Wind Turbine for Urban Environment

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Abstract: In this paper helical wind turbine for urban environment is discussed. Wind turbine Generator model is simulated by using MATLAB simulink tool, Prototype hardware model is designed in laboratory. Electronic controller for energy storage system is designed for low wind velocity. Difficulties, advantages and disadvantages are discussed. Simulated results are analysed with hardware model and results are concluded.

Keywords: Controller, Helical, Turbine, Low Wind, Urban.

I. INTRODUCTION

Wind energy is clean and in exhaustible energy source widely used as a working fluid for wind farms for centuries. Small wind turbines are defined as turbines that are specially designed for built environment, and can be located on buildings or on the ground next to buildings. This implies that the turbine has been adapted for the wind regime in the built environment and can, in theory at least, resist wind gusts and turbulences and that the shape and size of the turbine have been designed to visually integrate with the surrounding buildings. The capacity of these turbines is generally between 1 and 20 kW. These small wind turbines can also be referred to as “urban wind turbines”. In the urban environment, besides the industry and transport sector, a huge amount of energy is consumed. Housing was for a long time considered to merely shelter people, and the local energy needs were mostly covered and provided by centralized power plants, exploiting various energy sources and resources.

New trends e.g. in architecture and urban planning are to reduce energy needs. Several technologies are employed to achieve this, and one of the technologies, not new as such, is wind energy. Wind turbines are installed in cities, both by companies and private persons on both old and new buildings.

However, an overview of the energy content of the wind in cities and how consequently turbines shall be designed for such wind climates is lacking. Since turbines of this size are relatively easy to be integrated in the urban space and are in the financial range for small companies as well as for private persons. Elements important for the implementation of wind energy conversion systems are the macro and micro wind climate, the siting within a micro wind climate and the choice of a wind turbine model most appropriate for the selected site.

Not as a surprise, it can be concluded, that the average wind velocities and with that the wind energy available in a city is somewhat lower than at a rural site outside the city. Furthermore, the wind climate in cities is very dependent on the buildings character and higher turbulences are expected.

Therefore, methods are developed in this work to estimate the wind energy in cities depending on the built-up character, with both, simple and advanced calculation models. The energy produced by a wind turbine is also dependent on the turbine design, but especially on the rotor design.

The power in the Wind:

The power in the wind can be computed by using the concepts of kinetics. The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy. The kinetic energy of any particle is equal to one half its mass times the square of its velocity,

\[ KE = \frac{1}{2} mv^2 \]

Amount of Air passing is given by

\[ m = \rho AV \]  

Where,

\[ m = \text{mass of air transversing} \]

\[ A = \text{Area swept by the rotating blades of wind mill type} \]

\[ \rho = \text{Density of air} \]

\[ V = \text{velocity of air} \]

Substituting this value of the mass in expression of K.E

\[ = \frac{1}{2} \rho AV^2 \text{ watts} \]

\[ = \frac{1}{2} \rho AV^3 \text{ watts} \]  

Second equation tells us that the power available is proportional to air density \((1.225 \text{ kg/m}^3)\) & is proportional to the intercept area. Since the area is normally circular of diameter \(D\) in horizontal axis aero turbines, then,

\[ A = \text{Height} \times \text{Diameter} \]

II. WIND TURBINE DESIGN PARAMETERS

A. Wind Speed:
This is very important to the productivity of a windmill. The wind turbine only generates power with the wind. The wind rotates the axis (horizontal or vertical) and causes the shaft on the generator to sweep past the magnetic coils creating an electric current.

**B. Swept Area:**

The swept area is the section of air that encloses the turbine in its movement. The swept area is given by,

\[ A = h \cdot d \]

i.e Bigger area, Bigger power output for same wind conditions.

**C. Power and Power Coefficient:**

Power available,

\[ P_w = \frac{1}{2} \rho A V^3 \]

Where, \( \rho \) = Air Density Kg/m³

\( V \) = Velocity (m/s)

\( A \) = Swept Area

\[ C_p = \frac{\text{Captured Mechanical Power By Blades}}{\text{Available Power In The Wind}} \]

The Efficiency, of HAWT – 59.3% and of VAWT – 64%

**D. Tip Speed Ratio:**

\[ C_p \text{ dependant on TSR} \]

\[ \text{TSR} = \frac{\text{tangential speed at the blade tip}}{\text{Actual wind speed}} = \frac{R_w}{V_0} \]

Where,

\( \Omega \) = angular speed (rad/sec)

**E. Blade Chord:**

The chord is the length between leading edge and trailing edge of the blade profile. The blade thickness and shape is determine by type of airfoil is used

**F. Number of Blades:**

The number of blades has direct effect in the smoothness of rotor operation as they can compensate cycled aerodynamics loads

For easiness four or three blades have been contemplated

**G. Solidity Ratio:**

\[ \delta = \frac{N \cdot C}{R} \]

Where,

\( N \) = number of blades

\( C \) = blade chord

\( R \) = blade length

When, \( \delta \geq 0.4 \) self starting turbine is achieved

**III. ADVANTAGES AND DISADVANTAGES**

Advantages of Helix Vertical Wind Turbine:

1. Work speed range: The VAWT starts to work under lower wind speeds (about 3m/s) and can still work on high wind velocities (about 40m/s).
2. Capturing all wind directions: Such turbines can catch wind in all directions without requiring the heavy and expensive directional mechanism.
3. Efficiency over higher turbulence levels: The HAWT needs an axial wind incidence on the blades .Therefore, when wind turbulence increases, the efficiency decreases. However, VAWT catches the wind in all directions, which is common in cities, does not affect its efficiency.
4. Turbine size: The mechanism of VAWT is simpler and much smaller. HAWT can be over 30m high and 20m diameter VAWT
5. Construction, Transportation and Maintenance cost: As mentioned the VAWT is simpler and smaller therefore, the construction and maintenance are not complicated and due to the smaller scale, the cost for transportation is lower than HAWT.
6. Reduced noise pollution and visual disturbance levels: The Helix vertical axis wind turbine make less noise (about 50DB).
7. With Helix wind turbine, birds issue have rarely been concern. They are less susceptible to problems with crosswinds than bladed turbines.

Disadvantages of Helix Vertical Wind Turbine:

1. They are not as efficient as HAWT’s, any inefficiency is cancelled out by the fact that VAWT’s can harness more wind than HAWT’s.
2. They have relative high vibration because the air flow near the ground creates turbulent flow.

Application of helix Vertical Wind Turbine:

1. Urban Environment
2. Island environment.

**IV. CONTROL CIRCUIT FOR BATTERY CHARGING**

In this section, different topologies for control circuit for energy storage system are presented [3].

1. Three-phase Rectifier Graetz Bridge Type
2. Graetz Bridge with Buck Converter
3. Controlled Rectifier with Input
4. Proposed Topology
Above mentioned topologies have some advantages and disadvantages. The problems related to other topologies are solved in proposed topology.

Fig. 1. Proposed Control Topology

V. ANALYTICAL CALCULATIONS

Table 1. Wind Velocity 4m/s

<table>
<thead>
<tr>
<th>Diameter (meter)</th>
<th>Height (meter)</th>
<th>Power (Watt)</th>
<th>Speed (RPM)</th>
<th>Torque (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.385</td>
<td>7.546</td>
<td>152.86</td>
<td>0.47</td>
</tr>
<tr>
<td>0.7</td>
<td>0.539</td>
<td>14.790</td>
<td>109.19</td>
<td>1.29</td>
</tr>
<tr>
<td>1</td>
<td>0.77</td>
<td>30.184</td>
<td>76.43</td>
<td>3.77</td>
</tr>
<tr>
<td>1.2</td>
<td>0.924</td>
<td>43.46</td>
<td>63.69</td>
<td>6.51</td>
</tr>
<tr>
<td>1.5</td>
<td>1.155</td>
<td>67.91</td>
<td>50.95</td>
<td>12.73</td>
</tr>
</tbody>
</table>

Table 2. Wind Velocity 5m/s

<table>
<thead>
<tr>
<th>Diameter (meter)</th>
<th>Height (meter)</th>
<th>Power (Watt)</th>
<th>Speed (RPM)</th>
<th>Torque (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.385</td>
<td>14.738</td>
<td>191.06</td>
<td>0.73</td>
</tr>
<tr>
<td>0.7</td>
<td>0.539</td>
<td>28.88</td>
<td>136.48</td>
<td>2.02</td>
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<tr>
<td>1</td>
<td>0.77</td>
<td>58.95</td>
<td>95.54</td>
<td>5.89</td>
</tr>
<tr>
<td>1.2</td>
<td>0.924</td>
<td>84.89</td>
<td>79.61</td>
<td>10.18</td>
</tr>
<tr>
<td>1.5</td>
<td>1.155</td>
<td>132.64</td>
<td>63.69</td>
<td>19.89</td>
</tr>
</tbody>
</table>

A. Average of Readings:

Wind Velocity = 3.476 m/s
Speed = 141.4 rpm
Voltage = 322.46 mV
Current = 14.01 mA

B. Weather data of AMGOI Campus:

Table 3. Weather Data of AMGOI Campus, Kolhapur.


Table 4. Results are Recorded at Different Wind Speed

<table>
<thead>
<tr>
<th>Velocity (m/s)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Electrical Power (W)</th>
<th>Speed (rpm)</th>
<th>Torque (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>4.37</td>
<td>200</td>
<td>0.874</td>
<td>32.27</td>
<td>0.14</td>
</tr>
<tr>
<td>1.5</td>
<td>4.87</td>
<td>200</td>
<td>0.974</td>
<td>40.34</td>
<td>0.21</td>
</tr>
<tr>
<td>2</td>
<td>5.20</td>
<td>200</td>
<td>1.04</td>
<td>53.29</td>
<td>0.38</td>
</tr>
<tr>
<td>2.5</td>
<td>5.42</td>
<td>200</td>
<td>1.084</td>
<td>67.24</td>
<td>0.59</td>
</tr>
<tr>
<td>3</td>
<td>6.39</td>
<td>200</td>
<td>1.278</td>
<td>80.69</td>
<td>0.86</td>
</tr>
<tr>
<td>3.5</td>
<td>6.92</td>
<td>200</td>
<td>1.384</td>
<td>94.14</td>
<td>1.17</td>
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<tr>
<td>4</td>
<td>7.04</td>
<td>200</td>
<td>1.408</td>
<td>107.59</td>
<td>1.53</td>
</tr>
<tr>
<td>4.5</td>
<td>7.78</td>
<td>200</td>
<td>1.556</td>
<td>121.04</td>
<td>1.93</td>
</tr>
<tr>
<td>5</td>
<td>7.85</td>
<td>200</td>
<td>1.568</td>
<td>134.50</td>
<td>2.39</td>
</tr>
<tr>
<td>5.5</td>
<td>8.08</td>
<td>200</td>
<td>1.616</td>
<td>147.94</td>
<td>2.89</td>
</tr>
</tbody>
</table>

Table 5. Technical Specification of Designed VAWT

<table>
<thead>
<tr>
<th>Cut-in wind speed m/s</th>
<th>1.2 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival wind speed m/s</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Rated output at 4m/s</td>
<td>1.408 watts</td>
</tr>
<tr>
<td>Maximum output at 5.5m/s</td>
<td>1.616 watts</td>
</tr>
<tr>
<td>Maximum rotational speed at 4m/s</td>
<td>107.59 RPM</td>
</tr>
<tr>
<td>Maximum no load shaft torque (kg-cm)</td>
<td>1.53 N-m</td>
</tr>
<tr>
<td>Total weight</td>
<td>20 kg</td>
</tr>
<tr>
<td>Number of rotor blade</td>
<td>2</td>
</tr>
<tr>
<td>-----------------------</td>
<td>---</td>
</tr>
<tr>
<td>Rotor blade type</td>
<td>Helical Savinous type</td>
</tr>
<tr>
<td>Rotor diameter (m)</td>
<td>0.9144 m</td>
</tr>
<tr>
<td>Height</td>
<td>0.853 m</td>
</tr>
<tr>
<td>Swept area (m)</td>
<td>0.9144 m</td>
</tr>
<tr>
<td>Generator</td>
<td>GM-DC geared generator</td>
</tr>
<tr>
<td>Battery</td>
<td>12V, 1Ah</td>
</tr>
<tr>
<td>Typical output at AMGOI Campus</td>
<td></td>
</tr>
<tr>
<td>Avg. wind speed at 2m/s</td>
<td>1.38 watts</td>
</tr>
<tr>
<td>Avg. wind speed at 3m/s</td>
<td>4.66 watts</td>
</tr>
<tr>
<td>Avg. wind speed at 5m/s</td>
<td>21.59 watts</td>
</tr>
</tbody>
</table>

Fig. 2. Blade Design

Fig. 3. Prototype Wind Turbine Generator

Fig. 4. Simulation Wind Energy Generator System

Fig. 5. Wind Generator Output Voltage

From the simulation at wind speed 2.4m/s WTG generates enough power to supply the load. The synchronous machine operates as a synchronous down dc-dc converter. This topology allows charging the batteries even when generated voltage is less than batteries voltage which is not possible in some previous topologies.

The proposed topology has following advantages:
1. Low cost.
2. Robustness, it is not possible to close short arm.
3. Low speed energy transfer.
4. Over current and surge battery protection.
5. High efficiency due to reduced number of elements.

It has two modes of operation that are selected according to battery voltage.

Mode 1 – Low Battery Charge: In this mode the high frequency semi-controlled rectifier tracks maximum power available and delivers it to batteries. While the step-down dc-dc converter keeps the bus voltage at 70 V and protects battery from over-voltage.

Mode 2 - Battery Fully Charged: The semi-controlled rectifier keeps the bus voltage at 70 V, while the dc-dc converter controls the charging current and battery voltage, avoiding over current and over voltage damages.

VI. SIMULATION WIND ENERGY GENERATOR SYSTEM

From the simulation at wind speed 2.4m/s WTG generates enough power to supply the load. The synchronous machine operates as a synchronous
condenser with its mechanical power input ($P_m$) set at zero. As the asynchronous machine operates in generator mode, its speed is slightly greater than the synchronous speed. According to turbine characteristics for a 2.4m/s wind speed the turbine output power is 12W because of the asynchronous machine losses the wind turbine.

VII. CONCLUSION

The proposed model is simulated by MATLAB Simulink tool, generates 12W for 2.4m/s wind speed. Prototype model results are analyzed with simulated model. Accuracy in blade design and selection of generator meet the aim. It is difficult to store generated energy for low wind speed, proposed topology has two parts one is high frequency semi controlled rectifier other is step down DC-DC converter, which has low cost, robustness, low speed energy transfer and high efficient.

VII. REFERENCES


