A Review on Different Maximum Power Point Tracker (MPPT) Techniques for PV and Wind Systems

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***Abstract*—** Availability of renewable energy resources and their best utilization has now become most preferred research area among power and energy engineers. Due to the most promising features in terms of reliability and efficiency, wind energy can be kept in best corner among all green energy resources which are now being utilized for fulfilling electrical needs. The only negative point that degrades the performance of Wind Energy Conversion System (WECS) in terms of maximum utilization of available power is high variation in wind-velocity (ranging from 3 mts to 15 mts and above). Wind energy system has been widely researched so as to extract maximum active power at all possible wind speeds with least detrimental effects on overall performance of plant/system. Here sequential review on Maximum Power Point Tracking (MPPT) techniques is presented. Direct to concept approach is used to describe each method in a way that must be very useful for the beginners in this area. Proper comparison table and charts are used to summarize the work which makes readers more connected to the content. Criteria selected here for comparing different MPPT methods are efficiency, reliability, accuracy, ease in implementation, tracking speed and cost.

Keywords*-Green Energy, Wind Energy Conversion System Maximum Power Point Tracking Techniques*

I. INTRODUCTION

The existing fossil fuel resources are limited and have a significant adverse impact on the environment by raising the level of CO_2 in the atmosphere and contributing to global warming. Global wind power installations increased by 35,467 MW in 2013, bringing total installed capacity up to 318,117 MW [1]. Thus wind energy growth rate from year to year is consistently increasing showing its promising and reliable nature compared to other renewable sources [2]. Due to continuous changing nature of the wind it is essential to determine the optimal generator speed that ensures maximum energy yield regardless of wind speeds. A lot of research on capturing the largest wind energy is done. The most common control strategy is Maximum Power Point Tracking control (MPPT) in which maximum wind energy can be captured by controlling the output error (specified by algorithm) of the wind generator speed, when the wind speed changes. Kinetic energy carried by air in the form of wind velocity is called as aerodynamic power and serves as actual input for wind energy conversion system (WECS). A WECS differs from a conventional power system as wind speed varies continually throughout the day and makes output of WECS very fluctuating in contrast to conventional fixed input power plants. Wind turbines convert the kinetic energy present in the wind into mechanical power that runs a generator to produce clean electricity. In fixed speed wind turbine generator output is fed directly to the electrical grid but in variable speed wind turbine the generator output is first controlled by power electronic equipments and then fed to the grid so as to match grid frequency and other parameters. Variable speed wind turbine has adjustable speed shaft ensuring maximum power output for each particular wind speed [3], [4]. Blades on wind turbine can also be designed and controlled aerodynamically by varying pitch angle to capture the maximum energy from the wind [5].

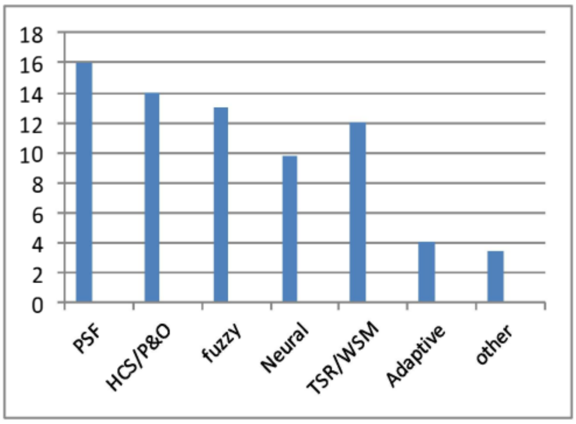


Fig.1. Number of Variations Implemented in Particular MPPT Algorithm

The difference of the proposed variations (Fig.1) in the algorithms lies in the number of sensors required, type or method of generation of the reference signals, convergence speed, complexity, memory requirement, performance under varying wind speeds etc. This paper summarizes all existing MPPT methods highlighting their strength and drawbacks with Comparative analysis using chart table.

II. WIND TURINE AND CONCEPT OF MPPT

The problem associated with WECS is to determine the optimum rotor speed of wind turbine corresponding to each instantaneous wind speed at which energy capture will be maximum. Basically all maximum power extraction methods work on change in turbine's rotor speed with change in wind speed accordingly. Below given mathematical model of wind turbine gives the basis of MPPT techniques.

Power in the air flow is $P_{air} = 1/2\ \rho A v^3$ (1)

Power extracted by the wind turbine rotor

$P_{wt} = C_p . P_{air}$ (2)

The aerodynamic efficiency of a wind turbine is described by the power coefficient function, $C_p(\lambda,\beta)$ is given by

$C_p = P_m / P_w$ (3)

It represents the amount of actual power extracted by the wind turbine over the amount of theoretical power available. The two variables that influence the efficiency are the pitch angle, p, and the Tip Speed Ratio, A. The Tip Speed Ratio (TSR) is defined to be the ratio of the rotor speed to wind speed, and is represented by

$TSR(\lambda) = RW_r / V_w$ (4)

Where; Pwt = Power Extracted by Wind Turbine Rotor (Watts); p = Air Density (Kg/m^3) Cp = Power Coefficient; A =Area Swept by Rotor Blades (m2); Vw= Wind Speed (m/s); W_r= Rotor Shaft Speed (rad/s); R = Radius of Rotor Swept Area (m).Pitch angle is the angle at which the blade is twisted along its longitudinal axis. TSR is defined as the ratio of rotor tip speed to the wind speed. Output generated power is maximum always at a particular TSR, called as optimum TSR (λ_{opt}). At this point power coefficient Cp will also be at its optimum value. Whenever wind speed changes, generator shaft/rotor speed must be varied in such a way so that value of optimum TSR may not get affected.

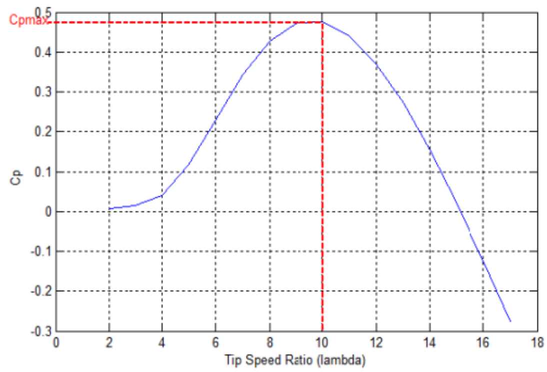


Fig. 2 Cp Vs. A Characteristic

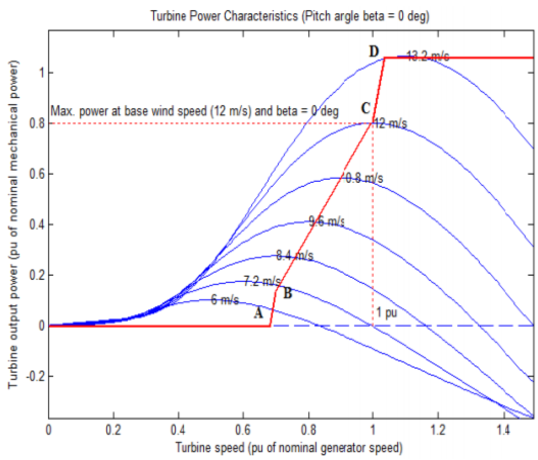


Fig. 3. Wind Turbine Power Vs Generator Speed Curves for Different Wind Velocities

The ABCD curve shows the turbine maximum power characteristics (Fig. 3). Actual speed of the turbine Or is measured and the corresponding mechanical power of the tracking characteristic is used as the reference power for the power control loop. The tracking characteristic is obtained over four points. From zero speed to speed of point A the reference power is zero. Between point A and point B the characteristic is a straight line, the speed of point B must be greater than the speed of point A. Between point B and point C the tracking characteristic is the locus of the maximum power of the turbine. The tracking characteristic is a straight line from point C and point D.

III. MPPT TECHIQUES

In a wider sense all MPPT techniques can be categorized into two types: Sensor based MPPT methods and Senseless MPPT methods based on sensor required for measuring the wind velocity. Further classification is shown in Fig. 4. Sensor based MPPT techniques consists of MPPT methods which uses anemometer to find out the actual wind speed at any instant; like TSR control or Wind Speed Measurement (WSM) technique. Sensor less MPPT technique comprises of algorithms which do not use any device (like anemometer) to measure wind velocity for extracting maximum power. Either they use indirect methods for it or may use separate algorithms which do not even require knowledge of wind speed at all.

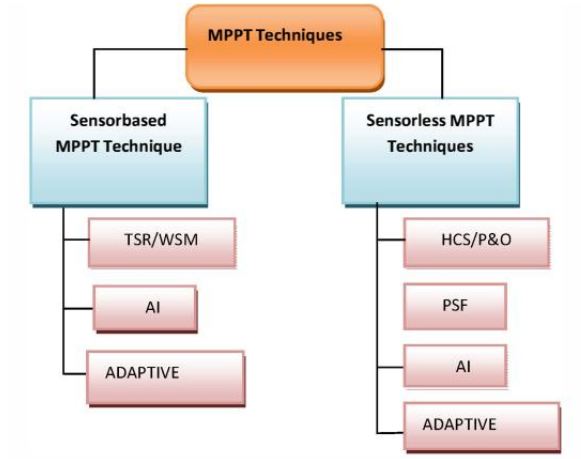


Fig. 4. Classification of MPPT Techniques

Artificial Intelligence technique; comprising application of fuzzy logic, Neural Network (NN) approach and adaptive methods can be placed in either of categories as they may or may not use sensors for wind speed measurement depending on particular algorithm being used.

A. Sensor based MPPT Techniques

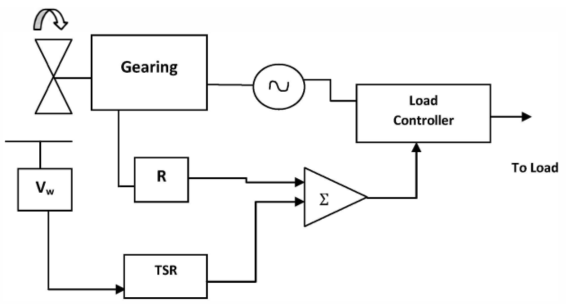


Fig. 5: Sensorbased MPPT Control with TSR/WSM Method

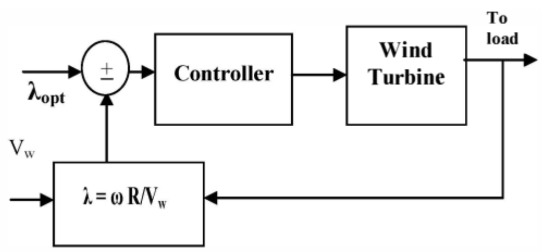


Fig. 6: Tip Speed Ratio Control of WECS

The TSR method controls the rotor speed of the generator in order to maintain the TSR to an optimum value at which maximum power is reached. Fig.5 shows the block diagram of a WECS with TSR control. In this, wind speed is measured locally via anemometer as shown in Fig. 5. The optimal/reference TSR for a given wind speed is obtained from the turbine's 'Power vs. Rotor Speed' characteristics (given by manufacturer). After that the optimal rotor speed or turbine speed is determined using the reference TSR. This method is also known as Tip Speed Ratio Method or Wind Speed Measurement method (WSM).

Advantage: These methods give simple, cheap and reliable control. Drawback: In this method additional sensors for measuring wind speed increases cost, size and weight of overall wind system. Frictional errors are induced due to anemometer which may increase inaccuracy in results.

B. Sensor less MPPT Techniques

Sensor less technique are more reliable, efficient, fast and cost-effective compared to sensor based [6]. These MPPT algorithms can be categorized mainly into two types; Power Signal Feedback (PSF) or look-up table based method and Hill climb search (HCS) or Perturb & Observe (P&O) method. These methods do not require measurement of wind speed via anemometer. To converge the power at the maximum point, firstly optimum TSR is obtained by adjusting rotor speeds. For this purpose some rules are developed to control the shaft speed.

1) Power Signal Feedback (PSF)

In PSF control algorithm maximum power vs rotor speed graph is necessary which can be obtained by simulations/tests performed on individual wind turbines. Now reference speed is obtained from this curve for particular rotor speed [7]. A lookup table can be used here to track maximum power corresponding to actual turbine speed.

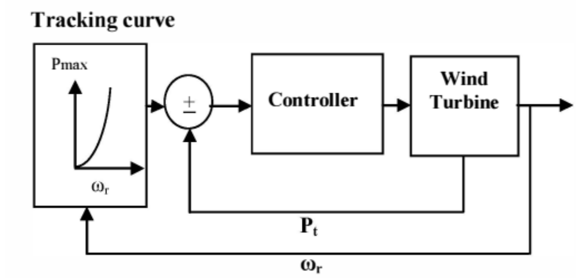
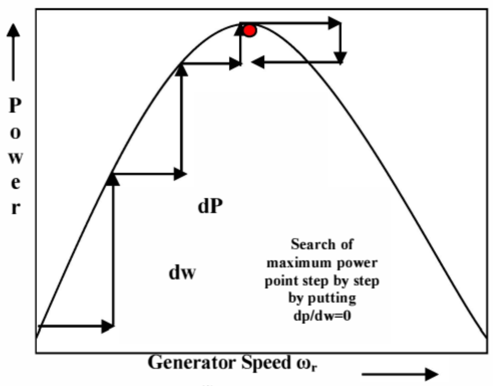


Fig. 7. Power Signal Feedback Control

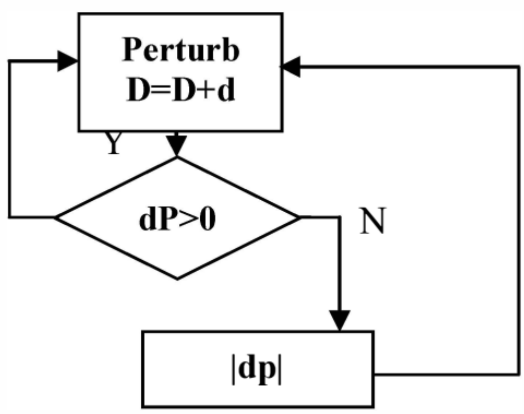
Advantages: By PSF method reference rotor speed cannot be determined instantaneously for change in wind speed as sudden change in wind velocity may not cause a sudden change in generator speed too. Drawback: PSF control requires excessive pre knowledge of turbine and generator speed. Thus the number of sensors and the control complexities are increased.

2) Hill Climb Search (HCS)

Above mentioned difficulties can be fixed by the HCS control algorithm which is based on continuous search for the peak power of the wind turbine.



(i)



(ii)

In this algorithm, desired optimum signal to drive the system to maximum power point depends on the location of the operating point and ratio of change in power and speed, at each search step [8]. See Fig. 8 (i). Fig. 8. (i) HCS MPPT Graph (ii). HCS MPPT Flow Chart Advantages: This method is independent from turbine or wind speed knowledge. It is simple, flexible and cost effective. It requires no memory hence is preferred most. Drawbacks: It works well only when the wind turbine inertia is small so that turbine react instantaneously to wind speeds (not true for MW wind turbines), also it needs several sampling steps hence tracking speed is slow generally.

3) Artificial Intelligent (AI) Methods

Advancements in microcontroller technology has made **Fuzzy Logic Control (FLC)** and Neural Network (NN) control popular in the field of wind energy maximum power control [19].

C. FLC

In fuzzy logic controllers, reference signal is generated by a set of if-then rules applied on fuzzy real time data. FLC may follow two types of algorithms for its implementation. First one is the indirect fuzzy MPPT control and second is direct fuzzy MPPT control In indirect control the output of fuzzy logic controller is generated with reference to another control block [12]. The second one is the indirect fuzzy MPPT control. In this output of fuzzy logic controller is the duty cycle for boost chopper or PWM index modulation which regulates fringe of controlled rectifier /dc-dc converter (boost) switch directly [17]. Fuzzy logic control has three stages: fuzzy-fication rule base table lookup, and de fuzzy-fication.

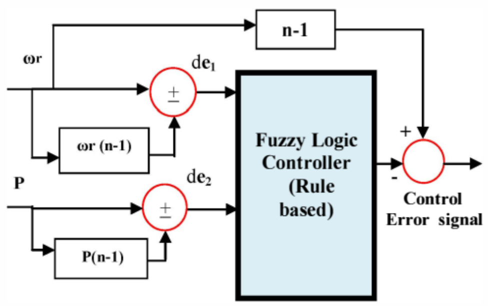


Fig. 9. FLC Generating Reference Rotor Speed for Wind MPPT

In the fuzzy-fication stage, input variables are converted into linguistic variables based on a membership function. Based on input, a rule base lookup table is obtained by prior knowledge of the response of system for various errors. In defuzzyfication step, output of FLC is again converted from a linguistic variable to a numerical value by the use of another membership function [15].

Advantages: It doesn't need knowledge of system parameters or equations. It gives much faster and efficient tracking of maximum power point. It is insensitive to parameter variations. It can also accept noisy and inaccurate signals.

Drawbacks: It may require speed sensors. Here main problem is to define an optimal set of rules and control actions. It is complex and requires rapid calculation which makes overall process slow. Error signal chosen as input and membership functions also must be selected very carefully to get right response.

D. Neural Networks

Neural Network has three layers: input, hidden and output layers and the number of nodes in each layer can be varied [24]. The input variables can be wind speed, pitch angle, rotor speed etc. The output may be a reference signal like duty cycle or reference rotor speed used to drive the power converter for getting maximum power point. NN principles may be used to estimate the wind velocity and generate reference rotor speed from predefined lookup table [23], [24]. Also maximum power can be tracked by controlling pitch angle of wind turbine blades using NN based pitch angle controller which further generate controlled firing angle signals to the converter switches/ chopper accordingly. A typical example of estimating wind speed using ANN is described below in Fig. 10.

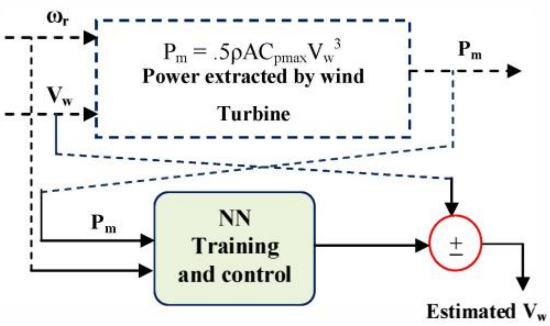


Fig. 10. ANN Controller to Estimate Wind Speed

Here, NN is used to determine the reference output power based on the average wind speed obtained fom anemometer, the measured wind speed and the past output power is the input data here for NN controller [22]. Advantages: If sufficiently trained, ANN based control can be quite effective for all kinds of operating conditions [23], [24]. It gives simple, cost effective, fast and reliable tracking of optimum rotational speed. Drawback: For the real time/field applications, long offline training makes ANN unappealing. At wind speeds higher than rated generator power, system may go out of MPPT mode and output power remains at its nominal value, as it is not possible to train ANN above the rated power of generator for real time applications.

DISCUSSION

From above explanation it can be said that now a day's emphasis should be on sensor less methods that do not impose many restrictions. Development of several modem techniques has extended the use of artificial neural network and fuzzy logic controllers towards the maximum power extraction from wind energy systems but still need improvement. All MPPT algorithms are summarized in short in below given table highlighting their pros and cons,

Table 1: Comparison of MPPT Techques

MPPT Methods	Design intricacy	Wind Speed Sensor	Memory level	Performance at varying wind speed	Track - ing Speed
TSR/WSM	Medium	Yes	Zero	Very Good	Fast
PSF	Simple	No	Low/ Med.	Good	Fast
HCS	Simple	No	Zero	Average	Slow
FLC	High	Depends	High	Very Good	Fast
NN	High	Depends	High	Very Good	Fast
Adaptive	High	Depends	High	Very Good	Med.

CONCLUSION

A brief review on almost all existing MPPT techniques published has been researched in this paper with their strengths and drawbacks. A number of variations are there that may use combination of one or more MPPT techniques at a time. A table comparing the important characteristics of all popular algorithms can fix the problem of users in selecting appropriate technique as per their requirement and needs.

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