International Journal of Advance Research and Innovation
Vol. 8(4), Oct-Dec 2020, pp. 93-99
Doi: 10.51976/ijari.842015
www.gla.ac.in/journals/ijari

Article Info

Received: 20 Feb 2020 | Revised Submission: 20 Oct 2020 | Accepted: 28 Oct 2020 | Available Online: 15 Dec 2020

Maximum Power Point Tracking Algorithms in Wind Energy System

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ABSTRACT

It is vital to determine or extract the highest obtainable wind energy at any wind speed because of the natures unforeseeable wind limitations. Therefore, a smart controller that can monitor the extreme pitch irrespective of wind velocity. This article concentrates on several previous and present techniques for achieving maximum wind energy capacity. The maximum power point tracking (MMPT) solution is numerous, but the issues lends itself to their efficient selection and requires expert understanding about every method to choose an efficient MPP method, as such method alone presents some benefits and drawbacks. Different MPP techniques are discussed and compered in terms of convergence moment, effectiveness, training and implementation complexity and they are characterized based on continual wind speed as well as variable wind speed.

Keywords: *Wind energy conversion system; Optimum relation based; Growing neural gas; Perturb; Observe method; Particle swarm optimization.*

1.0 Introduction

Adjustable speed wind energy devices with power electronics interface are introduced to extract the peak power from wind. The speed of the turbine should vary with the wind velocity for maximum power extraction, so that the optimum velocity rate is retained constantly. Different MPPT algorithms are established to extracts maximal wind turbine energy by producing an appropriate referral voltage to the dc-dc converter for cut-in to rated wind speeds [1]. Many techniques have been studied in literature, some of the methods used for adjusting turbine velocity to obtain maximum capacity directly or indirectly. Certain techniques used wind velocity, and few of them did not use wind velocity measurement [3]. On the main consideration of wind speed measurement (WSR), the MPPT approaches used are the tip speed ratio (TSR), power signal feedback (PSF). A less number of MPPT techniques does not need the WSR such as hill-climbing search (HCS), Multivariable perturbation and observation (MVPO), optimal relation-based (ORB) technique. There are some other approaches that depend on this, but not entirely, i.e. they need the ancient data affecting to the wind speed and they are fuzzy logic control (FLC), neural network (NN) and direct adaptive fuzzy proportional integral (PI) controller approaches. Here in this paper, the principles and procedure of various MPPT algorithms and talk over their benefits and drawbacks [1]. This makes an improved choice on which algorithm can be carefully chosen for a specified system for obtaining maximum power from WECS.

2.0 Modelling of wind energy system

Hypothetical thought says that, a wind system would extricate just about 59% of the dynamic vitality of the wind going through the region of its sharp edges. No tool can separate the complete breeze vitality in light of the fact that the propellers of the windmill restrict the progress of wind. This reason stabilises the progression of air through the rotor dependent on wind speeds. A 100% proficient wind generator would extract up to a limit of around 60% of accessible breeze vitality and it is changed over into electrical vitality. Well-planned sharp edges will regularly extricate 70% of wind vitality, however disasters happened in the rigging box, transmission system and generator could moderate

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by and large wind turbine proficiency to 35% or less [2].

A wind system deals with the rule of converting motor vitality of wind into mechanical vitality. Power is characterized as vitality utilization per unit time. The vitality accessible in the breeze is motor vitality. Motor vitality is characterized as a large portion of its mass circumstances the square of its speed [4].

$$K.E = \frac{1}{2} mV^2 \quad \ldots(1)$$

The quantity of air, through a region A, with speed V, is AV, and its mass m is equivalent to its volume is increased by its thickness of air. i. e.

$$m = \rho AV \quad \ldots(2)$$

Replacing equation (2) in equation (1), we get

$$K.E = \frac{1}{2} \rho AV * V \quad \ldots(3)$$

$$K.E = \frac{1}{2} \rho AV^3$$

Here, ρ = Air density (kg/ m^3)

A = Turbine Swept area (sq. m)

V = Speed of wind (m/s)

The above conditions presents the power accessible in the wind. The power moved to the wind turbine rotor is moderated by the power coefficient (Cp) [2]. The power coefficient of the breeze organization is given by,

$$C_p = \frac{P_{Windturbine}}{P_{Air}}$$

$$C_p = \frac{P_{Windturbine}}{0.5 \rho AV^3}$$

The coefficient of a wind turbine is an estimation of how productively the breeze turbine changes over the vitality in the wind into power. The power coefficient contrasts from the proficiency of a breeze generator. A perfect rotor would have a power coefficient roughly 0.59. Yet, such a rotor would not be sufficiently able to withstand the concerns to wind stream [5]. For the best useful rotors, the power coefficient is about 0.4 to 0.45.

$$\mathrm{P} = \frac{1}{2} C_p \rho AV^3 \quad \ldots(4)$$

Power coefficient is a combination of tip speed ratio (λ) as well as pitch angle (β).

$$\mathrm{P} = \frac{1}{2} C_{\mathrm{P}} (\lambda, \beta) \rho AV^3 \quad \ldots(5)$$

$$C_{\mathrm{P}} = C_1 \left(\frac{C_2}{\lambda_i} - C_3 \beta - C_4\right) e^{\frac{C_5}{\lambda_i}} + C_6 \lambda_i$$

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

3.0 MPPT Algorithms

This paper presents deferent mppt approaches to track maximum power from wind [6] [7] [8] [9] [10] [11] [12]. They are,

1. An optimum relation based maximum power point tracking
2. Growing Neural Gas based maximum power point tracking
3. Perturb and Observe maximum power point tracking algorithm
4. Particle swarm Optimization algorithm

3.1 An optimum relation based maximum power point tracking

This approach used to implement a Sensorless MPPT procedure to make the system works based on a pre-obtained system curvature. Such an approach is identified as optimum relation based (ORB) control. However, this technique wants awareness of the system constraints, which are inexact and can differ in real applications [8]. In addition, the optimum curves are difficult to be calculated theoretically allowing for the complex system models. Moreover the optimal curve is non-unique and efficiencies are not constant, this can result in the deviation of the actual optimum points from the calculated ones, causes to power losses.

A latest study resulting an equation for the optimal reference current as a gathering of the dc voltage to achieve the maximum power point (MPP). However, the equation consists one unidentified coefficient, which still requires pre-knowledge of the system. Fig. 1 shows the flowchart representation of maximum power point tracking using Optimum relation based approach.

In order to attain the MPPT without mechanical sensors, it is conceivable to inflict the relationship among the dc voltage and the dc current on the optimum operational points. The current vs. power curves in Fig. 2 clearly demonstrate the MPP can be traced by operating the optimal current curve at all times. It is also presented in Fig. 2 that for each wind speed there is an extreme current point, which signifies the extreme available turbine torque of the turbine.

Figure 1: Flowchart Representation for ORB Method

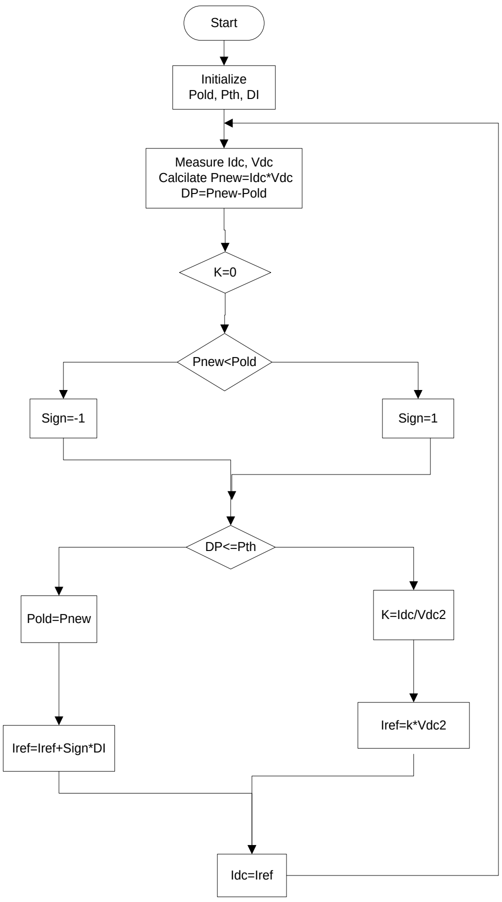
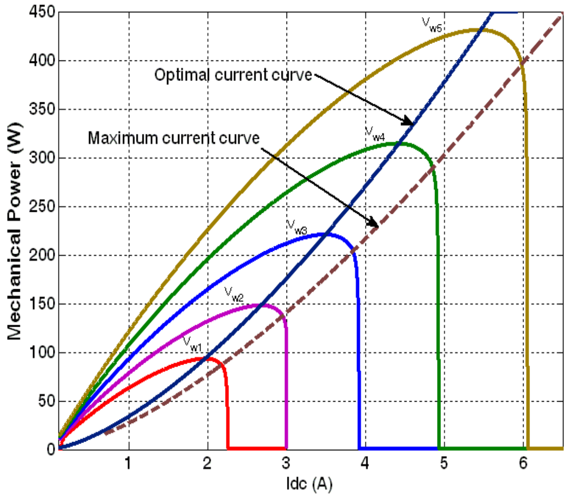


Figure 2: Characteristics of Turbine Power as a Function of the DC Side Current



Various studies have demonstrated that the estimated relationship between the optimum dc-side current (*Idc*) and dc voltage (*Vdc)* is as follows,

$$I_{dc} = kV_{dc}^{\ 2}$$

$$k = \frac{I_{dc}}{V_{dc}^{\ 2}} \qquad \ldots(6)$$

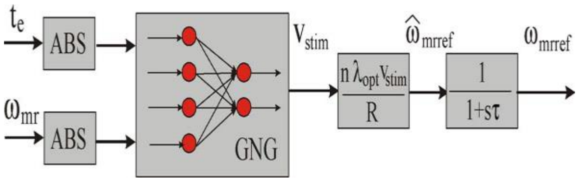
Here, *Vdc* and *Idc* are the dc voltage and dc current conforming to the MPP at a particular wind speed. However, in a way to calculate *k,* one peak point (OPP) of the system and its equivalent voltage and current is necessary. Not only is the struggle of calculating *k*, the power loss is also a problem that happen in the system due to the unsuitability of calculated value.

3.2 Growing neural gas based maximum power point tracking

It has been employed online to achieve the inversion of this function based on the probable torque as well as machine speed. The reference speed is then work out by the optimal tip speed ratio. For the investigational presentation, a back-to-back configuration with two voltage source converters has been considered: one on the machine side and other on the grid side. The first methodology retains the generator structure and equates the GNG MMPT with the classic perturb-and-observe MPPT, whereas the second methodology equates the squirrel-cage induction generator with doubly fed induction generator, both integrated with the GNG MPPT. Fig. 3 shows the block diagram representation of GNG based MPPT technique.

In GNG, these methodologies are adopted for field oriented control (FOC) and the voltage-oriented control (VOC). In specific, the GNG implements the projected wind speed outputs from the actual torque and machine speed. FOC scheme, current control is performed in the reference frame of the rotor-flux. The grid-side inverter provides the dc link control. Using a high performance method, i.e. VOC, the grid-side converter control was conducted. This technique works by decoupling the direct *d* and quadrature *q* components of the injected current instantly. Because the objective here is to regulate the dc-link voltage directly, the control scheme has been mildly altered by adding an additional control loop for the dc-link voltage, it outputs of the direct reference current.

Figure 3: Block Diagram of the GNG Based MPPT Algorithm



The awareness of the projected MPPT technique is to recover the generator reference speed ωmrref for any variable wind speed [9]. Once the wind speed vstim is expected, the generator reference speed ωmrref can be calculated with,

ωmrref = nvstimλopt/R,

Where λopt is the optimum tip speed ratio, depends on the turbine characteristics. For the purpose of stability, the ideal reference velocity of the generator is given to the machine control system by a first order filter with time τ. The MPPT technique's full block diagram is shown in Fig. 3

The complete algorithm of the GNG is summarized in the following steps [9].

- Initialize with two neurons *a* and *b* with random weights *wa* and *wb*, respectively, in n. Generate an input signal ξ from the training set.
- Find the adjacent neuron s1 and the subsequent adjacent neuron s2.
- Increase the age of all edges from s1. The age is a parameter that considers how strong the link between neurons is. The higher the age, the less significant the consistent neurons.
- Add the squared distance between the input signal as well as the adjacent neuron in the input space to a local counter variable as,

  Δ*error*(s1) = _ws1 − ξ_2.
- Move s1 in its direct topological neighbors toward ξ by fractions εb and εn, respectively, of the total distance, i.e.,

  Δws1 = ε*b*(ξ − ws1)

  Δw*n* = ε*n*(ξ − w*n*)

  For all direct neighbors *n* of s1.
- If s1 and s2 are connected by an edge, set the age of this edge to zero. If such an edge does not exist, create it.
- Remove edges with an age larger than amax. If this approach results in points with no emanating edges, remove them. amax is set by the user, but it does not significantly affect the result of the training phase.
- If the number of input signal generated so far is an integer multiple of a parameter λ (for simplicity, set to 1 in this case), generate a new neuron as follows. Determine the neuron *q*1 with the maximum accumulated error. Insert a new neuron *r* halfway between *q* and its neighbor *f* and remove the original edge between *q* and *f*. Reduce the error variables of *q* and *f* by multiplying them with a constant α. Initialize the error variable of *r* with the new value of the error variable of *q*.
- Lessening all error variables by multiplying them with a constant *d*.
- If ending criterion (e.g., the number of neurons equal to the maximum or any performance criterion) is not yet fulfilled, go to step 2.

3.3 Perturb and observe maximum power point tracking algorithm

The P&O scheming is likewise entitled "Hill climbing", while the dual tags introduce to an analogous intention be dependent on upon how it is executed. Hill climbing comprise of an annoyance on the duty cycle of the power converter as well the working voltage of breeze turbine and the power converter [10] [11].

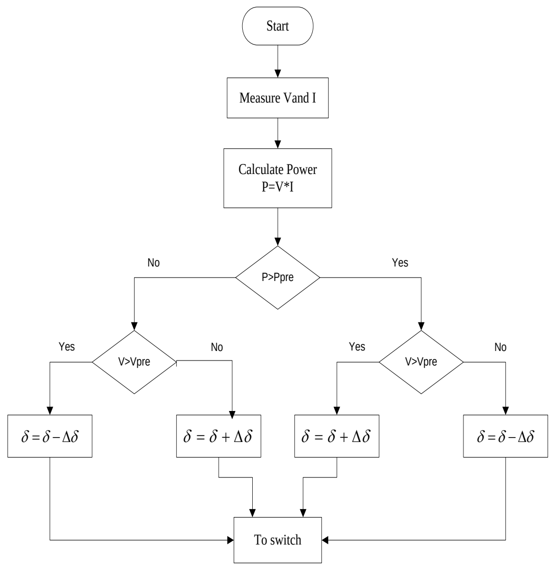
In this strategy, the sign of the last irritation as well as the indication of the last augmentation in the power are exploited to indicate what the following annoyance must to be on the left of the MPP enhancing the voltage builds the power whereas on the privilege decrementing the voltage expands the power. In the experience that there is an accumulation in the power, the annoyance ought to be retained an analogous approach and on the off chance that the power diminishes, at that point the succeeding inconveniency ought to be the other approach. In vision of these certainties, the intention is executed in ref. The procedure is revised till the MPP is come to. At that point the functioning point influences around the MPP [10]. This issue is basic additionally to the INC strategy, as was notice prior. A plan of the calculation is appeared in underneath Fig. 4.

Steps involved in perturb and observe method:

- Consider past voltage and power from ordinary base breeze conditions.
- Calculate the voltage and current from the breeze organization.
- Calculate power.

- Measure the power variety because of the past voltage change.
- If voltage varieties surpasses its cut off points differ the obligation proportion and figure the power and voltage.
- Measures the power variety and decides the new voltage dependent on the present and the past power varieties.

Figure 4 MPPT Procedure Utilizing Perturb and Observe Technique

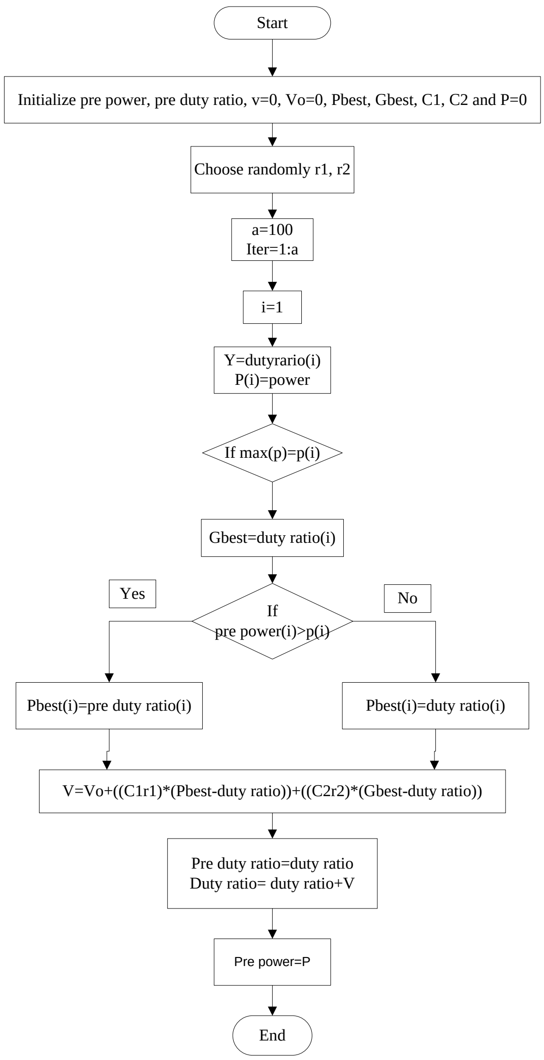


The PSO scheming was first obtainable by Dr. Kennedy as well as Dr. Eberhart in 1995 and its essential believed was encouraged by imitation of social conduct of individuals, for illustration, fowl rushing, fish tutoring, etc. The PSO scheming principally enlarged from creature's effort or conduct to gross attention of reorganization issues [12]. In PSO, every separable from the populace is known as a molecule and the populace is known as a swarm. Particles of a swarm convey unlimited locations to one alternative just as progressively modify their particular location and speed became from the best location of the particles. At long last, all particles will in general fly towards enhanced and superior positions over the looking through procedure until the swarm move to neighbouring an ideal of the wellness work. As contrasted and other improvement strategies, it is quicker, less expensive and increasingly effective.

Steps involved in particle swarm optimization are,

- Set constraints of particle swarm optimization.

Figure 5: MPPT Procedure Utilizing Particle Swarm Optimization Technique



- Initialize population of particles having positions P and velocities V.
- Fix iteration as a=1.
- Select Pbest and Gbest based on fitness function.
- Update velocity and positions of particles.
  $V = V_0 + c_1 r_1 (P_{best} - dutyratio) + c_2 r_2 (g_{best} - dutyratio)$
  $V = V_0$
  $dutyratio = predutyratio + V$
  Evaluate the power and find the index of the best particle.
- Update Pbest and Gbest.
- If the values are same go to next step otherwise increase iteration to a=a+1 and repeat the procedure.
- Print optimum solution as Gbest.

4.0 Comparison of Various MPPT techniques

After revising different MPPT procedures for maximum power extraction from WECS a relative Table 1 is obtainable in below. Choosing the best MPPT is a challenging task. A evaluation is through among variable performance indexes such as variable speed, memory, WSR, complexity, training etc. The objective of MPPT procedures is to trajectory the optimum power during variations in wind speed.

Table 1: Comparison of Various MPPT Techniques with Performance Index

Type of algorithm	Wind constraints	complexity	Memory	Convergence speed	Performance at varying wind speed	Dynamic response
ORB	Not required	Simple	Not necessary	Medium	Medium	Medium
GNG	Depends	More	Necessary	Fast	Excellent	Fast
P&O	Not required	Moderate	No need	Slow	Good	Slow
PSO	Not required	More	No need	Fast	Excellent	Fast

From the above MPPT techniques P&O and ORB are simple, the necessity of memory is also very less. These methods do not need any working out in determining the optimum power as well as WSR. The limitation of these methods are, these are not appropriate for variable wind speeds. These methods also do not requisite any sensors, assembling them inexpensive as well as reliable. The P&O is not pretentious by varying the generator constraints. The drawback of P&O is time taken to track MPP is high, then leads to power loss. If the step is lesser, then it consequences in slow MPP tracking as well as oscillates when step scope is improved. It also has a slow dynamic response, so the efficiency is a lesser amount associated with other approaches. The ORB is a modest MPPT technique as it necessitates dc voltage as well as dc current [9]. It neither needs prior information of the system nor any mechanical sensors. It is self-regulating and a flexible approach for MPP tracking and has efficient power tracing possessions. The main disadvantage of this technique is it has reduced efficiency compared with other approaches as well as convergence speed.

There are few more MPPT techniques such as Adaptive Neural Network, GNG as well as fuzzy logics are more effective as they can drive for non-linear systems [8]. The only drawback of these approaches are, they want prior training as well as information of the arrangement. From the above model's GNG approach permits to have an MPPT technique that usages the speed controller of the machine as a replacement of its torque controller. GNG network behaves as a virtual anemometer, authorising the wind speed to be expected by the transposition of the turbine model [9]. Once the system progressed, also with minor differences in terms of both machine torque as well as speed, from one of these operational points, the GNG would instantaneously assess the wind speed with consequential convergence in the direction of the MPP. After the MPPT is triggered, the GNG then assessment the wind speed as well as subsequently computes the machine speed, which is related to the MPP.

Particle swarm optimization (PSO), has been used across an extensive choice of applications to discover the comprehensive solutions. It is a computational technique that enhances a problem by iteratively trying to recover an applicant resolution with esteem to a given quantity of quality. The PSO-based MPPT is used to regulate the duty-cycle of the boost converter that interfaces the turbine to the load. As it neither needs a previous information of the system nor mechanical sensors, this algorithm is simple, independent, and flexible. Till now singular algorithms have been compared and their merits and demerits have been focused. The individual procedures drawbacks can be overwhelmed by hybrid methods.

5.0 Conclusions

In this paper, various approaches for extracting maximum power from the wind system have been deliberated. After associating dissimilar approaches for extracting power from the wind system, procedures have improved efficiency as well as provides fast response. P&O and ORB have slow response associated to others. Some procedures such as adaptive model and GNG models presented upward mobility in terms of time response with greater efficiency. In terms of implementation PSO and GNG is more complex than P&O and ORB, but PSO and GNG are accurate than P&O and ORB methods. Now, from these MPPT representations, it has been confined that MMPT give improved efficiency as well as fast time of convergence together with low cost of assembly. All the techniques have been summarised with their qualities as well as drawbacks.

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