A Novel Maximum Power Point Tracking System for Wind-Energy-Conversion System using Particle Swarm Optimization

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***Abstract*—In this paper, a novel maximum power point tracking (MPPT) controller using particle swarm optimization is proposed. Particle Swarm Optimization algorithm is used to optimize the value of power coefficient. By this method the total wind energy captured increases and therefore the overall efficiency. The design details on how to realize the improved MPPT method and the principle of choosing a proper system dynamics are both pointed out after analyzing the system dynamics. The system features higher reliability, lower complexity and cost, and less mechanical stress of the WG. The proposed algorithm shows enhanced stability and fast tracking capability under both high and low rate of change wind speed conditions. Experimental results of the proposed system indicate near optimal WG output power. The simulation results show that the proposed algorithm can achieve maximum power capture of wind power generation system, improve the dynamic response and efficiency.**

Keywords - Maximum Power Point Tracking (MPPT), MATLAB/Simulink, Particle Swarm Optimization, Tip speed Ratio, Wind generation system (WGS)

I. INTRODUCTION

Wind turbine have been widely used both in autonomous systems for power supplying remote loads and in grid-connected applications. The wind power generation system (WPGS) is one of the most effective power generation systems that convert the wind energy into electricity. In order to make the WPGS more efficient, a maximum power point tracking (MPPT) control strategy is necessary for maximizing the output power. Another important problem, which needs to be paid attention to, is how fast the control system dynamics should be designed to track the wind variations, which is relative to the principle of choosing a proper cut-off frequency of the control system.

Basically, the MPPT technique can roughly be classified into the following five strategies namely, the tip speed ratio (TSR) control, the optimal torque (OT) control, the power mapping control, the Hill Climbing search control, Power signal feedback control. For the TSR control, an anemometer is required to achieve maximum output control. As to the OT control strategy, the well-known OT, namely, $k\omega 2m$ is adopted as the command signal for controlling the generator torque to maximize the output power. Practically, the wind velocity is changing all the time. The steady-state wind velocity is in fact very unusual. Hence, as the wind speed is either increased or decreased, if the rotor speed of the generator cannot track the variation of the wind speed closely, then the extracted wind energy will be reduced greatly. In fact, to the authors' best knowledge; most existing papers consider the tracking along the maximum power trajectory of $k\omega 2m$. The oscillating control around the optimal point will certainly sacrifice the efficiency of the WPGS but with the proposed WPGS, these oscillations can be overcome and maximum power can be achieved using the proposed algorithm.

This paper is organized as follows. First, the characteristics of wind power generation system are discussed in section II. Section III outlines the concept of maximum power extraction from wind. In Section IV, the proposed system with MPPT method is presented. Section V shows the MATLAB/Simulink model of wind energy system. Some experimental results are then given in Section VI, to verify and validate the proposed system. Finally, Conclusions are given in Section VII.

II. CHARACTERISTICS OF WIND POWER

The power captured by the blades of wind turbine generators Pm is given below

$$P_m = \frac{1}{2}\pi\rho C_p(\lambda,\beta)R^2V^3 \quad (1)$$

where ρ is the air density (typically 1.12 kg/m3), β is the pitch angle (in degrees), $Cp(\lambda, \beta)$ is the wind-turbine power coefficient, R is the blade radius (in meters), and V is the wind speed (in m/s). Tip-Speed ratio λ, is given by

$$\lambda = \frac{\Omega R}{V} \quad (2)$$

where Ω is the WG rotor speed of rotation (rad/s)

The total power generated by wind power generator is given by

$$P=\eta_G P_m \tag{3}$$

The maximum power from wind can be obtained when a wind turbine is operated at its optimum power coefficient (Cp)opt . This can be achieved by operating the turbine at a desired speed to obtain the optimal tip-speed ratio λ_{opt}

The typical torque – speed characteristics and turbine power characteristics along with its MPPT curve at various wind speeds is shown in Fig. 1 and Fig. 2.

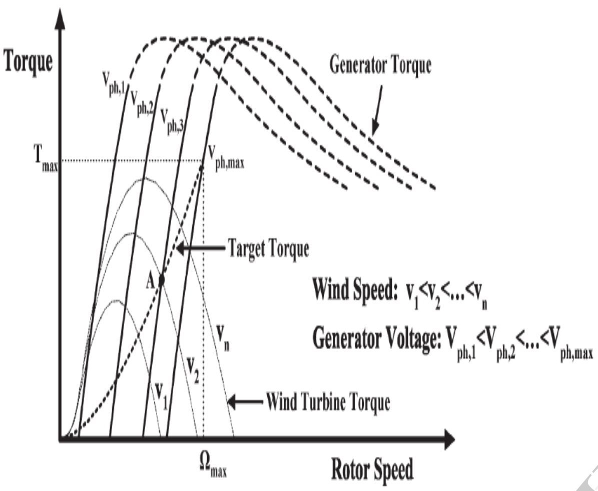

Fig. 1. Torque – Speed characteristics of the wind turbine and generator.

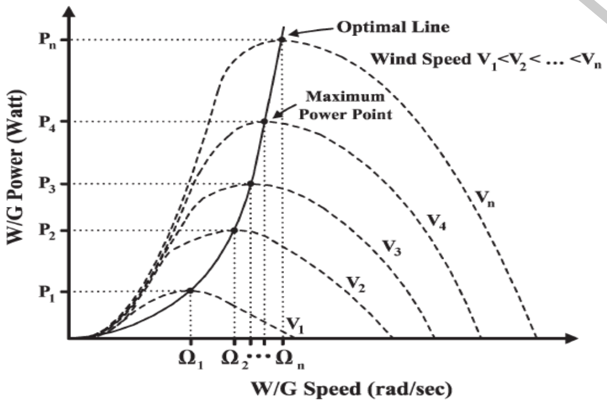

Fig. 2. Wind Generator power curves at various wind speeds.

III. EXISTING MPPT SCHEMES

MPPT algorithms are necessary in renewable energy sources to gain maximum power and efficiency. There is a large number of algorithms that are able to track MPPs. Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, hardware needed for the implementation.

The maximum extractable power depends not only on the strength of the source (i.e. wind) but also on the operating point of the WECS. The concept of MPPT is to optimize the generator speed relative to the wind velocity intercepted by the wind turbine such that the power is maximized. Variable-speed wind turbines are designed to operate at an optimal rotation speed as a function of the wind speed. The power electronic converter may control the turbine rotation speed to get the maximum possible power by means of a MPPT strategy. Following methods are used in WECS for MPPT

A. *Tip Speed Ratio Control (TSR) Control*

The TSR control method regulates the rotational speed of the generator in order to maintain the TSR to an optimum value at which power extracted is maximum. This method requires both the wind speed and the turbine speed to be measured or estimated in addition to requiring the knowledge of optimum TSR of the turbine in order for the system to be able extract maximum possible power.

B. *Power Signal Feedback (PSF) Control*

In PSF control, it is required to have the knowledge of the wind turbines maximum power curve, and track this curve through its control mechanisms. The maximum power curves need to be obtained via simulations or off-line experiment on individual wind turbines. In this method, reference power is generated either using a recorded maximum power curve or using the mechanical power equation of the wind turbine where wind speed or the rotor speed is used as the input.

C. *Hill Climbing Search (HCS) Control*

The HCS control algorithm continuously searches for the peak power of the wind turbine. It can overcome some of the common problems normally associated with the other two methods. 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.

IV. PROPOSED MPP TECHNIQUE

Wind power coefficient C_P is a nonlinear function of tip speed ratio λ and blade pitch angle β, and is given by

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_1} - C_3\beta - C_4\right)e^{\frac{C_5}{\lambda_1}} + C_6\lambda \tag{4}$$

C1-C6 are determined by the characteristics of the wind turbine. There is an optimum tip speed ratio of wind turbine that make the value of wind power coefficient C_p maximum, this makes the wind turbines to capture maximum wind power. Therefore, the tip speed ratio for the best value has been the key to obtaining the maximum wind power, thereby enabling the value of wind power coefficient C_p maximum. The main objective is to optimize this wind power coefficient to a maximum value. Equation (4) is taken as the objective function and tip speed ratio is defined as the variable and this value is optimized using particle swarm optimization technique. By this method C_p can maintain the maximum value even though wind speed greatly changes, so as to achieve the purpose of maximum power point tracking.

A. PSO Computational Procedure

The PSO algorithm works by simultaneously maintaining several candidate solutions in the search space. During each iteration of the algorithm, each candidate solution is evaluated by the objective function being optimized, determining the fitness of that solution. The PSO algorithm consists of three steps, which are repeated until some stopping condition is met,

1. Evaluate the fitness of each particle.
2. Update individual and global best fitness and positions.
3. Update velocity and position of each particle.

After every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. The fitness value is also stored. This value is called "pbest". Another "best" value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the population. This best value is a global best and called "gbest". After finding the two best values, the particle updates its velocity and positions.

The velocity of each particle in the swarm is updated using the following equation

$$v_i(t+1) = wv_i(t) + c_1 r_1 [\hat{x}_i(t) - x_i(t)] + c_2 r_2 [g(t) - x_i(t)] \quad (5)$$

Once the velocity for each particle is calculated, each particle's position is updated by applying the new velocity to the particle's previous position

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (6)$$

B. PSO Algorithm

The computational procedure of the proposed method is as follows

Step 1: Specify the lower and upper bounds of WTG-swept area, area of PV panels, number of batteries, and other predetermined parameters.

Step 2: Initialize the speed and position of each particle by randomly generating a particle population.

Step 3: Based on the method of pareto dominance position of each particle, D_i in the population is estimated.

Step 4: The non-dominated solutions estimated in the previous step is stored in the archives.

Step 5: Another archive is created for storing the memory details which contains information about initialization of each particle's personal best, pbest.

Step 6: Increase the iteration number by one.

Step 7: Evaluate the fitness values according the fitness function; in this paper, the fitness value is defined by cost function and can be calculated. According the fitness value, we will decide whether the solution is good or not. Update the personal-best position pbest and the gbest value based on the memory record.

Step 8: Update the member velocity 'v' of each individual using equation (5).

Step 9: Update the member position of each particle using equation (6).

Step 10: Archive that stores the non-dominated solutions should be updated based on the pareto optimality based selection condition.

Step 11: Pbest in the memory is updated based on the dominance of the current value of the individual. If pbest dominates over the current individual keep the memory same without any alteration else update the memory with new pbest value.

Step 12: If maximum value is reached go to next step else go to step 6.

Step 13: Stop.

This algorithm maximizes the C_p to extract the maximum available power from wind.

V. Wind Energy System Model

The Fig. 3. shows the MATLAB/Simulink model of a Permanent magnet synchronous generator based wind energy system. It is modelled using equation (1) to (4).

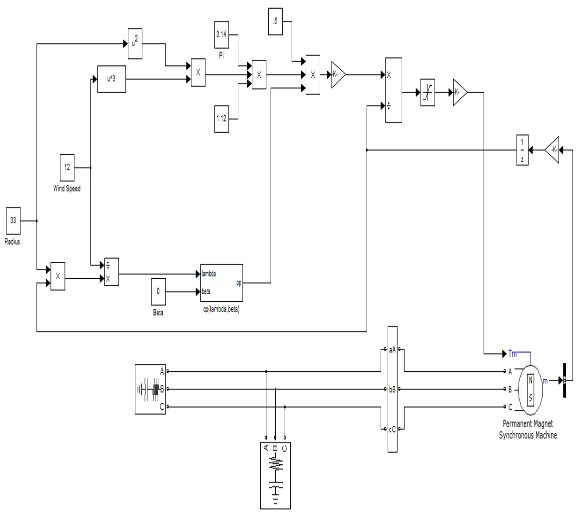

Fig. 3. Simulation module of wind power generation system

VI. SIMULATION RESULT

The simulation was performed for various wind speeds 9m/s, 10m/s, 11m/s and 12m/s. The value of C_p for all wind speeds is shown in table 1. From the simulation results it is observed that the PSO algorithm rapidly tracks the C_p value for which the output power is maximum. The simulation waveform of voltage and current for 0.2 sec with a wind speed of 12m/s is shown in the Fig. 4. and Fig. 5. From the results obtained in the simulation, it is obvious that the proposed method tracks the maximum power point by optimizing C_p value. It is also known that there is a small percentage of error in C_p values calculated but by increasing the time duration of simulation it is observed that the error value has significantly reduced.

Table I. Wind Power Coefficient Data ($C_{p)}$

S.No	Wind Speed(m/s)	Wind Power Coefficient (C_p)	Optimal Wind Power Coefficient	Error %
1	9	0.471	0.48	1.87%
2	10	0.463	0.48	3.54%
3	11	0.479	0.48	0.21%
4	12	0.473	0.48	1.46%

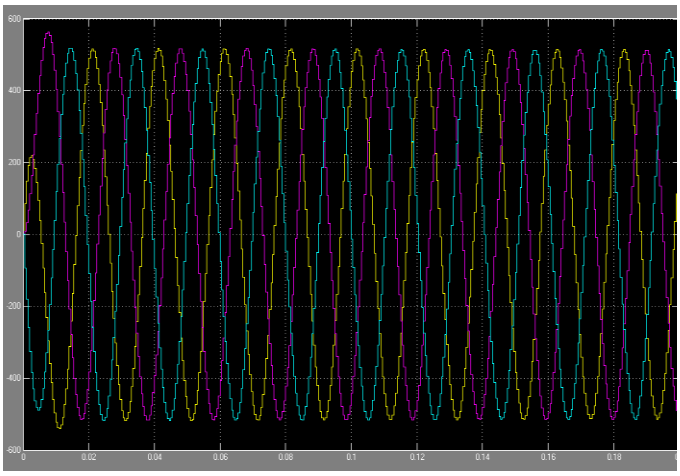

Fig. 4. Output voltage waveform for V_w=12 m/s, Cp=0.473, T=0.2 sec

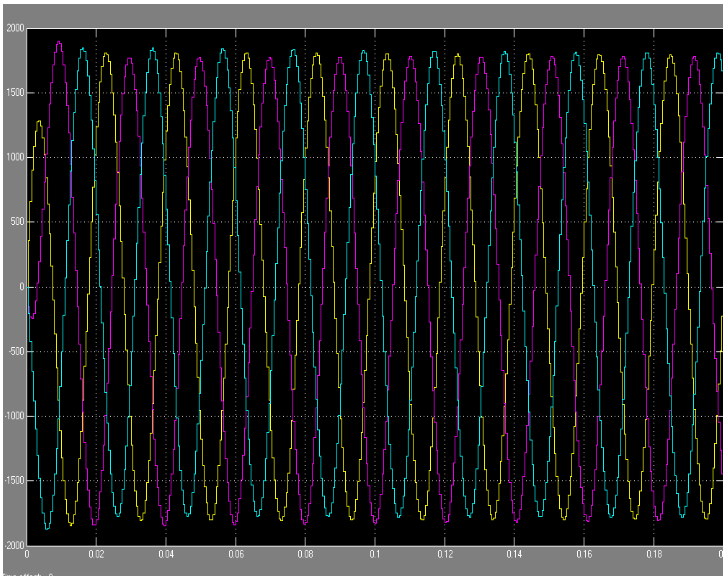

Fig. 5. Output current waveform for V_w=12 m/s, Cp=0.473, T=0.2 sec

VII. CONCLUSION

The total installed and individual capacity of wind turbines have both been steadily increasing in the last four decades – mainly driven by the needs for more renewable energies and also constantly to lower the cost of energy. The wind power nowadays play much more important role in the energy supply system. In this paper, a better control algorithm for tracking Maximum Power is developed, and is tested. The suggested methodology has considered both accuracy of obtained solutions and computational overhead of the WPG system. This paper has described techniques for estimating and optimizing the wind power coefficient of WPG system using particle swarm optimization. The proposed analysis allows the user to study the interaction among various operational factors and hence it offers a useful tool for the design and analysis of WPGS. Hence, with the help of this paper, it can become much easier for one to design an MPPT control strategy for a specific WECS. On the whole it is found that the total output energy can be increased significantly by using the proposed MPPT method.

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