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Design and Modeling of a Small Scale Wind Turbine Generator

Abhilash Sengupta[1], Sandeep Singh Solanki[2]
[1,2]Department of Electronics and Communication Engineering, Birla Institute of Technology Mesra, Ranchi, India

ABSTRACT: Harvesting of energy, wasted in the process of machine operation may be an important source of power generation. In the present project, we utilized the wind backlash generated during machine operation as a means of energy harvest. A small scale wind turbine is designed and modeled; such that it can be used as a voltage source with good power rating. The turbine is tested and is found to produce steady electric power. Curves and Equations are generated from the data obtained from the output voltage and current. Energy harvested from the above sources may be utilized by appropriate instrumentation. The power output of the wind turbine on mouth blowing by human respiratory effort may be correlated with the human lung function in health and in disease states.

I. INTRODUCTION

Use of non-conventional sources of energy and its newer exploration is a highly relevant area of academic inquiry and are essential for society and industry. Harvesting of energy, wasted in the process of machine operation may be an important source and these byproducts of machine operations can be suitably used to generate power.

Wind energy is a common source of alternate energy. It is basically the kinetic energy of the moving air which is used for human civilization for a long time. The basis of using wind energy is to use the energy to spin a shaft, which converts the force of the wind into turning force acting on the rotor blades attached with a shaft. The rotation of the shaft is used to drive a turbine which generates electric energy.

II. WORKING PRINCIPLE OF WIND TURBINE

Rotor blades act like airfoils. An airfoil is a structure around which airflow creates lift. Rotor blades have a special shape so that when the wind passes over them, it moves faster over one side. According to Bernoulli's Principle increased air velocity produces decreased pressure. Hence when the wind blows there is a pocket of low pressure formed on the downwind side of the blade. The blade is pulled toward the low pressure making the rotor turn. This is called *lift.* The lift force is stronger than the force, known as *drag*, acting on the front side of the blade.

The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. In wind turbine design, the objective is to have a high lift-to-drag ratio. This is accomplished by twisting the blades. The blades are twisted so that the wind hits them at the correct angle of attack. This twist is known a *pitch*.

Wind speed and energy:

The amount of energy that can be captured from the wind is exponentially proportional to the speed of the wind. If a windmill were perfectly efficient, the power generated is approximately equal to:

$P={}^{1}/_{2}DAV^{3}$ (Bergey, 1979)

Therefore, if wind speed is doubled, the power in the wind increases by a factor of eight. In reality, because of Betz's Limit (Betz, 1966) it doesn't have such affect.

The theoretical maximum power efficiency of *any* design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). After taking engineering requirements of a wind turbine - strength and durability into account the real world limit is well below the *Betz Limit* with values of 0.35-0.45. Taking other ineffiencies in a complete wind turbine system like the generator, bearings, power transmission and so on - only 10-30% of the power of the wind is converted into usable electricity.

In the last decade many articles have been published and many researches were conducted on various aspects of wind turbine. The main goals of these researches were to control and optimize the energy produced by a wind turbine. Various models had been proposed (Muljadi, 2001; Slootweg, 2001; Nichita, 2002; Miller, 2003), where the researches tried to obtain optimization by controlling load, pitch, rotor speed and many other turbine parameters. All these experiments came with their own simulations and real time machine performance results.

Researches were also conducted in various control strategies of wind turbine which resulted in development of many algorithms and control techniques (Tan, 2004; Wang, 2004; Lei, 2006). Many researchers studied to combine existing generator techniques to develop a control strategy for wind turbine. The most popular was the use of doubly fed induction generator. These generators were used to increase the efficiency of variable speed turbines. Researches were also conducted to study and test the stability, performance and efficiency of the doubly fed induction generator (Tapia, 2003;Liserre, 2006; Yao, 2007; López, 2009; ZHANG, 2011; Yao, 2012; Wang, 2012; Xiang 2012).

Based on all these findings the current authors devised a small scale model of wind turbine which unlike the previous stationary ones will be attached to a moving object like locomotives that undergoes a long journey in a good speed. The wind turbines will use the force of the backlash wind of the vehicles to generate voltage.

III. METHODOLOGY:-

A. Working principle:-

The turbine designed in this project is based on the property of dc motor that when the shaft of a dc motor is rotated then it produces voltage like a generator.

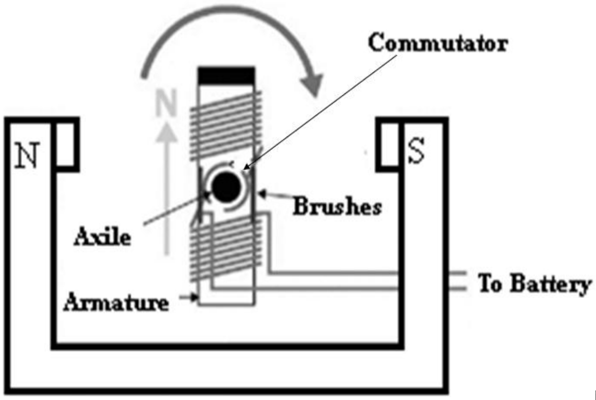

Fig 1 Inside of a DC motor

This model uses three dc motors (Table I) which are connected with blades to make them rotate when wind flow. As the blades rotate they cause the shaft of the dc motor to rotate as well (Fig. 1). Since the dc motor

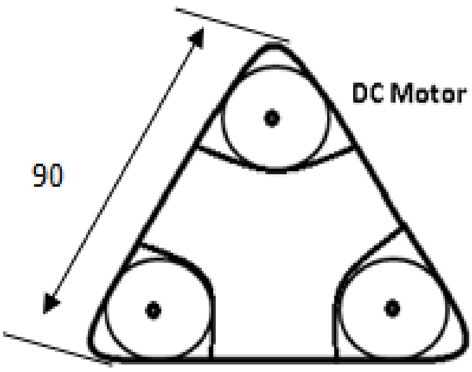

Fig 2 basic diagram of the turbine

works as a reverse generator as the shaft rotates it cause the coil inside the motor to rotate within a magnetic field and produces electricity.

B. Device Design:-

The turbine is constructed using aluminum strips of width 7 mm and thickness 2 mm. First, an Equilateral triangle is prepared with those strips with arm length 9 cm each. Then three dc motor (Rf-300fa) is fixed at the 3 corner of the triangle using aluminum strips of same dimension (Fig 2).

The blades of the turbine are made from aluminum foil with thickness 0.2-0.3 mm. each blade is 80 mm Long

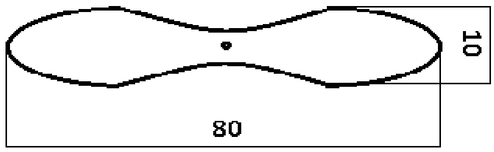

Fig 3 Blade diagram and dimension

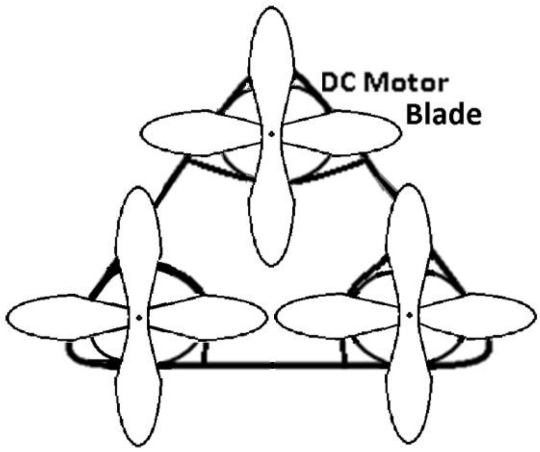

Fig 4 Final Structure of Wind turbine

and bent into pitch angle 45^o to rotate as wind pass them (Fig 3).

The blades are fixed on the dc motors with the help of glue. The final structure is as per figure 4.

For this model of wind turbine the amount of power available is described by the following equations.

Equations governing the behavior of the wind turbine generator:-

$w = rAv^3/2$[1] (1) where w is power, r is air density, A is the rotor area, and v is the wind speed.

As we know that only 10-30% of total power is available or can be captured hence taking the minimum amount of power into consideration we have

$w_{act}=w*0.1$ (2) where w_{act} is the actual power obtained from the turbine

When this power will be applied on the shaft, the shaft will rotate in speed

$\omega=w_{act}/T$ (3) Where ω is the rotating speed of the shaft in rad/sec and T is the minimum torque required for the motor and if we convert it into r.p.m. we have

$\omega_{rpm}=\omega*60/2\pi$ (4)

The DC motors used in this project are of RF 300FA-12350 with specifications:-

Table I The DC motors used in this project are of RF-300FA-12350 with specifications:-

MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY				
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT
		V	r/min	A	r/min	A	mN.m	g.cm	W
RF-300FA	1.5-6.0	3	3500	0.022	2830	0.093	0.48	4.9	0.14

The output of the system is taken across a load resistance R_l hence

$V_{o/p}=(w_{act}/R_l)$^.5 (5)

$I_{o/p}=w_{act}/V_{o/p}$ (6)

IV. EXPERIMENT AND RESULT

A. Power output of wind turbine generated from the Mouth blow

During experimental set up, we frequently used mouth blow to move the blades of the wind turbine, in order to test the power generation. We found that, as the force and velocity of blow changes by the voluntary effort of the human subject, the power generation changes in a controlled and predicted pattern.

Mouth blow by an adult human subject is basically an act of expiration of air from the lung. Regarding this, there are three standard volume quantifications,

1. Tidal volume: This is the volume of air expired or exhaled by the human subject by normal voluntary effort, after a normal inspiration. This is amounting to 500 ml, exhaled within 1 to 2 seconds
2. Expiratory capacity: This is the volume of air expired or exhaled by the human subject by forced voluntary effort, after a normal inspiration. This is amounting to 1000 ml, exhaled within 1 to 2 seconds.
3. Vital Capacity: This is the volume of air expired or exhaled by the human subject by forced voluntary effort, after a maximum effort of inspiration. This is amounting to 4000 ml, exhaled within 3 to 4 seconds, out of which about 3000 ml is exhaled within 2 seconds.

Table 2 Voltage, Current produced due to movement of different blades of the rotor (mV, mA)

	Blade A		Blade B		Blade C	
MODEl-1	mV	mA	mV	mA	mV	mA
Application of Tidal volume	0	0	0	0	1	0.1
Application of Expiratory capacity	18	4	22	5	1	0.1
Application of Vital Capacity	315	44	323	45	150	24
Model-2	mV	mA	mV	mA	mV	mA
Application of Tidal volume	0	0	0	0	0	0
Application of Expiratory capacity	3	0.2	1	0.01	0	0
Application of Vital Capacity	250	33	267	37	112	18

B. Power output of wind turbine generated from the Table Fan

This set of data is taken using a domestic table fan with 3 variable speeds setting as High, Medium and Low.

The table fan having the following specification:-

Model: DTF-300
Maximum speed: 2000 r.p.m.
Sweep diameter: 300 m.m.
No. of Blades: 3
Voltage: 220/240V Ac. 50 Hz

Table 3 Voltage, Current produced due to movement of different blades of the rotor and by the whole system

Model – 1

SL NO.	A		B		C		ALL	
	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
1	23 mv	3.7 ma	60 mv	11 ma	20 mv	3.1 mA	80-98mV	11-16mA
2	98-103 mv	17 ma	130 mv	24 ma	80 mv	8.9 ma	0.5-.7 V	39-48mA
3	180- 230mv	26-34 ma	280-310 mv	37 ma	160 mv	23-25 ma	1.2-1.5 V	90-95 mA

Model – 2								
SL NO.	A		B		C		ALL	
	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
1	30-40 mv	2-3.4 ma	30-40 mv	6-7 ma	10-12 mv	1-2 ma	8-9 mv	0.5-1 ma
2	120-125 mv	15-16 ma	130-140 ma	16-18 ma	53-60 mv	8-10 ma	.8-1 v	36-38 ma
3	220 mv	30 ma	220-270 mv	32-34 ma	90-105 mv	14-18 ma	1.5-2 v	70-78 ma

C. Power output of wind turbine generated in a car at variable speed

The test of the turbine is done in car. The main principle behind this test is that assuming the general wind speed is zero or ignorable the speed of the backlash wind would be equal to the speed of the car.

Table 4 Voltage, Current produced due to movement of the whole system

Velocity(Km/hr)	Voltage(V)		Current(A)	
	Model-1	Model-2	Model-1	Model-2
10	0	0	0	0
15	0	0	0	0
20	0	0	0	0
25	12 mv	1 ma	0	0
30	28 mv	3 ma	0	0
35	41 mv	5 ma	30 mv	6 ma
40	59 mv	6 ma	37 mv	6 ma
45	70 mv	7 ma	42 mv	7 ma
50	92 mv	9 ma	53 mv	10 ma
55	124 mv	14 ma	60 mv	10 ma
60	157 mv	24 ma	88 mv	15 ma

Table 5 Equations of the Cubic Polynomial Curve obtained from the voltage and current generated in the wind turbine model 1 and 2

Linear model Poly3==> f(x) = p1*x^3 + p2*x^2 + p3*x + p4					
Turbine model	Parameter	Coefficients (with 95% confidence bounds)			
		p1	p2	p3	p4
1	Voltage	0.0002704	0.03324	-0.3427	-2.727
	Current	0.0004009	-0.03016	0.8559	-6.909

2	Voltage	-0.0005750	0.09497	-2.5330	16.520
	Current	-0.0001166	0.01779	-0.4648	3.000

Turbine model	Parameter	Goodness of fit			
		SSE	R^2	Adjusted R^2	RMSE
1	Voltage	139.5	0.9951	0.9930	4.464
	Current	16.3	0.9699	0.9570	1.523
2	Voltage	397.9	0.9579	0.9399	7.539
	Current	15.6	0.9445	0.9207	1.493

Data of the output voltage and currents, obtained from the above test from Model 1 and Model 2 of the wind turbine generator, and as shown in the Table 4 were processed by Curve Fitting Tool in MATLAB platform. Curves were drawn putting Voltage (mV) and Current (mA) in the Y axis, against the velocity of the

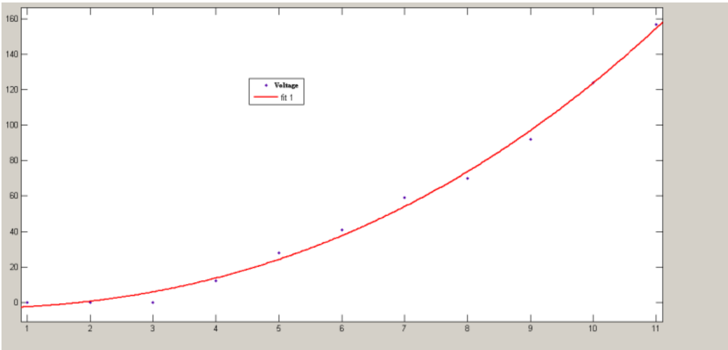

Fig 5 Voltage Generated in Model 1

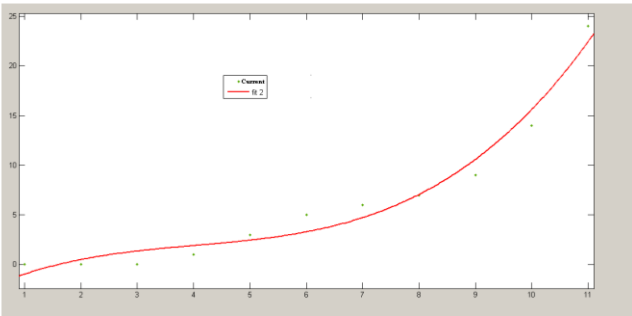

Fig 6 Current Generated in Model 1

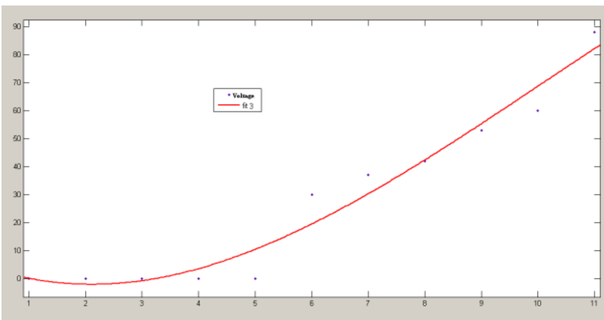

Fig 7 Voltage Generated in Model 2

moving vehicle in X axis. All the curves were fitted in Cubic Polynomial function, with reasonable degree of fitness (table 5). Equations obtained with corresponding coefficients, as presented in Table 5 and Figure 5 to Figure 8.

The results show (Fig 5,6,7,8) a stable and reasonably predictable outcome in terms of voltage and current output in the wind turbine generator. The four coefficients of the cubic polynomial function may be

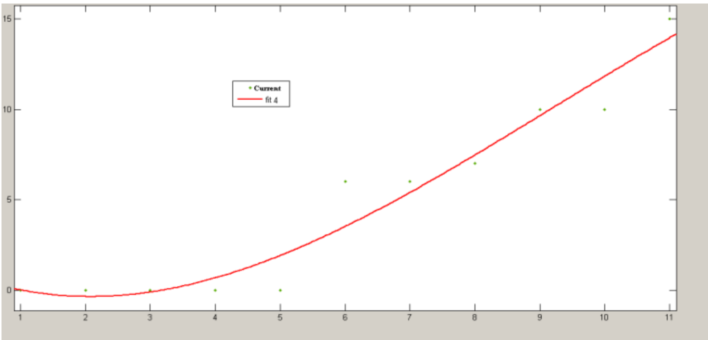

Fig 8 Voltage Generated in Model 2

correlated with different factors influencing the generator output like environment temperature, density of wind, pitch angle of the blades, resistance of the motors, swept area of the blades etc. The exact contribution of all these factors in wind turbine function is to be studied in detail.

D. LIMITATION

The design and the making of the blades of the small scale wind turbine model needed to be controlled for different situation of wind variables.

The developed model is tested only in uncontrolled conditions. A controlled experimented data set couldn't be obtained due to lack of calibrated facilities.

V. CONCLUSION

In the present project a small scale wind turbine is designed and modeled to utilize wind backlash generated during machine operation as a means of energy harvest. The generalized equations were also developed for small scale wind turbine generator using backlash wind as a source.

The device is tested and is found to produce controlled electric power. Curves and Equations are generated from the data obtained from the output voltage and current are found to be correlated satisfactorily with the expected values.

Continuous output voltage was obtained by the turbine in response to steady wind flow.

Energy harvested from the above source may be utilized by appropriate instrumentation and miniaturization to power the commonly used wireless devices.

The output voltage of current produced by the wind turbine in response to mouth blowing by human respiratory effort may be correlated with human lung function in health and disease states.

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