Maximum Power Point Tracking Approaches for Wind–Solar Hybrid Renewable Energy System—A Review

Surabhi Chandra, Prerna Gaur and Srishti

Abstract For effective energy conversion from renewable energy resources, maximum power point tracking (MPPT) algorithms are gaining significance due to their effectiveness and adaptability to handle nonlinear conditions. This paper reviews influence of numerous real-time MPPT control methodologies for wind–solar hybrid renewable energy system (HRES). From the past research surveys, this paper will present the common trends in MPPT schemes and a discussion on advanced trends in intelligent techniques for wind–solar hybrid energy system. An evaluation on state of the art and performance of new intelligent control techniques on several criteria, i.e., array dependency, wind speed, convergence time, handling shading conditions, implementation for practical work, will also be elucidated. This review work is to foresee the application of advanced artificial intelligence (AI) control strategies to serve as a reference for new developments in powerful usage of hybrid energy system.

Keywords MPPT · Solar · Wind · Hybrid renewable energy system
Artificial intelligence

1 Introduction

Due to the rapid exhaustion of fossil fuels and their effects like environmental hazards, the power systems are now upgrading toward green power generation [1, 2]. The widespread increase of renewable energy sources permits attaining more safe and viable energy prospects to overcome the challenge of growing energy consumption and utilization. The trend of renewable energy power generation is now heading

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toward generation of power from hybrid renewable energy resources, i.e., solar energy and wind energy.

According to Ministry of New and Renewable Energy (MNRE), the total Installed Grid Interactive Renewable Power Capacity in India as of July 31, 2016, is 44,783.33 MW and by 2022 it is targeted to rise around 175,000.00 MW. The major contributors in renewable energy generations are wind and solar energy [3–5].

Wind and solar renewable energy resources are intermittent in nature. A system comprising of wind and solar combined together as hybrid system can be designed to increase the power generation [6]. As these two resources are naturally available in nature, so they are also dependent upon climatic conditions. Wind power output varies with wind speed, and solar power is dependent upon solar irradiance. Hence, the power output keeps fluctuating depending upon the resource available. Therefore to extract maximum power from the renewable energy resources, maximum power tracking algorithms are implemented.

There are variety of MPPT techniques to improve the efficiency of renewable energy systems like perturb and observe [7–9], incremental conductance [10], current sweep, constant voltage, distributed MPPT, hill climbing, slide control method, ripple correlation control, DC link capacitor droop control, gauss newton technique, adaptive P&O, curve fitting technique, parasitic capacitance technique, linearization-based MPPT technique, $\mathrm{d}P/\mathrm{d}V$ or $\mathrm{d}P/\mathrm{d}I$ feedback control. Nowadays, intelligent MPPT control techniques are opening broad ways in research fields. Fuzzy logic, neural networks, genetic algorithms, evolutionary algorithms, expert systems, swarm intelligence systems like ant colony system, particle swarm optimization, artificial bee colony system, cuckoo search algorithms are some of the new techniques which are evolving very fast for MPPT systems.

2 Hybrid Renewable Energy System

HRES incorporates different renewable energy resources. In this paper, HRES is formed by integrating solar and wind energy conversion system. Both systems are coupled to the DC bus. To obtain maximum power, MPPT control is applied at the converter. DC is converted to AC by inverter which supplies AC to the grid (Fig. 1).

3 Maximum Power Point Tracking

3.1 PV *System*

The purpose of using MPPT is to make sure that in environmental situation like solar irradiance and temperature changes *PV* modules are able to supply maximum power.

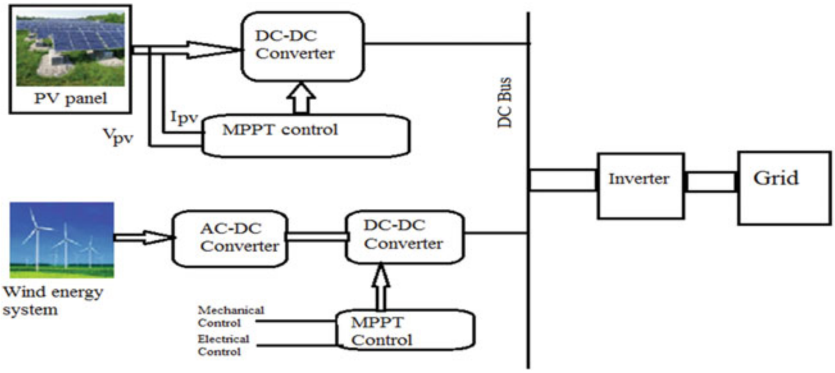

Fig. 1 Block diagram of HRES

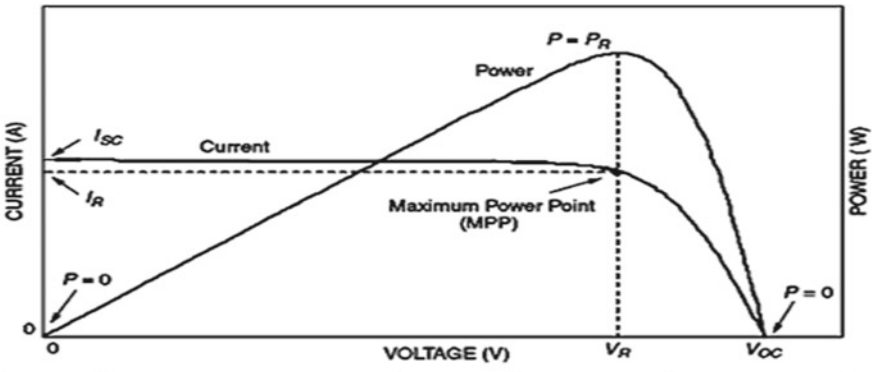

Fig. 2 MPPT characteristic of a *PV* cell

El-Khozondar [11] shows the typical maximum power point characteristic for a *PV* system. A characteristic curve has been plotted between voltage and current obtained from the *PV* cell, and the point of maxima of the curve is the point at which the *PV* cell should operate in order to generate maximum power (Fig. 2; Table 1).

3.2 Wind Energy System

The power output of wind turbine is proportional to the cubic function of the turbine speed. With the changes in wind speed, the wind energy systems are able to supply maximum power. Wei [12] has shown the wind turbine characteristic for wind turbine shaft speed to turbine power and has also obtained the optimal power curve at different wind speed. At the point where turbine power is maximum with respect to wind speed is maximum power point for wind turbine systems (Fig. 3).

Table 1 MPPT techniques for *PV* system

S. No.	MPPT technique	Remarks
1	Constant voltage	In low insulation environment, the constant voltage technique is more effective than P&O and IC method
2	Short current pulse method [15]	This method is adaptive to disturbances. By the help of proportional of parameter in a low-output-power region, MPPT performance is improved remarkably, especially in partial shading conditions and surface contamination
3	Open voltage method [16]	This method is based on constant voltage method, but it makes the assumption that the MPP voltage is always around 75% of the open-circuit voltage. So mainly, this technique takes into account the temperature. Besides, this technique can partially take into account the cell's aging
4	Perturb and observe method [17]	This technique commonly exhibits decent performance as long as the solar irradiation does not vary too quickly. The operating point usually fluctuates and oscillates around maximum power point
5	Incremental [17] conductance method	The benefit of this algorithm is that it is capable of tracking the maximum power point more specifically in different weather conditions and has the ability to determine the relative "distance" to the maximum power point (MPP)
6	Temperature gradient algorithm [18]	The temperature algorithm requires datasheet information regarding the *PV* array, and the algorithm has to be updated to ensure accurate operation of the *PV* system and compensate for parameter changes caused by system aging
7	I & T method [19]	The irradiance is estimated through the relation of the measured short-circuit current and its reference at standard test condition. This method uses low-cost sensors to measure temperature and current, which accurately define the MPP
8	Curve fitting technique	Offers simple indirect control of voltage *V* through a digital circuitry for a stand-alone system by modelling off-line based on mathematical equations or numerical approximations
9	Pilot cell algorithm [20]	This method is based on measuring short-circuit current and open-circuit voltage on a pilot cell (it is like a small solar cell having the characteristic of cells in the large array). This method leads to elimination of *PV* power loss during OC voltage and SC current measurement. But in this method, the pilot cell must be matched with *PV* array parameters which increases the system cost

(continued)

Table 1 (continued)

S. No.	MPPT technique	Remarks
10	Variable step size using commercial current mode control [21]	This method demonstrates an economically feasible method to control a current mode DC converter powered by *PV* panel. In the compensation pin of current mode DC regulator, a control voltage is injected to achieve MPPT. The advantage of this method is as they are small sized and easily available so the designing power system from *PV* system can be simplified
11	Fixed frequency finite-set model predictive control [22]	In this method, a model of the control system predicts the behavior of system and then an optimizer valuates the prediction results and finds out future control actions
12	Fuzzy logic control	The developed algorithm is able to track the maximum power with a convenient speed, and it shows a very dynamic response with sudden variations in environmental conditions. At the same time, the implementation of this algorithm is also possible with available components at a lower cost
13	Particle swarm optimization [23]	The swarm intelligence techniques are redundant, adaptable, extendable algorithm. In solar *PV* applications, PSO is used to adjust the duty cycle of DC converters to track the maximum power point. The swarm intelligence algorithm has the advantages to combine with other techniques and create a new approach for solving a problem
14	Neural network [24]	Neural networks find its best applications in the areas of nonlinear behavior or quite dynamic. It also provides analytical alternatives to conventional techniques
15	Genetic algorithm	GA can be combined with ANN and fuzzy logic techniques to expand the efficiency of the system performance A solution can be obtained by maximizing the fitness function. In genetic algorithm, the solution does not depend on initial conditions but works with a randomly generated population of individuals and chooses the best ones and hence it is able to search the exact maximum point
16	Artificial bee colony algorithm [25]	ABC algorithm is fairly recent member of swarm intelligence techniques. Based on natural behavior of honey bees in locating food resources, this algorithm develops a new methodology in search intelligence. Having the property of good accuracy and excellent tracking capability, this algorithm provides the facility of adjusting the duty cycle of the DC converter without using a linear controller

(continued)

Table 1 (continued)

S. No.	MPPT technique	Remarks
17	Cuckoo search algorithm [26]	This algorithm is one of the most recently developed. It is population-based algorithm, developed by simulating the intelligent breeding behavior of cuckoos through Levy's flight equation. This algorithm can be used as an optimization tool, or solving nonconvex and nonlinear problems
18	Firefly algorithm [27]	FA is based on flashing behavior of flies. This algorithm is based on assumption that since all the fireflies are unisex so they can be attracted to other fireflies irrespective of their sex and this attraction is proportional to the relative brightness; if there is no relative brightness, then each will move randomly. The landscape of the objective function finds the brightness of a firefly. For MPPT implementation, the brightness is simply proportional to the objective function

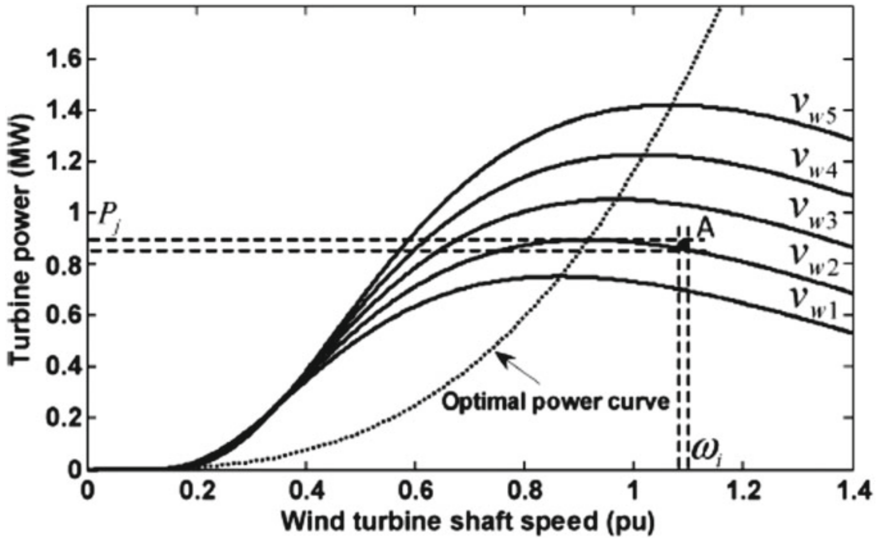

Fig. 3 MPPT characteristic of a wind turbine

4 Results

Sundareswaran [13] shows a comparison of variation of power, voltage, and current between P&O, PSO, and firefly algorithm for a *PV* system. From the graph, it can be clearly understood that the tracking speed of firefly algorithm is the fastest of all and has highest accuracy. Also, the steady state oscillations are fastest in firefly algorithm (Fig. 4).

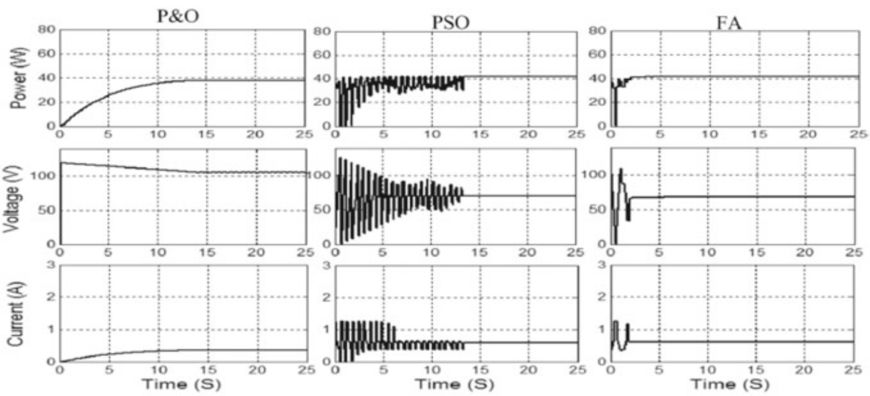

Fig. 4 Comparison of variation of power, voltage, and current between P&O, PSO, and firefly algorithm for a *PV* system [13]

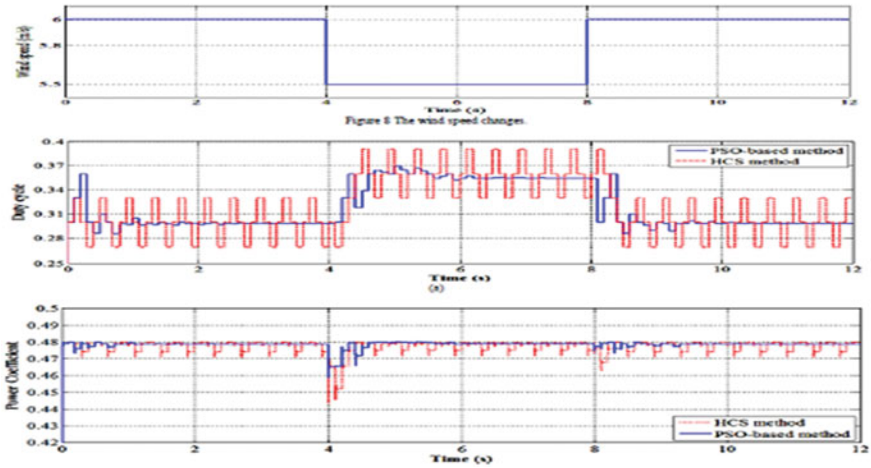

Fig. 5 PSO-based and HCS MPPT algorithms simulation results of **a** the duty cycle and **b** the power coefficient [14]

Abdullah [14] has shown implementation of swarm intelligence technique, i.e., particle swarm optimization to control the duty cycle of the boost converter. The converter provides the interface between wind turbine and the load by extracting maximum power from the wind. As shown from the result, the proposed PSO method has proven to be accurate and efficient to conventional hill climb search method (Fig. 5).

5 Conclusion

The classical optimization techniques for MPPT have numerous limitations on solving research models or mathematical models. The solution mechanisms of classical approaches are dependent on the type of function, i.e., linear or nonlinear and variable types, i.e., real or integer. The classical methods cannot be applied to problems involving different variable types and different objective functions. The conventional methods strictly follow sequential computations, produce precise answers, and require separate memory address for storing data. Hence, the above several limitations led to use of soft computing-based approaches. The soft computing strategies involve intelligent computational steps, and hence, computational time required is less.

Fuzzy systems and neural network systems relate the human way of thinking and interpretation. The genetic algorithms are related to the biological process in which the systems improve with time. The algorithms which are based on swarm intelligence techniques like ant colony optimization, particle swarm optimization, artificial bee colony optimization, cuckoo search algorithm imitate the intelligent behavior involved in animals, birds, insects, and microorganism. The particle swarm optimization is a special category of firefly algorithm. Many of the research papers have analyzed that firefly algorithm is superior in solving complex optimization problems. The firefly algorithm is more powerful in finding global optimum value in very less computing time. Due to some significant features, the cuckoo search algorithm provides faster convergence speed since it is based on Levy's flight equation.

The mentioned significance of the new optimization approaches can be used for maximum power point tracking systems in wind and solar energy systems. The cuckoo search algorithm and firefly algorithms can easily handle the shading conditions by their intelligent control approaches.

Apart from these research approaches, a combination of neuro-fuzzy, fuzzy genetic, and neurogenetic systems has also evolved to open new gateways for research. Each technique has their own merits and provides an efficient solution to the problems on different domains. This combination makes the system based on self-learning and decision making.

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