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ORIGINAL PAPER

Comparative Study of Optimization Techniques for Renewable Energy System

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Abstract

There is a sudden fluctuations in wind speed and change of direction that affects the generator speed thus power generation of wind turbine system, so a controller like maximum power point tracking (MPPT) algorithm is essential in tracking the maximum power out of the available wind speed. MPPT algorithm can be classified into two categories such as with and without sensor as well as according to the algorithms used to find the maximum peak. A comparative analysis of different types of MPPT control methods on the basis of different speed responses and ability to obtain maximum power has been conducted. The literature based on the simulation results points out that the optimal torque control is a better MPPT control method for achieving the maximum power from wind turbine energy system against the most frequently used perturb and observe (P&O) method. The P&O method on the other hand is flexible and easy to implement but provide fluctuations about the maximum power point and is less efficient. The different types of MPPT techniques have been studied for wind turbine renewable energy system. The study points out that MPPT may also include of different dc–dc power converter and various control methods, and hybrid renewable energy system can be developed with multi-input energy systems.

1 Introduction

Non-conventional sources provide the electrical generation throughout the world. The wind turbine (WT) renewable energy system is the most significant and powerful resource which is safe, abundant and clean. Contrasting conventional fuels, the wind energy system is the sustainable original power source permanent available in fundamentally each and every nation to the world. It generates the energy security assistances in favour of avoiding fuel costs, economic, fuel price for long-term and supply risks that derive with confidence on introduces fuels and political dependency on countries [1]. It has main drawbacks of irregularity of wind. Since of this problem, different high-efficiency controller arrangement has been described in latest years [2–8]. The use of squirrel cage induction generator in the wind turbine system provides lower cost and robustness. Wind energy system has two ways of generating power, viz., constant and variable speed processing with dc–dc power converters. Variable speed wind turbine system is attractive, for achieving maximum power at all wind speeds. Though, it needs sensor of rotor speed for vector control determinations, which roots degradation of reliability, work of wiring complex, expansion and system cost.

The permanent magnet synchronous generator (PMSG) is an electrical generator which converts mechanical energy to electrical energy and preferred with power density, reliability, light weight, gearbox, high efficiency, and self-exited features [9–13]. The MPP achieved by controlling PMSG can be done using a varying load with power electronic interface circuit. This interfacing can be done using back to back converter or using diode rectifier of three phase connected with the dc–dc converter. Rectifier and dc–dc boost converter are reliable and less expensive according to Zhipeng et al. [13]. Using controlling the duty-cycle of dc–dc converter that the apparent load established using generator can be regulated, and therefore, its shaft speed and the output voltage can be adjusted also. The operation of the dc–dc power converter in discontinuous-conduction mode (DCM), and applying the power factor correction (PFC) method offers reduction of total harmonic distortion (THD) and increased the power factor (PF) of the WT system [14, 15].

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In the WT system, determination of the optimum power point using MPPT control method. MPPT algorithm has been developed especially used for wind turbine system by Kazmi et al. [16]. It reviewed many techniques of MPPT for WT and settled that the two control methods designated in Kazmi et al. [17] and Hui and Bakhshai [18] provide the best solution with self-tuning capability and adapting tracking. Some MPPT techniques for the WT system have been compared especially used for PMSG [19–22]. Researcher [23] have been categorized of available MPPT techniques into nine parts constructed on the measurement requirements and specified performance. The proposed MPPT based on fixed pitch angle and control approach can be used for maximum power at below and high wind speed [24]. The analysis of theoretical and experimental for stand-alone WT system with low cost used for rural and urban areas, developing MPPT technique by hill climb searching through perturb and observe [25]. Authors focused on PMSG based wind energy system using various MPPT control methods [26]. Lahfaoui et al. [27, 28] proposed experimental optimization based on perturb and observe MPPT method using dSPACE 1104. The fuzzy technique, novel fuzzy logic controller technique, optimized techniques and Newton's search algorithm are used in [29–35]. Reviewed of the upwind biased techniques used for compressible follow computation by Lyra and Morgan [36]. In this paper, the comparative analysis of MPPT techniques in wind generation system which is beneficial to the researcher to increase the efficiency of the wind energy system with dc–dc power electronics converters. The block diagram of WT system with power electronics converters used for stand-alone and grid connected system is shown in Fig. 1.

This study has following sections: the mathematical modelling of wind generation system in Sect. 2, review of MPPT for WT system in Sect. 3, comparison analysis of MPPT methods in Sect. 4, the conclusion in Sect. 5 and research trends in Sect. 6 are discussed.

2 Mathematical Modelling of Wind Generation System

The WT converts the wind energy into kinetic energy i.e., an amount (m) of air mass, a velocity (V_w) for moving and the kinetic energy is:

$$E_K = \frac{1}{2} m v_w^2 \text{ [Nm]} \tag{1}$$

Consider the same mass (m) moving at a wind velocity (V_w) passing through an area (A), available mechanical power in the wind [37, 38]:

$$P_{wind} = \frac{1}{2} \rho A v_w^3 \text{ [W]} \tag{2}$$

The WT converts mechanical power which can be expressed as [39]:

$$P_{wind} = \frac{1}{2} \rho A\, C_P(\lambda, \beta)\, v_w^3 \text{ [W]} \tag{3}$$

where, air density is represented by (ρ =1.1839 kg/m^3 at 25 °C), the swept area by the rotor blades is (A), V_w represents the wind velocity, C_p represents the power coefficient, power coefficient of WT is maximum theoretical efficiency which is the ratio of attained maximum power from the wind to the entire power available [40]. The power coefficient (C_p) conversion, and thus the maximum power is extracted at a definite value of tip speed ratio, is called best tip speed ratio (λ_{opt}) as shown in Fig. 2.

$$C_P = \frac{P_{extract}}{P_{wind}} \tag{4}$$

C_p depends on tip-speed-ratio (TSR) which is represented by (λ) and pitch angle (β).

$$C_P(\lambda, \beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{\frac{21}{\lambda_i}} + 0.0068\lambda \tag{5}$$

$$\lambda_i = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{6}$$

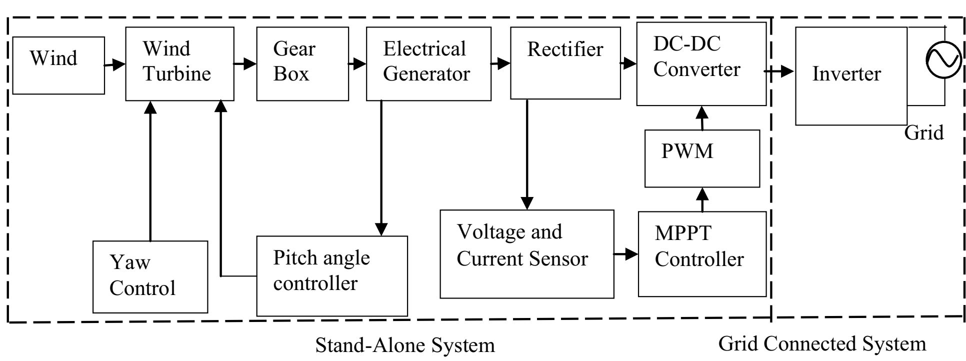

Fig. 1 Block diagram of WT renewable energy system using dc–dc converter and MPPT controller for stand-alone and/or grid connected

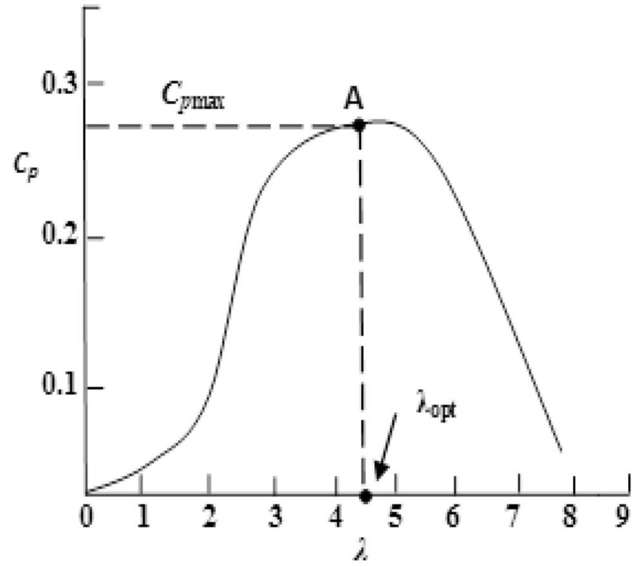

Fig. 2 Power coefficient Vs TSR

$$\lambda = \frac{\omega R}{v_w} \quad (7)$$

where, the rotor radius is represented by (R) and the rotor angular velocity represents (ω). It is possible that there is an inversely proportional between β and C_p; the torque can be expressed in [39].

$$T_m = \frac{P_{extract}}{\omega} = \frac{0.5\rho A\, C_p(\lambda,\beta)\, v_w^3}{\omega}[\text{Nm}] \quad (8)$$

3 Review of MPPT for WT System

In the WT, wind speed does not constant always all the time as the wind is irregular in nature. For particular wind speed here is a rotor speed which gives maximum power. In order to achieve maximum output power from the WT according to drive it at a rotor speed for a certain wind speed. Explanation of different MPPT techniques is given below.

3.1 Perturb and Observe MPPT Technique

Perturb and observe (P&O) MPPT technique is most useful technique because of easy for implementation and lower cost. The P&O MPPT techique has been performed to achieve maximum power at each instant.

Figure 3 shows the control action in favour of the MPPT method. The operating voltage is perturbed by each cycle of MPPT. Momentarily MPP is reached that it will fluctuate around the operating voltage ideally. For example, when the controller senses, the increase input power and decrease the voltage then it will decrease reference voltage to fetch it earlier to the MPP [41].

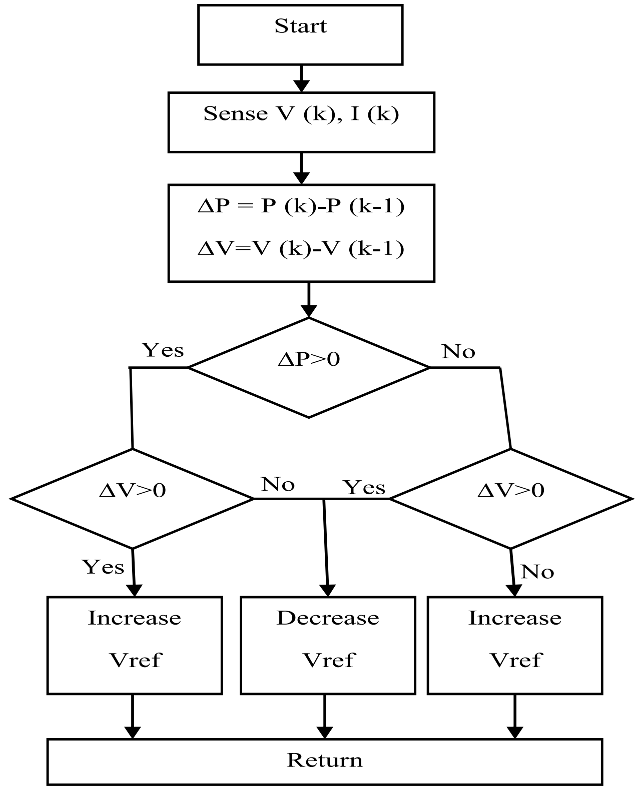

Fig. 3 Flow chart of the P&O MPPT method

3.2 Proposed MPPT Technique based on Incremental Conductance

The proposed algorithm by Rafael et al. considers the parameter between electrical and mechanical conformist systems, therefore, P approach to P_m, V approach to ω_m and I approach to τ_m. Analogously $dP_m/d\omega_m = 0$ that is the slope of mechanical power-speed at the MPP $d\tau_m/d\omega_m = -\tau_m/\omega_m$ for a specified wind velocity [42].

This algorithm based on incremental inductance [43] in PV system. Figure 4 shows the flow chart of proposed MPPT technique.

3.3 Proposed MPPT Technique

Figure 5 shows the proposed algorithm by authors Daili et al. which improve the output as compared to the previous P&O algorithm in WT. It has some steps for complete the process of the algorithm [44] in the flow chart, where K_{opt} is the optimal gain, α is the positive gain, it is defined carefully, as a large value of α consents a fast dynamic in tracing in favour of reference voltage although might outcome in

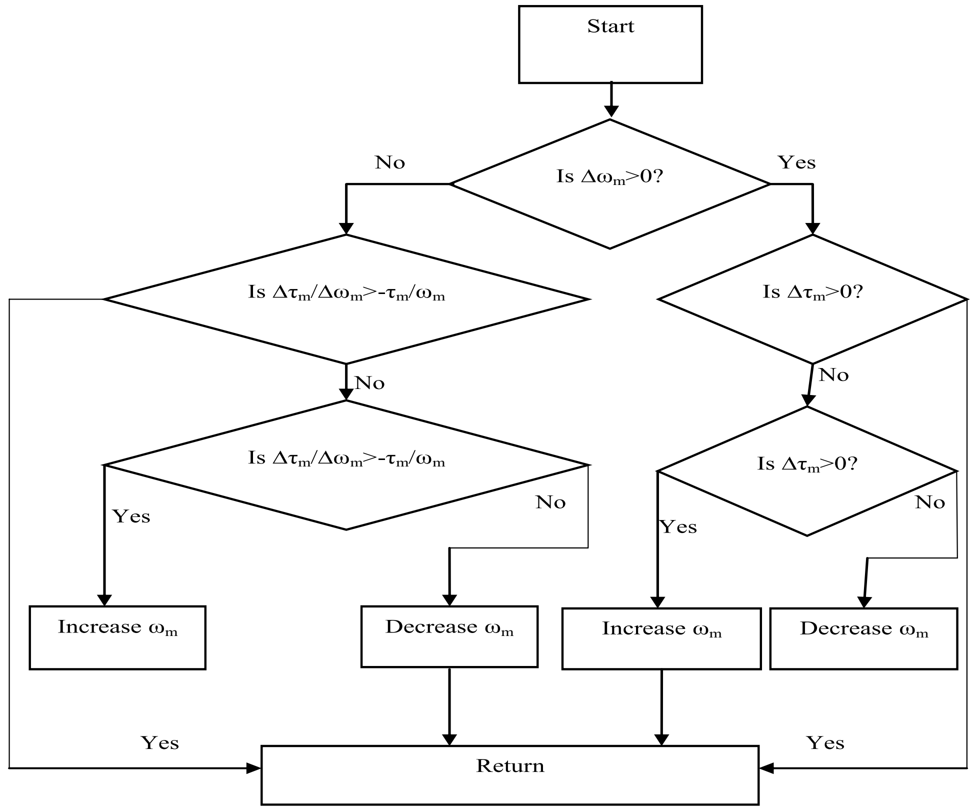

Fig. 4 Proposed MPPT technique

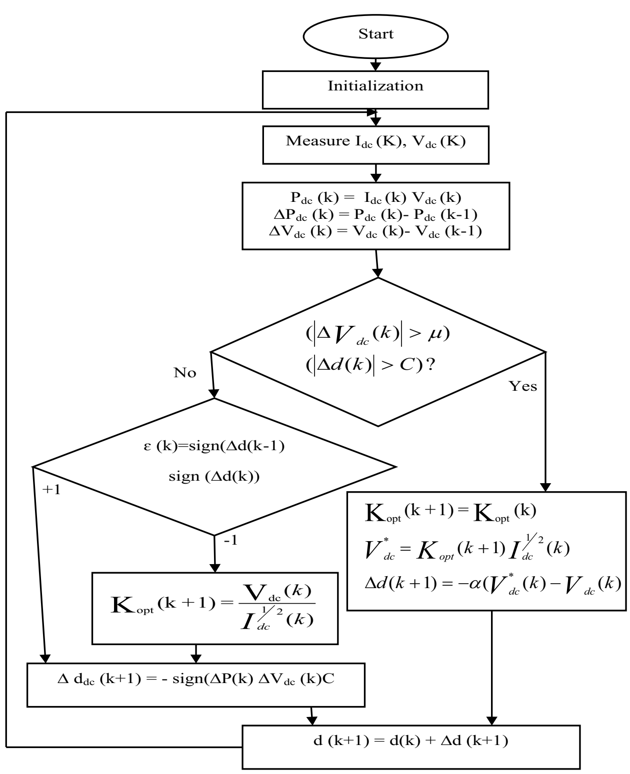

Fig. 5 Flowchart of proposed MPPT technique

fluctuations about reference voltage and μ is the rapid change in wind speed.

3.4 Recurrent Neural Network

The architecture of recurrent neural network (RNN) is shown in Fig. 6, which has three layers such as input, output and hidden layers. RNN MPPT algorithm proposed for the WT [45, 46], where ω_r^* is the reference to rotor speed, $\omega_r^{\wedge}$ represents the WT estimated rotor speed and *x, O, w, i, j, k* represents the input, output, weight, layers of input, hidden and output respectively.

3.5 Echo State Network

Echo state network (ESN) technique is the special kind of RNN. It has consisted of input, hidden and output layers as illustrated in Fig. 7. The hidden layer as the dynamic pool frequently comprehends sigmoid neurones while other two layers have linear neurones [47].

3.6 Radial Basic Function Network Based MPPT Technique

The radial basic function network (RBFN) is the three layers neural network as shown in Fig. 8. It is implemented as a described RBFN control method [48]. The RBFN based

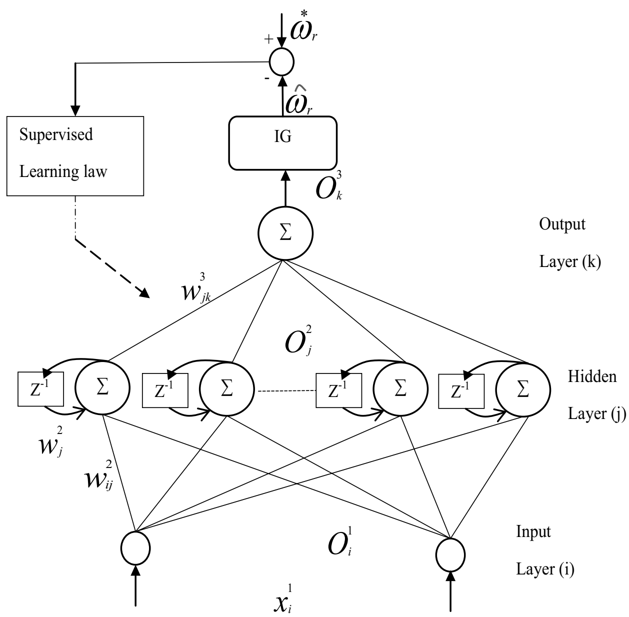

Fig. 6 Architecture of recurrent neural network

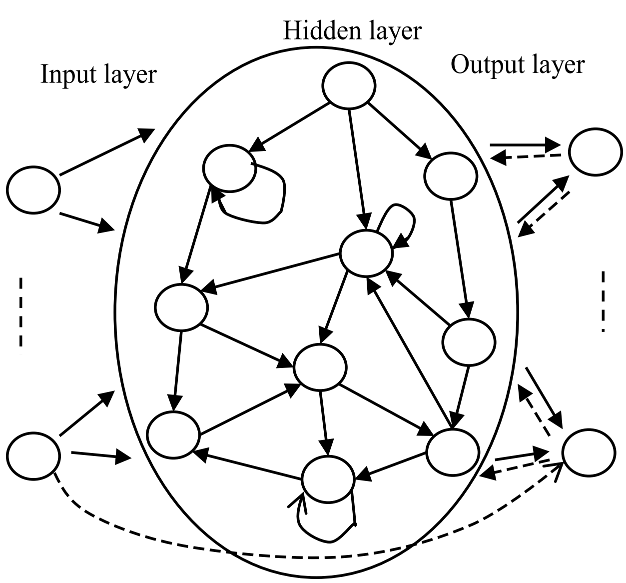

Fig. 7 Flowchart of Eco state network

modified particle swarm optimization (MPSO) technique is proposed by Chih et al. [49].

3.7 Sliding Mode Control Design with MPPT Technique

The sliding mode control design (SMCD) with MPPT technique is implemented with data of wind speed which is obtained by sensors of wind speed. But the measurement of wind velocity is not an easy task due to the large size of WT system. Therefore, many researchers are trying to develop control techniques which do not need of measurement of wind speed. Reviewing the different types of MPPT control method for WT system [50, 51]. Authors [52] chosen the output power that is controlled variable such as by power signal feedback (PSF) control in order to obtained power reference without using the measurement of wind velocity.

3.8 Particle Swart Optimization MPPT Technique

The particle swarm optimization (PSO) is the population-based optimization MPPT technique which is proposed by Kenndy and Eberhart are shown in Fig. 9. It catches the optimal solution by a population in favour of the particle. In this technique, each particle signifies a candidate solution in order to problematic. It is developed using bird flocking simulation in space of two dimensions [53].

3.9 Numerical Line Search MPPT Technique

Numerical line search algorithm (NLSA) is designated to determine the MPP of the WT due to simplicity and guaranteed conjunction properties. Figure 10 shows flowchart of numerical line search algorithm, compute the step size and direction in each iteration. Although the direction computes whether in order to decrease or increase the reference speed and step size provides change magnitude from earlier reference speed [54].

3.10 Proposed Technique Based on Calculus of Variation

The proposed algorithm is an MPPT technique which is mathematical branch consideration based on calculus variation as a generalization of calculus. It seeks to determine the surface, path, curve etc. due to given function has a static value. This function is a mapping from an established of functions in order to real number [55].

4 Comparative Analysis of MPPT Methods

In this section, compared to various MPPT techniques for the WT renewable system has been done in Table 1 [23, 41, 42, 56–83]. In addition, the fuzzy logic control (FLC) based MPPT technique provide the advantage of parameters such as fast convergence, insensitivity, acceptance of noisy and erroneous signals [84]. FLC method can be used for yield optimal step size for a conventional HCS control method [85, 86].

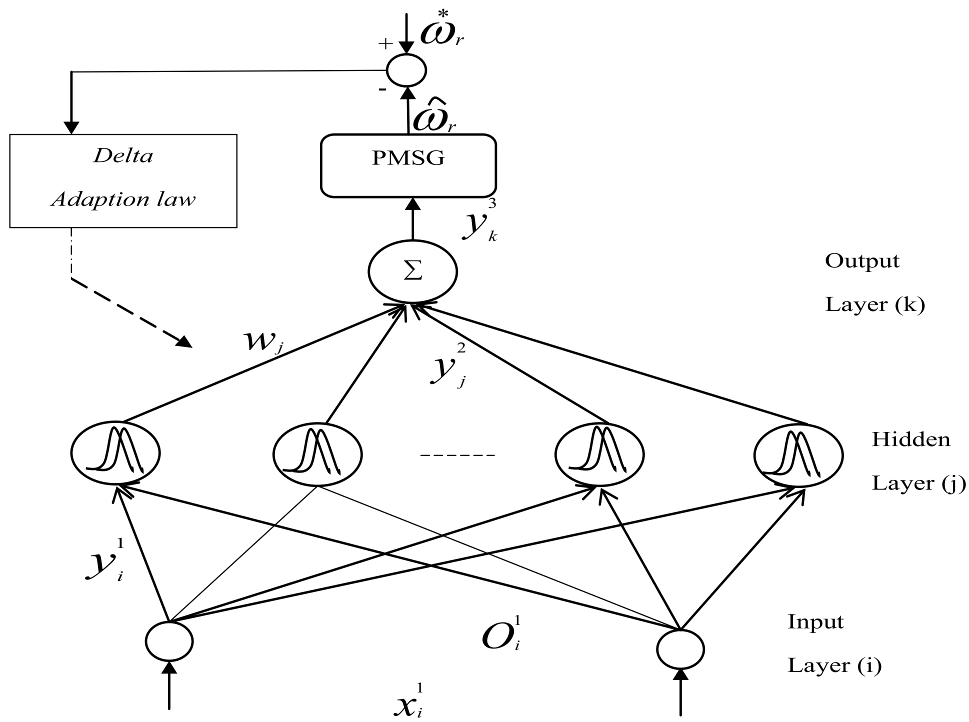

Fig. 8 Radial basic function network based MPPT technique

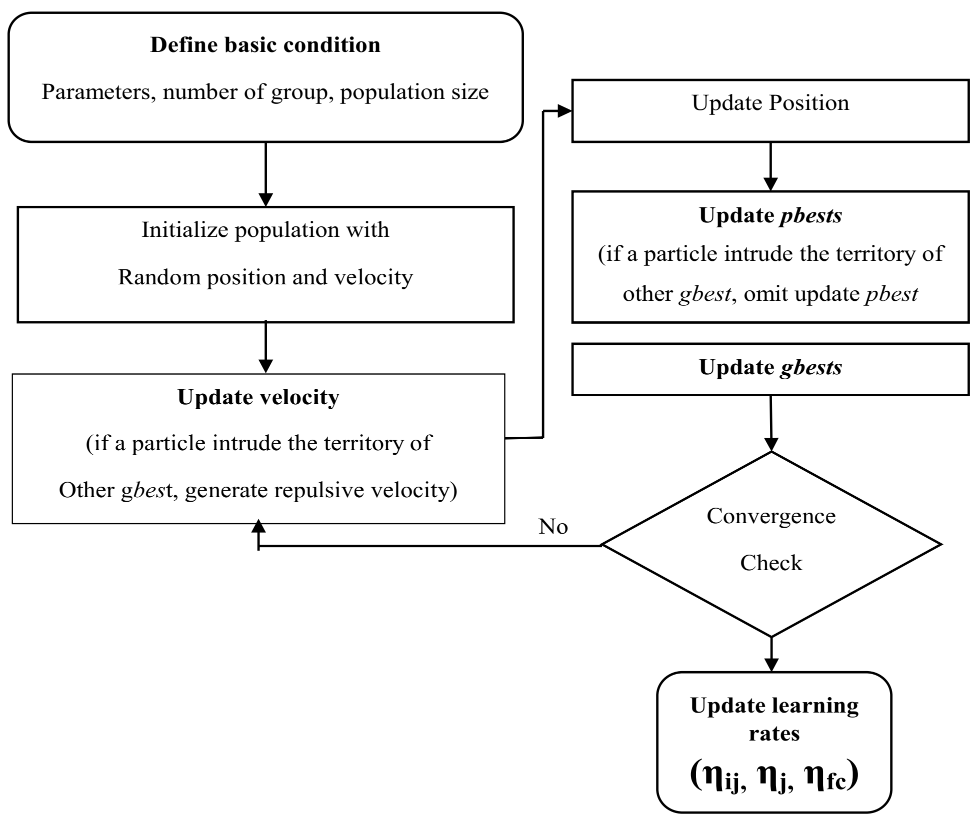

Fig. 9 Flow chart of particle swarm optimization technique

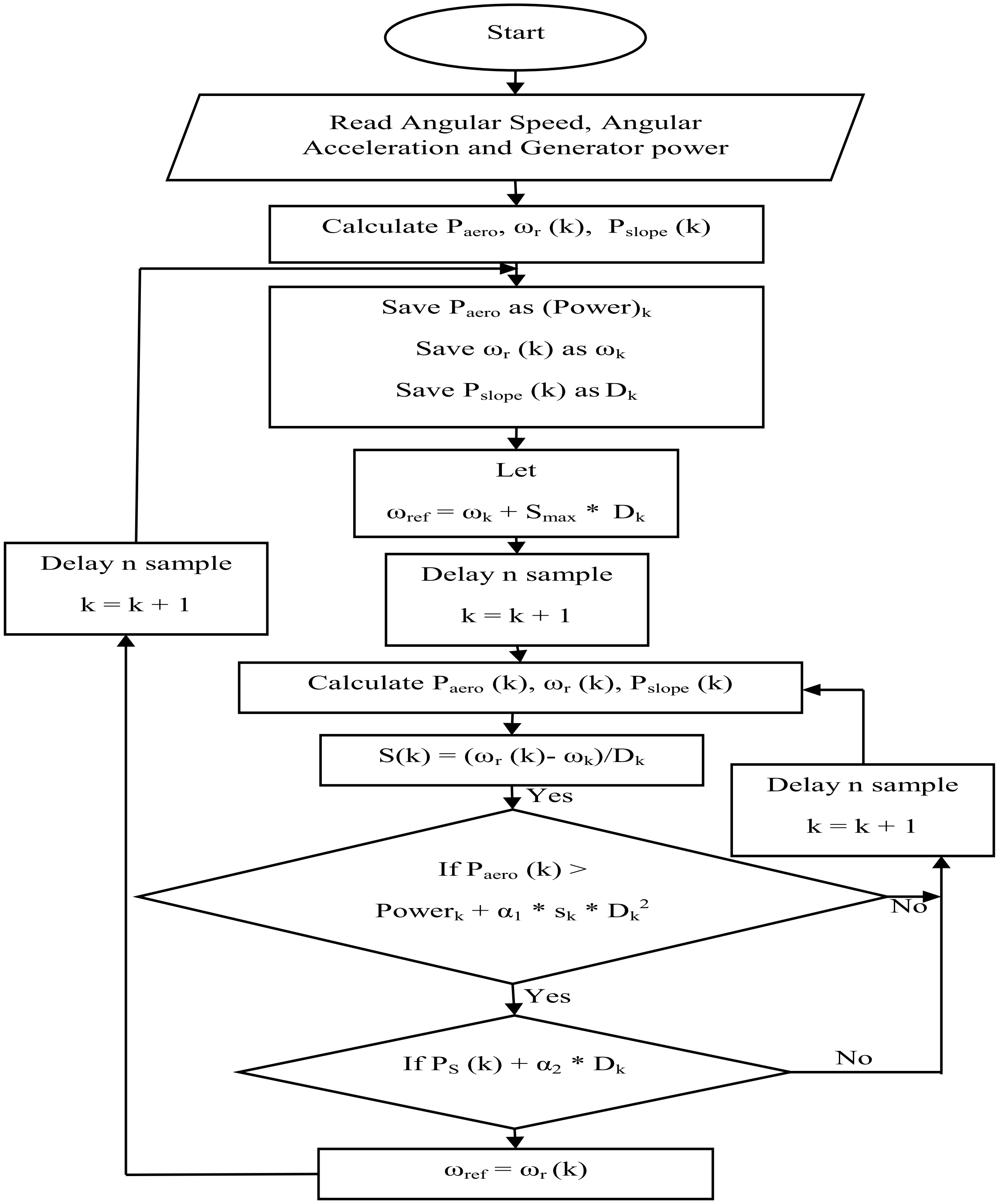

Fig. 10 Flowchart of numerical line search algorithm

5 Conclusion

The study presents a review of different MPPT techniques for WT system along with the analysis of the simulation and experimental characteristics of various MPPT techniques in terms of efficiency, system speed, cost, tracking time, precision, ease of implementation, etc. The review of MPPT control methods for WT renewable system supports in order to select particular MPPT method designed for a specific application.

The MPPT method has been compared for the perturbation of duty cycle and the input voltage to obtain better accuracy and response of the system. Computing the adaptive step-size techniques and merge two or more approaches of the available control methods will improve

Table 1 Comparison of characteristics of various MPPT methods

MPPT method	Prior training	Wind speed measurement	Memory requirement	Conservative speed	Implementation complexity
P&O	No	No	No	Varies	Low
Proposed method based on incremental conductance	No	No	No	Depends	Medium
Adaptive P&O control method	No	No	No	Medium	High
Tip speed ratio control	No	Yes	No	Fast	Low
Power signal feedback control	Yes	Yes	Yes	Fast	Low
Optimal torque control	Yes	No	No	Fast	Low
Other methods	Yes	No	Yes	High	Medium
PSO	No	No	Yes	Fast	High
RNN	Yes	No	Yes	Fast	High
FLC	No	No	Yes	Fast	High

the performance and overcome the hurdles found in the current control methods.

6 Research Trends

The WT system does not much effective and cannot guaranty continuous power flow to the load which can be incorporated by adding another system that is the hybrid renewable system. The hybrid MPPT technique such as combined of two MPPT techniques for finding maximum power from the WT system. Optimization of dc–dc converter design using control method would obtain improved efficiency of the system and power tracking capability.

Compliance with Ethical Standards

Conflict of interest Mohammad Junaid Khan and Lini Mathew declare that they have no conflict of interest.

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