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A fuzzy logic controller based vortex wind turbine for commercial applications

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ABSTRACT

The major intend of this article is to enhance utilization of renewable energy sources of which wind is given importance due to its advantages. A vortex based wind turbine employing a fuzzy based controller for commercial applications is presented in this paper. The fuzzy based controller provides smooth run over the output voltage of the transformer less boost converter used in vortex wind turbine. A fuzzy logic controller based turbine is anticipated to meet the high quality output, minimum Total Harmonics Distortion (THD), fast response and high robustness .A comparison over proportional Integral derivative (PID) controller and fuzzy logic controller based vortex wind turbine is performed in terms of THD, settling time ,peak overshoot. The results are verified using MATLAB simulink.

1. INTRODUCTION

The day to day changes in the environment due to the green house effect impacts the life of earth. Also the depletion of fossil fuels impacts the life of human beings. So it is required to look for an alternative which protects both the life of earth and also human beings. Utilization of renewable energy sources [1-2] can be a solution which provides continuous supply of power without pollution leading to the reduction of green house effect. There are number of renewable energy sources of which wind is a source in this paper.

Vortex is a phenomenon of producing power with wind and which involves low cost, less space requirement when compared to the conventional wind turbine. With the use of vortex forces [4-6] produced with in any bluff structure, it starts oscillating. But the oscillations have to be converted to usable parameter which is electrical energy. Oscillations of the bluff body can be converted by using piezoelectric material [3] but it involves lower power production .so to obtain required amount of power an AC Linear Variable Displacement Transducer (LVDT) [10] is proposed in this vortex wind turbine. But even the output produced from the LDVT cannot be directly used for commercial purposes and so a DC-DC converter has to be used .so to avoid the disadvantages of conventional boost converter transformer less boost converter [11] has been proposed. Generally to maintain the output of the converter at the required value a controller has to be used. Proportional integral derivative (PID) controller can be used to control the converter. But using of PID controller requires manual tuning, larger peak overshoot, and slow response [13-15]. So to overcome these disadvantages a fuzzy logic controller [18] has been proposed in this paper.

This proposed vortex turbine uses very less and low cost components and it can be used for residential and commercial applications and it is more advantageous to rural people which they can get power at a very low cost.

2. PROPOSED FUZZY LOGIC CONTROLLED VORTEX WIND TURBINE

The proposed vortex wind turbine is shown in below figure which works on the principle called vortex shedding .vortex shedding is a phenomenon in which vortex induced vibrations when any bluff body is submerged by a fluid flow or air flow which is wind in this paper. Due to these vortices that are induced within the body alternating lift forces are produced.

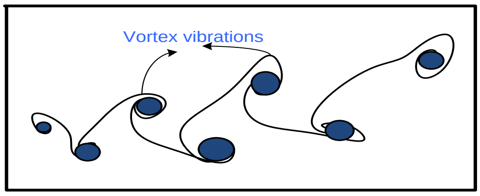

Figure 1. Vortex vibrations

The above figure 1 shows the vortex vibrations that are produced within the mast. Generally a stream factor that determines nature of vortex shedding can be given by Reynolds number (R_e) and the flow structure that is considered in this paper is completely turbulent and so range of Reynolds number can be given as 300<R_e<300000.

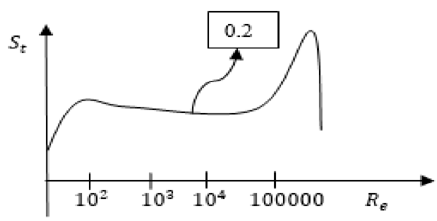

Figure 2. Relation between R_e and S_t

Another parameter which determines vortex flaking frequency to oscillating stream means is strouhal number (S_t) which is generally 0.2 based on Reynolds number.

The vortex vibrations increase when vortex flaking frequency becomes lock to natural frequency of the bluff arrangement. This makes the structure which is tapered cylindrical light weight material to displace with more oscillations .The displacement of the mast is converted into electrical power by using an AC Linear Variable Displacement Transducer (LVDT). When the mast displaces, core of the LVDT displaces which produces electrical energy at the secondary windings whose value is 48VAC. As it is known that wind is not available all the times and it is not a constant parameter. So a 48V lead acid battery is used for storage purpose.

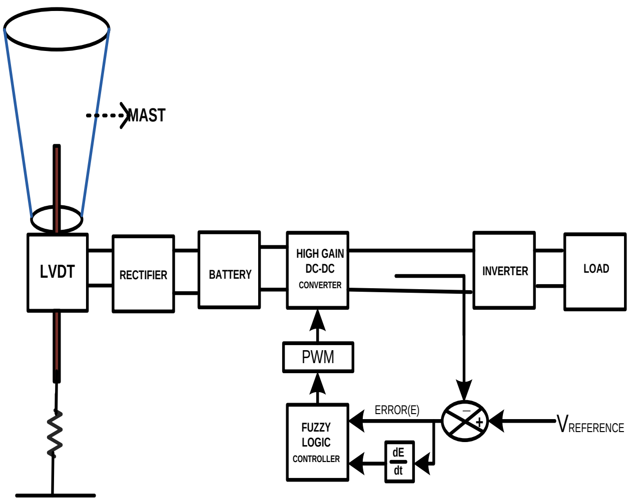

Figure 3. Block diagram of vortex wind turbine

But the available electrical power is very small which is boosted by a high gain step up DC-DC converter which overcomes the disadvantages of conventional boost converter. It is also known that wind is not a constant parameter and so to obtain constant output from the DC-DC converter a controller has to be used. There are different types of controllers like P, PI, PID, Neuro, and Fuzzy. The proposed turbine uses a fuzzy logic controller which controls the resultant voltage and provides constant value at the converter.

2.1 Tapered cylindrical mast

The equation involving alternating lift forces [1] on the tapered cylindrical mast is given by

$$F_L = \frac{1}{2} pU^2 AC_L Sin(2\Pi f_{st} t) \quad (1)$$

where U is velocity of Air, p is density of air, C_L is coefficient of lift, A is the area of the tapered cylinder, and f_{st} is the vortex shedding frequency.

The vortex system consists of tapered cylindrical mast, spring which provides second order equation can be given as

$$F_L = m\ddot{x} + Kx \quad (2)$$

where m is the mass of the tapered cylindrical mast, K is the spring stiffness and x is the displacement.

2.2 Transformer less boost converter

The output obtained from the battery is very low which cannot be directly used for AC loads. So a boost converter is required to step up the voltage. Conventional boost converter cannot be used to step up the voltage because of its disadvantage like requirement of higher duty cycle which involves higher losses. In order to avoid that a transformer less boost converter is proposed which produces larger output for lower duty cycle compared to conventional boost converter there by losses can be limited. The proposed DC-DC converter [11] is shown in below figure 4 consists of 1 switch, 4 diodes, 3 capacitors, 2 inductors.

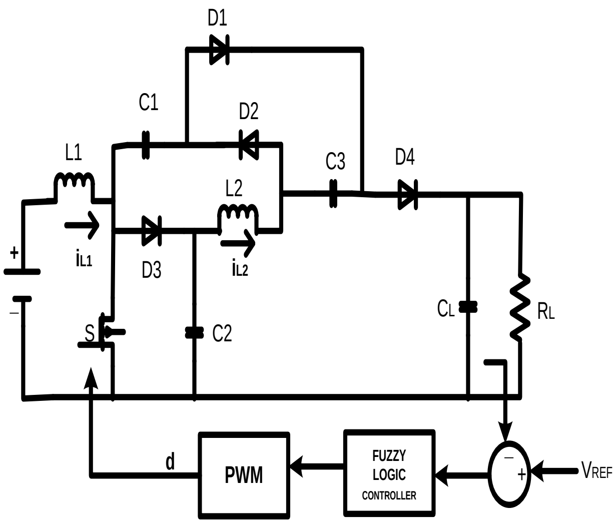

Figure 4. Transformer less boost converter

When voltage is applied at the input terminals of the converter and when switch is ON, then current flows through the inductors and the output can be collected at the resistor. The measured output is compared with the required value and the slip is fed to the fuzzy logic controller and it is processed which in turn produces duty cycle for the switch .there by switch activates and allows the input. In this way the duty cycle of the switch is varied through fuzzy logic controller and the required output can be obtained.

The equation for duty cycle D of the converter can be given as

$$D = \frac{2V_0 - 3V_i}{V_i + 2V_0} \quad (3)$$

The equations involving designing of L, C components in the converter [11] can be given as

$$L_1 = \frac{V_i D}{\Delta i_L f s} \quad (4)$$

$$L_2 = \frac{V_{C2}(1-D)}{\Delta i_L f s} \quad (5)$$

$$C_1 = C_2 = C_3 = \frac{I_{out} D}{\Delta V_C f s} \quad (6)$$

$$C_{out} = \frac{I_{out} D}{\Delta V_0 f s} \quad (7)$$

where f_S is the switching frequency, Δi_L is the inductor ripple current, ΔV_C is the capacitor ripple voltage, V_i is the input voltage of the converter, V_o is the output voltage of the converter.

3. PROPOSED FUZZY LOGIC CONTROLLER

Controller is necessary for boost converter to control its output voltage and provide constant value irrespective of load, environmental conditions. Basically there are different types of controllers like PID, neuro, fuzzy. This paper provides designing of fuzzy controller for DC-DC converter in vortex wind turbine. Fuzzy logic controller which is shown in below figure 5 consists of number of components like fuzzifier which converts crisp values into fuzzy values and fed as inputs to inference engine.

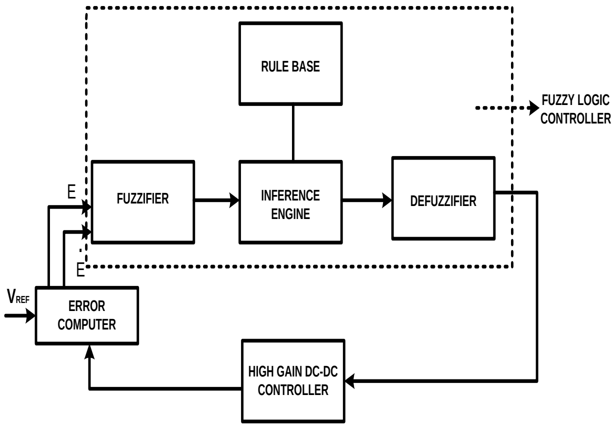

Figure 5. Fuzzy logic controller

In fuzzy inference engine fuzzy rules are applied to the inputs and processing will be done. After performing the task output is fed to defuzzifier to convert fuzzy into crisp values.

The designed fuzzy based controller consists of two inputs called as error and change in error. Error is the variation between actual output of the converter and expected value and change in error is the differentiation of error or the variation between current error and preceding error. The inference can be sugeno or mamdani but the proposed controller uses a mamdani type of inference engine and output is in between [-1 1]. Membership functions for inputs and outputs can be of different shapes but the proposed controller considers input and output membership functions as 7 in number and of triangular shape and among the different types of defuzzification methods, centroid method is used for defuzzification for the proposed controller. The output after defuzzification represents duty cycle which is in between [0 1] is fed to the switch of DC-DC converter which operates.

Table 1. Rules of the proposed fuzzy based controller

$\dot{e}$ / e	PL	PI	PT	Z	NT	NI	NL
NL	Z	NT	NI	NL	NL	NL	NL
NI	PT	Z	NT	NI	NL	NL	NL
NT	PI	PT	Z	NT	NI	NL	NL
Z	PL	PI	PT	Z	NT	NI	NL
PT	PL	PL	PI	PT	Z	NT	NI
PI	PL	PL	PL	PI	PT	Z	NT
PL	PL	PL	PL	PL	PI	PT	Z

The proposed fuzzy controller consists of seven member ship functions for both inputs and output, which are PL (POSITIVE LARGE), PT (POSITIVE TINY),PM (POSITIVE INTERMEDIATE), Z (ZERO), NL (NEGATIVE ARGE), NI (NEGATIVE INTERMEDIATE) NT (NEGATIVE TINY) [12] By using IF-THEN rule 49 rules are constructed which is shown in above table 1.Based on the constructed rules the fuzzy logic controller operates and respective duty cycle which can be zero, positive or negative is produced which is fed to DC-DC converter and required output can be achieved.

4. SOFTWARE REALIZATION OF VORTEX WIND TURBINE

The proposed vortex based wind turbine is simulated and verified using MATLAB simulink .The vortex turbine works with wind velocity as 2m/s whose requirement is very low when compared to the conventional wind turbine.

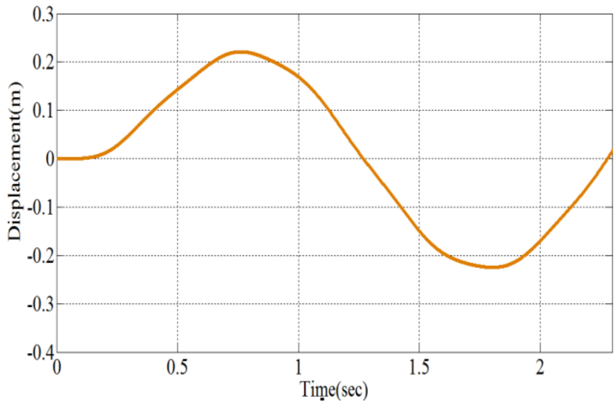

Figure 6. Displacement waveform of vortex structure

When wind passes over the mast, it starts displacing and the value of the displacement can be given as 0.22m which is shown in above figure and it is fed to LVDT to convert into electrical energy.

The output from the battery is fed to the transformer less boost converter and the amount of voltage produced by the boost converter is controlled by PID and Fuzzy controllers and the above figure gives the outputs from the controllers which shows that fuzzy controller has settling time when compared to PID controller.

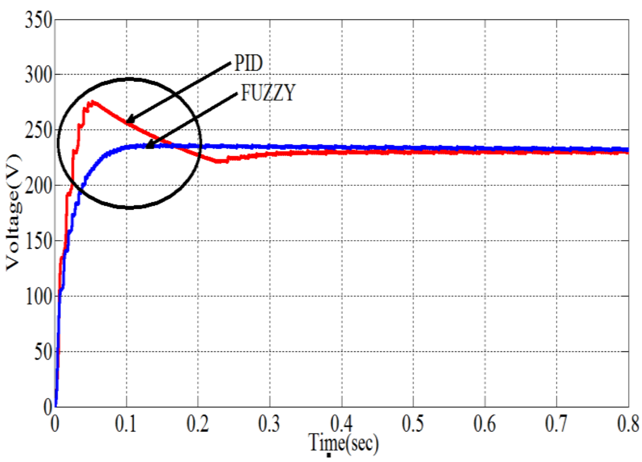

Figure 7. Comparison of Fuzzy over PID controller

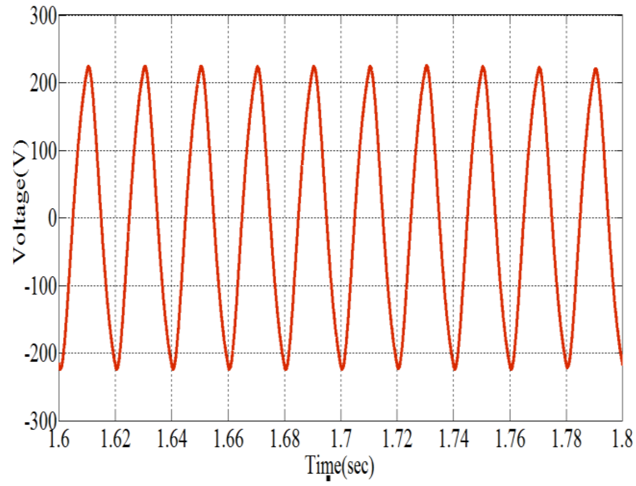

Figure 8. Voltage waveform of the inverter

The output from the Fuzzy controlled converter is fed to the single phase inverter which produces 230VAC output shown in the above figure.

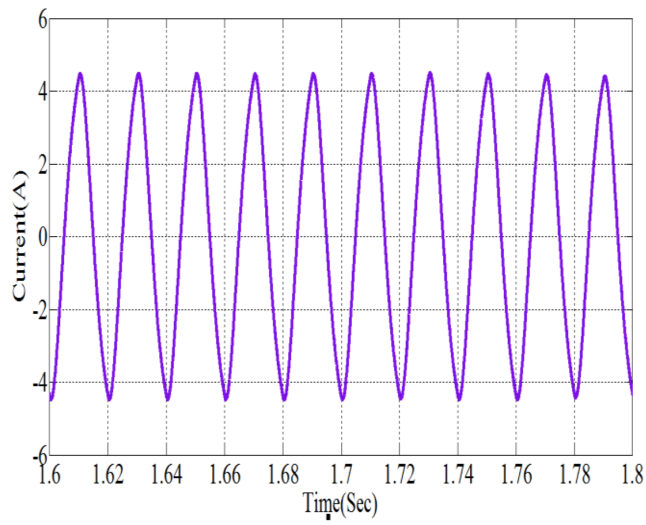

Figure 9. Current waveform of the inverter

The current obtained from the inverter is shown in above figure whose value is 4.8A.the output from the system is around 1KW which can be used for residential or commercial applications.

Table 2. Specifications of vortex wind turbine

S.NO.	PARAMETER	VALUE
1.	Rated voltage	230V
2.	Rated current	4.8A
3.	Rated power	1KW
4.	Wind velocity	2m/s
5.	Duty cycle	0.6
6.	Reynolds number	20000
7.	Strouhal number	0.2
8.	Input voltage of proposed boost converter	48V
9.	output voltage of proposed boost converter	230V
10.	Lead acid battery	48V

The above table gives the specifications of the proposed bladeless aero generator.

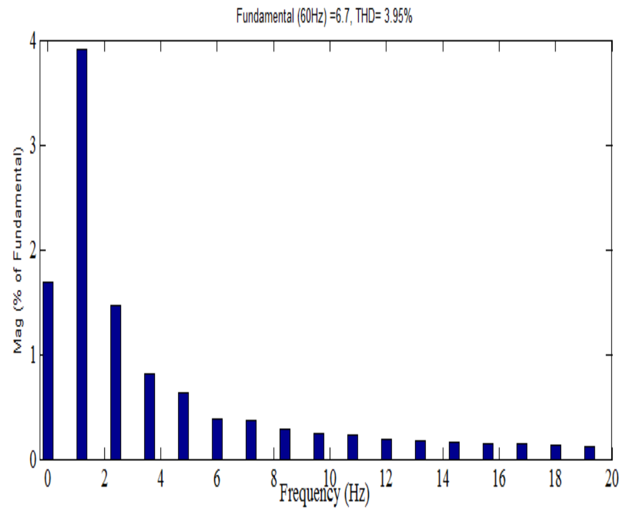

Figure 10. THD of vortex turbine with PID controller

The above figure shows the THD value of the bladeless aero generator with two level inverter which is 3.95%.

The below figure shows the THD value of the bladeless aero generator with three level inverter which is 1.56%.

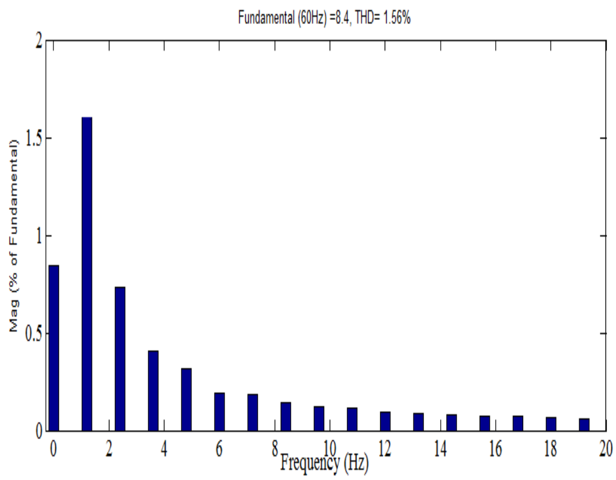

Figure 11. THD of vortex turbine with Fuzzy controller

The above figures shows THD values of vortex wind turbine with PID controller and Fuzzy logic controller whose values are 3.95% and 1.56% and from that it is concluded that fuzzy based controller performance is better compared to PID controller.

5. CONCLUSION

This paper provides analysis of fuzzy logic controller based vortex wind turbine. All the components of turbine have been simulated using MATLAB simulink. The THD analysis and settling time analysis was performed with PID controller based vortex turbine and fuzzy logic controller based vortex turbine. The results demonstrate that fuzzy logic controller based vortex turbine is advantageous over PID controller based vortex turbine.

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