Experimental Performance Evaluation of 600 W Small Wind Turbine to Overcome Energy Crisis in Pakistan

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Abstract - *Wind energy is one of the best renewable energy resources as compare to conventional fuel-based energy. In Pakistan, considering the energy crises, a family of 5-6 persons consumes about 1.2 - 1.5 KW of electricity per day on average. Hence there is a huge potential for mini windmills and necessity of developing horizontal axis wind turbine machine of capacity of 250 watts to 1600 watts, which can run on average wind speed of 1.5 to 4 m/s. Many Authors has made many attempts to resolve this problem. This paper deals with the design, development, fabrication and experimental evaluation of HAWM of 600 W for domestic application. The rotor blades are aerodynamically designed and are made up of Fiber material weighing 700 g each. The Permanent Magnet DC Generator is used for electricity. The machine is dynamically balanced before fitting on pole at roof prime for testing. During performance analysis it is determined that the machine runs on 2.8 m/s, against designed cut in wind speed of 3.6 m/s and reached most 987 RPM and developed 19.8 amperes current with 478.5 Watts of electrical power achieving 79.2% of its designed capacity during the continuous testing period of 180 hours as per code of standards. This prototype has potential for commercializing the product for domestic application in local market to meet energy requirement.*

Key Words: Windmills, Renewable Energy, Horizontal Axis, Electricity Consumption, High Efficiency

1. INTRODUCTION

Energy plays an important role in everyday life to carry out any task. The non-renewable energy resources such as oil, coal and gas are majorly used as energy nowadays. The main problem behind the non-renewable energy resources are not sustainable and create global warming which is hazardous to the environment. The renewable energy resources are best way to solve this issue. The renewable energy resources such as solar, wind, tidal and biogas are available in abundant and sustainable which can be utilized for the requirement. Wind energy is the purest form of renewable energy which is available highly for production of electricity. This project envisions the design and appropriate implementation of 600W electricity producing wind turbine. The turbine will ideally be designed to power individual house's electrical needs. The aim of the project is to design a wind energy converter comprising of a rotor system, and a generator that will successfully produce the specified electrical power. As wind turbines are not new technology the project will be aimed at proving and optimizing a system based on existing technology to achieve the desired power output. Considerations are taken in designing the turbine with an effective post life recycling scheme in mind so that there will be minimum wastage of resources once the turbine is made redundant. In the last one decade, wind power has emerged as the biggest renewable energy source in the world. Presently wind power alone is generating almost 26,000 MW capacities globally and has huge potential in Pakistan.

1.1 Design Objectives

The main aim of this study is

1) To collect the Design data for 0.6 KW HAWT.
2) To understand the Design methodology.
3) To understand the technology and manufacturing method.
4) To evaluate the barriers in development process.
5) To understand the test methodology and performance evaluation techniques.
6) To design cost effective system with better efficiency.

2. LITERATURE REVIEW

The usage of wind energy can be found in ancient times back to 5000 B.C. [1]. When sail boats were propelled across the river Nile. It was recorded that from 200 B.C. onwards wind was used as an energy source to pump water and grind grain in ancient China and Middle East. The first windmill concept was in a book Pneumatics by Hero of Alexandria around the first century B.C. [2]. Effectively, these windmills are used to convert kinetic energy into mechanical energy. The use of wind energy to generate electricity first appeared in the late 19th century [3]. The interest in wind energy was increased in the mid-1970s due to the oil crises and high concerns over resource conservation. Initially, wind energy started to gain popularity in electricity generation to charge batteries [4].

The horizontal axis windmills are a relatively newer invention than the vertical axis windmills. Though the first documentation of the horizontal axis windmills dates to the 12th century, the theoretical descriptions regarding the driving power of horizontal axis devices, i.e. lift forces on the blades, was investigated only during the beginning of the 20th century [5].

The fourth edition of the Global Wind Energy Outlook released on Nov 14, 2012 at Beijing by Greenpeace International and the Global Wind Energy Council states that wind power currently shares about 3.5% of global electricity demand and it is expected that the share could reach up to 12% by 2020 [6].

At present, horizontal axis wind turbines (HAWTs) are the most popular among all windmill designs. This is primarily because HAWTs generally have much higher efficiency than VAWTs. The maximum power coefficient of a modern HAWT has been reported up to 45% to 50% while that of an efficient VAWT normally lies below 40% [7]

In Pakistan wind energy has a huge positional. 150,000 megawatts can generate energy through wind according to USAID Pakistan while only in Sindh 40,000 megawatts can generated. For Pakistan, wind energy is a good option. Wind energy does not need any fuel, which are benefits. In Pakistan the power plant already, require fuel, which increases the cost of electricity per unit whenever the rate is increased [8]. Developing attention to rising levels of greenhouse gasses [9], An Earth-wide temperature boost and expanding costs of nonrenewable energy sources have prompted a move towards small wind turbines. Basic organized, reduced in outline, versatile and low clamor [10].

SWT are presently fundamental in the rustic, rural and even in the populated city territories where establishment of vast scale wind turbines would not be acknowledged because of space limitations and age of commotion. SWT accomplish control coefficients of 0.25 or more noteworthy in contrast with vast turbines which have CP values around 0.45 [11]. SWT have been coordinated on house rooftop [12]. A SWT is one that depends on streamlined powers to fire up and has a tail vane for uninvolved yawing. SWT are ordered as small scale (1 kW), mid-go (5 kW) and smaller than expected breeze turbines (20 kW+) [13]–[15]. A more itemized portrayal of SWT is given by Cooper as being appraised under 2.5 kW and industrially delivers control in the scope of 0.4 kW-1.5 kW at 12.5 m/s wind speed [16].

Although the design and fabrication of VAWT is easy as compare to HAWT [17]. Performance characteristics such as power output versus wind speed or versus angular velocity are more optimized in HAWT as compare to VAWT in order to compete with other energy sources which make the process economically and eco-friendly [18], [19]. The experimental results of many authors shows that wind turbine placed on the top of the building in an ideal position to produces electricity [20], [21].

3. EXPERIMENTAL SETUP

A SWT is designed including rotor blades, generator, yaw system, tower and assembled using commercially available parts. Rotor blades are fitted on blade fitting plate by means of nut bolts and connected to hub plate which is fitted on the hub bush. Then this hub is fitted on the main shaft of the generator by mean of jaw coupling. Generator is fitted in the nacelle. Cable is drawn through the yawing system and tower. Yawing system is welded to the nacelle base plate. Steel strips are welded to the tower for fitting it to the column at the roof of the Pakistan Institute of Engineering and Technology building.

3.1 DESIGN MODEL

i. Schematic Diagram

The schematic diagram was made on AutoCAD software

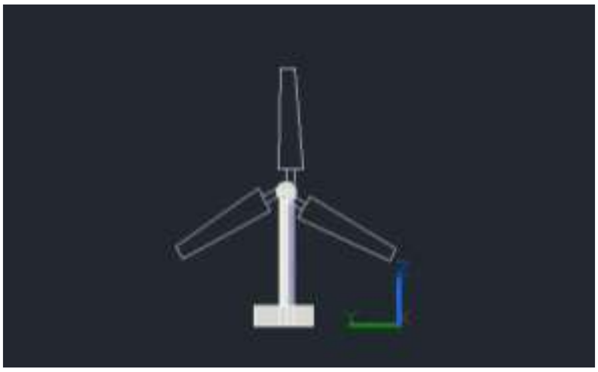

Fig -1: Schematic Diagram

ii. 3D Model

The 3D model was generated using Solid Works software

Fig -2: 3D Model

3.2 SPECIFICATIONS OF EXPERIMENTAL SETUP

Following are the specifications of the Small Wind Turbine machine which to be manufactured.

Table -1: Specifications of Small Wind Turbine

Number of Blades	3 Blades
Generator Type	Permanent Magnet DC
Generator specifications	24 Volt, 20 Amp.
Nacelle size	300mm x200mmx200mm
Tail length	700 mm
Rated Power	600 Watts
Voltage	24 Volts
Tower type	Tubular
Tower material	Mild Steel
Tower size	100 mm Diam., 3 m height
Weight	30 kg (without pole)
Cut in wind speed	2.8 - 3.0 m/s
Rated wind speed	10 m/s
Cut-out wind speed	15 m/s
Rotor situation	Up wind
Blade material	Fiber
Rotor diameter	0.65 m
Tower	Tubular concrete fitted
Height of wind turbine from ground	30 m (Building + pole ht.)
Yawing system	Fitted at top of the pole

3.4 INSTALLATION AND COMMISSIONING

The proposed site of installation of the test setup is at the roof of the Department of Mechanical Engineering, Pakistan Institute of Engineering and Technology. The wind data was studied for the perfect installation. It was found that the wind speed over the year ranges from 1 to 15 m/s. Assembly of the complete machine and testing of the project is carried out at the roof of the Department of Mechanical Engineering, Pakistan Institute of Engineering and Technology. Arrangement of Tower fixing, at the location selected for the installation Also the tower is hinged and welded by the heavy angles, to the previous column steel bars. Both the foundation and fixing are done to avoid the vibrations at the time of the heavy wind speed.

4. EXPERIMENTAL DATA AND CALCULATIONS

Prototype of 600W windmill has been tested under no load & full load conditions. This paper represents the results for full load conditions. One-dimensional theory considers a moving stream of air passing through a circular disk, The energy in the moving stream of air is given by the kinetic energy equation 1.

$E_k = ½ mV_w^2$ --------------------------------- (1)

Where: E_k = kinetic energy of the air stream (J)

m = mass of the air (kg)

v_w = velocity of the air (m/s)

The power in this air stream is given by equation 2 and 3

$P = E_k / t = ½ mV_w^2 / t$ --------------------- (2)

$= ½ m/t V_w^2 = ½ m V_w^2$ (W) ---------- (3)

Where m/t is the mass flow rate of the air stream and is given by equation 4

$m = \rho A v_w$ (Kg/s) ---------------------- (4)

thus the power of a moving stream of air, with density ρ and velocity v, that flows through a disk of area A is given by equation 5

$P = ½ \rho A v_w^2$ --------------------------- (5)

This expression gives the power available in a moving stream of air, but the power that can be extracted from this moving stream is what is required thus we can consider a ratio, known as the power coefficient, between the power in the wind, and the power of the rotor is given by equation 6

Cp = Rotor Power / Wind Power -- (6)

In theory, the maximum possible rotor power coefficient is given by the Betz Limit, CP = 16/27 = 0.593. So, the power output of the SWT can be summarized by equation 7

$P = Cp \eta \rho A v_w^3$ ------------------------ (7)

Where CP = power coefficient of the blades η = efficiency of the turbine, considering all mechanical and electrical losses [22].

Table 2 show the experimental data collected at department of mechanical engineering, Pakistan Institute of Engineering and Technology (PIET), Multan

Table -2: Experimental Data

Sr. No.	Wind Speed (m/s)	Speed of Turbine (rpm)	Voltage (V)	Current (amp)	Th. Power (W)	Actual Power (W)	Efficiency (%)
1	1.4	72	20.5	0.7	14.35	1.07	7.46
2	2.0	122	21.2	1.5	31.8	4.25	13.37
3	1.0	65	21	0.5	10.5	0.45	4.30
4	0.8	52	21.2	0.2	4.24	0.21	5.01
5	0.7	52	21.3	0.19	4.047	0.13	3.30
6	1.9	90	21.5	1.2	25.8	3.04	11.80
7	1.7	75	21.1	1	21.1	2.09	9.91
8	2.2	110	21.2	1.7	36.04	4.96	13.76
9	2.7	130	21.1	3.4	71.74	9.68	13.50
10	1.4	79	21	0.7	14.7	1.07	7.28
11	0.7	60	20.7	0.17	3.519	0.07	2.20
12	1.6	75	20.8	1	20.8	1.70	8.17
13	4.6	279	21.1	5.3	111.83	52.81	47.22
14	2.5	145	21.1	3.1	65.41	7.54	11.53
15	4.7	270	21.2	5.3	112.36	56.49	50.28
16	3.4	192	21	3.7	77.7	16.74	21.54

17	3.2	195	21.3	3.4	72.42	31.40	43.36
18	2.9	142	21.1	2.2	46.42	12.20	26.28
19	2.9	171	21.2	3.1	65.72	15.12	23.00
20	4.9	295	21.4	5.9	126.26	60.34	47.79
21	5.6	342	21.7	6.5	141.05	97.62	45.21
22	4.9	280	21.7	5.5	119.35	60.34	50.56
23	1.3	71	21.1	0.5	10.55	0.31	3.00
24	1.6	78	21.2	0.6	12.72	0.82	6.48
25	1.2	78	21.2	0.6	12.72	1.071	8.42
26	3.7	190	21.2	3.8	80.56	24.36	30.24
27	0.7	75	20.7	0.5	10.35	0.45	4.36
28	0.4	42	20.5	0.1	2.05	0.07	3.78
29	2.6	151	20.5	2.9	59.45	12.20	20.52
30	1.8	97	20.6	1.2	24.72	2.53	10.27
31	3.7	203	21.3	3.7	78.81	36.77	46.66
32	4..5	261	21.4	4.3	92.02	39.68	43.12
33	2.6	132	21.4	2	42.8	6.60	15.42
34	4.8	281	21.6	5.6	120.96	56.49	46.70
35	4.2	269	21.7	5.1	110.67	39.68	35.85
36	1.0	60	20.9	0.5	10.45	0.82	7.89
37	2.2	95	20.9	0.6	12.54	4.96	39.55
38	1.7	70	20.8	0.3	6.24	2.53	40.69
39	0.7	55	20.7	0.4	8.28	0.45	5.45
40	0.7	48	20.5	0.3	6.15	0.21	3.45
41	1.9	101	20.7	1.7	35.19	4.25	12.08
42	2.3	105	20.7	1.7	35.19	4.96	14.09
43	2.4	130	20.8	2.3	47.84	9.68	20.24
44	2.7	130	20.8	2.3	47.84	10.89	22.77
45	1.4	82	20.5	1.2	24.6	2.09	8.50
46	1.1	82	20.5	1.2	24.6	1.07	4.35
47	3.7	204	20.9	3.9	81.51	36.77	45.12
48	2.1	130	20.9	2.5	52.25	5.74	10.98
49	2.7	152	21	3	63	15.12	24.00
50	1.7	105	21	1.5	31.5	2.53	8.06
51	3.9	182	21.1	3.6	75.96	34.02	44.78
52	4.5	241	21.1	4.8	101.28	64.37	42.55
53	4.3	235	21.2	4.6	97.52	39.68	40.68
54	3.7	212	21.1	4.2	88.62	26.58	29.99
55	3.9	215	21.1	4.2	88.62	31.40	35.43
56	4.3	242	21.2	4.7	99.64	39.68	39.82
57	3.7	198	21	3.8	79.8	22.28	27.92
58	2.3	126	20.8	2.2	45.76	4.96	10.83
59	3.5	178	20.8	3.2	66.56	24.36	36.61
60	4.2	235	20.9	4.5	94.05	39.68	42.19
61	5.5	447	21.5	8.6	184.9	114.81	43.09
62	4.6	381	21.4	7.5	160.5	49.29	30.71
63	1.8	106	20.9	1.2	25.08	2.09	8.34
64	2.4	120	20.9	2	41.8	4.96	11.86
65	3.7	223	21.2	4.2	89.04	28.92	32.48
66	3.9	223	21.2	4.2	89.04	31.40	35.27
67	2.3	202	21.3	3.9	83.07	13.61	16.38
68	0.9	105	21.5	1.1	23.65	0.45	1.91
69	4.5	262	21.4	5.2	111.28	49.29	44.29
70	3.5	212	21.5	3.9	83.85	24.36	29.06
71	1.9	127	21.5	2.1	45.15	3.04	6.74
72	5.7	462	21.7	9.4	203.98	108.88	53.37
73	4.8	325	22.2	6.4	142.08	60.34	42.47
74	4.7	325	22.2	6.4	142.08	64.37	45.30
75	3.8	241	22.3	4.8	107.04	24.36	22.76
76	3.6	250	22.3	4.9	109.27	28.92	26.47
77	4.1	307	22.5	5.9	132.75	39.68	29.89
78	3.7	262	22.4	5	112	20.31	18.13
79	2.9	168	22.3	3	66.9	12.20	18.24
80	4.4	302	22.3	5.9	131.57	52.81	40.14
81	2.4	182	22.4	3.1	69.44	9.68	13.95
82	5.8	381	22.4	7.6	170.24	92.30	54.21

5. RESULTS AND DISCUSSION

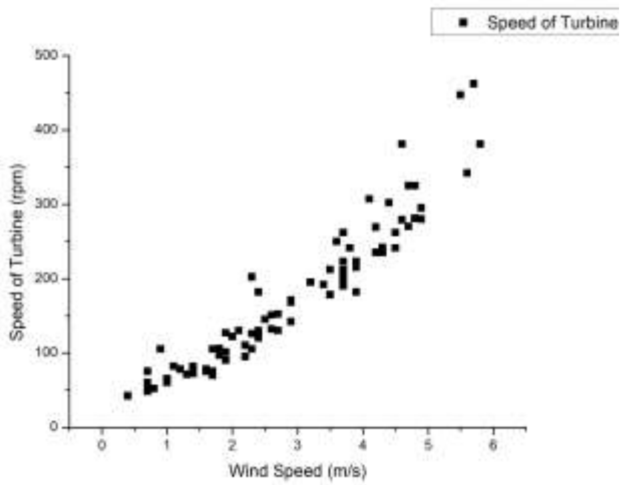

Fig -3: Speed of Turbine V/S Wind Speed

Fig. 3 shows variation of turbine speed with wind speed. It is common phenomenon that as wind speed increases speed of rotation of turbine enhances. With the system described it is possible to generate enough electrical energy.

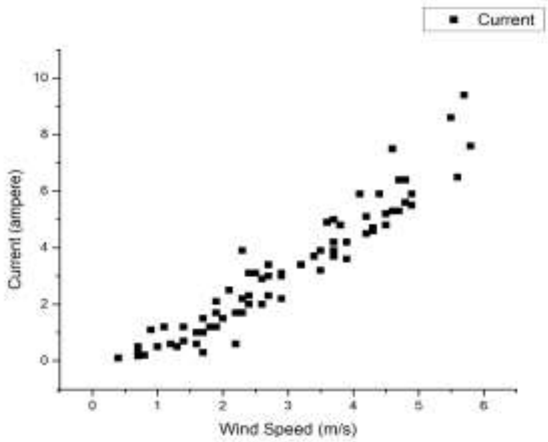

Fig -4: Wind Speed V/S Current

Fig 4 shows Wind Speed Vs Current. Wind Speed is plotted along X- axis and Current along Y-axis. As the wind speed increases linearly from 0 to 6 m/s the current increases from 0 to 10 Amperes.

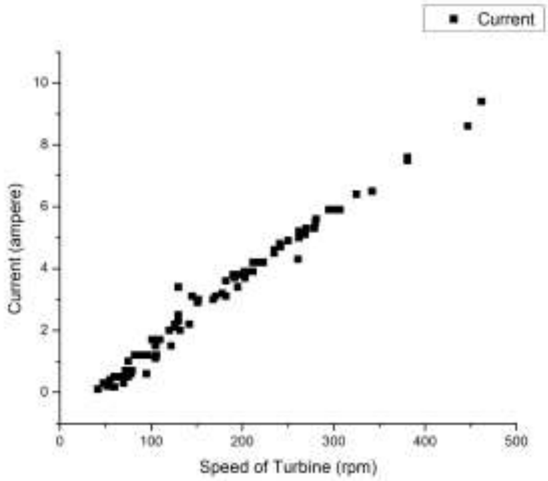

Fig -5: Speed of Turbine V/S Current

Fig 5 shows Current Vs Speed of Turbine. RPM is plotted along X- axis and Current along Y-axis. As the Turbine speed increases linearly from 0 to 500rpm the current increases from 0 to 10 Amperes.

5.1 PERRFORMACE COMPARISON

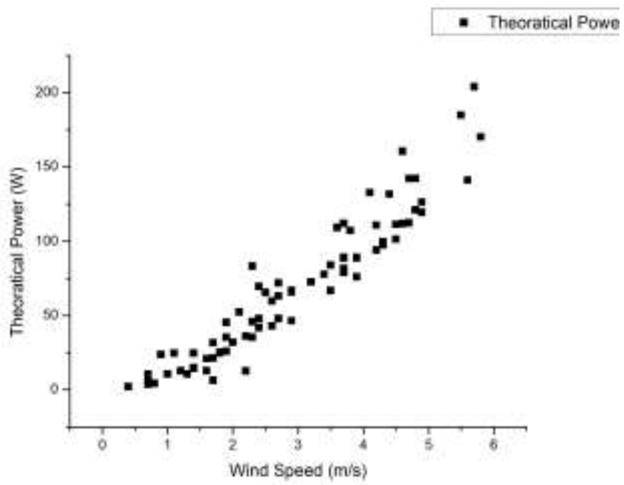

Fig -6: Wind Speed V/S Theoratical Power

Graph shows Wind Speed Vs Theoretical power. Wind Speed is plotted along X- axis and Theoretical power along Y-axis. As the wind speed increases linearly, from 0 to 6 m/s the power increases from 0 to 200 Watts.

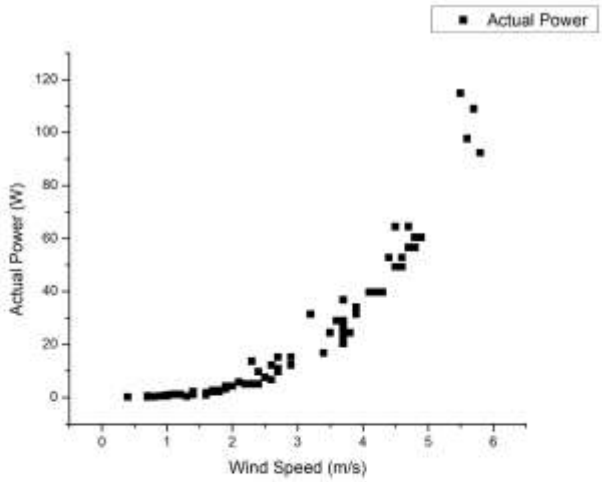

Fig -7: Wind Speed V/S Actual Power'

Graph shows Wind Speed Vs Actual power. Wind Speed is plotted along X- axis and Actual power along Y-axis. As the wind speed increases linearly, from 0 to 6 m/s the power increases from 0 to 120 Watts.

6. CONCLUSION

A new methodology was established for development of small wind machine technology, which considers design and performance for strength of rotor blades. During testing the machine start at 2.7 m/s at 100 rpm as against design cut in wind speed of 3.5 m/s. The fiber rotor blades having light weight and highest strength to weight ratio was selected and has fulfilled the conditions of low initial torque for lower cut in speeds. The mounting plates, power transmission, coupling, shaft bearings are designed based on regular practices of ASME, ASTM and BIS standards. While tested as per guideline procedures of IEC 61400-12-1 standards for performance characterization, it is found that the small wind machine manufactured and developed has resulted with one of the best average performance among available small wind turbines. Though it was designed for 10-14 m/s rated speed the actual maximum efficiency is observed at 8-10 m/s wind velocities. The machine has started at the cut in speed of 2.7 m/s. Due to limitations of wind velocities at site, it is not possible to calculate the performance at higher wind speeds above 12 m/s. The lower cut in wind speed and maximum efficiency at lower wind speed than designed rated speed could be because of selection of aero foil section NACA 4415, light weight rotor blades, bearing and tail vane selection and low rpm high permanent magnet strength generator used during the testing. The performance testing at higher wind speed is required, since maximum rotor blade tip rpm observed is at 987 rpm. The further wind speed testing requires safety measures.

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