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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Abstract

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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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 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 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 Specifi
cations 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.

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
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].
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

$$N = \frac{e}{\frac{d\phi}{dt}}$$

Fig. 2. HAWT with BTPS.
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 (Cp), coefficient of torque (CT) 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 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, Cp | Torque coefficient, Cr | Voltage (Volt) | Current (Amp) | Electrical Power Coefficient, Cp |
| 0 | 125 | 0 | 0.598095 | 0 | 0.007174 | 12 | 0 | 0 |
| 100 | 118 | 0.03924 | 0.564602 | 0.0127 | 0.013619 | 12 | 0.029392 | 0.005811 |
| 200 | 112 | 0.07848 | 0.532893 | 0.025414 | 0.019152 | 12 | 0.057175 | 0.011304 |
| 300 | 105 | 0.11771 | 0.501024 | 0.038121 | 0.024376 | 12 | 0.077497 | 0.015322 |
| 400 | 96 | 0.15696 | 0.459337 | 0.050828 | 0.029347 | 12 | 0.093291 | 0.018444 |
| 500 | 84 | 0.1962 | 0.401912 | 0.063536 | 0.025536 | 12 | 0.105913 | 0.02094 |
| 600 | 76 | 0.2344 | 0.363642 | 0.076243 | 0.027725 | 12 | 0.112187 | 0.02218 |
| 700 | 74 | 0.27468 | 0.340702 | 0.088945 | 0.031495 | 12 | 0.12107 | 0.023936 |
| 800 | 64 | 0.31392 | 0.306225 | 0.101657 | 0.03113 | 12 | 0.125965 | 0.02494 |
| 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 | 0.027235 |
| 1300 | 35 | 0.51012 | 0.167467 | 0.165193 | 0.027664 | 12 | 0.110541 | 0.021855 |
| 1400 | 30 | 0.54936 | 0.143543 | 0.1779 | 0.025356 | 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, Cp | Torque coefficient, Cr | Voltage (Volt) | Current (Amp) | Electrical Power Coefficient, Cp |
| 0 | 150 | 0 | 0.628 | 0 | 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 | 0.125322 | 0.024225 |
| 500 | 125 | 0.1962 | 0.523333 | 0.048644 | 0.025457 | 12 | 0.196354 | 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 | 0.038266 | 12 | 0.363163 | 0.071999 |
| 1100 | 81 | 0.43164 | 0.33912 | 0.107018 | 0.036292 | 12 | 0.439041 | 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 |
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               | 0               | 12            | 0            | 0.006226                      |
| 100 161     | 0.03924                           | 0.599159     | 0.007687        | 0.004606        | 0.017736        | 12            | 0.031494 | 0.025521                      |
| 400 155     | 0.15696                           | 0.57683      | 0.030748        | 0.011776        | 0.129085        | 12            | 0.129085 | 0.043047                      |
| 700 135     | 0.27468                           | 0.5024       | 0.053809        | 0.027034        | 0.217734        | 12            | 0.217734 | 0.060727                      |
| 1000 112    | 0.3924                            | 0.416806     | 0.07687         | 0.03204         | 0.307161        | 12            | 0.307161 | 0.081943                      |
| 1300 101    | 0.51012                           | 0.37587      | 0.099931        | 0.037561        | 0.414473        | 12            | 0.414473 | 0.112993                      |
| 1500 82     | 0.5886                            | 0.305161     | 0.115305        | 0.043518        | 0.466573        | 12            | 0.466573 | 0.144978                      |
| 1700 70     | 0.66708                           | 0.260504     | 0.130679        | 0.050482        | 0.502344        | 12            | 0.502344 | 0.177082                      |
| 2000 55     | 0.7848                            | 0.204681     | 0.153741        | 0.060024        | 0.622102        | 12            | 0.622102 | 0.20266                      |
| 2300 45     | 0.90252                           | 0.167467     | 0.176802        | 0.070035        | 0.733302        | 12            | 0.733302 | 0.24266                      |
| 2600 23     | 1.02024                           | 0.085594     | 0.199863        | 0.081042        | 0.808731        | 12            | 0.808731 | 0.27266                      |

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               | 0               | 12            | 0            | 0.00523                      |
| 100 191     | 0.03924                           | 0.639723     | 0.006226        | 0.003983        | 0.026453        | 12            | 0.026453 | 0.015504                      |
| 300 185     | 0.11772                           | 0.619627     | 0.018679        | 0.011574        | 0.078418        | 12            | 0.078418 | 0.020261                      |
| 600 166     | 0.23544                           | 0.559889     | 0.037359        | 0.020771        | 0.15306         | 12            | 0.15306  | 0.030261                      |
| 900 146     | 0.35316                           | 0.489003     | 0.056038        | 0.027403        | 0.223919        | 12            | 0.223919 | 0.04427                      |
| 1200 128    | 0.47088                           | 0.428715     | 0.074718        | 0.032033        | 0.309899        | 12            | 0.309899 | 0.061269                      |
| 1500 114    | 0.5886                            | 0.381824     | 0.093397        | 0.035661        | 0.377924        | 12            | 0.377924 | 0.074718                      |
| 1800 97     | 0.70632                           | 0.324885     | 0.112077        | 0.036412        | 0.430836        | 12            | 0.430836 | 0.085179                      |
| 2100 72     | 0.82404                           | 0.241152     | 0.130756        | 0.031532        | 0.529095        | 12            | 0.529095 | 0.104605                      |
| 2400 62     | 0.94176                           | 0.207659     | 0.149436        | 0.031032        | 0.619799        | 12            | 0.619799 | 0.122538                      |
| 2700 54     | 1.05948                           | 0.180864     | 0.168115        | 0.030406        | 0.680265        | 12            | 0.680265 | 0.134492                      |
| 3000 42     | 1.1772                            | 0.140672     | 0.186795        | 0.026277        | 0.784197        | 12            | 0.784197 | 0.15504                      |
| 3300 29     | 1.29492                           | 0.097131     | 0.205474        | 0.019958        | 0.878964        | 12            | 0.878964 | 0.15616                      |
| 3600 24     | 1.41264                           | 0.080384     | 0.224154        | 0.018018        | 0.956885        | 12            | 0.956885 | 0.177082                      |
| 3900 20     | 1.53036                           | 0.066987     | 0.242833        | 0.016267        | 0.982606        | 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 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 \((P_{ROTOR SHAFT}) = \frac{2\pi NT}{60}\) 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 \(\rho\) is the density of the wind (kg/m³), \(V\) is the velocity of the wind (m/s) and \(A\) is the cross sectional area of the HAWT with BTPS (m²).

\[
\text{Power coefficient } (C_p) = \frac{P_{ROTOR SHAFT}}{P_{AVAILABLE}} \tag{2}
\]

\[
\text{Coefficient of torque (CT) is mentioned as } \frac{T}{\frac{1}{2} \rho AV^2 R} = \frac{W \times R_{BRAKE DRUM DYNAMOMETER}}{\frac{1}{2} \rho AV^2 R} \tag{3}
\]

Tip speed ratio \((\lambda)\) of the turbine is expressed as

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

where \(\omega\) 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 \((\lambda)\) 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 \(V = 7 \text{ m/s}\). 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

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