# THE MPPT ALGORITHMS USED IN WIND ENERGY CONVERSION SYSTEMS: AN ANALYTICAL REVIEW

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**Abstract**
Renewable energy sources (RESs) have become viable alternatives to traditional energy sources due to the diminishing nature of fossil fuels and environmental challenges. Due to its low cost of production and zero carbon emissions, wind energy is one of the dispersed energy alternatives with the fastest increasing market. Although wind energy is abundant, it is intermittent, meaning that the wind speed varies from moment to moment. As a result, the goal is to maximize the output power from this changeable wind while it is there. To this end, a number of algorithms for maximum power operating point tracking (MPPT) have been suggested and effectively implemented. Nevertheless, as each algorithm has advantages and disadvantages, selecting the precise MPPT method for a given application needs a high level of competence. This paper presents a review of various MPPT algorithms suggested in the literature

## Introduction

Because to the current and upcoming energy crises as well as the finite nature of traditional sources, interest in electricity has surged generation using unconventional energy sources. The fastest-growing source of energy for the production of electricity is renewable, with an average annual growth rate of 2.9% from 2012 to 2040. Renewable resources are now essential components of electrification, with wind, solar, tidal, biomass, etc. being some of the main sources. Because to its zero carbon emissions and affordability, wind energy is the most quickly expanding method of distributed power generation and is thus garnering more and more support. According to Global Wind Energy Council report, 54 GW of wind power was added in 2016, bringing total global installed capacity to nearly 487 GW. China, the US, Germany, India and France are the leading users of wind energy.

## Wind Energy Concept

Since wind speed is highly unpredictable in nature and the output of wind energy conversion system (WECS) varies continuously with time. Thus, to achieve high efficiency, variable-speed wind energy conversion systems (VSWECS) like doubly-fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) based systems are preferred over fixed-speed WECS like squirrel cage induction generator based systems and maximum power point tracking (MPPT) algorithms are incorporated for maximizing energy harvest. However, choosing an appropriate MPPT algorithm for a particular case requires sufficient proficiency with each because each algorithm has its own merits and demerits. For this reason, a review of those algorithms is essential. The article is divided into four sections including the introductory section. These sections are as follows: the basic idea of maximum power tracking is given in Section 2. The classification of various MPPT algorithms is made in Section 3, and Section 4 provides the conclusion.

The mechanical power produced by a wind turbine is given by:

$$P=12\rho\pi R2CP\ (\lambda, \beta)\ vw3 \qquad (1)$$

Where ρ is the air density (kg/m3), R is the radius of the turbine blade (m), vw is the wind velocity (m/s), Cp is the turbine power coefficient which is a measure of turbine power conversion efficiency and is a function of tip speed ratio (λ) and blade pitch angle (β).
Tip speed ratio is defined as the ratio of the blade tip speed to the wind velocity striking the blades and can be expressed as [3]

$$\lambda = \omega R v w \quad (2)$$

where ω is the mechanical angular speed of the turbine (rad/s).
To obtain the maximum power, Cp should achieve its maximum value for a given wind turbine. It is apparent from the Cp - λ curve shown in Figure 1 that the maximum Cp (Cp_ max) occur at an optimum value of tip speed ratio ($\lambda_{opt}$).

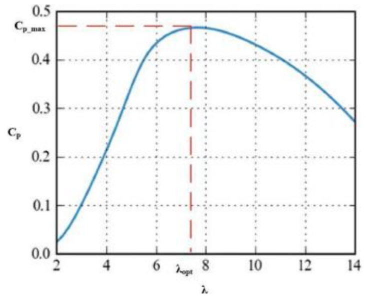



**Figure 1 Cp - λ curve.**

The $C_p$ - $v_w$ characteristics of an Enercon E40 2.3 kW gearless, variable speed, variable pitch control turbine data is plotted in Figure 2 as power coefficient $C_p$ versus $v_w$ and P versus $v_w$. The maximum value of power coefficient for E40 is 0.5. At this point, the wind turbine is getting its rated power at the wind speed of 16 m/sec (shown as a green line in Figure 2(b)) with power coefficient Cp = 0.23 (shown in Figure 2(a)). The MPPT algorithm is applied to maximise the extracted wind energy by maximisation of the power coefficients below the rated speed. The MPPT curve is shown by red line which depicts that the wind turbine is now abstracting the maximum power at 13 m/sec wind speed.

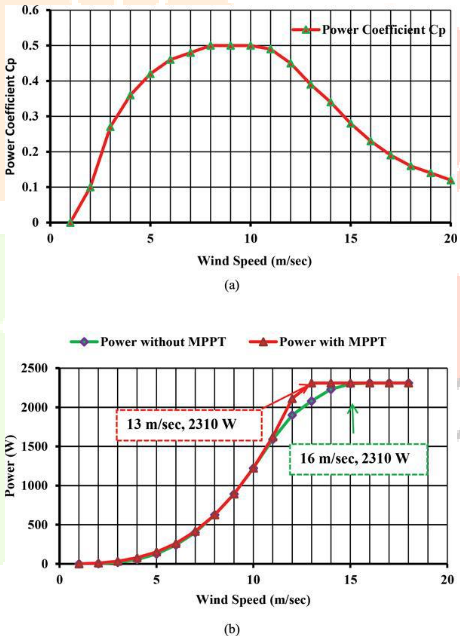



**Figure 2 The characteristics of an Enercon E40 2.3 kW gearless, variable speed, variable pitch control turbine. Curve (a) Cp - $v_w$ Curve (b) P - $v_w$ Curve.**

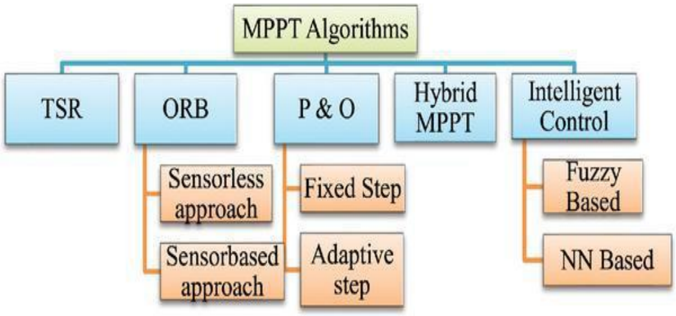
## 3. MPPT Application

The two broad classes of MPPT techniques used in wind energy conversion systems are 1) sensor-based methods and

2) sensor less techniques. Sensor based topologies use some mechanical sensors like anemometer for wind speed measurement and tacho-generator for rotor speed measurements whereas the later one makes use of electrical sensors for voltage, current or power sensing. An electromechanical generator generates the voltage roughly proportional to speed. With precise construction and design, it may produce particular voltage and may act as a speed measurement device for a certain range of speed. This type of generator is termed as tacho-generator. The polarity of the voltage generated by tacho-generator indicates the direction of rotation.

Other way of classification of MPPT techniques is shown in Figure 3. Different MPPT techniques employed in VSWECS are classified as 1) Tip-speed ratio (TSR) control, 2) Optimum relationship based (ORB) control, 3) Perturbation and observation (P&O) control, 4) Hybrid control and 5) Intelligent control techniques like fuzzy logic control, neural network control, etc.

All of the above MPPT algorithms are discussed in detail in the following sections.




wind speed is not possible since wind speed is not constant throughout the blade swept area. Installation of an array of anemometers can be a solution for accurate wind measurement, but it increases the cost of the system. Also, the TSR MPPT algorithm generates fluctuations in generator output power.

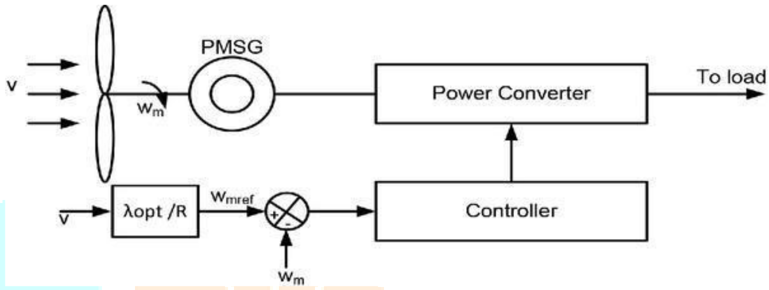



**Figure 3 Classification of MPPT algorithms.**

### 3.1 Tip Speed Ratio Control

In this algorithm, TSR (defined in Equation (2)) is kept at an optimum value to extract maximum power from the wind by regulating generator rotational speed on the fluctuation in wind velocity. The optimum TSR as shown in Figure 4 is set as a reference value which can be determined experimentally or theoretically. This method is straightforward and fast because it measures wind speed directly. It extracts more power from rapidly varying wind as it depicts non-minimum phase characteristics with higher gain at higher frequencies. On the other hand, it requires anemometer for wind measurement, so continuous and precise measurement of

### 3.2 Optimal Relationship Based (ORB) Algorithm

This algorithm relies on drawing optimum relationships between different parameters of wind energy conversion system like wind velocity, output mechanical power, rectified dc voltage, rectified current, output electrical power, etc. Such techniques utilize lookup table or predefined curves to track the MPP. It is also termed as power signal feedback (PSF) control. Most of the ORB techniques are based on the field test to obtain the data for fast and accurate MPPT tracking. Further, ORB methods are classified as sensor based and sensor-less approaches.

#### 3.2.1 Sensor based approach

These techniques require some mechanical sensors to obtain the data. In, the relationship between electromagnetic torque and rotor speed (optimum torque method) is used. The operating principle of this method is to adjust the generator torque (Figure 5) according to the maximum value of a reference torque curve. The optimal value of torque is obtained at $\lambda = \lambda_{op}$t and $C_p = C_{p\_}$ max is given by:

Tmopt=12ρπR5Cp_maxλopt3ωm2Tmopt= koptωm2 (3)

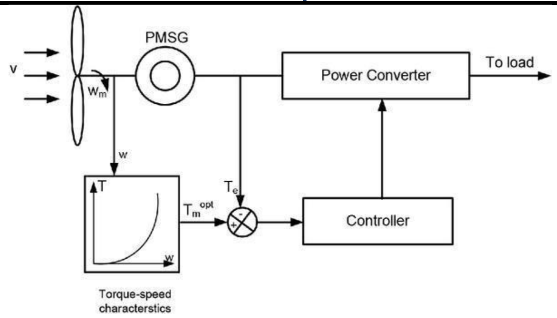



**Figure 5 Optimum torque approach.**

The predefined power versus rotor speed curve or look up table of the wind turbine is used to track the MPP in power signal feedback (PSF) (Figure 6) method to determine the maximum power at optimum rotor speed. It works on the same principle as that of optimal torque algorithm. Here instead of torque-speed characteristic, power speed characteristic

is used. The maximum power can be obtained either using the expression of turbine output power or using a pre-obtained turbine power-speed curve through simulation or experimental result. The following expression gives the maximum power corresponding to optimum generator speed:

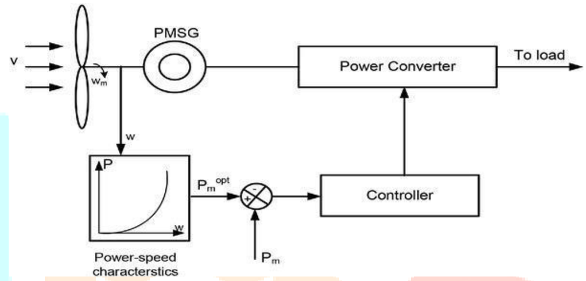



Figure 6 Power signal feedback approach. Popt=πR5ρCp_maxωopt3/2λopt3=koptωpt 3

The major drawback of these methods is that they need mechanical sensors which increase the cost and reduce the reliability of the system.

### 3.2.2 Sensor-less approach

In WECS configuration with an uncontrolled rectifier, the relationship between power versus rectified voltage or rectified dc voltage and rectified current are used to track the MPP. Both these methods require only electrical sensors and remove the need for mechanical sensors.

The ORB algorithm is a straightforward approach with an excellent dynamic response. One of its limitations is that it requires prior knowledge of system parameters which are highly dependent upon the ageing effect and can vary in physical applications from one system to another.

In, an intermediate variable β is created as a function of power and shaft speed and MPPT is tracked by keeping this variable constant irrespective of mechanical specifications.

### 3.3 Hill Climb Search Method

The HCS is also called perturbation and observation (P&O) since it observes the perturbation in power and according to that it provides the corrections in the particular parameter like duty cycle of the DC–DC converter to control the dc voltage or to regulate current in order to adjust the rotor speed and track the MPP. This method is based on perturbing control variable in arbitrary small steps, and the next perturbation is decided on observing the changes in power curve due to preceding perturbation. P&O approach is a widely used MPPT algorithm because of its simplicity and absence of mechanical speed sensor or anemometer for implementation.

This method suffers from following two drawbacks: sluggish response especially for low step size and inefficient operation under rapid wind variations. A large oscillation will appear around the MPP if the selected step size is large. However, this problem can be eradicated using adaptive step size depending upon scaled measure of power slope with perturbing variable as proposed in to make a balance between tracking speed and control efficiency. Still, the problem of misleading direction in rapidly varying wind remains. Authors in proposed to modify P&O approach to suppress the above problem by two modes of operation: 1) The conventional P&O approach for slower wind speed and 2) a prediction mode based capacitor voltage slope for rapidly varying wind. The rectified current is selected as the perturbing variable. A flow chart of the P&O algorithm is shown in Figure 7.

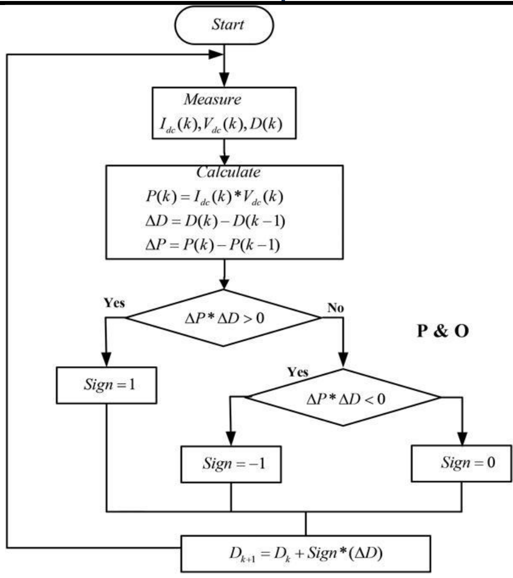



**Figure 7 Flow chart of Perturbation and Observation (P&O) algorithm**

### 3.4 Hybrid MPPT Algorithm

A hybrid method (flow chart is shown in Figure 8) is the combination of two approaches that overcome the drawbacks of one method by utilizing the advantages of the second one. An example of these methods was proposed by authors, where the ORB method was merged with P&O to solve the two problems associated with conventional P&O that are speed efficiency trade-off and wrong directionality under rapid wind change. Further, authors in proposed hybrid algorithm by combining the attributes of ORB and P&O methods to mitigate the limitations of both algorithms. The author in proposed the so-called one power point (OPP) method in which a relationship between the rectified voltage and inductor current is developed by the knowledge of maximum power status for one local wind speed. Further, there is one coefficient in the developed equation. The wind turbine design and power coefficient drop are not considered in this paper. Another example was the combining of PSF control and HCS in to develop a sensor-less and flexible method that applies to all wind turbine levels. The main drawback with these algorithms is that most of these algorithms need P&O or any other algorithms to develop the relationship. The performance of such algorithm deteriorates with the age of the system.

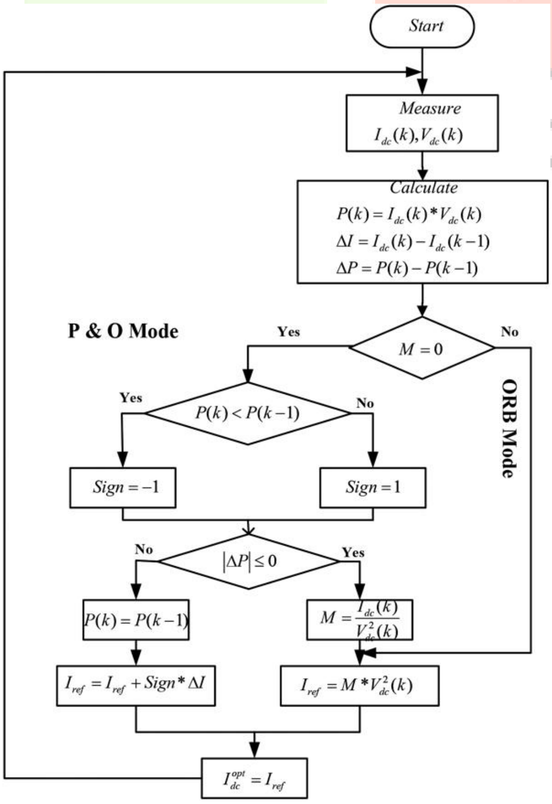



**Figure 8 Flow chart of hybrid MPPT algorithm.**

## Conclusion

WECS uses maximum power point tracking techniques to improve energy extraction and hasten convergence. In the study, a thorough analysis of several MPPT algorithms has been provided. These techniques may be generally divided into five types, each of which has pros and cons. The use of the term "semi-autonomous" refers to the ability of the system to operate autonomously without the need for human intervention. As they don't require mechanical sensors, sensor less systems like HCS and ORB are more affordable and dependable, but they are unable to detect the precise MPP during rapid wind variations. The hybrid algorithms are more accurate, robust and are advantageous than the above two categories of methods. Thus, knowledge of all the techniques is necessary to design the best MPPT algorithm for a particular type of WECS.

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