In the proposed paper, the intelligent controller techniques have been developed to extract maximum amount of energy from the wind. Thus ensuring that for any given wind speed; the wind turbine is able to produce the maximum power.

To tackle with the challenges from the scale of calculation, it is necessary to introduce an artificial intelligence method to seek the optimal in the large solution space. Here, we choose the particle swarm optimization (PSO) as the optimization approach for its adaptability and quick converging capacity.

PSO is selected partly because it has been used in solving similar problems such as part machine grouping [5] and manufacturing cell design [6], as well as it is found more robust [7]. On the other hand, the authors prefer PSO for its high efficiency in maintaining the diversity of the swarm, ease to adjust parameters, and no requirement for differentiable optimization problem.

The PSO algorithm was first introduced by Kennedy and Eberhart [8].The PSO provides a population-based search procedure in which the individuals, called particles, change their positions with time. Each particle adjusts its position according to its own best experience and the best experience of neighbouring particles. The particle swarm optimization (PSO) algorithm is a stochastic search technique, motivated by social behavior simulation of bird flocking or fish schooling, first developed by Kennedy and Eberhart. Compared to other evolutionary algorithm, it has many advantages such as easy realized, fast convergent, promising performance on nonlinear function optimization. In this paper, a PSO pitch angle controller is designed and analyzed. The simulations of the pitch angle control strategies are carried out and the conclusions are drawn at last.

2 Modeling of the Wind Turbine

The wind turbine converts energy of wind flow into mechanical energy. The turbine shaft drives the generator rotor through drive train. A wind turbine is a complicated mechanical structure which consists of rotating blades, shafts, gearbox, electric machine, i.e., generator, and tower [10]-[11]. Sophisticated design codes are necessary for predicting a wind turbine's performance and structural responses in a turbulent wind field. However, the simple drive train model of Fig. 1 and the Wind turbine drive-train dynamics Fig.2 are sufficient for the control system design [9][12].

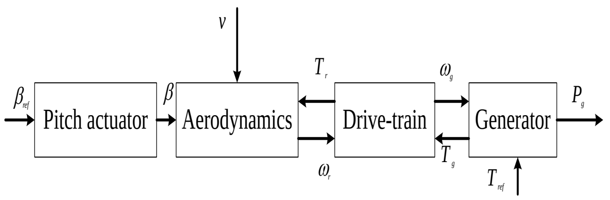

Fig.1. Overall structure of the wind turbine model.

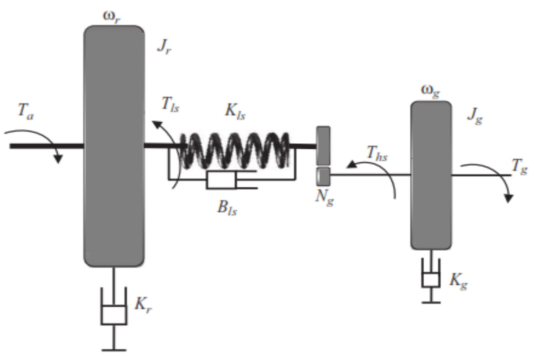

Fig.2. Wind turbine drive-train dynamics.

The mechanical power of an air mass which has a flow rate of $\frac{dm}{dt}$ with a constant speed of v is given by Eq. (1).

$$P_{wind} = \frac{d(E)}{dt} = \frac{d\left(1/2mv^2\right)}{dt} = \frac{1}{2}\frac{dm}{dt}v^2 = \frac{1}{2}\rho A v^3. \quad (1)$$

Where ρ is the air density and A is the cross-sectional area of the air mass. Only a portion of the wind power given by Eq. (2) is converted to electric power by a wind turbine. The efficiency of the power conversion depends on the aerodynamic design and operational strategy of the wind turbine. Usually, the Power generated by the wind turbine is represented by:

$$P = C_p P_{wind} = C_p\left(\frac{1}{2}\rho\pi R^2 v^3\right) \quad (2)$$

Where Cp value is calculated using a generic equation proposed in [5] given by Eq. (3) (Fig.3).

$$C_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3.\beta - c_4\right)e^{\left(-\frac{c_5}{\lambda_i}\right)} + c_6.\lambda. \quad (3)$$

Where $\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3}$

And tip speed ratio λ which is defined as:

$$\lambda = \frac{R\Omega_r}{v}$$

Where Ω_r is the mechanical angular velocity of the turbine in rad/s, v is the undisturbed wind speed in m/s.

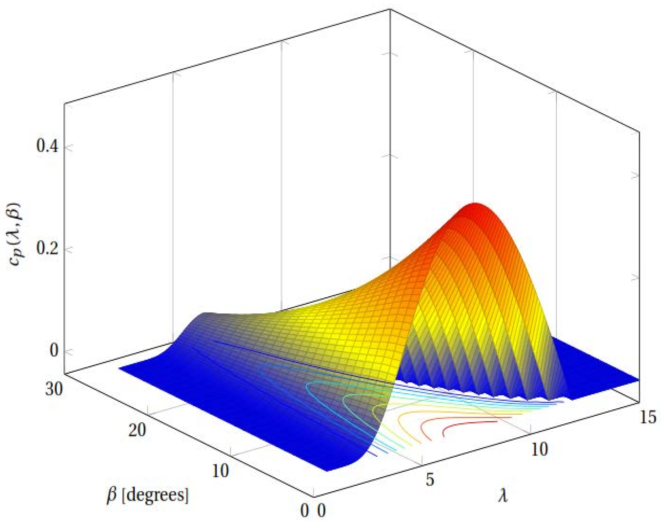

Fig.3. Power coefficient as a function of the tip-speed ratio and pitch angle.

Where Cp represents the efficiency of wind power conversion and is called the power coefficient. R in the above equation is the rotor radius. The ideal maximum value of Cp is 16/27= 0.593, which is known as the Betz limit [13]. As shown in Fig.4, the power coefficient, Cp is a function of pitch angle β.

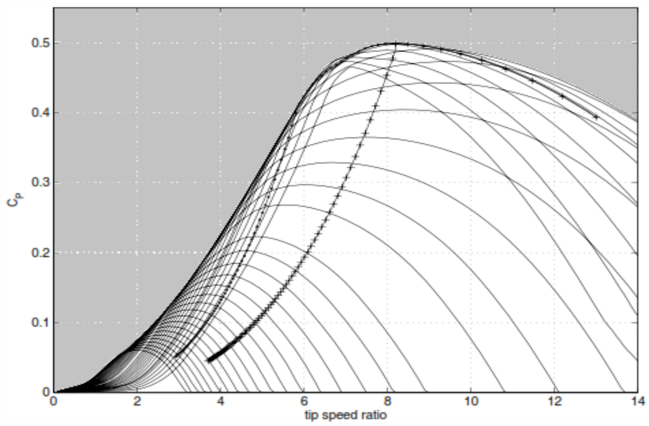

Fig.4. Power coefficient Cp vs tip speed ratio for various of pitch angles.

The operating region of a wind turbine depends on the wind speed and is divided into three zones: the no generation zone, the partial load zone, and the full load zone, shown in Fig.5 [14]-[15].

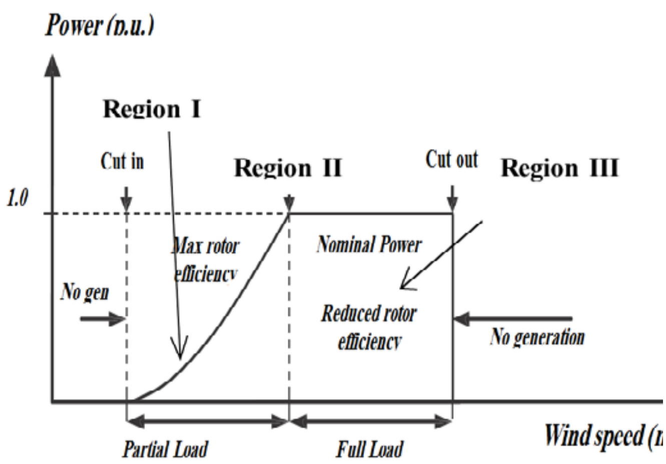

Fig.5. Wind turbine operating regions.

Region I: The blade pitch angle is fixed at β_0 and the rotor speed is varied so as to maintain the tip speed ratio constant (λ_0). Therefore, the rotor speed changes proportional to the wind speed by controlling the generator reaction torque. In the region I, only the generator torque control is active, while the blade pitch is fixed at β_0.

Region II: This is a transition region between the other two regions, that is, the Cp_{MAX} (Region I) and power regulation region (Region III). Several requirements, such as a smooth transition between the two regions, a blade-tip noise limit, minimal output power fluctuations, etc., are important issues in defining control strategies for this region.

Region III: This is the above rated wind speed region, where wind turbine power is regulated at the rated power. Therefore, the rotor speed and the generator reaction torque are maintained at their rated values. In this power regulation region, the blade pitch control plays a major role [16].

3 The Particle Swarm Optimization

The PSO simulates the behavior of social species, such as bird flocking. Consider the following scenario. Let us suppose that a group of birds are randomly searching for food in an area [17]-[20]. There is only one piece of food in that area being searched. All the birds do not know where the food is, but they know how far the food is in each iteration. So what is the best strategy to find the food? The effective one is to follow the bird which is nearest to the food.

PSO learned from this scenario and used it to solve the optimization problems. In PSO, each single solution is a “bird” in the search space.

Here it is called as a “particle”. All the particles have fitness values, which are evaluated by the fitness function to be optimized and have velocities which direct the flight of the particles. The particles are “flown” through the problem space by following the current optimum particles.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating gene- rations. In every iteration, each particle is updated by fol- lowing the two “best” values. The first one is the best solution (fitness) it has achieved so far (the fitness value is stored). This value is called as the p-best. Another “best” value is tracked by the particle swarm optimizer is the best value, obtained so far by any other particle in the population.

This best value is the global best and called as the g-best. When a particle takes part of the population and its topological neighbors, the best value is the local best and is called the i-best. After finding the two best values, the particle updates its velocity and positions with following Eq. (4) and (5) [9].

$$V_i(t+1)=wV_i(t)+c_1 r_1(P_{pbest}(t)-P_i(t)) +c_2 r_2(P_{gbest}(t)-P_i(t)) \quad (4)$$

$$V_i(t+1)=wV_i(t)+V_i(t+1) \quad (5)$$

The vector $P_i(t)=[p_{i1}, p_{i2} \dots p_{in}]^T$ stands for the position of the ith particle;

$V_i(t)=[v_{i1}, v_{i2} \dots v_{in}]^T$ stands for the velocity of the ith particle;

P_{pbest} is the best position that the ith particle has achieved so far; and P_{gbest} is the best position of current generation.

w is the inertia weight, small value benefits for local convergence and the large value benefits for global convergence. In general, the value of w is between 0.4 and 0.9.

c1, and c2 are called cognitive learning rate and social learning rate, respectively; their typical values are equal to 2, the pseudocode of PSO is shown in Fig.6.

If $v_i(t+1)>v_{max}$.
  Then $v_i(t+1)=v_{max}$.
Else *If* $v_i(t+1)<-v_{max}$.
  Then $v_i(t+1)=-v_{max}$.

If $p_{id}(t+1)>p_{max}$.
  Then $p_{id}(t+1)=p_{max}$.
Else *If* $p_{id}(t+1)<p_{min}$.
  Then $p_{id}(t+1)=p_{min}$.

Fig.6. The pseudocode of PSO.

where p_{max} and p_{min} are the maximum and minimal radii of variables, respectively; v_{max} is the maximum velocity of particles.

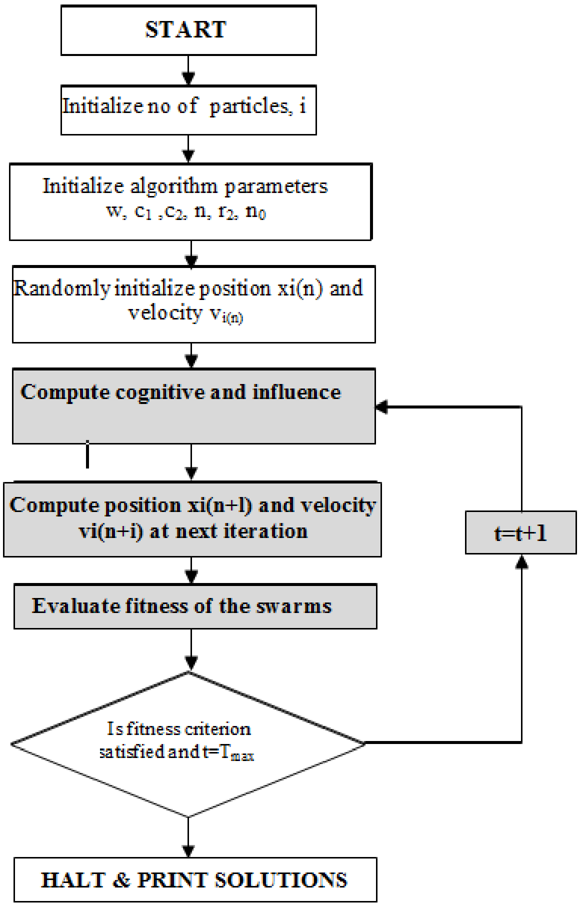

Fig .7. The PSO flowchart.

5 Simulation Results

In this section in order to evaluate the performance of the PSO controller.

The simulation model developed using MATLAB-Simulink and the results obtained are presented and discussed.

The curves Fig. 3 show the variation of Cp with λ tip speed ratio for a fixed pitch angle of β in β0. As the pitch angle is away from β0, the value of Cp becomes. smaller. Therefore, Cp has the maximum with the condition of λ0 and β0 by proposed PSO control strategy. For a wind turbine to extract the maximum energy from the wind, the wind turbine should be operated with the CpMAX condition, Fig 8 shows the overall control strategy.

That is, the wind turbine should be controlled to maintain the fixed tip speed ratio of λ in λ0 with the fixed pitch of β0 =βPSO in spite of varying wind speed. Referring to Eq. there ought to be a proportional relationship between the wind speed v and the rotor speed Ωr to keep the tip speed ratio at constant value of λ0. The wind turbine simulation based on the PSO flowchart is shown in Figs 9.

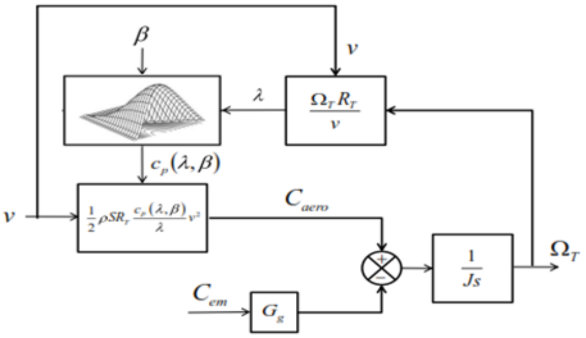

Fig .8. The Overall Control Strategy PSO.

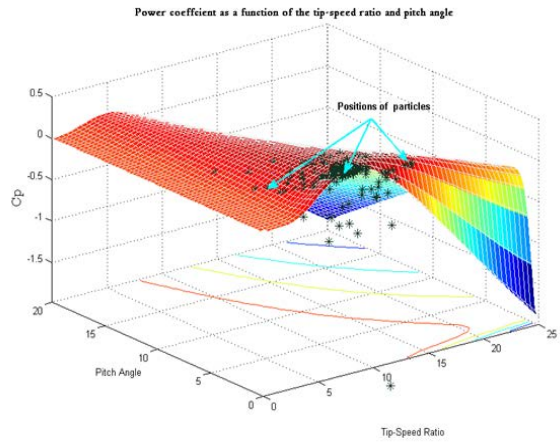

Fig .9-a. The evolution the PSO Controller for the pitch angle of wind turbine t=0**.**

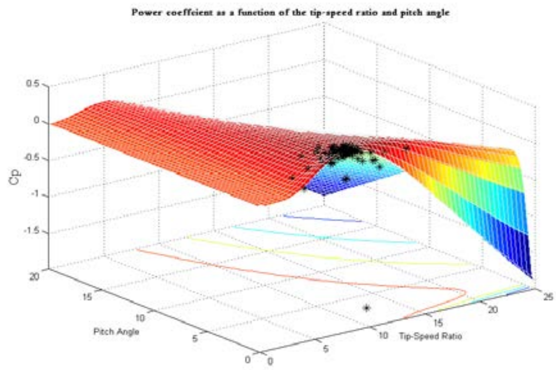

Fig .9-b. The evolution the PSO controller for the pitch angle of wind turbine t_i.

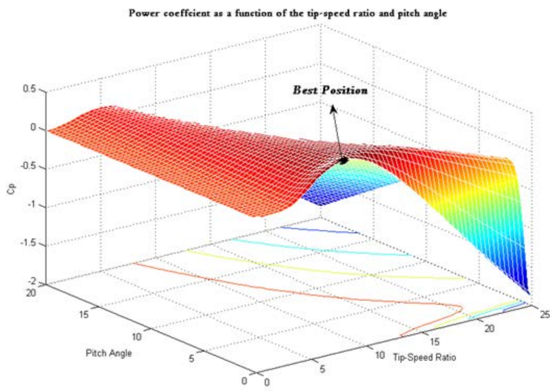

Fig .9-c. The evolution the PSO controller for the pitch angle of wind turbine t=$T_{MAX.}$

In PSO Controllers, variable wind speed data given in Fig.10–a is applied to test the system. Wind speeds varied considerably in short periods of time between t=0s and t= 50s. The proposed optimization strategies are examined in figs.10, The values of the PSO parameters obtained are shown in table 1.

Table .1 Parameters of PSO.

Parameters	Values
Swarm size	20
Max iteration	100
Inertia weight factor (w)	0.73

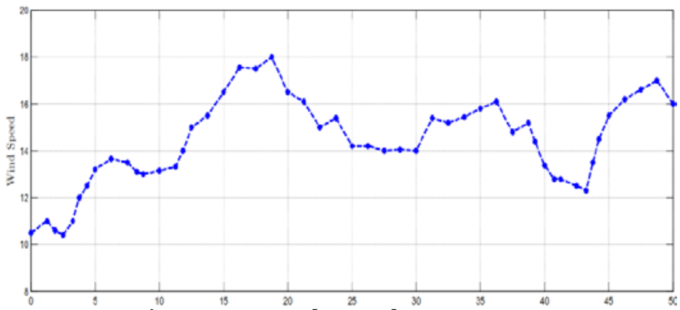

Fig .10-a. Wind Speed Variations.

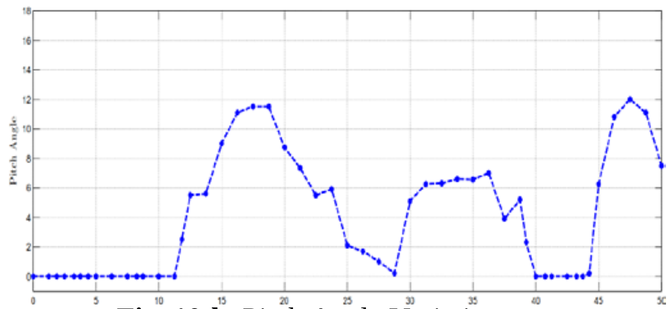

Fig .10-b. Pitch Angle Variations.

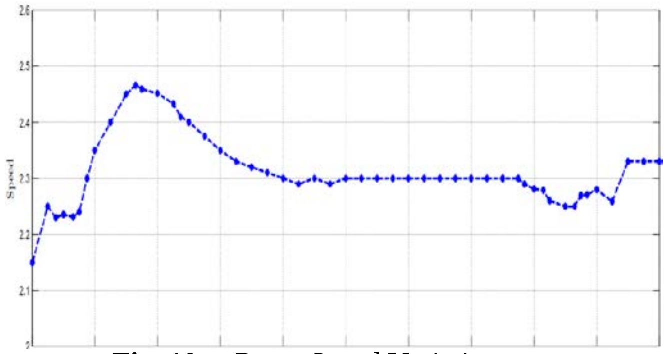

Fig .10-c. Rotor Speed Variations.

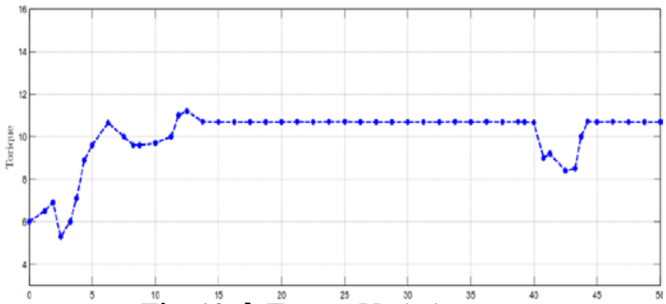

Fig .10-d. Torque Variations.

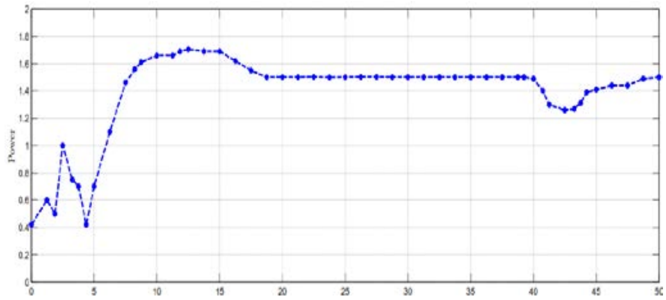

Fig .10-e. Power Variations.

Power generation is below the rated power due to the wind speed being low <13m/s, between t=0s and t = 12s; and between t = 40s and t = 44s. The wind is changed from 14 m/s to 19 m/s, As can be seen from Figs 10 , the time responses for the speed and torque

In the study, pitch angle intelligent controllers are used to make the braking of the turbine blades in the wind speeds most >13m/s. When the wind speed increases over the nominal speed, the field controller prevents overcharging of the turbine, and does not allow the production of a superior power than the rated power of the system.

The angle of inclination of the blade is increased so that of turbine blades are braked and slowed down as can be seen in Fig. 10-b. The pitch angles of the performances were modified according controller outputs PSO trained.

The intelligent controller is proposed to blade pitch position control above the rated wind speed. Actually, the controller gave better results. Simulated wind turbine parameters are obtained from a real turbine and generating system. Hence, proposed controllers can be easily adapted to real time applications.

4 Conclusion

The proposed optimization strategies are examined, the wind turbine is a complicated non-linear process involving multi parameters, multi inputs and multi outputs. In this research, the optimization by particle swarm optimization gave better results in terms of accuracy as well as in convergence to the optimal solution. The evolution algorithm of PSO is applied to obtain for wind turbine is operated so as to extract the maximum energy from the wind. The validity of the model and the optimization technique is validated using a case study on a wind turbine model. The simulation results have shown the superiority of proposed method in comparison with the commonly used methods in capturing maximum power.

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