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Data Article

Experimental data on analysis of a horizontal axis small wind turbine with blade tip power system using permanent magnetic generator

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A B S T R A C T

The data on performance parameters of a horizontal axis small wind turbine (HAWT) with blade tip power system (BTPS) using permanent magnetic generator is presented. The tests are carried out for low wind velocities ranging from 7 m/s to 10 m/s. The data is acquired using data acquisition system equipped with Labview© software and the processed data is represented in terms of non-dimensional parameters, namely power coefficient (C_P), torque coefficient (C_T) and tip speed ratio (λ). Moreover, as permanent magnetic generator is used in this HAWT with BTPS, the frictional as well as other losses are significantly reduced. This is reflected in terms of non-dimensional electrical power coefficient. The mechanical and electrical power coefficient values are closer with respect to each other. This measured data at laboratory conditions provides a benchmark for future open field environment tests and numerical simulation studies of this small wind turbine.

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Specifications table

Subject area	*Renewable energy*
More specific subject area	*Wind energy*
Type of data	*Table, graph, figure*
How data was acquired	*Speed sensor, anemometer, torque, voltage, current, data acquisition system using LABVIEW©*
Data format	*Raw, filtered, analyzed, calculated, tabulated*
Experimental factors	*Data are normalized as per norms used in wind turbine study*
Experimental features	*Horizontal axis wind turbine with blade tip power system involving permanent magnets kept at the rotor's periphery and magnetic coils at the stator are tested in an experimental setup in laboratory with wind speeds varied from* 7 m/s *to* 10 m/s.
Data source location	*Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India*
Data accessibility	*Data is included in this article*
Related research article	Ghulam Ahmad, Uzma Amin, Design, construction and study of small scale vertical axis wind turbine based on magnetically levitated axial flux permanent magnet generator, Renewable Energy, 101, 2017, pp. 286–292.

Value of the data

- The data set on horizontal axis wind turbine (HAWT) with blade tip power system (BTPS) involving permanent magnets at the rotor and magnetic coils at the stator provides an insight on the performance characteristics of this unique type of HAWT.
- The data would enable the researchers to further develop this HAWT with BTPS into a better compact power generating system that can be installed in urban roof tops to generate a small power using low rated wind energy.
- This measured data at laboratory conditions provides a benchmark for future open field environment tests and numerical simulation studies of this small wind turbine.

1. Data

Fig. 1(a) shows the schematic arrangement of the proposed HAWT which uses a combination of permanent magnets placed along the rotor's periphery ring and magnetic coils fixed in the stator (i.e., outer ring casing) of the HAWT. The electrical generator and gearbox, which is coupled to the former, is replaced with an innovative blade tip power system (BTPS) [1] involving passive permanent magnets (as seen in Fig. 2) which is used in this present data article, reduces the power loss and hence the overall cost of HAWT. Besides, the bearings and couplings are replaced with magnetic levitation which ensures a friction less motion of HAWT [2]. Data are obtained by conducting tests on the HAWT with BTPS at varying wind velocity from 7 m/s to 10 m/s using experimental test setup as shown in Fig. 3. Tables 2–5 lists the data obtained by varying the loading conditions from no load to maximum load for different wind speed regimes. The performance of HAWT with BTPS in terms of non-dimensional parameters namely, tip speed ratio (λ), coefficient of power (C_p) and coefficient of torque (C_T) are also listed in Tables 2–5 The influence of λ on the performance of HAWT with BTPS is shown Fig. 4 by plotting the variations between C_p and λ.

2. Experimental design, materials and methods

The major design drawback of existing HAWT is the use of gear box mechanism, bearings, couplings which cause losses as well as increased cost [3]. In this HAWT, the shaft rotates in the horizontal axis. The power is produced by the rotational motion of the HAWT in the direction normal to the wind flow direction. The proposed horizontal axis wind turbine uses a combination of permanent magnets and magnetic coils placed along the rotor's periphery ring and outer ring casing (i.e., stator) of the HAWT respectively. The magnetic levitation by permanent magnets ensures a completely levitating rotor which is free from mechanical contact and getting rid of other mechanical parts like gear box, bearing, etc. The levitation is achieved by using a set of radially magnetized permanent magnets kept in a way that it is in repelling state [4,5]. The first permanent magnet is firmly attached along the periphery of the rotor as shown in Fig. 1(b). This rotor plate is made of iron material and radially magnetized

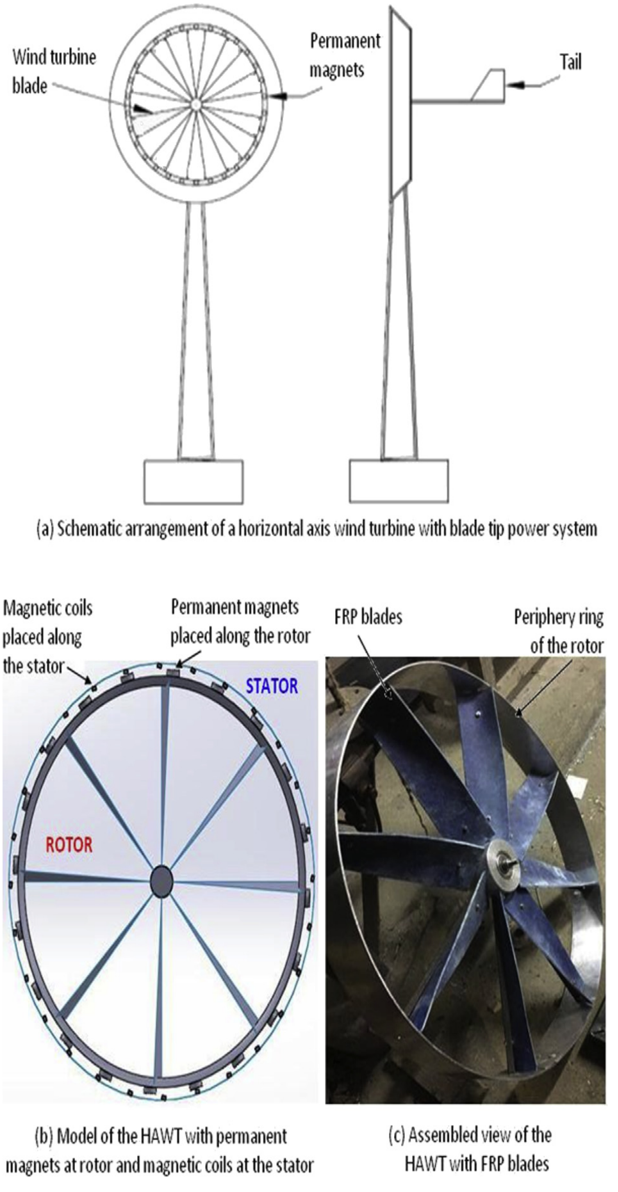

Fig. 1. **(a)** Schematic representation of the HAWT with BTPS. **(b)** Location of permanent magnets in the rotor and magnetic coils in the stator. **(c)** Assembled FRP blades to the rotor.

permanent magnets in N–S–N–S arrangements are fixed along the periphery of the rotor. Each permanent magnets in the rotor are positioned with ‘N’ facing ‘S’.

The outer ring casing which represents as stator in this present HAWT is lined with non-conducting non-magnetic materials and also holds the magnetic wire coil which is needed to produce the voltage. The magnetic coils are kept under the outer ring casing of HAWT as seen in Fig. 1(b). The number of coil turns is estimated by using Faraday's law of induction which is expressed as Bumby and Martin (2005) [6].

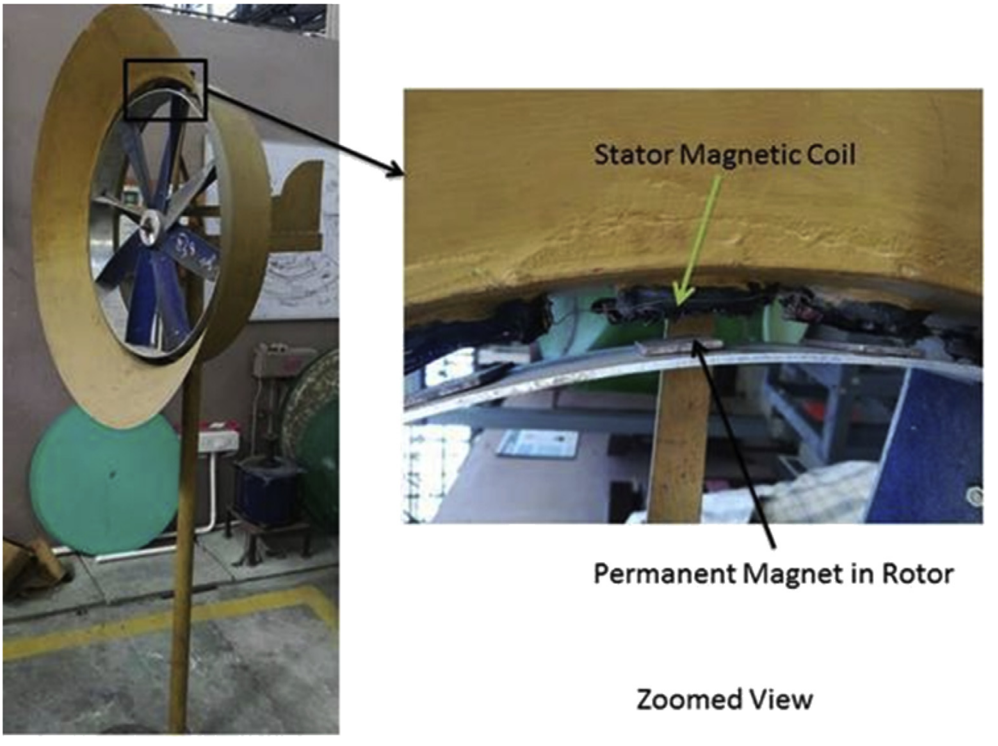

Fig. 2. HAWT with BTPS.

$$N = \frac{e}{d\phi/dt} \tag{1}$$

Due to magnetic repulsion, the rotor and the outer ring casing are levitated. In order to obtain a three-phase output wave form, as pointed out by Ghulam Ahmad and Uzma Amin [3], a ratio of 3:4 is to be maintained between the number of stator coils and the number of permanent magnets positioned along the periphery of the rotor. This ratio is chosen due to availability of space along the rotor periphery.

Thus, the HAWT with BTPS consists of a rotor shaft with blades, outer ring casing which acts as a stator, tower, tail, yaw mechanism and magnetically levitated generator. The blades, which are fixed along the rotor, as seen in Fig. 1(c) are made using composite material named fibreglass reinforced plastics (FRP). The blade surfaces are convex and these blades are coupled to the shaft using guide bushes. The distance between the two blades is equally divided and the specification details of the HAWT with BTPS are given in Table 1.

The mechanical structure of the HAWT with BTPS, as seen in Fig. 2, is simple as it eliminates bearings, couplings, gearing mechanism and other driving components. The output power is taken out through the magnetic wire coils mounted on the stator.

The experimental test rig of HAWT with BTPS is shown in Fig. 3. A variable frequency driven (VFD) axial fan of ABB™ make is used to force the free stream of air on HAWT with BTPS with air velocity varied from 7 m/s to 10 m/s. The wind speed (V) is measured using a cup type anemometer. The torque (T) generated by HAWT with BTPS is measured using torque sensor of Sushma© make [7]. The rotational speed of HAWT with BTPS (N) is measured using non-contact type photo electric sensor. A data

Fig. 3. Experimental test rig of HAWT with BTPS.

Table 1
Specifications details of HAWT with BTPS.

Length of the FRP blade	26.50 cm
Breadth of the FRP blade	6 cm
Twisting angle of the FRP blade	45°
Inner diameter of the aluminum rim	64 cm
Outer diameter of the shell	68 cm
Number of FRP blades	8
Number of windings	28
Number of permanent magnets	28
Length of the tail	40 cm

Table 2
Performance parameters at wind velocity of 7 m/s.

Load, W (kg)	Speed of the turbine rotor, N (rpm)	Torque, T (Nm)	Tip speed ratio, λ	Mechanical Power coefficient, C_p	Torque coefficient, C_T	Voltage (Volt)	Current (Amp)	Electrical Power Coefficient, C_p
0	125	0	0.598095	0	0	12	0	0
100	118	0.03924	0.564602	0.0127	0.007174	12	0.029392	0.005811
200	112	0.07848	0.535893	0.025414	0.013619	12	0.057175	0.011304
300	105	0.11771	0.5024	0.038121	0.019152	12	0.077497	0.015322
400	96	0.15696	0.459337	0.050828	0.023347	12	0.093291	0.018444
500	84	0.1962	0.40192	0.063536	0.025536	12	0.105913	0.02094
600	76	0.23544	0.363642	0.076243	0.027725	12	0.112187	0.02218
700	74	0.27468	0.354072	0.08895	0.031495	12	0.12107	0.023936
800	64	0.31392	0.306225	0.101657	0.03113	12	0.125965	0.024904
900	64	0.35316	0.306225	0.114364	0.035021	12	0.145253	0.028717
1000	54	0.3924	0.258377	0.127071	0.032832	12	0.132852	0.026266
1100	46	0.43164	0.220099	0.139778	0.030765	12	0.129157	0.025535
1200	41	0.47088	0.196175	0.152485	0.029914	12	0.114993	0.022735
1300	35	0.51012	0.167467	0.165193	0.027664	12	0.110541	0.021855
1400	30	0.54936	0.143543	0.1779	0.025536	12	0.10333	0.020429
1500	25	0.5886	0.119619	0.190607	0.0228	12	0.092259	0.01824
1600	15	0.62784	0.071771	0.203314	0.014592	12	0.060522	0.011965

Table 3
Performance parameters at wind velocity of 8 m/s.

Load, W (kg)	Speed of the turbine rotor, N (rpm)	Torque, T (Nm)	Tip speed ratio, λ	Power coefficient, C_p	Torque coefficient, C_t	Voltage (Volt)	Current (Amp)	Electrical Power Coefficient, C_p
0	150	0	0.628	0	0	12	0	0
100	146	0.03924	0.611253	0.009729	0.005947	12	0.040352	0.007978
300	137	0.11772	0.573573	0.029187	0.016741	12	0.122532	0.024225
500	125	0.1962	0.523333	0.048644	0.025457	12	0.196834	0.038915
700	113	0.27468	0.473093	0.068102	0.032219	12	0.272125	0.053801
900	95	0.35316	0.397733	0.08756	0.034826	12	0.363163	0.071799
1100	81	0.43164	0.33912	0.107018	0.036292	12	0.433041	0.085614
1300	74	0.51012	0.309813	0.126476	0.039184	12	0.486187	0.096122
1500	65	0.5886	0.272133	0.145933	0.039713	12	0.583126	0.115287
1700	50	0.66708	0.209333	0.165391	0.034622	12	0.685974	0.135621
1900	44	0.74556	0.184213	0.184849	0.034052	12	0.747978	0.147879
2100	25	0.82404	0.104667	0.204307	0.021384	12	0.857715	0.169575

acquisition system equipped with Labview© software of NI instruments make records all the measured data in a computer [8]. Using these measured data, the coefficient of power (C_p), coefficient of torque (C_T) and tip speed ratio are found. Based on the standard of error estimation [9], the error of these calculated parameters is estimated as ±2.23%.

Table 4
Performance parameters at wind velocity of 9 m/s.

Load, W (kg)	Speed of the turbine rotor, N (rpm)	Torque, T (Nm)	Tip speed ratio, λ	Power coefficient, C_p	Torque coefficient, C_t	Voltage (Volt)	Current (Amp)	Electrical Power Coefficient, C_p
0	176	0	0.654981	0	0	12	0	0
100	161	0.03924	0.599159	0.007687	0.004606	12	0.031494	0.006226
400	155	0.15696	0.57683	0.030748	0.017736	12	0.129085	0.025521
700	135	0.27468	0.5024	0.053809	0.027034	12	0.217734	0.043047
1000	112	0.3924	0.416806	0.07687	0.03204	12	0.307161	0.060727
1300	101	0.51012	0.37587	0.099931	0.037561	12	0.414473	0.081943
1500	82	0.5886	0.305161	0.115305	0.035187	12	0.466573	0.092244
1700	70	0.66708	0.260504	0.130679	0.034042	12	0.502344	0.099316
2000	55	0.7848	0.204681	0.153741	0.031468	12	0.622102	0.122993
2300	45	0.90252	0.167467	0.176802	0.029608	12	0.733302	0.144978
2600	23	1.02024	0.085594	0.199863	0.017107	12	0.808731	0.15989

Table 5
Performance parameters at wind velocity of 10 m/s.

Load, W (kg)	Speed of the turbine rotor, N (rpm)	Torque, T (Nm)	Tip speed ratio, λ	Power coefficient, C_p	Torque coefficient, C_t	Voltage (Volt)	Current (Amp)	Electrical Power Coefficient, C_p
0	196	0	0.656469	0	0	12	0	0
100	191	0.03924	0.639723	0.006226	0.003983	12	0.026453	0.00523
300	185	0.11772	0.619627	0.018679	0.011574	12	0.078418	0.015504
600	166	0.23544	0.555989	0.037359	0.020771	12	0.15306	0.030261
900	146	0.35316	0.489003	0.056038	0.027403	12	0.223919	0.04427
1200	128	0.47088	0.428715	0.074718	0.032033	12	0.309899	0.061269
1500	114	0.5886	0.381824	0.093397	0.035661	12	0.377924	0.074718
1800	97	0.70632	0.324885	0.112077	0.036412	12	0.430836	0.085179
2100	72	0.82404	0.241152	0.130756	0.031532	12	0.529095	0.104605
2400	62	0.94176	0.207659	0.149436	0.031032	12	0.619799	0.122538
2700	54	1.05948	0.180864	0.168115	0.030406	12	0.680265	0.134492
3000	42	1.1772	0.140672	0.186795	0.026277	12	0.784197	0.15504
3300	29	1.29492	0.097131	0.205474	0.019958	12	0.789864	0.15616
3600	24	1.41264	0.080384	0.224154	0.018018	12	0.895685	0.177082
3900	20	1.53036	0.066987	0.242833	0.016267	12	0.982606	0.194266

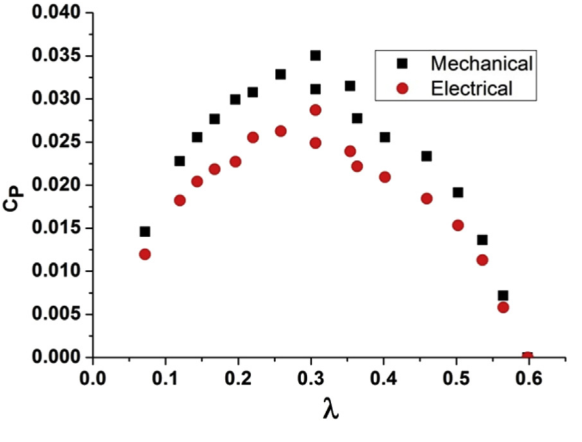

Fig. 4. Comparison of coefficient of power (C_p) at wind velocity V = 7 m/s.

The performance characteristics of the HAWT with BTPS are found by carrying out trials using mechanical loading method. A brake drum type dynamometer is used to simulate the loading conditions on HAWT with BTPS. A fishing nylon type thread of 1 mm thick [10] is wrapped over the groove of the drum which is in turn attached to the rotor shaft of HAWT with BTPS. A weighing pan is attached to one end of the nylon thread and its other end is kept fixed. The entire tests are conducted by varying the wind velocity from 7 m/s to 10 m/s using variable frequency drive. The performance test on the HAWT with BTPS is done by varying the loading conditions from no load to maximum load for different wind speed regimes.

The performance indices of the HAWT with BTPS are expressed as power coefficient (C_p) and coefficient of torque (C_T) are given in equations (2) and (3).

Torque (T) = WR, where W is the load placed on the weighing pan (N) and R is the radius of the brake drum type dynamometer (m).

Power available at the rotor shaft of HAWT with BTPS (P_{ROTOR_SHAFT}) = 2πNT/60 where N is the rotational speed of the shaft of HAWT with BTPS (rpm) and T is torque generated by the rotor shaft of HAWT with BTPS (Nm).

Theoretical power available in the wind is expressed as $P_{AVAILABLE} = \frac{1}{2}\rho A v^3$ where ρ is the density of the wind (kg/m^3), V is the velocity of the wind (m/s) and A is the cross sectional area of the HAWT with BTPS (m^2).

$$\text{Power coefficient } (C_p) = \frac{P_{ROTOR\_SHAFT}}{P_{AVAILABLE}} \tag{2}$$

$$\text{Coefficient of torque (CT) is mentioned as} \frac{T}{\frac{1}{2}\rho A V^2 R} = \frac{W \times R_{BRAKE\_DRUM\_DYNAMOMETER}}{\frac{1}{2}\rho A V^2 R} \tag{3}$$

Tip speed ratio (λ) of the turbine is expressed as

$$\wedge = \frac{\text{Tip peripheral velocity of the turbine rotor}}{\text{Velocity of the wind}} = \frac{U}{V} = (\omega \times R)/V = \left(\frac{2\pi N}{60}\right) \times R)/V \tag{4}$$

where ω is the angular velocity of the rotor (radians/second) and R is the rotor radius (m).

Tables 2–5 lists the performance characteristics parameters of the HAWT with BTPS at various wind velocities ranging from 7 m/s to 10 m/s at loading conditions from no load to maximum loads. The torque coefficient (C_T) is observed to reduce as the tip speed ratio (λ) of the HAWT with BTPS increases for different wind velocity data presented here. Similarly, maximum power coefficient (C_p) is observed at lower tip speed ratio and it decreases as the tip speed ratio increases. This trend is observed for different wind velocity data presented here. Based on this data, a general observation can be made that peak values of torque coefficient, and power coefficient are obtained at low tip speed ratios which is an interesting outcome of the HAWT with BTPS compared to traditional HAWTs. Fig. 4 shows the comparison of coefficient of power (C_p) between electrical and mechanical loading at wind velocity V = 7 m/s. Moreover, as permanent magnetic generator is used in this HAWT with BTPS, the friction as well as losses is significantly reduced compared to traditional HAWTs. This is reflected in terms of values of electrical power coefficient. As can be seen in Tables 2–5, the mechanical and electrical power coefficient values are nearer with respect to each other.

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Transparency document

Transparency document related to this article can be found online at https://doi.org/10.1016/j.dib.2019.103716.

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