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An Algorithmic Approach for Maximum Power Point Tracking of Wind Turbine using Particle Swarm Optimization

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ABSTRACT: Due to the nature of unpredicted wind speed, determining the optimal speed of wind turbine generator to extract the maximum available wind power at any wind speed is essential. By controlling the pitch angle of the wind turbine blades we can control the rotational speed and the output power. To get the maximum output power under lower wind speed and to maintain the stable rated output power under higher wind speed, the proper method must be used. In this paper, particle swarm optimization (PSO)-based maximum power point tracking (MPPT) algorithm is used to trace the maximum power when wind speed is lower than the rated speed and to get the proper pitch angle to limit the output power when the wind speed is greater than the rated speed. The simulation results performed on MATLAB/Simulink show the variations of the wind turbine generator output power, rotor speed, torque, pitch angle of wind turbine blades and wind velocities at those instants.

KEYWORDS: Particle Swarm Optimization (PSO); Maximum Power Point Tracking (MPPT); Hill-climbing search (HCS)

I. INTRODUCTION

Wind energy systems have gained tremendous attention over the past decade as one of the most promising renewable energy sources due to the probable depletion, high costs, and negative environmental impacts of conventional energy sources. Wind energy is a pollution-free and inexhaustible source. Therefore, a wind energy generation system could be one of the potential sources of alternative energy for the future [1], [2].

Besides being dependent on the wind speed, the amount of mechanical energy that can be extracted from the wind is governed by the ratio of the rotational speed to wind speed. There is a specific optimal ratio for each wind turbine, which is called the optimal tip speed ratio (TSR) or at which the extracted power is maximum. As the wind speed is instantaneously varying, it is essential for the rotational speed to be variable to maintain the equality of the TSR to the desirable one at all times [2]. TSR calculation requires the measured value of wind speed and turbine speed data. Wind speed measurement increases the system cost and also leads to practical difficulties. Optimal values of TSR differ from one system to another.

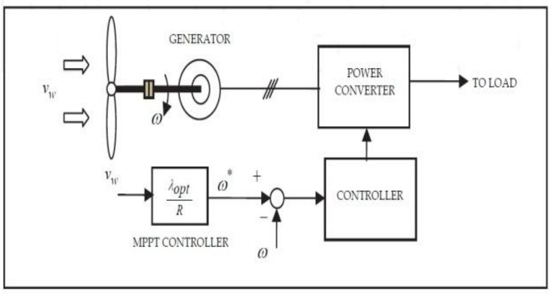

Fig. 1 TSR control scheme

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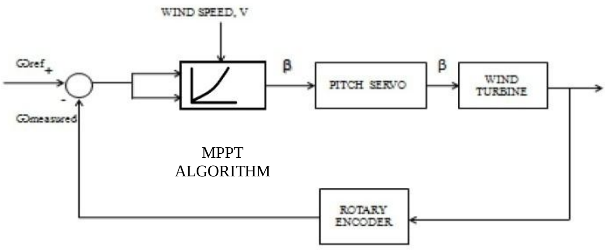

Fig. 2 Pitch angle control scheme

Wind turbine consists of three blades, a servomotor, a controller, rotor rotation sensor, a generator, and some mechanical components. A Servomotor is used to control the pitch angle of the blade in case of pitch control scheme. A rotary encoder is used to measure rotational speed of wind turbine rotor. Fig. 2 shows a diagram block of pitch angle control of wind turbine. The pitch angle of the blade is controlled to maximize the rotational speed of wind [10].

In order to determine the optimal operating point of the wind turbine, including a MPPT algorithm to the system is essential. Much has been written on the topic of MPPT algorithms, especially for wind energy systems. Among the available MPPT algorithms, hill-climbing search (HCS) method is widely used in wind energy systems to determine the optimal operating point that will maximize the extracted energy.

In recent years, a swarm intelligence-based algorithm, a particle swarm optimization (PSO), has been used across a wide range of applications to locate the global optimal solutions. It is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Compared with HCS, PSO increases the efficiency of the renewable energy conversion system, where it provides an adaptive step-size that may approach zero at the maximum point, so that it does not produce the oscillations around the peak point [2].

In this work, the PSO-based MPPT along with pitch control scheme is also used to control the output power of the wind turbine generator in a way that guarantees extracting the maximum available power from the wind. The remainder of the paper is organized as follows: section II describes the wind turbine aerodynamics; III describes the Hill climbing search technique applied on wind turbine; section IV, PSO-based MPPT algorithm is explained and applied to the wind turbine; section V experimental results are showed with the simulation results in MATLAB are presented and discussed and finally, a conclusion is drawn.

II. WIND TURBINE AERODYNAMICS

The energy conversion in a wind turbine can be described by the nonlinear equations [3], [4]:

$$\text{Power} = 1/2\ \rho C p A v^3 \qquad (1)$$

where ρ is the air density(kg/m^3), Cp is the coefficient of power, A (m^2) is area covered by turbine blades (m^2)and v (m/sec) is the velocity of available wind.

The power captured by the wind turbine depends highly on Cp for a given wind speed and the relationship of Cp with λ represents output characteristics of the wind turbine:

$$Cp = 0.5176\left(\frac{116}{\lambda i} - 0.4\beta - 5\right)e^{\left(-\frac{21}{\lambda i}\right)} + 0.0068 * \lambda \qquad (2)$$

where λ is tip speed ratio, a variable expressing the linear speeds of blade tip to the rotational speed of wind turbine, can be expressed by the following equation:

$$\lambda = \omega R / v \qquad (3)$$

$$1/\lambda i = 1/(\lambda + 0.08\beta) - 0.035/(\beta^3 + 1) \qquad (4)$$

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By using (2), the typical Cp versus λ curve is shown in fig. 3. As aforementioned, there is an optimum value of TSR that leads to maximum power coefficient. The maximum theoritical value of Cp is approximately 0.59 [9], but in this work we found it between 0.4 to 0.45 which corresponds to lamda_opt 10.

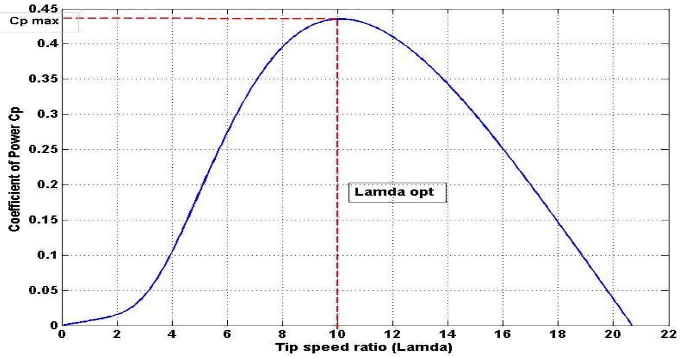

Fig. 3 Coefficient of power as a function of TSR

If the TSR is maintained constantly at its optimal value, this ensures that the energy extracted is in its maximum operating point too, as shown in fig. 4.

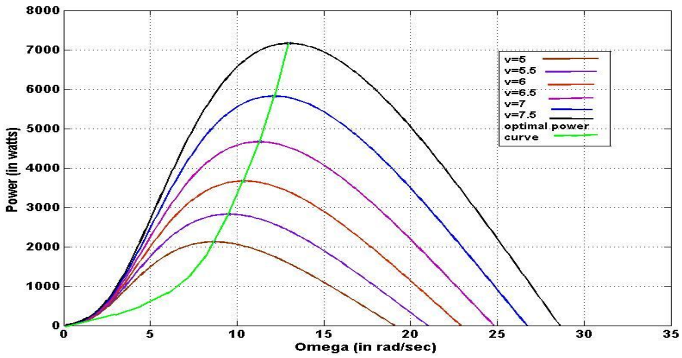

Fig. 4 Characteristics of turbine power as a function of the rotor speed for different wind speeds speeds

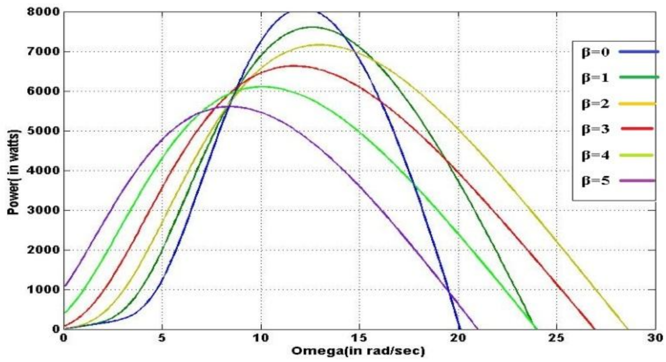

Fig.5 Characteristics of turbine power as a function of the rotor speed for different pitch angles

Fig.5 shows how power of wind turbine varies with ω for different β at the rated wind speed which is assumed to be 7.5m/sec to produce rated power 7.5kW. Maximum power is reached at β=0 but as β increases power decreases. This is useful to prevent mechanical overloading of the wind turbine when wind speed exceeds rated wind speed.

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The torque produced by wind turbine can be described the equation [5]:

$$\text{Torque} = \frac{1}{2}\rho\pi v^2 R^3 C_T \qquad (5)$$

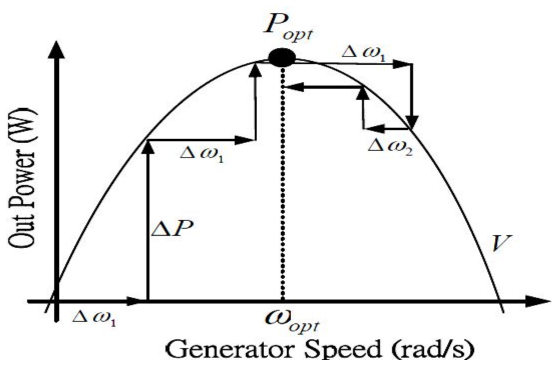
where, C_T is the torque coefficient, which is defined by following equation :

$$C_T = Cp/\lambda \qquad (6)$$

III. HILL CLIMBING SEARCH (HCS)

The HCS control algorithm continuously searches for the peak power of the wind turbine generator. The tracking algorithm, depending upon the location of the operating point and relation between the changes in power and speed, computes the desired optimum signal in order to drive the system to the point of maximum power [2].

This method is based on perturbing a control variable in small step-size and observing the resulting changes in the target function until the slope becomes zero as shown in fig.6. Since it does not require prior knowledge of the wind turbine generator characteristic curve, HCS method is independent, simple and flexible. However, it fails to reach the maximum power points under rapid wind variations if used for large and medium inertia wind turbines.



Additionally, choosing an appropriate step-size in MPPT algorithm is not an easy task; though larger step-size means a faster response but it creates more oscillations around the peak point which reduces the system efficiency; a smaller step-size improves efficiency yet reduces the convergence speed [2],[6] .

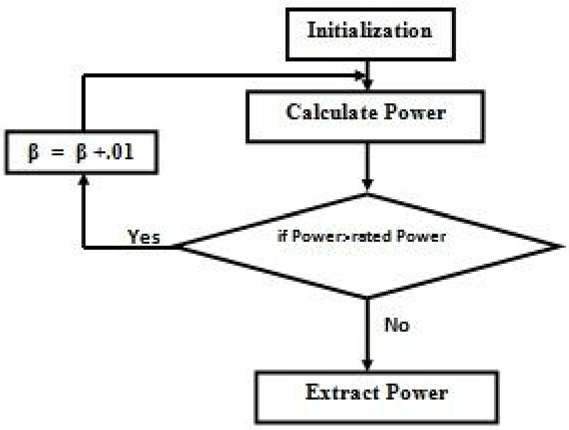


Fig. 7 Flowchart of HCS

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IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is an evolutionary soft computation optimization technique (a search method based on a natural system) developed by Kennedy and Eberhart [7]. The system initially has a population of random selective solutions. Each potential solution is called a particle. Each particle is given a random velocity and is flown through the problem space. The particles have memory and each particle keeps track of its previous best position (called the Pbest) and its corresponding fitness. There exist a number of Pbest for the respective particles in the swarm and the particle with greatest fitness is called the global best (Gbest) of the swarm. The basic concept of the PSO technique lies in accelerating each particle towards its Pbest and Gbest locations, with a random weighted acceleration at each time step.

The main steps in the particle swarm optimization algorithm and selection process are described as follows [7]:
(a) Initialize a population of particles with random positions and velocities in d dimensions of the problem space and fly them.
(b) Evaluate the fitness of each particle in the swarm.
(c) For every iteration, compare each particle's fitness with its previous best fitness (Pbest) obtained. If the current value is better than Pbest, then set Pbest equal to the current value and the Pbest location equal to the current location in the d-dimensional space.
(d) Compare Pbest of particles with each other and update the swarm global best location with the greatest fitness (Gbest).
(e) Change the velocity and position of the particle according to equations (7) and (8) respectively:

$$v_{id}=\omega\times v_{id} + c1\times rand1(p_{id}-x_{id})+c2\times rand2(p_{gd}-x_{id}) \quad (7)$$

$$x_{id}=x_{id}+v_{id} \quad (8)$$

where, v_{id} and x_{id} represent the velocity and position of the i^{th} particle with d dimensions, respectively. rand1 and rand2 are two uniform random functions, and ω is the inertia weight, which is chosen beforehand.
(f) Repeat steps (b) to (e) until convergence is reached.

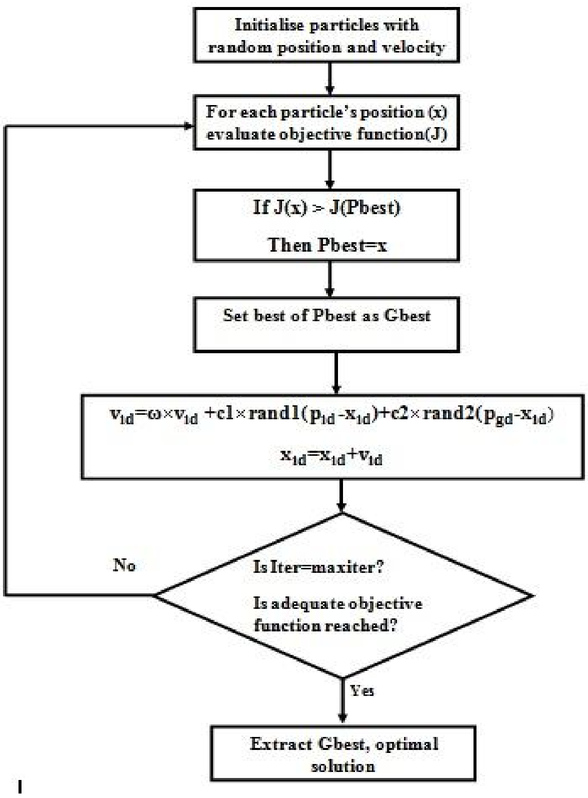

Fig.8 Flowchart of PSO

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V. EXPERIMENTAL RESULTS AND DISCUSSION

To keep tracking of optimal value of output power, control techniques must adapt the generator angular speed ω according to the available wind speed. In this sense pitch controlling of wind turbine blades is adopted to present the incidence of the generator angular speed. To present these, the following parameters are considered:

Table 1: Wind turbine Parameters

SL. No	Parameters	Values
1	Radius of blade (m)	5
2	Air density ρ (Kg/m^3)	1.08
3	Pitch angle β (degree)	0
4	Rated Power(watt)	7500

Table 2: PSO parameters

SL NO	Parameters	Values
1	c1	2
2	c2	4-c1
3	no of particle	20
4	maxiteration	20

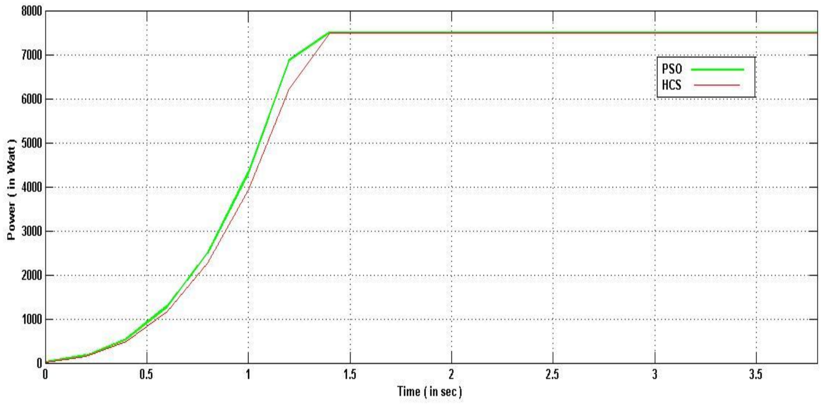

Fig.9 Curve of the generated power vs Time with PSO-based MPPT & HCS MPPT algorithm in Matlab

In the fig 9, it shows that both the methods are based on search optimization. Neverthless PSO based algorithm is an adaptive method whereas the conventional HCS method is a fixed step method. In fig. 9 it clearly shows that the compitional time of PSO is faster than the conventional HCS method throughout the way of tracking of maximum power which is restricted to a limit of 7.5kW.

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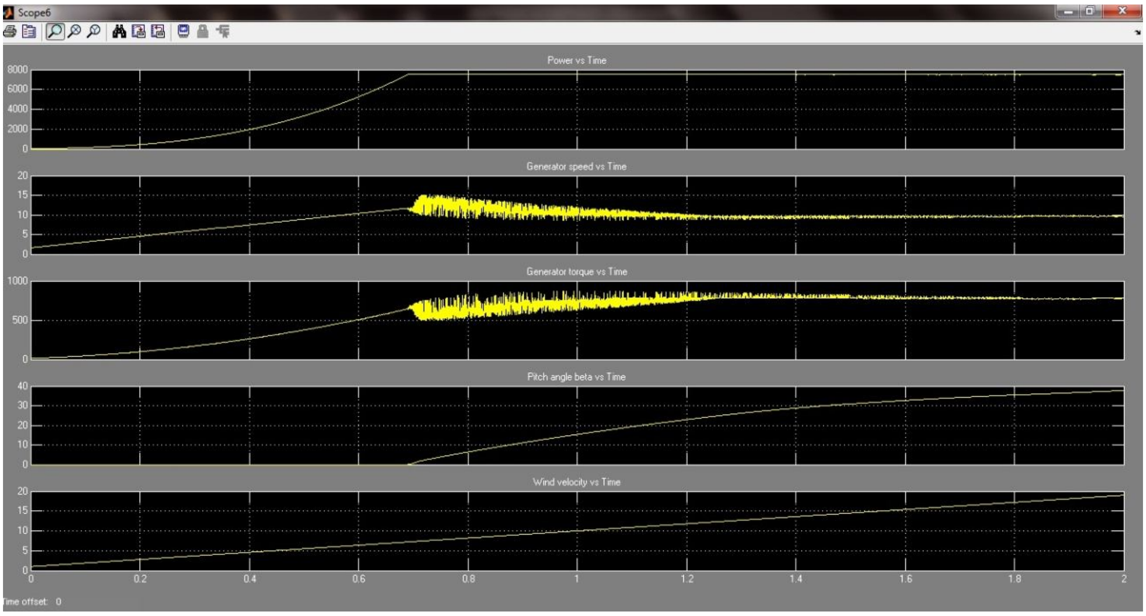

Fig.10 Matlab Simulation using HCS algorithm

In the fig 10, it shows the simulation of throughput of wind turbine generator's output power, angular speed, torque, pitch angle, available wind speed Vs Time using HCS algorithm. In order to maintain maximum power point, some fluctuations in generator speed and torque is detected.

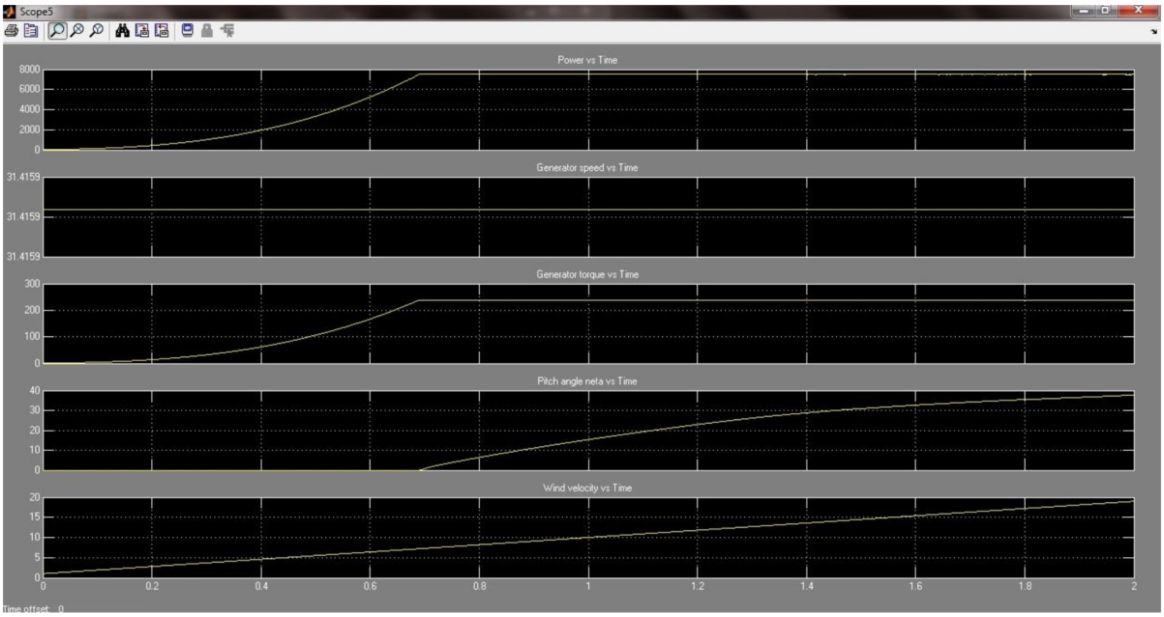

Fig.11 Matlab Simulation using PSO algorithm

In fig 11, it shows the simulation of throughput of wind turbine generator's output power, angular speed, torque, pitch angle, available wind speed Vs Time using PSO algorithm. This method shows a smoother control than conventional HCS method over generator speed and torque.

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VI. CONCLUSION

This paper discussed the some of the available MPPT algorithms for wind energy systems. In addition, an analysis is done by simulation and comparison of two selected methods in terms of optimal control and speed of response. Simulation results demonstrated the superiority of the PSO based method in terms of simplicity and accuracy. This method obtained the maximum value of output power and maintained it at its maximum even with changes in wind speed. Nevertheless, its dependency on wind turbine characteristics made it inflexible. On the other hand, the HCS method is flexible and simple in implementation, but is less efficient and can be problematic in determining the optimum step-size. Determining the adaptive step-size algorithms and combining two or more of the available methods will improve the performance and overcome some of the obstacles found in the current methods.

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BIOGRAPHY

Kishore Kumar Das received BE degree in Electrical Engineering from Gauhati University, Assam, India in 2012. He is currently a PG student at Jorhat Engineering College, Assam, India, under specialization in Instrumentation and Control. His research interest include optimization of wind power generation using evolutionary algorithms.

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