Design and comparison of MPPT based oscillatory wind turbine with conventional wind turbine

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ABSTRACT. The advantages of renewable energy resources encourage to implement an alternative for clean power generation. This paper presents design of a new oscillatory wind turbine which works on the principle of vortex vibrations. The power extracted from the oscillations is fed to Maximum power point tracking (MPPT) with fuzzy proportional derivative integral (PID) controller to track maximum power all the times. The resultant duty cycle of the MPPT with fuzzy PID controller is used for switching operations of high gain step up converter to boost up the voltage. A three level inverter has been used for DC-AC power conversion and the obtained electrical energy can be used for residential and commercial applications. In this paper a comparison has been made between power obtained from the conventional horizontal axis wind turbine, oscillatory wind turbine without MPPT & with MPPT for different wind speeds. The designing of the energy system and the results are verified using MATLAB simulink.

RÉSUMÉ. Les avantages des sources d'énergie renouvelables incitent à mettre en œuvre une alternative pour la production d'énergie propre. Cet article présente la conception d'une nouvelle éolienne oscillante qui fonctionne sur le principe des vibrations vortex. La puissance extraite des oscillations est introduit dans le suivi de point de puissance maximale (MPPT) avec un régulaeur flou intégral dérivé proportionnel (PID) pour suivre la puissance maximale de tous les temps. Le cycle de travail résultant du MPPT avec un régulaeur flou PID est utilisé pour les opérations de commutation du convertisseur élévateur à gain élevé afin d'augmenter la tension. Un onduleur à trois niveaux a été utilisé pour la conversion de puissance DC-AC et l'énergie électrique obtenue peut être utilisée pour des applications résidentielles et commerciales. Dans cet article, une comparaison a été faite entre la puissance obtenue d'une éolienne à axe horizontal conventionnelle, d'une éolienne oscillante sans MPPT et avec MPPT pour différentes vitesses de vent. La conception du système énergétique et les résultats sont vérifiés à l'aide de MATLAB simulink.

KEYWORDS: oscillatory wind turbine, perturb and observe maximum power point tracking (MPPT), fuzzy PID controller, conventional wind Turbine.

MOTS-CLÉS: éolienne oscillante, perturbation et observation de points de puissance maximale (MPPT), régulateur flou PID, éolienne classique.

1. Introduction

Now a days there is a huge growth in power consumption, leading to diminution of conventional sources and increase in the pollution around the world. So a solution is required which provides power unlimitedly and leading to clean power production results in usage of renewable energy sources. As it is known there are number of renewable energy sources like wind, solar, tidal, biomass, etc., wind has advantages like clean, unlimited, environmental friendly and so wind is considered as a source for power production. Conventional horizontal axis wind turbine has been in usage for a number of years but it is not around the world because of huge investment, higher wind speed requirement, larger space requirement. So a system using wind advantages, eradicating its disadvantages has to be implemented.

Vortex based structural vibrations (Manfrida *et al.*, 2016; Heinz *et al.*, 2016; Ruscheweyh, 1994) is one of the new technology in which a structure vibrates with the passage of wind and these vibrations or oscillations of the structure can be converted to required form of energy. Among the number of oscillatory energy conversion devices like piezo electric cells, linear alternator, crack and pinion mechanism, an AC transducer (Baidwan and Kumar, 2015) has advantages like low cost, high power conversion, accuracy. As wind conditions (Wang, 2013; Cannistraro *et al.*, 2017) vary all the times and so to utilize the power all the times battery has been used for storage. To achieve maximum power for varying wind conditions an MPPT Controller (Ali, 2016) can be used. But to achieve fast dynamic response fuzzy PID technique (Arulmurugan and Vanitha, 2013; Swain *et al.*, 2016; Bouchakour *et al.*, 2015) is attached to MPPT controller .The energy obtained from the oscillatory system may not be sufficient to run AC loads and to boost up the voltage to the required value high gain step up converter (Shuklal and Shrivastava, 2015) has been used in place of conventional boost converter having its own disadvantage like higher duty cycle requirement for larger voltage boosting. This boosted DC power can be converted to AC power using conventional inverter but it has disadvantages like larger THD, higher filter value requirement and so a three level inverter (Joshi and Agrawal, 2014) with less number of switches has been used.

The paper is organized as follows; the first section of the paper is dealing with the explanation of proposed oscillatory wind turbine. The second section explains MPPT with fuzzy PID controller and the third part discusses with the software realization of proposed system, results and discussion of the proposed system and the fourth part deals with the conclusion.

2. Proposed oscillatory wind turbine

The proposed oscillatory wind turbine which is shown in figure 1 works on the phenomenon of vortex based structural vibrations where the structure can be of any shape which is considered as tapered cylindrical structure because of symmetrical axis resulting in larger oscillations.
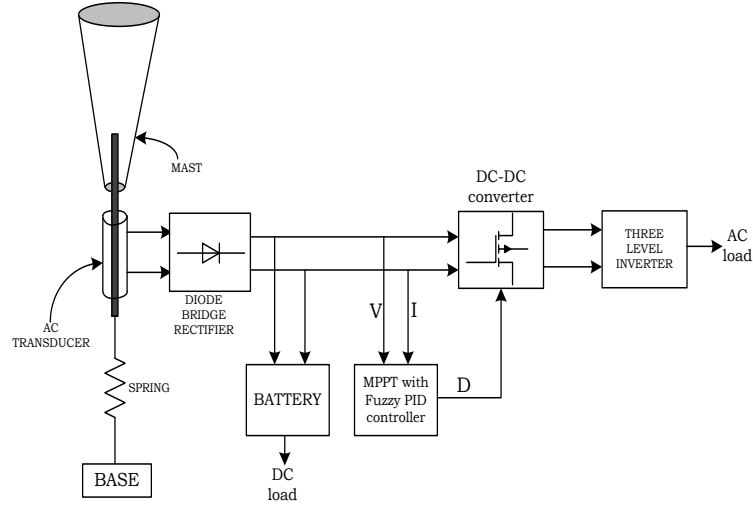
Figure 1. Block diagram of proposed oscillatory wind turbine

When wind passes over the cylindrical structure vibrations are induced within the body and alternating lift forces (Manfrida *et al.*, 2016) are developed around the structure which can be given as

$$F_{Lift} = 0.5 \, \rho U^2 \, A_S \, C_{Lift} \, \sin(\, w_v \, t + \Phi \,)$$

(1)

These alternating lift forces around the structure causes the structure oscillate and the resultant displacement of the structure can be given as

$$X = \frac{F_{Lift} - m\ddot{x}}{K}$$

(2)

A rod is placed within the structure attached to the transducer. Transducer is identical to the transformer but with two secondary windings consisting of magnetic core displaces with the structure and energy is induced in the two secondary windings.

Where X is the displacement, U is the wind speed, K is spring stiffness, ϕ is the phase angle between structure and wind direction.

The resultant energy out of the transducer (Baidwan and Kumar, 2015) can be expressed as

$$V_{outAC} = \frac{V_{inAC} \ (T_{sec} C \ (L_S{}^2 - L_P{}^2 \ ))}{(4 \, b_s \, T_{pri} \, C_T \ )} \tag{3}$$

This AC energy is converted into DC using diode bridge rectifier and fed to the battery for storage. But for general usage this energy is not sufficient and so high step up boost converter is used to boost up the converted oscillatory energy and the related expression can be

$$\frac{V_{outDC}}{V_{inDC}} = \frac{3+K}{2-2K} \tag{4}$$

This DC energy is converted to AC using three level inverter and can be used for residential and commercial applications.

Where T_{sec} is the number of turns of secondary winding, T_{pri} is the number of turns of primary winding, C_T is the total magnetic conductance.

3. MPPT controller

As it is known that wind is not constant and so to constant power may not be obtained from the system all the times. So a controller which tracks the maximum power has to be designed which is Perturb & observe maximum power point tracker. But at the same time fast and dynamic response is also required and so fuzzy with Proportional integral derivative controller (PID) is attached to the MPPT controller which continuously tracks maximum power based on all the environmental conditions.

The proposed MPPT with fuzzy PID controller is shown in below figure 2.
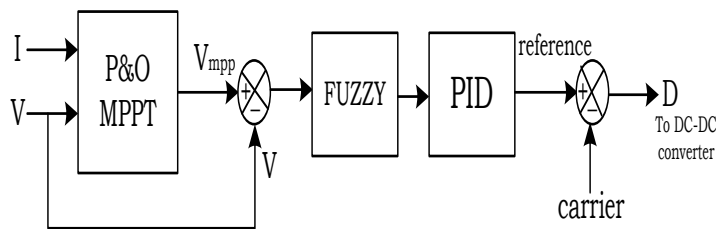

Figure 2. Block diagram of MPPT with fuzzy PID controller

The DC values of voltage and current are collected from the diode bridge rectifier, fed to the controller and the resultant generated duty cycle is fed to the high gain step up converter. The flow chart explaining the step by step operation of the MPPT with fuzzy PID controller is shown in below figure 3.
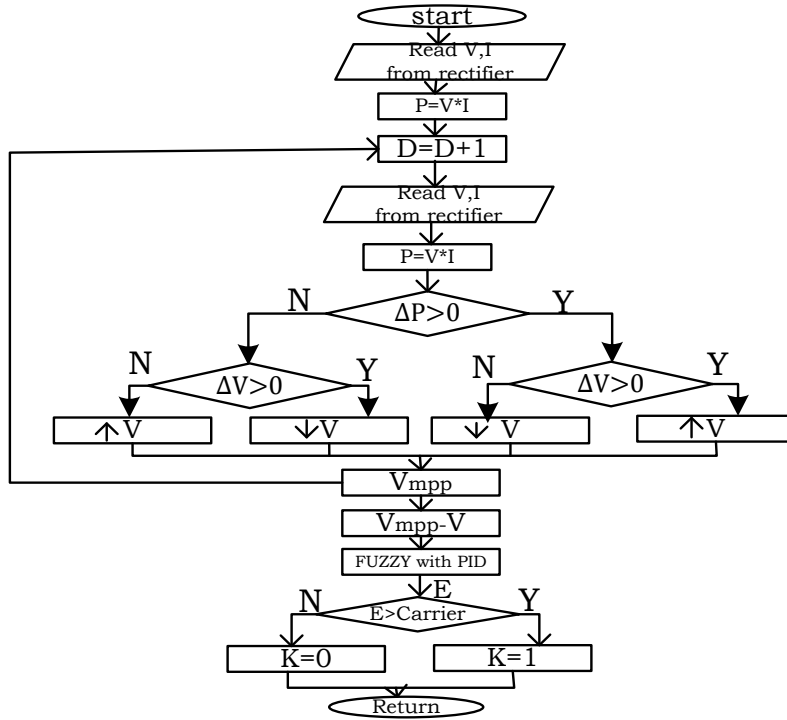
Figure 3. Block Diagram of MPPT with Fuzzy PID controller

The operation of MPPT with Fuzzy PID controller is explained in the following steps

i.) Read DC values of voltage and current from the diode bridge rectifier and fed to the perturb and observe tracker which tracks the maximum power until it is obtained with a number of perturbations and with a particular step size and the resultant is maximum voltage V_{mpp} which is maintained maximum at all the wind conditions.

ii.) This V_{mpp} is compared with the voltage from the diode bridge rectifier and the error is fed to fuzzy PID controller which processes the error with fuzzification and defuzzification.

iii.) This processed error is compared with the carrier and generates duty cycle for high gain step up converter.

The following are the fuzzy member ship functions for input and output in which seven membership functions are considered for the two inputs and rule base was constructed based on the membership functions and respective output membership functions are generated.
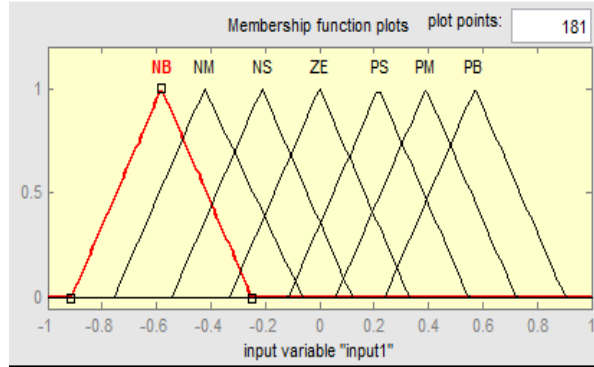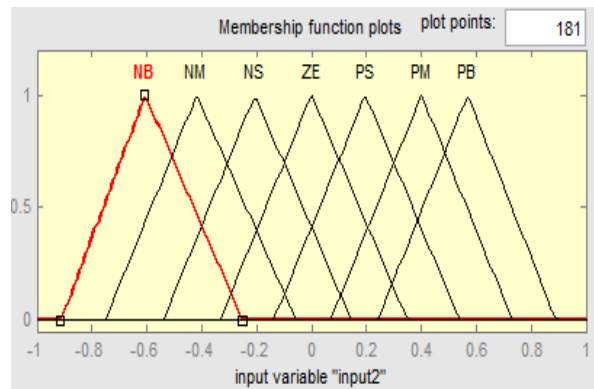
Figure 4. Input-1 membership function

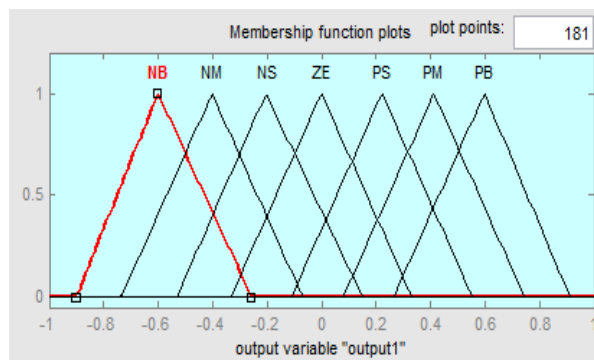*Figure 5. Input-2 membership function*

Figure 6. Output membership function

4. Results and discussion

The proposed oscillatory wind turbine is simulated using MATLAB simulink and the following are the obtained results.

When the structure is passed by the wind due to vortex action it displaces and the value of displacement done by the structure is given in figure 7 for different wind speeds as 05m/s,1m/s,1.5m/s,2m/s where 2m/s is considered as running wind speed.
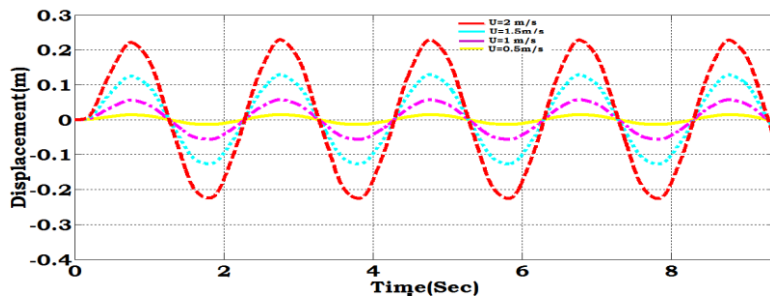
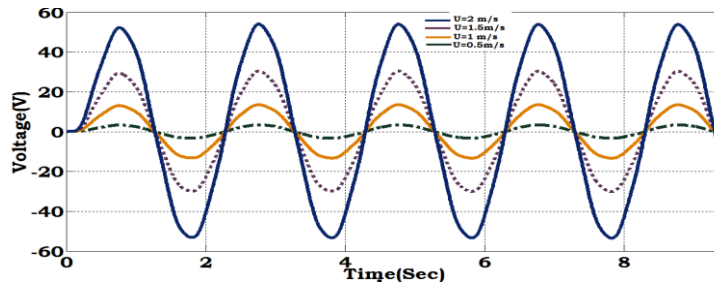*Figure 7. Displacement made by the structure for different wind speeds*

Figure 8. Output voltage of transducer

The above figure 8 shows the voltage obtained from AC transducer which is 52V AC.
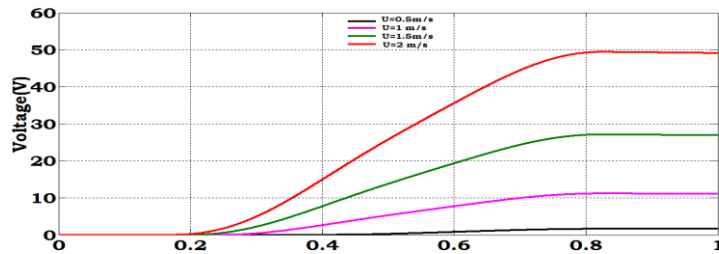

Figure 9. Output voltage of diode bridge rectifier

The above figure 9 shows the voltage obtained from Diode Bridge Rectifier which is 49V DC.
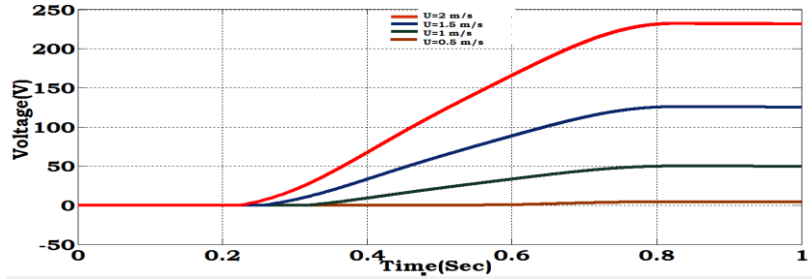

Figure 10. Output voltage of high gain step up converter with out MPPT

The above figure 10 shows the voltage obtained from high gain DC-DC converter which is 230V DC without MPPT for different wind speeds.
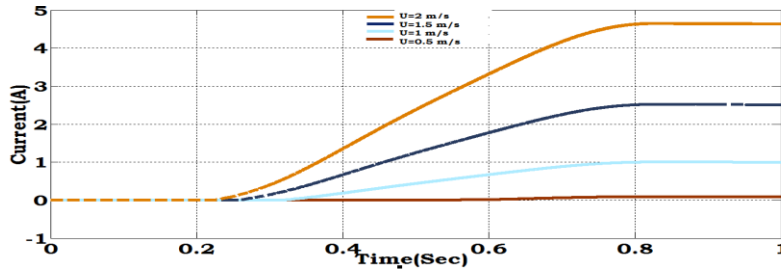

Figure 11. Output current of high gain step up converter with out MPPT

The above figure 11 shows the current obtained from high gain DC-DC converter which is 4.5A without MPPT for working wind speed.
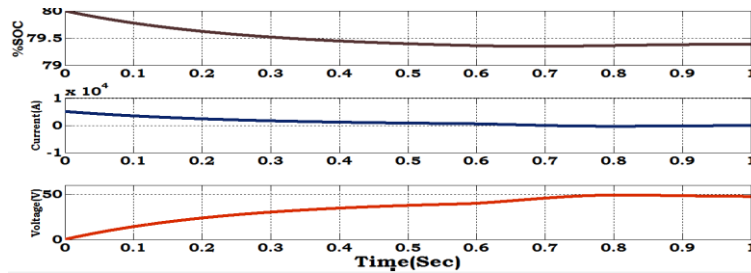

Figure 12. Battery SOC, voltage and current

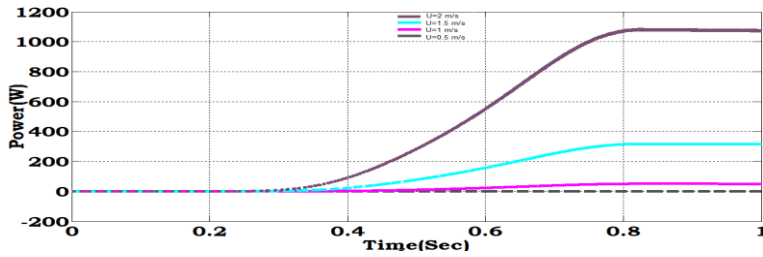The above figure 12 shows the battery voltage current and % SOC.

Figure 13. Power of high gain step up converter without MPPT

The above figure 13 shows the voltage obtained from high gain DC-DC converter which is 1080W without MPPT for different wind speeds.

The below figure 14 shows the voltage obtained from high gain DC-DC converter which is 360V DC with MPPT for working wind speed.
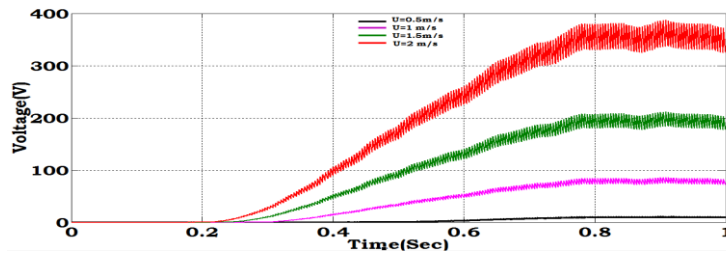

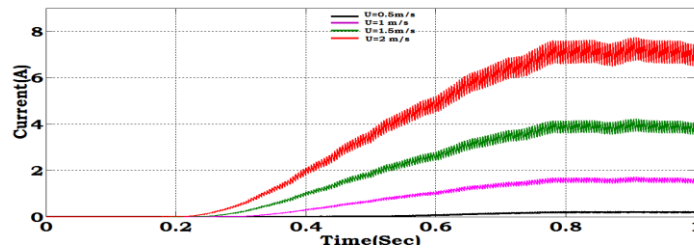*Figure 14. Output voltage of high gain step up converter with MPPT*

Figure 15. Output current of high gain step up converter with MPPT

The above figure 15 shows the current obtained from high gain DC-DC converter which is 6.8A with MPPT for working wind speed.
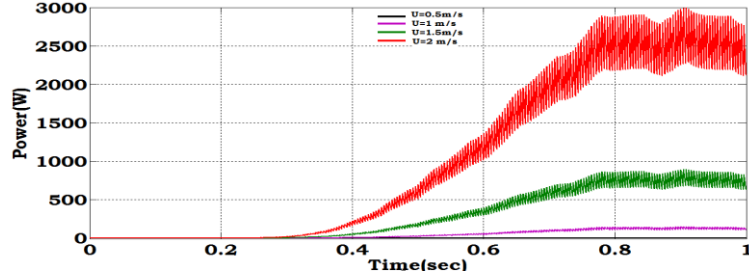
Figure 16. Power of high gain step up converter with MPPT

The above figure 16 shows the power obtained from high gain DC-DC converter which is 2600W with MPPT for working wind speed.

Table 1. Comparison between conventional wind turbine and proposed oscillatory wind turbine with MPPT

Wind speed (m/s)		Proposed oscillatory wind turbine		Conventional wind turbine with MPPT
		Without MPPT	Fuzzy MPPT	
0.5	V	4.88V	10V	1.225V
	I	0.1A	0.2A	0.001A
	P	0.5W	2W	0.001255W
1	V	51.84V	73V	1.3V
	I	1.037 A	1.5A	0.0018A
	P	52W	110W	0.00234W
1.5	V	130.1V	185V	1.6V
	I	2.6A	3.7A	0.0021A
	P	338W	685W	0.00336W
2.0	V	230V	350V	2V
	I	4.2A	6.8A	0.0025A
	P	1000W	2300W	0.0052W

The above table 1 shows the voltage, current, power of conventional horizontal axis wind turbine with MPPT, proposed oscillatory wind and without MPPT which shows that proposed oscillatory wind turbine works with lower wind speed and produces higher power when compared to the conventional wind turbine with lower wind speed.

Table 2. Specifications of the proposed oscillatory wind turbine

S.No.	Parameter	Value
1.	Length of the structure	2m
2.	Inner diameter of structure	100mm
3.	outer diameter of structure	200mm
4.	Reynolds number	2,45,000
5.	Strouhal number	0.2
6.	Natural frequency	3Hz
7.	Input voltage of AC transducer	5Vrms
8.	Battery type	Lead acid
9.	Battery capacity	50Ah
10.	Battery voltage	48V
11.	Working wind speed	2m/s

The above table 2 shows the specifications used for designing oscillatory wind turbine.

5. Conclusion

An oscillatory wind turbine has been designed using MATLAB simulink and an MPPT based fuzzy PID controller has been used for generating pulse to high gain step up converter. The proposed wind turbine is compared with conventional wind turbine which shows that proposed oscillatory wind turbine with MPPT based Fuzzy PID controller generates high power when compared to conventional wind turbine with MPPT controller at lower wind speeds and results are verified using MATLAB simulink.

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