Relative Study of MPPT Algorithms using Wind Turbines with Different Dimensions

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Abstract
Wind energy is considered as a most reliable and developed renewable energy source. With the rapid growth in this area, new techniques and control are seen to achieve maximum utilization of wind power and operating the wind turbine (WT) at its optimal condition. Various maximum power point tracking (MPPT) algorithms are available; however, a choice has to be made for the appropriate one as each algorithm has its own merits and demerits. This paper presents the comparison of three MPPT control algorithms: Tip speed ratio (TSR), Hili c1imb search (HCS) and Fuzzy based MPPT algorithm on three different size turbines of different power rating, in terms of their ability to extract maximum power output, number of iterations required i.e. speed responses and complexity using MATLAB. The results obtained in this paper may help the researchers to refer a suitable algorithm for their requirement.
Keywords-*Maximum Power Point Tracking; Wind Turbine Characteristics; Tip Speed Ratio; Hili Climbing Search; Fuzzy Logic Control.*

1.INTRODUCTION

Rapid growth in power electronics techniques has made wind energy more interesting and reliable for power generation. Through power converters, the power in the wind can easily be converted to a stable power supply [2]. For any system the efficiency plays a major role in deciding the worth for setting that generation plant to get maximum profit and ensuring a reliable power supply. The techniques for increasing the power output of a wind turbine are necessary. Fig.1 shows the power (P) and rotational speed (w) characteristic curve at different wind speed. The maximum power curve is also shown in the figure through dotted lines that need to be tracked to achieve optimum operating point. The region between cutin wind speed to rated wind speed is the region where wind turbine controller operates to extract as much power as possible through MPPT algorithms [5,6]. Thus, MPPT algorithm is needed to be implemented within this region [1]. In MPPT strategies, the wind turbine rotational speed is adjusted as wind speed changes in order to track the maximum power point [4]. Many algorithms have been developed by the researchers for the optimum wind power extraction. Some of the common MPPT algorithms are:

- Optimal torque based Hili c1imbing search
- Tip speed ratio
- Power signal feedback
- Hybrid mppt algorithm

This paper presents three MPPT algorithms and each of them are compared and analyzed for three different size turbines. The first type is Tip speed ratio (TSR) algorithm which requires an anemometer. This control method adjusts the wind turbine rotational speed in order to maintain the optimal tip speed

ISSN: 2005-4238 IJAST

ratio which the change in wind speed. This optimal tip speed ratio corresponds to the maximum power coefficient. The second type is Hili c1imbing search (HCM) algorithm which is one of the sensor less method to locate maximum power point. It basically has a control variable which is adjusted in some step-size and the changes are observed in the objective function until the slope becomes zero. Apart from the above two conventional method used in this paper, the third type is Fuzzy control based MPPT algorithm which is based on variable step-size control of wind turbine rotational speed as wind speed changes

This paper gives a brief introduction on wind turbine characteristics and MPPT algorithms. Case studies are done by analyzing each MPPT algorithm on three different size turbines. The main contribution of this paper is to know the appropriate algorithm for each turbine with the changing wind speed and its speed response.

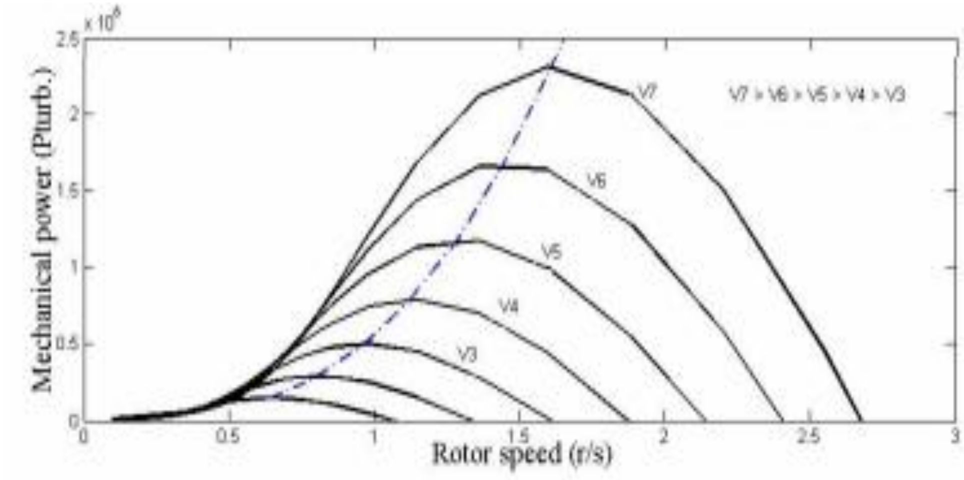

Figure. 1: Wind Turbine P-w Characterstics and the Trajectory Shows Maximum Power Tracking

2. CLASSIFICATION OF MPPT ALGORITHMS

The two broad classes of MPPT techniques used in wind energy conversion systems are

1) sensor-based methods and
2) sensorless 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 ceratin 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.

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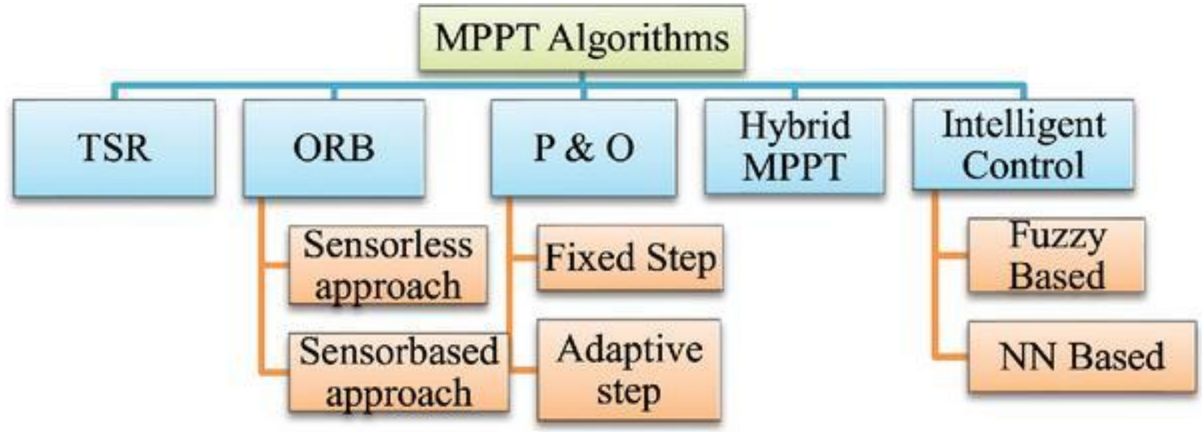

Figure 2. MPPT algorithms

2.1 Tip Speed Ratio (TSR) MPPT Algorithm

In the TSR control method we keep the tip speed ratio to an optimal value for which the power coefficient is maximum and so the power extracted is maximized by regulating the rotational speed of the turbine. In this method the tracking process needs the turbine characteristics. The value of optimal rotati on al speed is given by:

$$w_{opt} = \frac{\lambda_{opt}}{v} * R \qquad (3)$$

The value of Λopt (optimal tip speed ratio) can be substituted in equation (1) to obtain the maximum power output, as given in equation (4).

$$P_{turb,max} = \frac{1}{2} \cdot \frac{C_{p,max}}{\lambda_{opt}} . \rho . \Pi . R^5 . w^3 \qquad (4)$$

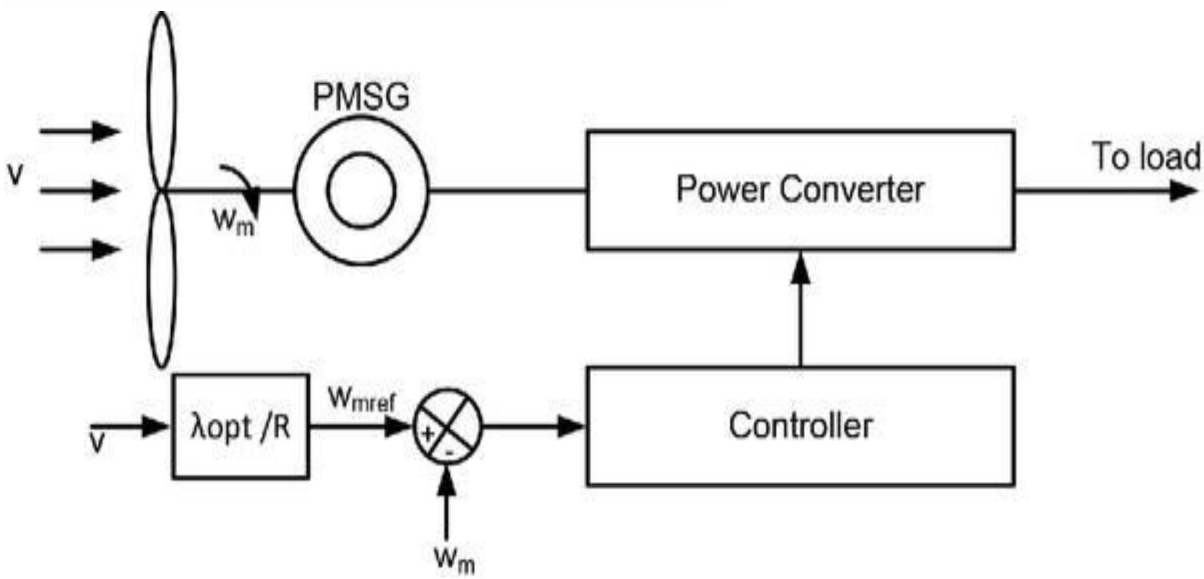

Figure 3. Tip Speed Ratio Control.

2.2 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.

2.3 Hili Climbing Searching ,Method (HCM) MPPT Algorithm

The basic methodology of hill climbing search algorithm is to detect the slope of power VS rotor speed curve. Here the control variable is the turbine rotational speed which is adjusted in small step-size to obtain maximum power point. With the change the wind speed, the rotor speed needs to be adjusted to track the maximum power else the efficiency of turbine will decrease. For increase in wind speed, the turbine rotati on al speed is increased. If the value of mechanical power also increases then the slope is positive which shows that the search process is in the correct direction. If the power is decreased from its previous value then the search will be in the opposite direction. This control method continues until the slope becomes zero.

The flow chart for HCM algorithm is given in the Fig. 4.

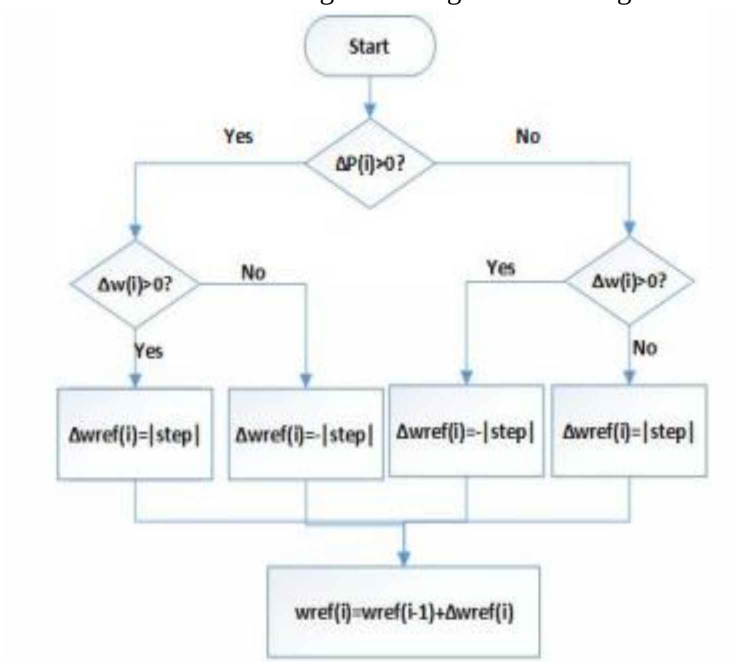

Figure 4: Flow Chart for HCM MPPT A1gorithm

2.4 Fuzzy Contral based MPPT Algorithm

The fuzzy based control algorithm tracks the maximum power point by determining a reference value of rotational speed through variable step size control. As shown in figure5, the inputs given to the fuzzy controller are the LiP and Liw, where LiP is the change in the mechanical power and Liw is the variable step size applied for that change in power. The reference rotational speed Liwrer is the output variable of the fuzzy control which is calculated from the fuzzy rules. Through this fuzzy based algorithm, the step

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size can be large when the operating point is far away from the maximum power point (MPP) and will keep on decreasing as we approach close to the MPP.

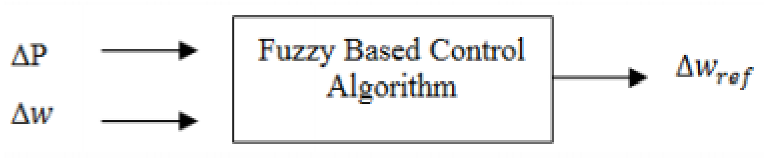

Figure 5: Block Diagram of Fuzzy Control Toolbox
The fuzzy controller is characterized by its input variables, output variables, membership functions and fuzzy rules. The fuzzy rules implement if-then operation with the help of 'AND' operator. The input variables can be expressed as:

$$\Delta P(i) = P(i+1) - P(i) \quad (5)$$
$$\Delta w(i) = w(i+1) - w(i) \quad (6)$$

The membership functions of input and output variables are defined as follows in trapezoidal form: there are seven membership functions for input variable ΔP(i): NL (negative large), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (positive medium), PL (positive large) as shown in fig.4 and three membership functions for Δ w(i): N (negative), Z (zero), P (positive) as shown in fig.7.

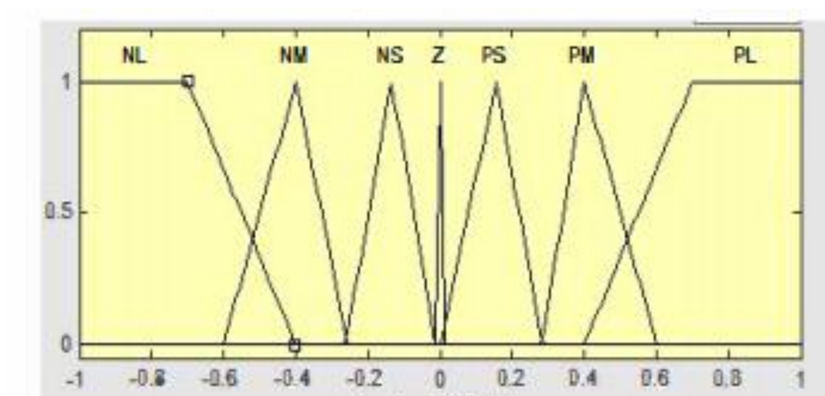

Figure 6: Membership Functions of input Variable ΔP (i)

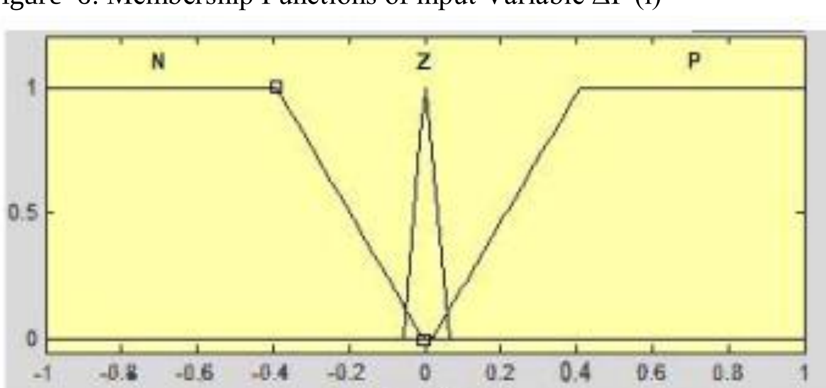

Figure 7: Membership Function of input Variable Δ weil

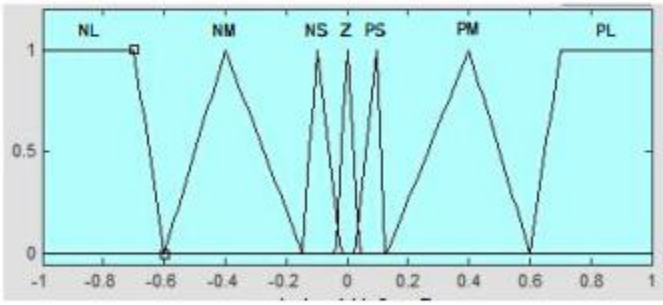

Figure 8: Membership Function o Output Variable Δwref

The membership functions for output variable LiWret are same as that of LiP i.e. NL, NM, NS, Z, PS, PM, PL shown in Fig. 6. The fuzzy rule basically depicts the nature of output variable, derived from the system behavior. It uses If-Then rwes, AND operator to get the reference value of rotational speed in such a way that it always achieves the optimal operating point. Thus it reduces the time response of the system.

Table1. Show the rwes of fuzzy controller.

Δw	ΔP						
	NL	***NM***	***NS***	***Z***	***PS***	***PM***	***PL***
N	PL	PM	PS	NS	NS	NM	NL
Z	NM	NS	NS	Z	PS	PS	PM
P	NL	NM	NS	PS	PS	PM	PL

Table 1: Rules For Fuzzy Controller

3.WIND TURBINE CHARACTERISTICS

The mechanical power extracted by the wind turbine, Pturb is given in equation (1). The power depends on rotor swept area, power coefficient, wind speed and air density.

$$P_{turb} = \frac{1}{2}.C_p(\lambda,\beta).a.\rho.v_w^3 \qquad (1)$$

Where C_p = power coefficient
ρ = air density
a = rotor swept area
λ = tip speed ratio
β = pitch angle
v_w = wind speed

The tip speed ratio can be expressed as

$$\lambda = \frac{w_t}{v_w} * R \qquad (2)$$

Where w_t = turbine rotational speed
R = turbine radius

4.CASE STUDIES

Three wind turbines of different sizes are taken for simulation results and each turbine is implemented with all the three algorithms discussed above. The wind speed is increased linearly from its cut-in to rated

ISSN: 2005-4238 IJAST

value and the maximum power is tracked by finding the optimal rotational speed value with the help of algorithms. This case study may help the future researchers to go for the suitable algorithm for a particular turbine as per their requirements.

Sometimes the maximum power extraction is more important rather than the time taken by the system and on the other hand a slight compromise may be done regarding the power generation but speed of the response is required to be fast.

4.1 Case 1

In first case we take a small size turbine of Vestas of radius R=13.5m, 225 KW. The MPP is tracked for this turbine by all the three algorithms, TSR, HCS and Fuzzy. Table 2 shows the value of optimal rotational speed Wpp (radian per sec.) and the maximum power extracted Pmax (W) obtained through each algorithrn.

	MPPT Algorithms					
Wind Speed (v)	TSR MPPT Algorithm		HCM MPPT Algorithm		Fuzzy based MPPT Algorithm	
	w_{mpp}	P_{max} (W)	w_{mpp}	P_{max} (W)	w_{mpp}	P_{max} (W)
4	2.223	10590	2.453	10760	2.426	10778
5	2.778	20690	3.032	21050	3.022	21055
6	3.334	35750	3.651	36370	3.57	36382
7	3.889	56760	4.225	57750	4.182	57784
8	4.44	84730	4.836	86240	4.786	86252
9	5	120640	5.420	122810	5.399	122810
10	5.56	165490	6.049	168430	5.965	168450
11	6.12	220270	6.35	224180	6.27	224190
12	6.67	285970	7.02	291060	6.94	291120
13	7.23	363590	7.50	370060	7.42	370090
14	7.78	454110	8.05	462210	7.97	462230

Table 2: Mppt Of Turbine I (R=13.5m)

4.2 Case 2

In the second case we take a medium size turbine of GE (General Electric) of radius R=50m, 2 MW. As shown in Table 3, the three MPPT algorithms are used to find the maximum power extraction Pmax (W) by this turbine and its optimal rotational speed wmpp (radi an per sec.) required for it.

	MPPT Algorithms					
Wind speed (v)	TSR MPPT Algorithm		HCM MPPT Algorithm		Fuzzy based MPPT Algorithm	
	w_{mpp}	$P_{max}(W)$	w_{mpp}	P_{max} (W)	w_{mpp}	P_{max} (W)
4	0.644	147800	0.648	147800	0.647	147800
5	0.805	288600	0.811	288640	0.810	288644
6	0.966	498700	0.971	498770	0.97	498770
7	1.127	791900	1.133	792030	1.126	792040
8	1.288	1182100	1.295	1182300	1.29	1182300
9	1.449	1683200	1.457	1683400	1.44	1683410
10	1.61	2308900	1.619	2309100	1.60	2309105

TAble 3: Mppt Of Turbine 2 (R=50m)

4.3 Case 3

In the third case the turbine Sea-Titan, large rotor size of radius R=95m, 10 MW is taken for the analysis. The rated wind speed of the turbine is Ilm/s at which it will give the rated power. Through MPPT techniques the maximum power is extracted and the rated power can be achieved at a much lower wind speed. Table 4, shows the maximum power output Pmax (KW) and the rotation al speed wmpp (radi an per sec.) with increase in wind speed.

Wind speed (v)	MPPT Algorithms					
	TSR MPPT Algorithm		HCM MPPT Algorithm		Fuzzy based MPPT Algorithm	
	w_{mpp}	P_{max} (KW)	w_{mpp}	P_{max}	w_{mpp}	P_{max}
4	0.3158	524	0.3398	533.48	0.3318	533.48
5	0.3947	1024	0.4258	1042	0.4178	1043
6	0.4737	1769	0.5108	1800	0.503	1805
7	0.5526	2809	0.597	2859.2	0.589	2860.2
8	0.6316	4193	0.682	4268	0.674	4269
9	0.7105	5970	0.7675	6076.9	0.767	6076.8
10	0.7895	8189	0.8527	8336	0.8447	8336.52
11	0.8684	10899	0.938	11095	0.93	11096.5

T Able 4: Mppt Of Turbine 3 (R=95m)

From simulation resuIts it can be obtained that:

TSR algorithm is not preferable for small size and low rating wind turbine. Although, it can be used for MPPT of medium and large size turbines.

- HCM algorithm gives good results for all types of turbines but due to fixed step-size they are not implemented when the response of the system is required to be faster.
- Fuzzy based MPPT algorithm is preferable over the other two control methods as the number of iterations required is less. For all the three type of turbines, this method gives best results irrespective of the dimension and rating of the turbines.

5. CONCLUSION

This paper gives a brief introduction and comparison of three algorithms i.e. TSR, HCM and Fuzzy based MPPT control. All the three algorithms are analyzed on three turbines of different sizes and ratings to search the suitable MPPT technique for each turbine giving the best optimal resuIts. Both the accuracy and speed are required for the good working of a turbine. The rate and the precision of obtaining the optimal rotational speed as the wind speed changes are the main performance indices analyzed in this paper. The results are obtained through MA TLAB software and are listed in the tables showing the value of rotational speed and power extracted with the help of MPPT algorithms.

The TSR algorithm requires the turbine parameters to evaluate the MPP, which may, not always available. For small size the turbines the power extracted by TSR algorithm is lower as compared with the rest of the two algorithms. HCM and Fuzzy based MPPT algorithms are more preferable due to their simplicity and independence of system characteristics and thus they are more rapid and efficient. For any wind turbine the best results can be seen obtained by Fuzzy based MPPT algorithm which realizes the variable step-size and achieves both tracking speed and maximum power output. The step-size dynamically changes with the change in wind speed that helps the turbine to get maximum power quickly and smoothly. Although for the medium and large size turbines, the power extraction by HCM and Fuzzy control are almost same but due to variable step-size in Fuzzy algorithm, the number of iterations required to track the MPP is much lower and thus can be obtained more quickly.

REFERENCES

1. D. Kumar and K. Chatterjee, "A review of conventional and advanced MPPT algorithms for wind energy systems," Renewable and sustainable energy reviews, vol. 55,20 I 6, pp. 957-970.
2. A. Mirecki, X. Roboam, and F. Richardeau, "Comparitive study of maximum power strategy in wind turbines," IEEE Trans. Ind. Electronics, vol. 2,2004, pp. 993-998.
3. T. Thriringer, and J. Linders, "Control by Variable Rotor Speed of a Fixed-Pitch Wind Turbine Operating in a Wide Speed Range," IEEE Trans. On Energy Conversion, vol. 8, 1993, pp. 520-526.
4. M. Simoes, B. Bose, and R. Spiegel, "Fuzzy logic based intelligence control of a variable speed cage machine generation systems," IEEE Trans. On Power Electronics, 1997, pp. 87-95.
5. E. Koutroulis, and K. Kalaitzakis, "Design of a maximum power tracking system for wind-energy conversion appl ications," IEEE Trans. On Industrial Electronics, vol. 53,2006, pp.486-494.
6. R. Datta, and V. T. Ranganathan, "A method of tracking the peak power points for a variable speed wind energy conversion system," IEEE Trans. On Energy Conversion, vol. 18,2003, pp. 163-168.
7. R Majumder, I Mukherjee, B. Tudu and D. Paul. "Review on feasibility of wind energy potential for India." International conference on non-conventional enrgy,16-I7 Jan. 2014, pp. 190-192.
8. D. Ting, S. Bin and S. Sheng-wen. " Study on the wind energy resources assessment in wind power generation." International conference on artificial intelligence, management science and electronic commerce,8-10 Aug. 201 I, pp. 6804-6807.
9. D. Thanh and M. H. Rashid. " Introduction, history, and theory of wind power." North american power symposium, 4-6 Oct. 2009, pp. 1-6.
10. R. Billinton and H. Chen. " Effect of wind turbine parameters on the capacity adequacy of generating systems using wind energy." IEEE conference on communications, power and computing, 22-23 May. 1997, pp. 47-52.

ISSN: 2005-4238 IJAST